Graft Selection in Posterior Cruciate Ligament Surgery

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Introduction

There are many factors to take into account when assessing patients with PCL injuries. Here, we present a brief overview of some of the issues influencing management of PCL rupture. The type of graft selected by a surgeon can have a significant impact on the clinical management and outcome of these patients. Thus, it is necessary for surgeons to have a broad understanding of the variety of graft options available. Unfortunately, for multiple reasons, many surgeons do not have much specific knowledge surrounding the tissue grafts that are commercially available to them at individual hospitals and surgery centers [1]. There exists wide variation among allograft distributors with regard to the donor pool from which the grafts are obtained, the screening process of donors, and possible sterilization processes. In addition, there are multiple different allograft tissue types that can be selected for PCL reconstruction. In this chapter, we will present the medically relevant differences among the many graft options currently utilized in PCL reconstruction including a discussion of their biomechanical properties and biological differences.

Patient Factors

Several patient-related factors including patient age, activity level, acuity of injury, surgical history, and medical comorbidities are important to consider. The age of the patient is a key factor in developing an appropriate treatment plan specific to a given patient. In skeletally immature patients, the surgeon may consider employing surgical techniques and specific grafts to minimize the risk of physeal arrest and the risk of resultant angular deformities. Allografts may be particularly beneficial in middle-aged and older patients who are hoping to avoid donor-site morbidity associated with the use of autografts, to minimize postoperative pain, and to reduce time away from work. In addition, a patient's desired activity level, the types of activities in which they participate, and their profession can also influence management and graft selection.

The acuity of the PCL injury and presence of concomitant injuries can also influence the reconstructive approach. With an isolated tear, the PCL has a greater likelihood of spontaneous healing than the anterior cruciate ligament (ACL) in the subacute or acute stages [2]. However, residual laxity or PCL rupture associated with other injuries, such as those causing posterolateral rotary instability, may necessitate surgical intervention [3]. In high-energy PCL injuries, which generally involve multiple ligaments, compromise of vascular structures, compartment syndrome, or the presence of an open or irreducible joint can necessitate an urgent surgical intervention consisting of revascularization, surgical reduction, or compartment release; however, most surgeons prefer to delay ligament reconstruction for a few weeks in an attempt to decrease swelling of the soft tissue envelope. In general, definitive ligament repairs and/or reconstructions performed within 2–3 weeks from the time of injury have been associated with better outcomes [4–7]. Chronic injuries may necessitate ligament reconstructions be performed in conjunction with osteotomies either concurrently or in a staged one [8, 9].

Prior surgical procedures can present challenges as a result of retained hardware, prior autograft tissue harvest, prior tunnel placement, tunnel osteolysis, and geography of prior skin incisions. Additionally, medical comorbidities, psychological impairment, and concomitant central nervous system (CNS) injury all can influence surgical recommendations.

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Graft Factors

The goal of surgical intervention is to obtain an anatomic repair, when possible, or reconstruction of any associated ligamentous and capsular injuries. Several options exist regarding the material used to perform PCL reconstruction with the mainstays of treatment consisting of either allograft or autograft. Each option has a multitude of advantages and disadvantages, which will be further discussed. It is essential that treating surgeons have an understanding of the particular grafts that are available for implantation in their individual surgical practice because the recruitment of donors, harvesting, screening, possible sterilization, and assaying of grafts can vary among graft distributors. The use of allograft versus autograft tissue for ligamentous reconstruction is still debated in the literature with some authors advocating autograft as the gold standard and yet others have been demonstrating decreased pain and stiffness with equivalent objective and subjective outcomes with allograft compared to autograft [10–16]. Some authors recommend use of different autografts for specific surgical techniques, such as a hamstring tendon autograft for transtibial tunnel PCL reconstruction and use of quadriceps tendon autograft for femoral inlay [17, 18]. Others suggest use of Achilles tendon allograft for single-bundle reconstruction with a tibialis anterior allograft for the second graft in a double-bundle procedure [19]. Despite the controversy, the efficacy of all of these graft options has been demonstrated and, thus, both appear to be good choices [13, 20–29].

