# Allografts in Anterior Cruciate Ligament Reconstruction

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## Contents

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## Introduction

The patient's occupation, activity level, and expectations determine mostly the decision for anterior cruciate ligament (ACL) reconstruction. Even if sedentary patients and those willing to modify their activities can consider nonoperative treatment, this injury results in increased risk for meniscal and chondral lesions and, subsequently, high possibility for early cartilage degeneration [11]. Consequently, ACL reconstruction is the method of choice, with no specific chronologic age as contraindication [42] and with numerous procedures annually performed all over the world.

For most active patients, ACL reconstruction provides an excellent chance to return to their preinjury activities. The use of autologous grafts is very popular and there are many clinical studies reporting good results [13, 25, 26]. However, there are many second thoughts such as how to avoid autogenous tissue sacrifice and reduce donor-site morbidity [60]. Although patellar tendon has become the most common graft source for ACL reconstruction (bone-patellar tendon-bone/BPTB autograft) [19, 41, 60], there are significant complications from the donor site, such as quadriceps weakness, patellofemoral pain, loss of range of motion (ROM), patella fracture, patellar tendonitis, patella infera syndrome, early cartilage degenerative changes, and arthrofibrosis [2, 28, 37]. On the other hand, hamstrings autografts (semitendinosus and gracilis) have also been popular as graft option, with functional results similar to BPTB but without the extensor mechanism deficit. However, it has been reported that there are some disadvantages including knee flexor strength, variability in hamstring size, fixation limitations, and delayed incorporation [1, 52, 62]. For these reasons, as surgeons try to limit the significant morbidity associated with autograft harvesting, the use of allogenic tissue from a cadaver has emerged as an excellent option [45]. However, ACL reconstruction with allografts carries specific problems and, therefore, there is a dilemma when deciding graft type.

The advantage of no donor-site morbidity is the most important for allograft use. In addition, allografts offer larger graft sizes, which could be ordered, low incidence of arthrofibrosis, shorter operative time, and improved overall

health-related quality of life. However, there are considerable disadvantages including cost, slower graft embodiment, and potential disease transmission (bacterial, viral, and prion) [19]. Thus, the optimal graft choice is still a matter of debate. One can say that the optimal graft should be able to reproduce the anatomy and biomechanics of the native ACL, be incorporated rapidly, provide strong initial fixation, and cause low donor-site morbidity. This chapter reviews the literature about the use of allografts in ACL reconstruction, reporting experimental, clinical, and comparison studies.

## Allograft Sources

Usual allografts for ACL reconstruction are patellar ligament, Achilles tendon, tibialis anterior, and posterior. The use of peroneus longus, hamstrings, and fascia latae has also been reported [36]. One study reported that the ultimate failure load for doubled tibialis anterior, tibialis posterior, and peroneus longus were 3,412, 3,391, and 2,483 N, respectively. These values are almost the same or higher than the usual failure loads of all the currently described ACL graft sources [5]. Another study recommended the use of soft tissue allografts such as tibialis anterior tendon or doubled STG rather than allografts with bone plugs such as BPTB and Achilles tendon. This is attributed to the slow incorporation of the allograft bone plug, the greater cross-sectional area available with the soft tissue allograft, and the fact that soft tissue grafts are more readily available since each donor provides six soft tissues but only four bone plug grafts [32].

Another issue that the surgeon should take into account is the possible graft-construct mismatch when ordering an allograft. This obviously relates to BPTB allografts, for example, when a graft from a tall donor is used for a shorter patient. For this reason, it is better to provide the bone bank all the information about the recipient's height and length parameters of the graft in order to avoid any possibility of a significant graft-construct mismatch.

## Disease Transmission with Allografts

The main concern for patients, families, and physicians in cases of allograft ACL reconstruction is the possibility of viral or bacterial infection. Human immunodeficiency virus (HIV), hepatitis B (HBV) and C (HCV) viruses, human T-cell leukemia virus (HTLV), syphilis, aerobic, and anaerobic bacteria are the main pathogens implicated in allograft infection. Recently, additional concerns have been raised about newly emerging pathogens, such as the West Nile virus, the severe acute respiratory syndrome (SARS) coronavirus, and prions, which are associated with transmissible

spongiform encephalopathies, such as the Creutzfeldt–Jacob disease. The Centers for Disease Control and Prevention (CDC) defines allograft-associated infections as the ones that occur during the first year after implantation in patients with no known risk factors who are otherwise healthy. Bacterial or fungal infections commonly emerge with signs of inflammation or infection in or near the operative site. Positive wound or blood cultures are necessary to confirm the diagnosis. Viral or parasitic infections are followed by symptoms and signs characteristic of the infectious agent (e.g., fever, lymphadenopathy, weakness) and by positive serological or molecular test results.

