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Abstract

Current literature surrounding anterior cruciate ligament (ACL) reconstruction outlines four primary classes of grafts used to replace the existing ACL. These classes include bone-patellar tendon-bone (BPTB) autografts, hamstring tendon (HT) autographs, allografts and synthetic grafts.[26] Research has been conducted on each of these primary ACL reconstruction strategies and through this research we are looking to answer the question on which of these classes of ACL grafts in turn leads to the most improved long-term knee stability. In addition to analyzing these classes of grafts we will also inspect options along the non-surgical route to ACL repair, a more conservative approach, and its impact on knee stability in the long-term. Many studies have been conducted with a short-term follow up in their design. It is our goal to determine which ACL reconstruction graft option leads to the best long-term outcome for patients, as well as outlining pros and cons to each graft choice to help guide patients to the choice of the best ACL graft for them.

Question:

Does an ACL autograft, allograft or synthetic graft lead to improved long-term knee stability?

Introduction

ACL injuries are known to be one of the more devastation injuries that anyone can suffer, especially those that are participating in athletic settings. In the past an ACL injury was considered career threatening for athletes and, as for life outside of sports, it could lead to long-

term consequences such as chronic knee instability and recurrent knee injuries. As many as 120,000 ACL reconstruction are performed each year in the United States of America, with a documented five year revision rate between two and five percent. (Anatomy Review) The ACL is the ligament in the knee that prevents the tibia from displacing anteriorly and thus keeping the knee joint stable throughout the knee's range of motion in our daily lives. Other ligaments in the knee include the Medial Collateral Ligament (MCL), Lateral Collateral Ligament (LCL) and Posterior Cruciate Ligament (PCL), each functioning to keep the tibia aligned with the femur and preserving the stability of the knee joint. The PCL counters the ACL by not allowing the tibia to displace posteriorly from anterior forces to the knee joint. The MCL and LCL stabilize the medial and lateral sides of the knee joint respectively. Of the four knee ligaments, the one that is most frequently associated with long-term knee stability risk is the ACL. In this research, I will be looking specifically, at which ACL reconstruction option including, ACL autograft, allograft or synthetic graft, lead to improved long-term knee stability. Much research has been done on the topic of knee stability after ACL injuries but few have looked at long term sustainability. Most ACL knee stability studies follow up with patients in the range of one to five years, but as clinicians the more important outcomes from an ACL reconstruction may lie well outside of the five year range. When a patient has a procedure such as ACL reconstruction we should strive to achieve the best long-term outcomes as possible for the patient. In this research I hope to find an answer as to which ACL graft option will allow the patients to have the best long-term outcomes.

Options that exist for treatment include non-surgical options (such as physical therapy and rehabilitation options) and surgical options where the use of a graft is placed in the knee to replace the injured ACL. The different grafts that are currently available include autografts, allografts and synthetic grafts. Autografts are ones that come from the patient with the injured

ACL, Allografts are ones that come from a donor or cadaver and synthetic grafts are ones that are artificially made. Autografts that are used most frequently are Bone-Patellar Tendon-Bone (BPTB) grafts and Hamstring Tendon (HT) grafts. Allografts that are most frequently used include the tibialis anterior, tibialis posterior, achilles tendon grafts, as well as HT and BPTB grafts. Synthetic grafts used include the LAD, LK, LARS, PGA-Dacron.[17] Earlier types of synthetic grafts are the LAD and LK options. Newer options available for ACL reconstruction are the LARS and PGA-Dacron. With the numerous options for ACL reconstruction there are many pros and cons for each type of graft selection that goes into the selection process.[26] There of course is still the option to go with the non-operative route added into the mix of all the surgical options. Non-operative treatment for an ACL rupture is generally not taken for younger, more active patients.[13] This is due to the likelihood and desire for younger patients to return to their previous activity level as well as the desired knee stability that can not always be achieved through conservative measures such as non-operative rehabilitation