Availability of Graft

Limited supply of both autograft and allograft tendons can restrict the availability of grafts for clinical use. Autograft is particularly limited in the case of multiligamentous injuries that require multiple grafts, and harvesting can cause donor-site morbidity. For these reasons, many authors have advocated the use of allograft tissues for PCL reconstruction. However, allograft also has limited availability, and this availability can vary greatly by geographic region. Allograft distributors acquire specimens from a limited donor pool, as the preferred grafts arise from uninjured, young, appropriately screened donors who have themselves or by proxy of their family members voluntarily agreed to donate their tissues [1]. Although the grafts are tested for infectious diseases including hepatitis B virus (HBV), hepatitis C virus (HCV), and HIV, it is still possible that these illnesses or others could be transmitted.

Although unavailable in the USA, an alternative to autograft and allograft ligaments in other countries is synthetic grafts. Synthetic grafts theoretically would have the advantages of availability, consistency, and appropriate mechanical strength, while eliminating concerns regarding autograft morbidity as well as the risk of disease transmission associated with allograft. Carbon fiber, Dacron, bundled polytetrafluoroethylene (GORE-TEX™), ABC carbon, polyester, and ligament augmentation devices have all been investigated either in animal models or even implanted clinically in the past. Some of these implants exhibited promising initial results; however, longer term follow-up demonstrated recurrent instability and chronic effusions as a result of catastrophic failures, chronic inflammatory reactions, particulate debris, or poor biologic scaffolding properties [30–39]. As a result, the use of synthetic ligaments for PCL reconstruction is not currently recommended, and none of these are unconditionally approved by the Food and Drug Administration (FDA) for clinical use in the USA.

Bioengineered ligament grafts are also not currently approved for implantation in the USA. However, clinical applications of this technology are actively being pursued and have demonstrated considerable promise. Hopefully, bioengineered ligaments will be available in the future as their use could potentially eliminate the risks currently associated with the use of both autografts and allografts [40–46].

Autograft

Several autograft tissue options are available for harvest either in the ipsilateral or contralateral extremity among patients with a posterior cruciate ligament injury, including bone–patellar tendon–bone (B-PT-B), hamstring (semitendinosus and/or gracilis), and quadriceps tendon–patellar bone (QTB). A meta-analysis of 12 studies of autograft used in isolated PCL reconstruction found that hamstring tendon was used in 72% of patients, followed by B-PT-B in 16%, and QTB in 12% [13]. The extensor mechanism acts synergistically with the PCL to prevent posterior tibial translation; thus, weakening the quadriceps is a theoretical concern when using it as an autograft [47]. For this and other reasons, QTB is less popular than other graft options [48, 49]. However, good short- and long-term results have been reported for PCL reconstruction with quadriceps tendon [50, 51], hamstring [52–59], and B-PT-B autografts [52, 57, 60], with no significant difference found in direct comparisons of QTB with hamstrings [51] or B-PT-B with hamstring grafts [52, 60]. Thus, there is no uniformly ideal autograft choice. Each graft has its own strengths and weaknesses with regard to biomechanical properties, ease of harvest, morbidity, biology of healing, and fixation strength.

Autograft does enjoy several advantages over the use of allograft for ligamentous reconstructions. Autograft tissues have no risk of transmission of an infectious disease; they

exhibit faster incorporation with adjacent tissues, and have no risk of immune-mediated tissue rejection. Additionally, autograft tissues are not exposed to sterilization or other sterilization modalities, which could have a negative impact on both the biomechanical and biological properties of the graft.

However, donor-site morbidity is associated with autograft tissue harvest, potentially representing a distinct disadvantage. Autograft hamstring harvest has been associated with symptomatic neuroma, numbness, arthrosis, symptomatic hardware requiring removal, posterior knee pain tunnel osteolysis, and terminal flexion hamstring weakness [1–66]. B-PT-B harvest is associated with patella fracture, patellar tendon rupture, infrapatellar contracture, loss of range of motion, arthrosis, patellar tendonitis, quadriceps weakness, and, most significantly, an increased incidence of anterior knee pain [29, 49, 62, 67–75]. QTP has a similar constellation of associated complications to B-PT-B, albeit to a lesser degree, consisting of a low incidence of decreased range of motion, anterior knee numbness, and anterior knee pain [76, 77]. Moreover, the larger skin and soft tissue incisions as well as bony cuts that are associated with autograft harvest expose an already injured body region to further trauma. Although some authors propose that hamstring tendons can regenerate after harvesting and that anterior knee pain is not exclusively observed in autograft B-PT-B grafted patients, there is no doubt that the risk of morbidity associated with autograft tissue harvest is significant and necessitates appropriate surgeon consideration and preoperative patient counseling [47, 78, 79]. This is of particular importance in patients with multiple ligament injuries in which multiple grafts will be required for surgical reconstruction. Also, there can be a limited quantity of available autografts. For these reasons, most surgeons prefer allograft, when available, for most PCL reconstructions.