Disease transmission during allograft transplantation can occur through two different ways. The first way is by transmission from an infected donor as a result of an occult perimortem infection, prolonged tissue recovery time, or a donor screening failure. Infectious agents may also come from the breakdown of the donor's gastrointestinal or respiratory system. The second way is by contamination by the healthcare provider during the tissue procurement, sterilization, and preservation procedure. In general, the risk of disease transmission depends mainly on tissue type and preparation method.

There are no definite data available regarding the risk of disease transmission from allograft tissue transplantation. It is believed that such events are usually underreported and are difficult to confirm. Surveillance of adverse effects or disease transmission incidents after allograft implantation occurs, in most countries, in a voluntary basis. Buck et al. estimated that the risk of HIV transmission from an infected donor through transplanted tissue is approximately 1 in 1,667,000 [8]. The risk of contracting hepatitis B or C is estimated to be much higher due to the greater prevalence of hepatitis in the general population. Current donor screening, sterilization and preservation techniques have diminished the possibility of distributing allograft material from donors with active viral infection. Concerns remain, however, regarding the initial "window period," during which viral antigen or antibody levels may not be detectable despite infection. The application of advanced serological testing, such as nucleic acid tests, has managed to decrease this "window period" to approximately 7 days for HIV and HCV and 8 days for HBV infection. The risk of implanting tissue from an HIV-positive donor is currently estimated at one in 173,000 to one in one million. The risk of implanting HCV-infected tissue is estimated at 1 in 421,000 [69].

Bacterial infection following ACL reconstruction is another important concern. There have been several such reports of infections following allograft transplantation. The CDC reported in 2002 a total of 26 cases of bacterial infections associated with musculoskeletal allografts. Half of these cases involved contamination with *Clostridium* species [9]. Eight of the reported infections occurred after ACL

reconstruction using tendon allografts. Barbour et al. reported four additional cases of Clostridium septicum infection after ACL reconstruction [6]. In all of the above cases, disease transmission was attributed to the tissue processing conditions. The postoperative infection rate following autograft and allograft ACL reconstruction was investigated by two large retrospective studies. Williams et al. [67] and Indelli et al. [21] reviewed 2,500 and 3,500 ACL reconstructions, respectively. The infection rates found were 0.3% and 0.14%, respectively. There was no significant difference in infection rates between autograft and allograft reconstructions. In a more recent study, Katz et al. also failed to find a higher deep infection rate in allograft compared to autograft ACL reconstruction [27]. With the advent of more advanced sterilization methods, disinfection of musculoskeletal allografts from bacteria can be practically ensured.

## Preparation of Allografts

The tissue preparation procedure can be divided into several successive steps. The first step is to prevent infected tissue from entering the donation pool through careful donor selection. The second step is to prevent contamination by ensuring an aseptic graft procurement process. The third step is to eliminate any residual infectious agents. This is accomplished during tissue processing and final sterilization.

Appropriate donor selection is one of the primary ways to prevent disease transmission by allografts [17]. Most tissue banks accept donors from 15 to 50 years of age. The most important step is a careful history and identification of risk factors. Data concerning any communicable disease history or high risk behavior (intravenous drug use or traveling history to areas with high infection rate) are obtained by surviving family members, medical or blood donation records, physical examination, or even autopsy reports. The next step is testing for active infection. However, the "window period" for the detection of antibodies or viral antigens still limits the effectiveness of serologic tests, even with modern Nucleic Acid Tests used.

