Current Concepts

Anterior Cruciate Ligament Reconstruction: Which Graft Is Best?

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Abstract: For the last 4 decades, since the initial use of the patellar tendon for anterior cruciate ligament (ACL) reconstruction, there has been controversy regarding the ideal graft choice for this procedure. Beside bone–patellar tendon–bone autografts, several other graft choices have become popular, including hamstring tendon and a variety of allografts. Within the past 5 years, several randomized and nonrandomized studies have compared the graft choices in ACL reconstruction. However, the question still remains: Is there an ideal graft for ACL reconstruction? The purpose of this review is to assess the most recent data, identifying if there truly is an ideal graft choice. **Key Words:** Anterior cruciate ligament—Autograft—Allograft.

When treating a torn anterior cruciate ligament (ACL), many decisions must be made. If surgery is to be performed, the decision regarding graft choice is both critical and controversial. There are several options that the patient and surgeon can consider concerning the graft used for ACL reconstruction. The graft could be autograft, allograft, or synthetic. Although the synthetic option is not frequently exercised owing to high failure rates[1,2] and other complications, there are many options in both the autograft and allograft categories. The 2 most common autografts for ACL reconstruction are bone–patellar tendon–bone (BPTB) and hamstring tendon. In the last few years, several controlled studies have been published comparing these 2 autografts.[3-17] Several studies have also been performed looking at the success rates of allografts versus autografts.[18-24] The perfect graft would have no harvest-site morbidity, have rapid and secure fixation, and consistently restore the patient's activity level back to preinjury levels. This article is designed to provide a review of graft choices for ACL reconstruction while at the same time focus on the most recent controlled studies published on the subject matter.

AUTOGRAFTS

There have been several different autografts used for ACL reconstruction, all with varying results. Although BPTB and hamstring tendon are currently the most common autografts used, quadriceps tendon and iliotibial band have also been tried. No longer common, the iliotibial band was used mainly in extra-articular procedures.[1] The quadriceps graft is still used by some surgeons,[25] but is not a procedure that is frequently performed.

To begin the discussion of ACL autografts, it must be made apparent that the BPTB autograft has been deemed the gold standard to which the effectiveness of all others are compared. The graft consists of the central one third of the patellar tendon and includes a bone plug at each end—proximally from the patella and distally from the tibia. Because the patellar tendon has a high strength and

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stiffness, and the bone-to-bone interference screw fixation allows for solid fixation and rapid graft incorporation, the BPTB graft is the most commonly used graft for ACL reconstruction.[26] However, the graft is criticized for resulting in significant harvest-site morbidity, including complications such as anterior knee pain, pain when kneeling, patellar fracture,[27] patellofemoral crepitation,[3] numbness caused by damage of the infrapatellar branch of the saphenous nerve,[4] and possible loss of quadriceps strength.

To avoid some of the harvest-site morbidity, there has been an increase in popularity of the use of hamstring tendons as the autograft for ACL reconstruction. The hamstring tendon graft is typically semitendinosus and gracilis tendons, or semitendinosus alone. The tendons are looped over to create a quadruple strand structure that is sutured together to form the final graft. Although the hamstring graft is not completely free of donor-site morbidity, and some investigators have actually found no significant difference in anterior knee pain between hamstring and BPTB,[3,5-9] there still exists the perception that there is less donor-site morbidity associated with hamstring autografts. Ejerhed et al.[8] hypothesized that the infrapatellar nerve branches injured during the BPTB graft harvest form neuromas that are in direct contact with the floor when kneeling. The possible neuromas that form with the hamstring harvest are outside the loaded area of the knee, resulting in less overall pain.

Another interesting fact about the hamstring tendon autograft is the hypothesis that the semitendinosus and gracilis tendons actually regenerate after harvest. This hypothesis had only been supported radiographically until Ferretti et al.[28] surgically visualized fibrous bands reproducing the path of the native semitendinosus tendon. The researchers' finding was further reinforced by histologic examination revealing spindle-shaped cells that closely resemble tenocytes. Although these findings are very promising, further prospective randomized studies must be performed before these results can be considered conclusive.

There are 2 major criticisms to the use of hamstring tendon autograft for ACL reconstruction. One issue involves the strength and stiffness of the graft. Initial reports of the hamstring autograft stated that it did not have the same strength or stiffness as the native ACL or other autografts, leading to early graft failure. Later techniques improved the strength and stiffness by utilizing a quadrupled hamstring graft.