Surgical Technique

Harvesting of autograft tissue can be performed via multiple approaches with regard to separate skin incisions and desired dimensions of the harvested graft; however, the basic techniques described below are quite similar. A brief surgical description of specific autograft harvesting techniques is discussed below.

Patellar Tendon

An infrapatellar midline incision is performed, slightly medial to the midline. Dissection is carried out down to the subcutaneous tissue and the paratenon is identified. The paratenon is sharply incised and reflected, thus exposing the patellar tendon. A central section of the tendon is excised measuring 9–11 mm wide throughout its length. Bone plugs of 20–30 mm in length on both the tibia and the patella are created with an oscillating saw and osteotomies [61].

Hamstrings

The hamstring tendons insert 2 cm distal and 2 cm medial to the tibial tubercle. The sartorius fascia is identified and incised. The semitendinosus and gracilis tendons are located directly beneath the Sartorius fascia with the interval between them being more easily distinguishable proximally. Careful blunt and sharp dissection can be used to further isolate the tendons and to free them from the surrounding tissues. A tendon stripper is passed up the tendons proximally to release them from the muscle [20].

Quadriceps Tendon

Quadriceps tendon autograft is harvested through a longitudinal midline incision extending from the superior pole of the patella. After dissecting through subcutaneous tissues, the prepatellar retinaculum is isolated and preserved. The quadriceps tendon and its junction with the vastus medialis obliquus and vastus lateralis obliquus are identified proximally (Fig. 8.1). An incision is carried out through some or all layers of the quadriceps tendon. The graft may be harvested with or without a bone plug from the superior patella [80, 81].

Allograft

The American Orthopaedic Society for Sports Medicine (AOSSM) has estimated that approximately 60,000 allografts were used in knee reconstruction procedures alone in 2005 [82]. Because of potential graft necrosis and the relatively large size of the native PCL, larger graft options are preferred for allograft PCL reconstruction. The Achilles tendon (Figs. 8.2 and 8.3), with its large cross-sectional area, is currently the most frequently used graft for acute (43 %) and chronic (50 %) PCL reconstructions [78] due to its large size. Double-stranded anterior and posterior tibial tendons (Figs. 8.4 and 8.5) are also commonly used allografts. Other allograft options include B-PT-B (Fig. 8.6), hamstrings (Fig. 8.7), and QTB (Figs. 8.1 and 8.8).

Surgeons are attracted to allograft ligament reconstructions because they eliminate donor-site morbidity as well as the additional risks associated with autograft tissue harvest. Furthermore, allografts provide multiple graft size options, shorter operative and tourniquet times, as well as fewer incisions as a result of not needing to harvest autograft tissue

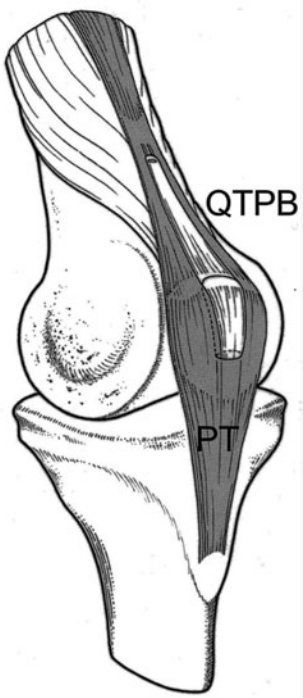

Fig. 8.1 Diagram of quadriceps tendon-patella bone (QTPB) harvesting. PT denotes patellar tendon [119]

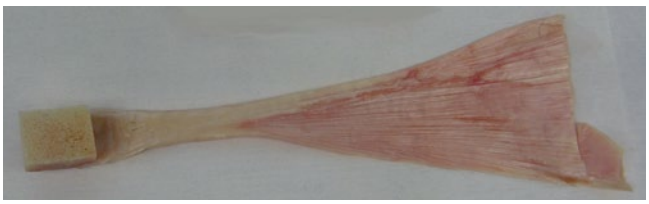

Fig. 8.2 Achilles tendon–bone allograft removed from package. Image kindly provided by Musculoskeletal Transplant Foundation (MTF) [120]

[22, 27, 83, 84]. Unfortunately, the use of allograft tissues is also associated with its own set of complications, such as small risk of infectious disease transmission, slower incorporation of graft tissue, and the potential for immunologic rejection [1, 21, 34, 85–91].