Tissue from accredited donors is procured in an aseptic environment. Standard operating room techniques are used, including prepping and draping. Time to harvest is also important to reduce the risk of infection. The time limit for most tissue banks is 12 h if the body is kept in room temperature and 24 h if the body is refrigerated [64]. However, aseptically recovered tissues should not be considered sterile. Therefore, the recovered tissues usually undergo chemical soaking with biologic detergents and antibiotic or antiseptic solutions to reduce their bio-burden. These solutions are mostly effective against surface contaminants since they lack tissue penetration. Surface swab cultures are also commonly performed to examine the presence of bacteria and fungi. The sensitivity of swab cultures has been found to range at best between 78% and 92% [65]. Consequently, it was suggested that cultures should not be used as evidence of sterilization but only to monitor previously validated sterilizing procedures.

Human tissue grafts cannot be sterilized using methods applied to other implantable medical devices. In particular, the complex three-dimensional structure and the increased tissue density of musculoskeletal grafts make it difficult for reagents to penetrate tissue and to eliminate pathogens. Ideally, a sterilization process should provide a disease-free graft while preserving the mechanical properties and the incorporation characteristics of the graft. Additionally, the reagents used should penetrate adequately the tissue and should be safely removed from tissue without residue. Tissue banks currently use many different proprietary processes and protocols to achieve successful disinfection and sterilization of allografts. No such protocol to date has been shown to be superior. Governmental agencies, such as the FDA in the USA, do not dictate which protocol to be used. The FDA, however, requires that each tissue bank is in a position to prove the efficacy of the sterilization process used with validated data.

The process of removing contamination from allograft tissue is called disinfection. Sterility is defined as the process of killing all forms of life, including microorganisms. The effectiveness of the sterilization procedure is expressed by the sterility assurance level (SAL), which measures the likelihood that a viable pathogen exists in or on the allograft tissue. Currently, most tissue banks attempt to reach a SAL of $10^{-6}$, according to the standards set by the American Association of Tissue Banks (AATB).

The two main processes for sterilization are irradiation and proprietary chemical processing. Ethylene Oxide (EO) is an industrial fumigant originally used for sterilizing medical devices which was introduced into musculoskeletal allograft processing. EO has excellent external sterilization properties but does not penetrate tissue adequately. However, studies with ACL allografts processed with EO have shown poor results. A high rate of intra-articular reactions was recorded, including persistent effusion, chronic synovitis, bone dissolution, and ultimately graft failure [48]. Host tissue reactions caused by chemical residues left in moist tissue were considered responsible for these findings. It was also suggested that this agent is carcinogenic [57], although there is no evidence that EO processed allografts have induced cancer. The use of EO treated allografts is currently not recommended for ACL reconstruction [45].

Gamma-irradiation has been proven effective for sterilization through two different mechanisms: the generation of free radicals and the direct destruction of the organism's genome. Doses of 40 kGy are required to neutralize HIV

from BPTB allografts [15]. Bacteria can be eliminated at lower doses. Studies, however, have indicated that there is a dose-dependent effect of irradiation on the biomechanical properties of the graft [50]. Doses as low as 25 and 40 kGy have been shown to alter significantly the tensile strength of ACL reconstruction allografts [35]. The mechanism by which this may occur is not well understood. It is possible that the collagen structure is affected by free radical production. Other studies have suggested that doses less than 25 kGy have no effect on ACL reconstruction outcomes [47]. The gamma-irradiation dose that most tissue banks currently use ranges from 1 to 35 kGy.

In vivo studies comparing irradiated and nonirradiated allografts have shown disappointing results. A study of patients who underwent Achilles tendon allograft ACL reconstruction found a significantly higher failure rate in the irradiated (dose 20–25 kGy) compared to the nonirradiated group (33% and 2.4%, respectively) [46]. A similar trend was confirmed in a goat model study of patellar tendon ACL reconstruction with irradiated (40 kGy) and nonirradiated allografts. Differences between the two groups were recorded in stiffness and maximum force but not in maximum stress or material properties [51]. Recently, the pretreatment of allograft tissue with radioprotectant scavengers was introduced in an attempt to block the activity of free radicals and to minimize the structural damage caused by irradiation [53]. Studies have shown that bone and tendon allografts irradiated at high doses (50 kGy) after pretreatment with radioprotectants demonstrated preimplantation properties similar to conventionally irradiated and nonirradiated allografts [18].