In the past 20 years, studies have been published comparing the biomechanical aspects of the different grafts. Many of the studies were flawed in that they used inappropriately sized grafts, used different fixation techniques between the grafts, or did not compare the grafts with regard to forces that would occur in the anatomic position. Recently, Wilson et al.[10] compared the biomechanics of the BPTB and hamstring grafts. Using the same fixation techniques with both grafts, they found that in the quadrupled state, the hamstring graft has an average load failure of 2,422 N versus 1,784 N for the patellar tendon graft. Further, there was no statistically significant difference in stiffness between grafts (patellar tendon, 210 N/mm; hamstring tendon, 238 N/mm). To the best of our knowledge, this study is the first to actually compare the quadrupled hamstring tendon to the BPTB graft. Other studies looking at strength and stiffness have tested the gracilis and semitendinosus alone and then extrapolated from these results to the actual strength when in the quadrupled state.

Related to strength and stiffness, the hamstring tendon autograft has also been considered inferior to the BPTB autograft in regard to fixation strength. Because the BPTB graft has a bone plug at each end of the graft, it is able to be rigidly fixated at both the femoral and tibial tunnels through the use of interference screws. With the hamstring tendon autograft, there is the need to fix soft tissue to bone. Several techniques have been described for hamstring fixation including fairly new soft tissue interference screws. Different surgeons have their own preference for a particular fixation method making comparisons between different autografts difficult.

Within the last 5 years, several controlled studies have been performed specifically comparing the BPTB autograft with the hamstring autograft for ACL reconstruction. Because different techniques, fixation devices, assessment tools, subjective scores, and follow-up periods were used, it is necessary to evaluate each study for the quality of its results.

Many studies have followed the principle that the correct way to compare the grafts is to use the same fixation method for both types of autograft. Ejerhed et al.[8] reported a prospective randomized study comparing BPTB and semitendinosus tendon autografts, both with interference screw fixation. After a 2-year follow-up, the authors compared reconstructions on the basis of Lysholm score, Tegner activity level, KT-1000 measurements, single-leg hop test, International Knee Documentation Committee (IKDC) classification results, anterior knee pain, and kneeling discomfort. Through the various evaluations, the study found no statistically significant difference between the groups except for the fact that the individuals who received the semitendinosus graft had a statistically significant better ability to walk on their knees.

Shaieb et al.[11] reported a prospective randomized study similar to the Ejerhed study, looking at the BPTB autograft versus a semitendinosus and gracilis tendon autograft. In this study, 70 patients were followed up at 2 years and interference screws were used for fixation of both types of graft. The only statistically significant findings included less range of motion and more patellofemoral pain with the BPTB autograft.

Beard et al.[6] looked at 60 patients who were randomized to receive either the BPTB autograft or a 4-strand semitendinosus gracilis autograft. With a follow-up period of 12 months, there were no statistically significant differences between the 2 types of autografts in reference to any of the evaluation parameters. Further, no difference was found in anterior knee pain between the 2 groups.

The study with the longest follow-up was performed by Pinczewski et al.[12] In this nonrandomized study, 180 patients were followed for 5 years, 90 with BPTB autograft, and 90 with hamstring tendon autograft. In the BPTB group, there were a statistically significant greater number of patients with kneeling pain. Furthermore, by radiological assessment, the patellar tendon group also seemed to have more joint space narrowing, evidence of early osteoarthritic change. Corry et al.[13] also reported on a nonrandomized study. With a 2-year follow-up, there were no differences between the 2 grafts except for an increased mean laxity in female patients who received the hamstring tendon, and increased kneeling pain in the patellar tendon group. Although the results of the last 2 studies may be consistent with other studies, when interpreting the results of the nonrandomized studies, it must be remembered that significant bias can result from the nonrandomized study design.

Several studies have also been reported in which different techniques of fixation are used for the BPTB and hamstring autografts. Although the use of different fixation devices has been criticized as a means of comparing 2 types of grafts, one can rationalize that these studies are comparing the entire surgical procedure rather than just the isolated graft tissue. Jansson et al.[4] reported a prospective randomized study comparing BPTB and hamstring tendon autografts for ACL reconstruction. With a 21-month follow-up, the investigators looked at 43 patients in the BPTB group and 46 patients in the hamstring group. The BPTB autograft was fixated with metal interference screws. The hamstring technique utilized double-looped semitendinosus and gracilis, forming the quadrupled structure, fixated proximally with a metal plate and distally with a screw and washer. At the follow-up, there were no statistically significant differences between the 2 groups.