Fig. 8.4 Tibialis anterior allograft. Image kindly provided by Musculoskeletal Transplant Foundation (MTF) [120]

Fig. 8.5 Tibialis anterior allograft ready for implantation. Image kindly provided by Musculoskeletal Transplant Foundation (MTF) [120]

Fig. 8.6 Bone–patellar tendon–bone allograft ready for implantation. Image kindly provided by Musculoskeletal Transplant Foundation (MTF) [120]

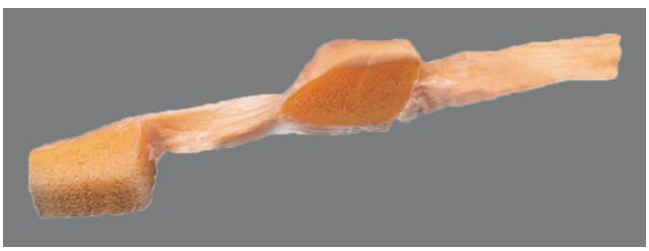

Fig. 8.7 Quadriceps tendon–patellar bone–patellar tendon–tibial bone allograft after removal of packaging [120]

Fig. 8.3 Achilles tendon–bone allograft being prepared for implantation. Image kindly provided by Musculoskeletal Transplant Foundation (MTF) [120]

Fig. 8.8 Quadrupled hamstrings allograft

Risk of Infectious Disease Transmission

Infectious disease transmission, albeit exceedingly rare, is a distinct possibility when implanting allograft musculoskeletal tissues and there have been multiple documented cases of disease transmission in this manner, some of which have resulted in the death of the patient [1]. It is possible to transmit human immunodeficiency (HIV) virus type 1 and type 2, HBV, HCV, bacteria, such as clostridia or treponema pallidum, fungi, parasites, West Nile virus (WNV), and human transmissible spongiform encephalopathies.

The risk of HIV transmission in a properly screened donor ranges between 1 in 173,000 and 1 in 1 million and the corresponding risk of HCV is 1 in 421,000 for unprocessed tissue [1]. The most concerning incident regarding HIV transmission in the setting of allograft ligament implantation was in 1986 when a fresh-frozen B-PT-B allograft, which was not secondarily sterilized and was derived from a young male donor with no known risk factors for HIV whom tested negative for HIV-1 antibodies, was implanted into a patient [86]. Three weeks following surgery the recipient was treated with supportive therapy for flu-like illness and lymphopenia was noted. The patient was not diagnosed with HIV until several years later after an investigation was carried out to identify the cause of seroconversion in a woman whose only risk factor for HIV was the receipt of bone allograft from the same donor. Other non-musculoskeletal allografts from the same donor also resulted in disease transmission. At the time of this incident, HIV testing of donors was performed via detecting the presence of anti-HIV antibodies, which may take several months to become detectable in the peripheral blood of recently infected individuals [86]. Currently, nucleic acid testing (NAT) is now required by American Association of Tissue Banks (AATB). HIV, although it is a retrovirus, synthesizes DNA that is detectable within the leukocytes it infects and NAT can be carried out effectively within 48 h of a donor's death. In addition to this case of HIV transmission, there have been at least two separate documented reports of hepatitis C transmission as a result of receiving patellar ligament allografts from infected donors [92, 93]. Again, these incidents occurred as a result of harvesting tissue from an anti-HCV antibody negative donor where NAT was not performed. Although the pool of allograft donors who fall into the category of anti-HCV antibody negative yet HCV-RNA positive is unknown, in 2003 this serology pattern was present in approximately four out of every one million blood transfusion donors [92]. Although sterilization of allografts will be discussed later, it should be noted that studies have demonstrated that although freeze-drying and radiation may decrease the already low risk of HIV transmission it does not eliminate this risk completely [86, 94, 95].