Allograft tissue can be preserved by three different methods: deep fresh-freezing, freeze-drying, and cryopreservation. Deep freezing is the simplest and most widely used technique. Tissues are stored after controlled freezing, at temperatures of at least −70°C to −80°C, which allows their preservation for 3–5 years [55]. This method has no effect on the strength of the graft [22] and it has been shown to reduce graft antigenicity by destroying class II major histocompatibility proteins [3]. Freeze-drying is also commonly used. It involves dehydration of the grafts during freezing in a vacuum to a residual water content level of less than 5%. Therefore, the grafts need to be rehydrated for at least 30 min before implantation, especially if they contain bone blocks along with the soft tissue. Viral load of infected tissue can be decreased to sub-infectious levels with this method [4], although this has been argued by other reports [12]. Graft antigenicity is also reduced with freeze-drying. This method allows for storage at room temperatures for up to 5 years. However, the time interval between procurement and implantation has been positively correlated with allograft failure rates in ACL reconstruction, thus questioning the shelf life of freeze-dried tissues [58]. Clinical results of freeze-dried allografts have been successful overall [34], although slightly

better results have been reported for fresh-frozen allografts [20]. The third method of tissue preservation is cryopreservation, which employs a controlled rate of freezing with a cryoprotectant media but it has shown no known advantages over fresh-freezing while incurring a considerably higher cost.

## Surgical Technique

There are no significant differences in surgical technique when using allografts. The most popular type of allografts, fresh-frozen, do not require rehydration and have good results in clinical and basic science research [20]. They also allow the use of identical instrumentation for autograft or allograft procedures and if there are bone-blocks, like BPTB grafts, there is excellent bone-to-bone healing and rigid interference fixation.

The graft is thawed when the evaluation under anesthesia confirms the ACL deficiency. It should not be placed directly into warm saline solution, because it can become edematous and hypertrophy. It is best thawed by keeping the tendon in the plastic bag while in the solution. Alternatively, thawing the graft can begin once diagnostic arthroscopy confirms the ACL rupture. The thawed allograft is evaluated to confirm tissue integrity and quality. Soft tissue size (length and diameter) is measured and recorded. If we have a patella tendon, its central third is harvested similarly to autograft harvest. To avoid splintering, care should be taken to avoid forcible levering of the bone plugs from their beds. If a soft tissue graft is used, the thawing process is the same. The rest of ACL reconstruction technique steps are almost the same when using autografts. For the double-bundle technique, soft tissue allografts (most popular tibialis anterior or posterior) provide an excellent graft source for both surgical process and final functional result [63].

## Biomechanics and Biology of Allograft Healing

The major factors that contribute to a successful allograft implantation are sterility, reduction of antigenicity, and preservation of the biomechanical and biologic properties of the graft [61].

Allograft antigenicity is based on class I and II antigens encoded by genes of the major histocompatibility complex. Antigenic epitopes may be present on donor cells in the ligamentous or bone components and also inside the matrix of the allograft. Fresh and cryopreserved allografts contain viable donor cells and are most likely to elicit a host immune response. Deep-frozen and freeze-dried allografts are relatively hypocellular. However, they have also been shown to

cause a detectable immune response [68]. A T-lymphocyte cell-mediated response is the principal mechanism of host rejection, which may often mimic infection or mechanical failure [59]. The clinical consequences of such a response are currently unknown.

Allografts, in general, heal in the same manner as autografts: donor cell death is followed by inflammation, revascularization-repopulation, and finally remodeling of the graft. In the case of deep-frozen or freeze-dried allografts, donor cell death has already occurred before implantation. Tendon allografts heal through the formation of fibrovascular scar tissue at the graft-tunnel interface followed by the formation of Sharpey's fibers and new bone production. Bone blocks contained in allografts first undergo osteonecrosis followed by incorporation of the graft by the surrounding host cancellous bone. The intra-articular part of the graft acts as a collagen scaffold for host cells to repopulate. Graft revascularization occurs from the infrapatellar fat pad distally and the posterior synovial tissues proximally [39]. Finally, collagen remodeling involves the replacement of the original large-diameter fibrils with smaller-diameter ones.