Eriksson et al.[9] prospectively randomized 164 patients to either BPTB autograft with interference screw fixation or the quadrupled semitendinosus autograft with EndoButton (Smith & Nephew, Andover, MA) fixation. Using many of the same assessment techniques as previous studies at an approximately 31-month follow-up, there were again no significant differences between groups.

In a follow-up report of a previous study,[14] O'Neill[15] followed 225 patients for a minimum of 6 years. O'Neill compared the outcomes of 3 techniques: doubled hamstring autograft with 2-incision technique, BPTB autograft with 2-incision technique, and BPTB with single-incision technique. Hamstring grafts were fixated with staples proximally and distally and BPTB grafts were fixated with interference screws. There were statistically significant flexion deficits in the hamstring group and extension deficits in the BPTB groups. However, there were no significant differences between the groups regarding functional outcome.

Not all recent studies have found the 2 grafts to be functionally equivalently. Aune et al.[5] performed a randomized study comparing quadrupled hamstring tendon and BPTB autografts. This study looked at 61 patients who had a follow-up 24 months after surgery. With the hamstring group, there was less kneeling pain, superior single-leg hop test results, and higher patient satisfaction. Regarding strength differences, the hamstring group showed inferior flexion strength even at the 24-month follow-up. These results on flexion strength are contradictory to the hypothesis that the semitendinosus and gracilis tendons regenerate.

In a study looking at flexion strength deficits with hamstring harvest, Tashiro et al.[16] found that patients who had reconstruction with both semitendinosus and gracilis autografts had more flexion deficits compared with patients who had the semitendinosus autograft harvested alone.

Beynnon et al.[7] compared the BPTB autograft with hamstring autografts, using 2-strand hamstring grafts rather than the quadrupled graft. At a 3-year follow-up, 22 patients with the BPTB autograft were compared with 22 patients who had the hamstring autograft. The authors report that, at the 3-year follow-up, there was decreased flexion strength in the hamstring autograft group. The investigators also reported increased laxity in the hamstring group. Clearly, the results of this study are in favor of the BPTB autograft.

In a prospective randomized study with a 2-year follow-up, Anderson et al.[3] evaluated 102 patients: 35 with the BPTB autograft, 34 with semitendinosus and gracilis autograft with an iliotibial band extra-articular procedure, and 33 with the semitendinosus and gracilis autograft alone. The BPTB graft was fixated using interference screws, and the quadrupled semitendinosus and gracilis autograft was fixated with staples proximally, and sutures distally. Increased laxity was found in both groups that received the hamstring tendon graft. The extra-articular procedure did not help these laxity issues. Further, they found that the final IKDC rating indicated that the patients with the BPTB graft had a higher incidence of normal results than the other 2 groups. It is hard to determine if the fixation technique used in the hamstring group could account for the increase in laxity. Nevertheless, the results of the study show the BPTB autograft as the more successful procedure.

Most recently, Feller et al.[17] compared the autografts in 57 patients at a 3-year follow-up. Although different fixation measures were used distally, EndoButton fixation was used at the femoral tunnel for both types of autograft. Anterior knee pain and pain while kneeling had a higher incidence in the BPTB group. There were no statistically significant differences in Cincinnati or IKDC scores, yet 88% of the BPTB group versus 68% of the hamstring tendon group reported level I or II activity levels at the 3-year follow-up ($P = .1$).

Because of the numerous studies that have been carried out in the last 2 decades comparing the BPTB autograft with the hamstring tendon autograft, in recent years, 2 meta-analyses have been completed on the subject. It is obviously difficult to perform a prospective randomized design that also has a large sample size. With the meta-analysis, the investigators are able to group the results of several similar studies and gain more statistical power with a larger sample size. In terms of this review, these meta-analyses allow a summary of the studies that did not occur in the last 5 years but over the last 20 years.

In the most recent meta-analysis, Freedman et al.[29] pooled data from 34 studies. This grouping of studies enabled the authors to calculate data from 1,976 subjects, clearly more than any of the prospective studies previously discussed. The study found significantly lower rates of graft failure, less laxity, and higher patient satisfaction in the BPTB group. However, there was a higher incidence of anterior knee pain in the BPTB group.

Another meta-analysis performed 2 years earlier by Yunes et al.[30] only allowed 4 studies to fit into the inclusion criteria. Grouping of these studies allowed the data review of 411 subjects, which is still far more than any of the prospective controlled studies. The authors found that the BPTB group had significantly less laxity than the hamstring group when evaluated by the KT-1000 arthrometer at 20 lb. Further, all 4 of the included studies suggested that the BPTB group had a higher rate of "return to preinjury level of activity." The study was unable to compare donor-site morbidity between groups because the included studies did not have comparable information.