Graft selection is a debated topic to this day, due to the risk and benefits of each graft. allografts have statistically been shown to have higher graft rupture rates compared to autografts, while autografts have included morbidity since the graft is taken from a tendon of there own. The most common morbidities being anterior knee pain and kneeling discomfort.[18] Older synthetic graft options (LAD, LK) have been show to have higher rupture rates[17], where as newer synthetic options (LARS, PGA-Dacron) have show superior results to previous older synthetic grafts but have limited research and results compared to other options available since they are newer options that have just become available in the past few years.[26] The most proven, through research and testing results, in regards of knee laxity and knee function of the graft selections has been the autograft group. Within the autograft group there is debate on which graft type is

superior. Between the BPTB and HT graft options there have been conflicting results. As well there can be provider bias based on their past experiences and their comfort performing the various techniques. Other valuable components of graft selection include information about the patient. Major factors include patient age, activity level, severity of the ACL injury, knee stability and future goals of knee function. For any surgical procedure there is always the risk of infections that can develop where as non-operative management does not have this risk.

Throughout research when comparing graft quality there are certain measures that are commonly looked at. The first being knee laxity, measuring the "looseness" of the knee ligaments. Knee ligaments are supposed to allow the knee to move through its normal range of motion of flexion and extension. The more lax that knee ligaments are the more motion the knee joint can go through. This can be damaging to the knee ligament if it is stretched too far leading to a tear or rupture. Laxity of the ACL is measured through physical exam techniques such as the Anterior Drawer test and Lachman test, as well as through the use of a device called a KT1000 that specifically measures the amount of tibial displacement through a similar technique as a Lachman test. The KT1000 allows providers to quantify the amount of knee displacement whereas the Anterior Drawer and Lachman test go by provider feel, or provider discretion, of the knee ligament having a firm endpoint and not allowing for excessive movement of the tibia. Other tests used to assess knee function include a one legged hop, either a single or triple hop, where the injured and non-injured sides can be compared to each other. Return to pre-injury activity level is always a closely monitored factor in order to prevent re-injury/rupture of the ACL. ACL's that require a second reconstruction have poorer outcomes.

The outcomes that are most documented in current literature include graft laxity and graft rupture rate, other studies have also documented return to previous activity level and have used

other tests such as one-legged or triple-hop tests. Graft laxity is a measure of the "looseness" or the amount of stretch that a ligament allows for. This is an important measure since ligaments should allow some stretch for the joint to move through its range of motion but too much laxity may mean the ligament is damaged, may rupture, or is already ruptured. Ligament laxity can be measured quantitatively through the use of a KT-1000 or KT-2000 or qualitatively through an Anterior Drawer Test or Lachman Test. The quantitative data, through the use of the KT-1000/KT2000, is able to specifically measure how far displaced the tibia can move anteriorly. The more anteriorly the tibia can be displaced the greater laxity the ligament has, and the greater laxity may conclude that the ligament is damaged in some form. The qualitative data is obtained by a provider through the Anterior Drawer or Lachman Test. These are physical exam techniques that assess if the ligament demonstrates a firm end point that prevents the tibia from being displaced anteriorly. If a firm end point is not felt from the ligament when the tibia is displaced, then that indicates a positive test and thus enhanced ligament laxity is present.

An ACL is rarely the only ligament or structure injured when the injury occurs. ACL tears or ruptures are commonly associated with MCL injuries as well as meniscal injuries. If there are other injuries involved this can lead to a more complicated knee injury. An added meniscal injury can lead to a delayed surgery, as providers want to let the meniscus heal on its own before performing ACL surgery. The delayed reconstruction can lead to delayed return to function, decreased activity levels post-surgery and decreased patient satisfaction. MCL injuries are generally treated through non-surgical management regardless of associated injuries so this type of injury may not delay reconstruction but can contribute to long-term knee instability if not healed properly. Ligaments in the human body do not get sufficient blood flow since they are avascular structures which is why they have delayed healing time compared to other injuries.