The incorporation rate of graft tissue may be an important consideration when determining graft choice, rehabilitation protocol, or time to return to play. Compared to autografts, allografts were found to demonstrate a prolonged inflammatory response, a greater decrease in structural and mechanical properties and a slower rate of biologic incorporation after implantation [23]. Allogenic tendons also demonstrated a slower onset and rate of revascularization [38]. Greater bone tunnel enlargement observed after allograft ACL reconstruction may also suggest suboptimal healing of allograft tissue [14]. Although allografts seem to lose more of their time-zero strength during remodeling, this has not been associated with a poorer prognosis [24]. The general conclusion is that allografts seem to heal in the same pattern but at a slower rate than autografts.

## Clinical Studies Comparing Allograft and Autograft Use in ACL Reconstruction

A true prospective, randomized clinical trial of autograft versus allograft ACL reconstruction is difficult because graft choice is influenced by patient age, activity level, comorbidities, and preoperative evaluation, as well as by surgeon preference and experience. Patients should be informed about all the possible risks and benefits of each option. In addition, there are specific limitations including the several different scoring scales, the different kinds of patients with different prognoses, and different surgeons or rehabilitation regimes [16]. During the last years, the international literature presented 14 published clinical comparative studies about allograft and autograft use in ACL reconstruction (Table 1). Most of them reported little differences in a long-term basis [19, 31, 33, 41, 43, 49, 54, 56]. However, some studies have reported high rupture rates postoperatively with allografts [10, 60] and others have suggested that use of allograft should be reduced due to increased laxity over time [66]. It is also important to say that all the comparative studies used allografts with bone-blocks (mostly BPTB) and there is a significant lack of comparisons between soft tissue allo- and autografts, which would be extremely useful for evaluating the double-bundle technique. In specific reviews and meta-analyses, the literature moves from accepting the use of allograft tissue to be much more favorable than unfavorable [36], into presenting the autografts as graft of choice for routine ACL reconstruction with allografts better reserved for multiple ligament-injured knees where extra tissue may be required [44]. In another review, ACL reconstruction with BPTB autograft was favored over BPTB allograft for graft rupture and hop test parameters. However, in the latter study, the irradiated and chemically processed allografts were excluded and the results were not significantly different between the two graft types [30].

Early in the 1990s, Lephart et al. [33] looked at 33 active male patients (mean age, 24.3 years) who had ACL reconstructions 12–24 months earlier using BPTB autograft ($N=15$) or allograft ($N=18$). They retrospectively compared quadriceps strength and functional recovery and found no significant difference between the groups in either of these parameters. They concluded that harvesting the central third of the patellar tendon does not diminish quadriceps strength in demanding active patients who have intensive rehabilitation. However, the study was retrospective and did not report selection criteria of each group.

During the same period, Sademmi et al. retrospectively reported the results of 50 patients (31 autograft and 19 allograft patients) who underwent arthroscopic BPTB ACL reconstruction [49]. They analyzed each group regarding hospital stay, swelling, thigh atrophy, laxity, strength, endurance, range of motion, patellofemoral symptoms, and complications after a minimum follow-up of 2 years. They found no significant difference between the groups with regard to perioperative morbidity and clinical image. There was one traumatic rupture in each group. Two allograft patients demonstrated persistent effusions, which were statistically significant ($p<0.05$). This study is limited by its retrospective design and small sample ($N=50$). Additionally, there was no subjective or functional evaluation and no description of group characteristics, such as activity level.

Shino et al. [56] evaluated 92 patients who had an ACL reconstruction before 18–36 months (45 patients received BPTB autograft and 47 fresh-frozen allograft). They found that the anterior laxity and knee extensor torque were significantly better in the allograft group. However, there are again