When reviewing these meta-analyses, it is easy to be persuaded by the results because of the large sample size. However, it is extremely important to note that, although inclusion criteria are met for the studies included in the meta-analysis, there are several differences between the grouped studies. For example, some of the included studies are not randomized, there is no consistency among fixation techniques, there were different rates of comorbidity associated with ACL rupture, and the meta-analyses depend on the consistency of evaluation parameters between the studies so as to be able to group the data in an accurate method. Just as the prospective randomized studies are flawed owing to the fact that they have a small sample size, the meta-analyses are far from being perfect studies.

After a review of the most recent studies concerning BPTB autografts versus hamstring autografts for ACL reconstruction, it is clear that the controversial debate is far from over. Although some of the best-designed prospective randomized studies show no difference between patellar and hamstring tendon autografts, it can still be argued that the subject size is too small and the follow-up is too short. The meta-analysis is a method that can be used to alleviate the small sample size, yet as discussed earlier, it is a design that has problems of its own. Although patients who have occupations requiring significant amounts of kneeling and those whose religions require kneeling may wish to consider this harvest-site morbidity, to date, there have yet to be data that disprove the BPTB autograft as the functional gold standard autograft in ACL reconstruction.

ALLOGRAFTS

In an attempt to completely prevent issues associated with donor-site morbidity, the allograft is an option for ACL reconstruction that has gained popularity in recent years. Beside having less donor-site morbidity, allografts also lead to less surgical time, improved cosmetic result, and the possibility of an earlier and faster rehabilitation.

There are many allograft options for ACL reconstruction. In recent years, the Achilles tendon, BPTB, and fascia lata have been the most frequently used. There are also studies looking at the use of the tibialis anterior tendon as a successful allograft in ACL reconstruction. Caborn et al.[31] support use of the tibialis anterior allograft on the grounds that it is a strong tendon that can be prepared with only one doubling of the graft.

Allografts are not without their faults. One of the main concerns with an allograft is the transmission of disease. For example, in 2001, a patient died of *Clostridium sordellii* septic shock after receiving an infected allograft 2 days earlier.[32] Yet with proper aseptic tissue processing, tissue sterilization, and extensive donor screening, the risk of disease transmission from the allograft is very small. In fact, HIV transmission from properly screened allografts has been currently estimated to be as low as 1 in 1,500,000,[33] The American Association of Tissue Banks currently screen for hepatitis B surface antigen, hepatitis B core antibody, hepatitis C antibody, syphilis, HTLV-1 antibody, HIV I and HIV II antibodies, and HIV P24 antigen.[34]

In addition to extensive screening, allografts can also be sterilized. The 2 most common methods of sterilization have been ethylene oxide treatment and gamma irradiation. Ethylene oxide is no longer used because of associated synovitis and intra-articular graft destruction. Gamma irradiation is thought to create free radicals and modify nucleic acids leading to virus and bacterial destruction. However, it has been found that greater than 2 Mrad of radiation can affect the structural integrity of ligaments,[35] a dose that is insufficient to destroy HIV. Currently, because of complications, sterilization techniques are not used on allografts for ACL reconstruction. Extensive donor screening and aseptic harvest techniques are presently the main mechanisms to stop allograft disease transmission.

Other negative aspects of allograft use include added cost to the surgical procedure, immunogenic responses of the host to the graft, and delayed graft incorporation when compared with autografts. Malinin et al.[36] reported a recent study on the remodeling and cellular replacement of retrieved allografts. In this study, the investigators examined 9 ACL allografts that were obtained at autopsy. The authors note that in a specimen transplanted 2 years earlier, the center portion of the allograft had yet to be vascularized and remained acellular. Unlike previous studies stating that complete allograft repopulation occurs at 18 months,[37] this study shows that allograft repopulation can take up to 3 years or longer.

Although there are many concerns with the use of allografts, they are still frequently used. It is essential to look at the controlled studies to see if the data support allograft tissue as an ideal graft for ACL reconstruction. Because the BPTB autograft is deemed the gold standard in ACL reconstruction, several studies have been published comparing it with a variety of allografts.

Shelton et al.[18] compared 30 allograft patients with 30 autograft patients over a 2-year period. Using BPTB grafts with interference screw fixation in all cases, there were no statistically significant differences between the groups at a 2-year follow-up. One would expect to see less morbidity in the allograft group because of the complete lack of donor-site trauma; however, significant differences were not discovered.