In more recent history of ACL reconstruction there has been a decrease in the amount of time to return to previous activity level as well as lower documented graft rupture rates. This is very promising news for those that suffer from an ACL injury. This injury can still be devastating due to the associated injuries that can also occur simultaneously with an ACL rupture. Commonly the MCL and meniscus are also injured along with the ACL.[17] The added ligament and cartilage injuries can greatly impact a patient's return to normal function and sport performance. Depending on the circumstances a delay in ACL reconstruction may be required before the ACL can be repaired if other injuries need to heal prior to reconstruction surgery or if prior surgery is needed to repair portions of the knee joint other than the ACL. A delay in ACL reconstruction can lead to a prolonged recovery time as well as a potential for decreased knee function.[19]

Background

As discussed prior, a large portion of ACL research has been conducted with follow up ranging between one and five years. This research then only looks at the short and medium-term results of an ACL reconstruction. The short to medium-term follow up results have shown that autografts have a longer rehabilitation time frame, in some cases up to one year, whereas synthetic grafts have seen a return to sporting activities as quick as 3 months.[17] Newer generation synthetic graphs have early reports of showing similar results to those of autografts but long term follow up studies have seen an increased graft failure rate for various reasons that will be discussed later. In young (under 25 years old) active patients allografts have been shown to fail at a significantly higher rate than autografts in a follow up of two to four years.[14] Graft failure is always a risk and one that is normally heavily documented in research on ACL reconstruction,

but with certain grafts that are available currently this risk is higher whereas others have proven to hold up very well for patients over many years of follow up. In this research we will look at research that discusses long-term follow up results and how the long-term outcomes need to be discussed with patients so they can make the best educated decision possible on which ACL graft is best for them both in the short-term and long-term as they go throughout their daily activities.

Methods

When looking for research to include I wanted to look at all graft options for ACL reconstruction as well as comparing some data taken from research done of patients who were treated conservatively without ACL reconstruction after an ACL rupture. Articles that were included were ones that look specifically at ACL injuries without other associated ligament or structural injuries. If patients had other associated injuries they were noted on in the research and many of them were excluded from the study. Studies included documented results through the use of Lachman or Anterior Drawer testing, KT-1000/KT-2000, or graft rupture rates. There is assumption of graft re-rupture rate with a side-to-side difference measurement of greater than 5 mm through measurement with KT-1000/KT2000.[25] The KT-1000 and KT-2000 are similar in that they both can measure anterior and posterior displacement of the tibia from the femur but the KT-2000 can also plot data of the tibial translation at a given magnitude of applied force.[11] The International Knee Documentation Committee Subjective Knee Evaluation Form (IKDC) is a commonly documented form used to assess the patient's symptoms, activity level, and overall feeling of how functional their knee performs during activities of daily living. (Figure 1)[10] The IKDC survey has shown internal consistency and test-retest reliability of 0.92 and 0.95, and

based on test-retest reliability the value for a true change in the score is 9.0 .[10] The purpose of incorporating the IKDC survey is that it is knee specific rather than disease specific, allowing it to be used in a wide variety of settings to assess the patients knee overall function.[10] Another knee scoring system used is the Knee Injury and Osteoarthritis Outcome Score (KOOS) that scores from 0 (worst) to 100 (best) in five subscales of, pain, symptoms, sport and recreation function, quality of life and function in activities of daily living.[9]

Discussion

Non-Operative

Non-operative ACL rehabilitation is an option that should always be included when it comes to treatment options. ACL reconstruction is almost always going to be the preferred route for a patient to take that is younger and desiring the return to their pre-injury activity level. For patients that are older the non-operative route may be desirable to avoid the risks that come along with performing ACL reconstruction surgery. It was found that non-operative ACL rehab lead to resumed knee function and return to pre-injury activity level after 1 year of ACL injury.[13] Of the non-operative patients, those who were able to resume their activity level had less episodes of giving way, subluxation event of the knee, compared to those who did not resume activity level at one year follow up.[13] Treatment with exercise therapy alone for a ruptured ACL is a prognostic factor to have less knee symptoms when compared with those undergoing early reconstruction plus exercise therapy, but those that have had a previous knee surgery or have underlying knee cartilage or structural damage may have a worse outcome on their KOOS score