**Table 1** Results of clinical studies comparing allograft versus autograft ACL reconstruction

| Study | Graft type | | No | | Mean age (years) | | Follow-up | Most important results/conclusions |
|---|---|---|---|---|---|---|---|---|
| | Allo | Auto | Allo | Auto | | | | |
| Lephart et al. [33] | BPTB | BPTB | 18 | 15 | 24.3 | | 12–24 m | No significant difference in quadriceps strength and functional recovery |
| Sademi et al. [49] | BPTB | BPTB | 19 | 31 | 23 | | Minimum 2 years | No significant difference in perioperative morbidity and last clinical image |
| Shino et al. [56] | BPTB | BPTB | 47 | 45 | | | 18–36 months | Anterior laxity and knee extensor torque significantly better in the allograft group |
| Harner et al. [19] | BPTB | BPTB | 64 | 26 | 23.9 | | 3–5 years | No significant clinical differences between patients with autograft versus allograft BPTB ACL reconstruction |
| Stringham et al. [60] | BPTB | BPTB | 31 | 47 | 25 | | 34 months | Autograft BPTB first choice for ACL reconstruction, and allograft tissue preferred graft choice when autograft contraindicated or in multiligament injuries |
| Shelton et al. [54] | BPTB | BPTB | 30 | 30 | 27 | 25 | 2 years | BPTB autograft and allograft ACL reconstruction with statistically similar results at both 2 and 5 years and allograft an acceptable choice for primary ACL reconstruction |
| Victor et al. [66] | BPTB | BPTB | | | 28 | | 6, 12, 24 months | No significant differences between groups in thigh muscle strength, knee anterior laxity, functional scores, one-leg hop test, knee swelling, or quadriceps atrophy |
| Kleipool et al. [29] | BPTB | BPTB | 36 | 26 | 28 | | Minimum 4 years | BPTB allograft was a good alternative for ACL reconstruction |
| Peterson et al. [41] | BPTB | BPTB | 30 | 30 | 28 | 25 | 63 months | No differences except for a greater loss of extension in autograft group compared to the allograft group but without clinical significance |
| Chang et al. [10] | BPTB | BPTB | 46 | 33 | 33.1 | 27.8 | Minimum 2 years | No significant differences in the subjective scores, in Lachman and pivot shift tests, knee anterior laxity, crepitus, atrophy or joint effusion. Autograft BPTB "gold standard," allograft reasonable alternative |
| Kustos et al. [31] | BPTB | BPTB | 53 | 26 | 25.6 | 24.5 | 38 months | No differences in Lysholm, Tegner activity and IKDC score. BPTB allograft is good alternative to autograft |
| Barrett et al. [7] | BPTB | BPTB | 38 | 25 | 47.1 | 44.5 | Minimum 2 years | No functional differences. Both grafts highly effective |
| Phoehling et al. [43] | Achilles soft tis. | BPTB | 41 | 118 | 29.7 | 25.4 | 4.2 years sub/2.2 years obj | Similar long-term results in stability and function. Patients with allograft had less pain and functional limitations in the early p.o. |
| Rihn et al. [47] | BPTB | BPTB | 39 | 63 | 44 | 25.3 | 4.2 years | Similar patient-reported and objective outcomes with both grafts |
| Ozenci et al. [40] | BPTB | BPTB | 20 | 20 | 30.2 | 29.5 | Minimum 12 months | Auto- and allograft reconstructions not different from each other and controls according to proprioceptive measurements |

considerable limitations such as that they included only the subjects who were rated as successes and also that the allograft group included more acute cases and less meniscectomies than the autograft group. Finally, all patients had a cast immobilization for 5–19 days, so it is difficult to generalize their results as currently we use more aggressive rehabilitation.

More recently, Harner et al. [19] reviewed the clinical results, after 3–5 years, of 64 patients with allograft BPTB ACL reconstruction and 26 patients with autograft BPTB ACL reconstruction. Detailed symptoms, activity level, functional outcome, physical examination, and instrumented knee laxity were recorded. The only significant difference was found in the extension loss which was higher in the autograft group. The ultimate conclusion of the study was that there were no significant clinical differences in outcome between patients who underwent autograft or allograft BPTB ACL reconstruction. Although this study had detailed methodology and long-term follow-up, there were also limitations including that the rehabilitation program was less aggressive than the ones commonly used today. Most importantly, the groups were not identical, as 81% of the allograft group had acute injuries compared to only 4% of the autograft group.