In addition to viral transmissions, several bacterial infections have resulted from musculoskeletal allograft implantation [1, 96]. Allograft tissues distributed by vendors operating with questionable standards that occurred between 2001 and 2005 prompted the FDA to require more stringent surveillance of organizations procuring allograft tissue. As a result, all tissue banks are now required to register with the FDA and follow Current Good Tissue Practice requirements designed to minimize risk to allograft recipients [1, 96]. These examples bring three points to light: (1) there is a definite time lag between a donor contracting a virus and our current ability to detect its presence (approximately 7–10 days with NAT testing), (2) secondary processing and sterilization processes have the potential to effectively decrease the risk of viral disease transmission yet, and (3) there will always be a finite risk to patients when implanting musculoskeletal allografts [1, 97].

As mentioned previously, the risk of HIV and HCV is exceedingly low and the authors are unaware of any documented transmissions in the setting of appropriately screened donors and modern NAT. Additionally, an investigation by Greenberg et al. in a large series of patients failed to demonstrate an increased risk of bacterial disease transmission associated with implantation of allograft tissues [98]. Again, this underscores the importance of the surgeon becoming knowledgeable about the procurement practices of their allograft provider so that the surgeon can help patients make informed decisions about their care.

Delayed Incorporation of Allograft

Healing of a ligament graft occurs in three phases: inflammatory, proliferative, and remodeling. Within the inflammatory phase, neutrophils and other inflammatory cells arise and the water content of the graft increases ultimately leading to decreased biomechanical properties of the tendon itself. Graft necrosis then occurs, which is believed to be the cause of the permanent strength loss observed in reconstructed ligaments, when compared to their biomechanical strength at the time of implantation [87]. Next is the proliferative phase in which fibroblasts and synovial cells infiltrate the graft from the bone tunnels and vascular granulation tissue engrafts into the ligament matrix. Finally, the disorganized fibroblast and extracellular matrix mass is reorganized into a more highly

cellular tissue with tensile-strength properties. This process is termed "ligamentization." Although a similar pattern of revascularization and incorporation of the graft with host tissue occurs among both autograft and allograft tissues, it has been well documented that autograft tissues incorporate faster than allograft tissues [87–90, 99]. It may take up to one and a half times longer for allograft to completely remodel and gain comparable strength to autograft [100]. ACL retrieval studies at autopsy suggest that allograft incorporation continues for more than 2 years [101]. Despite the slower rate of incorporation, the eventual healing is almost identical to the healing of autograft [102, 103]. Inherent to this delayed incorporation is the potential for graft rejection. Although this has been reported in musculoskeletal allograft, it rarely impacts the clinical course of the patient [104, 105].

Procurement of Allograft Donor Tissue

The screening of acceptable donors is quite rigorous as this is the first barrier to preventing disease transmission. Prospective donors or their relevant family begin by completing a questionnaire detailing their medical, social, and sexual history. An inquiry is made regarding drug use, neurologic diseases, autoimmune diseases such as rheumatoid arthritis, metabolic disease, collagen disorders, and exposure to hepatitis, HIV, or Creutzfeld–Jacob disease, or unprotected anal sex. Any positive response disqualifies them as a donor. Next, a thorough physical exam is performed, evaluating for signs of infectious diseases such as sexually transmitted diseases, hepatosplenomegaly, lymphadenopathy, thrush, and skin lesions. Again, any positive findings disqualify the donor. Next, a blood sample is obtained. The FDA requires that recovered tissue must be negative for HIV-1 NAT, HCV NAT, and hepatitis B core antibody. American Association of Tissue Banks (AATB)-accredited banks require additional testing for HIV type 1 and type 2 antibody, hepatitis B surface antigen, total antibody to hepatitis B core antigen (IgG and IgM), HTLV-I/HTLV-II antibody, HCV antibody, a syphilis assay, as well as NAT for HCV and HIV-1. Tissues are then harvested using sterile techniques within 15 h of asystole for an unrefrigerated donor or within 24 h of asystole for refrigerated donors. Specimens are contained in wet ice for transport with a maximum of 72 h on wet ice before transfer to colder environment is required [1, 96, 97].

Sterilization of Allografts

In 2006, a survey of 365 members of the AOSSM indicated that 86% of them utilized allografts, yet 21% were not aware of whether their allograft source was accredited by the AATB [1]. Furthermore, the vast majority of surgeons surveyed believed that the sterilization process had deleterious effects on the biomechanical strength of these allograft tissues. Gamma irradiation to 1.5 mrad, combined with antibiotic soaks, is a common method of sterilization. Yet, gamma irradiation to a level of greater than 3.5 mrad is estimated to be required to eliminate HIV [95]. Furthermore, gamma irradiation above 3 mrad has been shown to decrease allograft maximum failure force by up to 27% and strain energy to maximum force by up to 40% and, as a result, doses below 2.5 mrad are currently recommended to prevent damage to graft biomechanical properties [97, 106]. In response to this, research involving the use of free radical scavengers in conjunction with radiation is currently underway in order to balance adequate prevention of infectious disease with the preservation of biomechanical properties [107].