at the five-year mark.[9] When considering non-operative treatment it is important to keep in mind the age and activity level the patient desires to return to as well as any underlying structural damage that may be present, as ACL injuries are commonly associated with other subsequent injuries. Patients that scored better on both the IKDC and KOOS had returned earlier to their prior activity level.[13] A study of 141 young, active adults separated into two groups of ACL reconstruction or conservative treatment with the option to have delayed ACL reconstruction. At two and five-year follow up there was no difference in KOOS scoring. In the non-surgery group the main complication was knee instability. 39% of the non-operative group did have ACL reconstruction at the two-year mark and 51% of the group had ACL reconstruction by the five-year mark.[22] While conservative non-surgical approaches can be taken there remains a probability that ACL reconstruction may be needed in the long term to help with knee instability complications.

Autografts

Autografts have been historically seen as the gold standard for ACL reconstruction. They have had the most research performed and thus giving us a good amount of data to support their use. The most commonly used Autografts are the BPTB and HT grafts. The most commonly used HT graft comes from the Semitendinosis. There has been recent debate over which autograft is superior to the other. The past decade has seen a slight shift in thinking that the HT graft may be more favorable to the BPTB graft due to donor site morbidity but that still remains to be seen in long-term results.[19] Each of these grafts are taken from the ipsilateral knee that the ACL reconstruction is taking place on. The major downfall of the autograft is donor site

morbidity as part of the patients tendon that helps support and move the knee joint through its range of motion is taken away from the body to be used as the ACL graft. Morbidity that is commonly seen from autograft techniques is kneeling pain and skin sensation loss, specifically from the BPTB graft option.[19] With this downfall of added morbidity the upside of autograft use is the low graft rupture rate. A meta-analysis of BPTB and HT autograft use in ACL reconstruction showed there was a slight increased risk of graft rupture in the HT group compared to the BPTB group though the failure rates were low in each of the groups.[21] Few differences were seen in terms of graft laxity through the use of the KT-2000 or Lachman Test.[21] Between the BPTB and HT grafts in an eight year follow up study showed no difference between the grafts in both range of motion or laxity. As well as both grafts having comparable knee function through the use of the IKDC scoring.[19] For patients that had earlier ACL reconstruction following ACL injury, they had a better return to previous activity levels and a better perceived quality of life at eight year follow up as well. Reasons for ACL reconstruction being delayed included meniscus tear injuries or other structural damage to the knee joint. Those who have an ACL injury with associated meniscus injuries leads to a negative prognostic factor regarding knee stability, knee function and quality of life following ACL reconstruction.[19] Another downside to autografts is that the return to pre-injury activity level and functions is delayed from that of allografts and synthetic Grafts.[20,25,26]

Of the most widely used autograft options, the graft with the quickest return to activity has generally been the BPTB grafts compared to the HT grafts.[20] Although a more recent study from Smith et al. found that out of 79 patients the autograph that showed the longest delay in order for the patient to get return to sport clearance was the BPTB when compared to the HT autograft. This group took six weeks longer than the HT group and nine and a half weeks longer

than the allograft group The BPTB autograft group took longer to meet postoperative clinical milestones in order to be cleared to return to sporting activities. If an athlete is considering an accelerated return to sport following ACL reconstruction, opting for an allograft or HT autograft may facilitate faster rehabilitation and return to play. The study importantly notes that despite the decreased time frame in return to sports clearance seen in the HT autograft group, they may be more susceptible to sustaining another knee injury since current literature has found that at least 1 in 4 young athletes experience a second ACL injury following return to sporting activity and these injuries usually occur early after return.[1] A 1 year follow up comparing BPTB and HT grafts showed that all patients were able to return to pre-operative activities through the addition of a standardized postoperative rehabilitation program. The rehabilitation program included early emphasis on pain control, swelling, protected weight bearing, restoration of full passive knee extension symmetrical to the noninvolved knee, maintenance of patellar mobility and regaining of quadriceps strength. A postoperative brace was used for approximately 4 weeks until the knee was able to be comfortably flexed beyond 100 degrees, and then crutches were used until they were able to walk without deviation to their gait. Patients progressed weight bearing and weight bearing progressive resistance exercises as well as balance and perturbation activities as tolerated (Table 1).[8,20]