In the same period, there was a retrospective study not favorable to the use of allograft for primary ACL reconstruction [60]. Seventy-eight patients were examined 34 months following ACL reconstruction with BPTB autograft (47 patients) or allograft (31 patients). It was important that the two groups were matched in demographic details (age 25 years), activity level, time from injury to surgery, associated injuries, and the type of fixation used on both tibial and femoral sides. No significant differences were reported between groups in subjective results, joint effusion, knee tenderness, range of motion, patellofemoral scores, laxity, knee muscle strength, or quadriceps atrophy. The authors, however, recorded two trends of potential significance. Eighty percent of autograft versus 70% of allograft recipients achieved good-to-excellent restoration of anteroposterior stability (<3 mm side-to-side laxity difference), and patients from the allograft group showed favorable results in concentric peak extension torque at 60°/s. There were four traumatic ruptures only in the allograft group at an average of 11 months p.o. For these reasons the authors concluded that autograft BPTB was their first choice for ACL reconstruction and allograft tissue was the preferred graft choice only when the use of autologous tissue was contraindicated or a knee had multiple ligament injuries. Although this study was well designed, it was biased as one-third of patients were lost in the follow-up, and again there was no randomization.

In a prospective but nonrandomized study, two groups with 30 patients each underwent ACL reconstruction with BPTB allografts and autografts [54]. They were followed for 2 and 5 years. At 2 years there was no difference in pain, giving way, motion, or patellofemoral crepitus. The groups were well matched for most characteristics but there were 24 acute injuries in the autograft group and only 15 in the allograft group. The authors concluded that BPTB autograft and allograft ACL reconstruction produced statistically similar results at both 2 and 5 years and that allograft was an acceptable choice for primary ACL reconstruction. However, they did not use a validated questionnaire or a functional score.

In another prospective study, Victor et al. [66] followed 73 patients after ACL reconstruction using a BPTB autograft or allograft. They found no significant differences between groups in thigh muscle strength, knee anterior laxity, functional scores, one-leg hop test, knee swelling, or quadriceps atrophy. Interestingly, the allograft group showed slightly greater quadriceps strength and reduced anterior knee laxity at 6 and 12 months, but in 24 months these parameters were better for the autograft group. Although KT-1000 evaluation showed no significant trend of increasing laxity with time in the allograft group, the authors concluded that allografts are not recommended as stability deteriorates with time and that, by 2 years, quadriceps strength returns to normal following autograft ACLR.

Kleipool et al. [29] prospectively followed 62 patients who underwent ACL reconstruction with either fresh-frozen BPTB allograft (36 patients) or autograft (26 patients). All the patients had similar age, activity level, and associated injuries. In addition, the preoperative examination revealed worse Lachman and anterior drawer tests for the allograft group. At a mean follow-up of 4 years, normal or nearly normal IKDC scale had been achieved in 70% of the autograft group and 85% of the allograft group. The Lysholm score averaged 95 in the autograft group and 94 in the allograft group. No differences in Lachman, anterior drawer, pivot-shift and one-leg hop tests, or KT-1000 side-to-side laxity were detected between groups. Mild-to-moderate anterior knee pain was found in 42% of autograft and 53% of allograft recipients. The main conclusion was that BPTB allograft was a good alternative for ACL reconstruction.

More recently, Peterson et al. [41] compared, in a prospective nonrandomized trial, 30 BPTB allografts and 30 BPTB autografts. At a mean follow-up of 63 months, patients were assessed through Lysholm and Tegner scores and recorded the swelling, pain, range of movement, crepitus, and laxity using a KT-1000. There were no differences. Additionally, there was no increase in knee stretching in allografts group after 2 years p.o. Although the authors did not explain the exclusion criteria for choosing 60 patients from the total of 119, they concluded that the use of allografts is an acceptable choice for ACL reconstruction.

Chang et al. [10] retrospectively reviewed 46 patients with BPTB allografts and 33 with BPTB autografts after a minimum 2-year follow-up period. One surgeon performed

the reconstruction and in all cases there was augmentation with iliotibial band tenodesis. They found no significant differences in the subjective scores in Lachman and pivot shift tests, knee anterior laxity, crepitus, atrophy, or joint effusion. The allograft group had three traumatic ruptures, nonsignificantly higher incidence of anterior knee pain, and a significantly higher incidence of flexion deficit (although this was only 5°). On the basis of these results, the authors suggested that autograft BPTB should remain the "gold standard," but allograft remains a reasonable alternative. However, the allograft group was older; it had greater preoperative laxity and a higher rate of medial tibial plateau chondral lesions.