Ethylene oxide (EtO) was formerly a commonly implemented sterilization technique. However, after an association of a resultant chronic inflammatory reactions (effusions) and increased graft failures with its use was demonstrated, it was eliminated from AATB approved tissue banks [108, 109].

There are many other proprietary sterilization techniques involving serial soaks alternating tissue-culture-grade water with denatured 70% ethanol, biologic detergents, dimehtylsulfoxide, antibiotics, or hydrogen peroxide. Additional treatments may consist of ultrasound, centrifugation, and repeated irradiation cycles [96]. Some tissue banks with proprietary sterilization techniques claim that tissue integrity is not damaged by the sterilization processes [110]. However, sterilized grafts have been associated with poor clinical outcomes in several investigations [111–113].

Storage of Allograft

Cryopreservation is a process of slowly cooling a graft while extracting the intracellular water using various chemical soaks such as dimethylsulfoxide or glycerol. Following the chemical soaks, a controlled rate of progressive freezing to −135 °C is carried out, with the graft ultimately being stored at −196 °C for up to 10 years. This controlled freezing in cryoprotectant solution inhibits the formation of ice crystals and thus preserves collagen integrity. It was theorized that this would also preserve cellular integrity and thus be associated with an increased risk of graft rejection. However, a minimal histological inflammatory response at the allograft ligament as well as normal, rather than accelerated, rejection of corresponding allograft full-thickness skin graft was demonstrated. This, as well as a complete absence of donor DNA by 4 weeks post-transplantation, indicated that there was minimal cell survival among these cryopreserved allografts [113].

Fresh-frozen treatment of allografts is the most commonly utilized storage modality and consists of rapid freezing of the graft to −80 °C or −100 °C without additional sterilization processing. It has been shown to eliminate cellular components that lead to immunologic rejection of allograft tissue [88]. Freeze-dried samples are created by removing the marrow and blood from the specimen and freezing the tissue for a quarantine period. After quarantine, the tissues are thawed, treated with antibiotic soaks, and exposed to serial alcohol rinses in order to dehydrate the specimens. They are subsequently lyophilized and packaged. The resultant graft can be stored for up to 5 years. There is very little immunogenic response when implanted. However, unlike freeze-dried bone, the biomechanical properties of freeze-dried tendons have been demonstrated to be inferior to fresh-frozen specimens and the potential for viral disease transmission is not completely eliminated [94, 114, 115].

Author's Recommendation

It is clear that allograft tissue plays a substantial role in PCL reconstruction. Any surgeon utilizing banked tissue should become familiar with the practices, protocols, and proven results of whichever allograft vendor is to be utilized. Some organizations providing allograft tissues surpass the requirements of the AATB and US Food and Drug Administration (US FDA). It is our recommendation that surgeons, at the very least, utilize allograft tissues from organizations whose processing and distribution comply with all of the required AATB and US FDA criteria for current good manufacturing practices. Furthermore, surgeons should be familiar with any sterilization processes used for grafts which will be implanted. Because of the potential deleterious effects of the sterilization processes on both the biomechanical and biological properties of allografts, the authors currently utilize only fresh-frozen nonirradiated allografts from an AATB member tissue bank. Routine culturing of allograft tissue in the operating room immediately prior to implantation is not currently recommended because there is little correlation with swab culture results and future allograft-associated infection [1, 116].

Conclusion

Graft selection in PCL reconstruction remains controversial, as there is a relative paucity of research on graft options for PCL reconstruction as compared to ACL reconstruction. While much of the knowledge of graft selection is based upon the experience with ACL grafts, the PCL is biomechanically different from the ACL [117, 118], and thus the results of specific graft use in PCL reconstruction may vary from those of the ACL [13]. To date, the literature has not shown significant differences in clinical outcomes with the use of autograft versus allograft or among the different types of each graft. Thus, the patient's specific characteristics and goals should be considered to help the patient make an informed decision.

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