In a study comparing 64 allograft with 26 autograft patients with a 3- to 5-year follow-up, Harner et al.[19] found results similar to the aforementioned study. The only significant difference found between the groups was regarding extension and flexion. The authors found that patients receiving an autograft had a higher incidence of limited knee extension ($>6°$ side-to-side difference). As with previously discussed studies, it must be remembered that significant differences could be hidden by lack of sample size and short time of follow-up.

Long-term structural integrity is also a concern about the use of allograft tissue. Victor et al.[20] looked at the morbidity associated with autografts compared with that of allografts, the hypothesis being that there would be less morbidity with the allografts. At the 2-year follow-up, the investigators found no significant difference in morbidity. However, 3 of the allografts had ruptured and there was increased laxity in the allograft group. Because of these claims of increased laxity and graft rupture, they speculate about a slow deterioration of the allograft over a long period of time. Stringham et al.[21] also found a significantly increased number of traumatic ruptures in the allograft group after a 34-month follow-up. Because of the finding of these studies, it may seem that the decrease in donor-site morbidity gained by the allograft may be offset by long-term instability of the graft.

To assess the claims regarding the long-term structural integrity of allografts, Noyes et al.[38] looked at 68 patients who had ACL reconstruction with either a BPTB or fascia lata allograft over a 7-year average follow-up. At the late follow-up, patients had less laxity than was measured at earlier examinations and their satisfaction rating was higher. Clearly, maintenance of graft stiffness in a 7-year follow-up refutes the hypothesis that there is degeneration of the allograft over a long period of time.

Kleipool et al.[22] looked at 36 BPTB allograft patients versus 26 autograft patients with an average 46-month follow-up. Interestingly, this study showed no difference in graft integrity, and no difference in overall morbidity.

Most recently, Peterson et al.[23] reported a nonrandomized study comparing autografts with allografts with a 5-year follow-up. The study found no increase in allograft stretching, graft rupture, or glide on pivot-shift testing. Chang et al.[24] performed a retrospective review with a 2-year clinical outcome comparing 46 BPTB allograft patients with 33 BPTB autograft patients, both reconstructions augmented with an iliotibial band tenodesis. Once again, there was no significant difference seen between the groups according to any of the evaluation parameters.

When considering the use of an allograft, the question that finally arises is, "What allograft is best?" Only one study to date, published within the last year, has actually compared allografts used for ACL reconstruction. Siebold et al.[39] compared BPTB allografts with Achilles tendon allografts; 183 patients with BPTB allografts were compared with 42 patients with Achilles tendon allografts over an average 37.7-month follow-up period. Using the same clinical evaluation parameters as previous studies, the investigators found similar results between the 2 allografts with the Achilles tendon-bone allograft having a lower failure rate. The investigators did mention that the total failure rate of the allografts was higher than that in comparable data collected for autograft ACL reconstruction.

When deciding to surgically perform an ACL reconstruction, the decision must be made whether to use allograft or autograft tissue. Several of the recent studies have shown that the 2 different options are comparable. However, the reduction in overall morbidity from the procedure with the use of allograft tissue has not been supported as one might intuitively be led to believe. Also, with the use of allograft tissue, although it is rare, one needs to realize the risk of disease transmission. Even though many tissue banks perform extensive background checks and tissue screening, not all tissue bank procedures are standardized or regulated.[35] There is also the possibility of unidentified viruses or prions that could be transmitted through the autografts. Despite the risks, some investigators believe that allografts have the potential to be used for routine ACL reconstruction.[33] In terms of this review, the benefits gained with allograft tissue do not outweigh the associated costs.

SUMMARY

Through the review of the recent literature it is clear that a perfect graft for ACL reconstruction does not exist. Because of this, the surgeon must be familiar with all varieties of possible graft choices. With the knowledge and ability to use the most appropriate graft, the surgeon can cater the procedure to each individual case. With regard to BPTB graft as the gold standard in ACL reconstruction, after careful review of the literature, there are no data that refute this claim. Even criticisms of the graft in terms of anterior knee pain have not shown statistical significance in prospective randomized studies when compared with hamstring tendon autografts or a variety of allografts. Granted, the lack of statistical significance could result from the small sample sizes observed in these studies.

The frequency of anterior knee pain could also be caused by different rehabilitation protocols that were followed in the different studies. Further research must be performed examining the optimal rehabilitation design after ACL reconstruction; different rehabilitation protocols could have different outcomes with the different grafts used. Clearly, each patient's individual needs must be considered when determining the perfect graft for that patient.

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