On the contrary, Kustos et al. [31] after a retrospective, nonrandomized trial concluded that BPTB allograft is a good alternative to autograft and should be offered to patients as an alternative graft choice. They compared 26 patients with BPTB autograft with 53 patients with allograft. All the patients were young (25 years) and at a mean follow-up of 38 months an independent examiner checked the Lysholm knee scoring scale, the Tegner activity score, and the IKDC knee ligament evaluation form. There was no difference in all the above scores but the study had significant limitations such as no data of patients' characteristics apart from age and gender and no report of associated injuries.

Barrett et al. [7] recorded the results of patients 40 years or older having at least a 2-year follow-up after BPTB autograft or allograft ACL reconstruction. There were no differences in a self-reported questionnaire and in Tegner activity and Lysholm scores too. IKDC functional levels were normal or nearly normal in 87% of patients in the allograft group and in 96% of patients in the autograft group. KT-1000 side-to-side differences were 1.46 mm for the allograft group and 0.104 mm for the autograft group. Interestingly, patients in the allograft group returned earlier to activities. The authors concluded that both graft choices were highly effective.

Poehling et al. [43] compared prospectively 41 patients with freeze-dried Achilles tendon allografts (without bone-block) and 118 BPTB autografts for up to 5 years of follow-up (average of 4.2 years for subjective measures and 2.2 years for objective measures). Patients were evaluated preoperatively and postoperatively at 1–2 weeks, 6 weeks, 3 months, 6 months, and then annually for 5 years. Objective outcome measures included KT-1000 measurements, range of motion, quadriceps atrophy, and IKDC score. Subjectively, patients completed five questionnaires documenting functional status, pain and health-related quality of life. Their results led to the conclusion that despite differences in graft type, fixation, and treating surgeon, similar long-term results in stability and function were achieved with BPTB autograft and Achilles tendon allograft reconstruction of the ACL. However, patients treated with allograft reconstruction had less pain and functional limitations in the early postoperative period.

In 2006, Rihn and al. [47] reviewed, retrospectively, the results of 63 patients with BPTB autograft ACL reconstruction and 39 patients with BPTB allograft sterilized with 2.5 Mrad of irradiation at an average of 4.2 years of follow-up. They reported that allograft group were significantly older (44 years versus 25 years) and had a longer delay from injury to surgery (17.1 weeks versus 9.7 weeks) but had no difference in IKDC subjective knee scores (86.7 for allograft versus 88 for autograft). Clinical evaluation recorded no significant difference in patellofemoral symptoms, range of motion, vertical jump. or single-legged hop tests. The allograft group had slightly improved side-to-side pivot-shift results and a reduced KT-1000 maximum manual side-to-side difference. They concluded that similar patient-reported and objective outcomes can be obtained with both autograft and allograft BPTB ACL reconstructions.

Finally, a retrospective study about the restoration of proprioception after ACL reconstruction with BPTB autograft and allograft was conducted by Ozenci et al. [40]. They compared four groups of 20 subjects each including ACL deficient, autograft reconstructed and allograft reconstructed patients and healthy controls. Auto- and allograft reconstructions were not different from each other and controls according to proprioceptive measurements. They also reported that proprioception was not correlated to postoperative anterior knee laxity. Although their study was retrospective and selective in nature, with a relatively small number of patients, they concluded that auto- and allograft ACL reconstructions are identical according to proprioceptive functions.

## Conclusions

ACL reconstruction is a usual procedure for sports medicine orthopedists today. Autografts and, more specifically, the "golden" standard BPTB and hamstrings tendons have good-to-excellent results in terms of knee stability, patient satisfaction, and return to athletic activity. However, autografts and especially BPTB could cause specific donor-site morbidity and for that allografts have become an alternative option. Allografts have the advantages of no donor-site morbidity, shorter operative time, small incisions, easier and possibly less painful rehabilitation, and no size restrictions. However, questions remain concerning the actual risk of infection and disease transmission after implantation. Even if there is significant progress in screening, processing and sterilization techniques, the risk has not been eliminated. Additionally, when using allograft tissue, one must be aware that it may generate a low-level immune response. It has also been reported that allografts have delayed embodiment time and greater cost, and that the mechanical and biologic effects of the sterilization processes on allograft tissue remain

unknown. Overall, the choice of graft material depends on surgeon and patient preference since no graft can match completely the biomechanical properties and function of the native ACL.

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