A complication to any surgical procedure is one of infection. A meta-analysis looking at incidence of infection rates between BPTB and HT autografts found that a significantly lower incidence of deep infections after ACL reconstruction with BPTB autografts compared with HT autografts. The BPTB autograft group had a 77% lower incidence of infections compared with the HT autograft group. Though this complication of a deep infection is still considered to be a

rare occurrence it non the less should be part of the overall consideration when deciding with the patient which graft option is best for them.[15]

Allografts

Allografts are a popular alternative to autografts. Due to donor site morbidity of autografts the search began for allografts that could be viable options for ACL reconstruction. The use of allograft can appeal to a patient due to the complete lack of donor site morbidity as well as availability and a wide range of graft sizes that can be used. Risks that have been documented from allograft use include an immunogenic reaction or disease transmission and allografts are also an expensive option when compared to autografts. Allografts are also used in situations of revision surgery where autograft options have already been exhausted and a different graft option is needed for a patient.[26]

The most commonly used allografts come from the tibialis posterior/anterior and Achilles tendon. Other used allografts include the patellar tendon and hamstring tendon. These allografts are harvested from cadavers or donors where they can also include a bone block attached to the graft. After the grafts are harvested they need to be sterilized and prepped for use in reconstruction. The sterilization technique performed can hinder the graft quality though. Older studies often used high dose irradiation or ethylene glycol which led to structurally inferior grafts. There has been a dose-dependent relationship between higher levels of gamma irradiation leading to decreased force the graft can undergo. Newer studies have led to the recommendation of using low dose gamma irradiation (<21kGy) that has led to only a slight reduction in biomechanical properties or no change in biomechanical properties (Lansdown). The

biomechanical properties include load to failure and graft stiffness. A recent study analyzing the use of allografts for primary ACL reconstruction found that allografts should be frozen and non-irradiated for the best results. Allografts that have undergone a slower rehabilitation protocol have had more favorable results. Although, results with allografts for primary ACL reconstruction have been poor for those under the age of 25 who are highly active patients.[23]

Bottoni et al reported on a minimum 10 year follow up comparing a tibialis posterior (TP) allograft to a HT autograft in a younger population of 99 patients where 95% of the participants were active duty military. Reports on graft failure at the minimum 10 year follow up were found to be 8.3% in the HT autograft group and 26.5% in the TP allograft group. These graft failures all required revision surgery. The study concluded that young athletic patients who have primary ACL reconstruction with an allograft are 3 times more likely to have a graft failure than those with an autograft.[24]

Sun et al. conducted research comparing HT autografts to HT allografts that included a follow up on average of 7.8 years. Near identical results were found when documenting side to side difference and IKDC scores. From this research they concluded that fresh frozen, nonirradiated HT allografts are a reasonable alternative to HT autografts.

A meta-analysis comparing autographs and allografts by Kan et al. looked at studies of allografts of different graft type (BPTB, HT, tibialis anterior, tibialis posterior and Achilles tendon) either irradiated or nonirradiated compared to typical autographs (BPTB and HT). The meta-analysis concluded that autografts significantly decreased clinical failures for patients. They additionally found that autografts reduced instrumented laxity testing and increased IKDC scores.[2]

Long-term studies are not readily available about the use of allografts as most of the studies that have been conducted have an end follow up of around 48 months.[26] The studies included above demonstrated the potential downfalls to the use of allografts in the long term. Although there has been positive documentation from allografts in the short term in regards to decreased surgery time, as it removes technically demanding stages of ACL reconstruction, and the absence of donor site morbidity. Allografts can be valuable in certain patient groups, particularly those with multi-ligament deficiencies or in the revision reconstruction scenario.[26]

Synthetic Grafts

Synthetic grafts offer a wide variety of options. These options include the Leeds-Keio (LK), Ligament Augmentation Device (LAD), Ligament Augmentation Reconstruction System (LARS) and Polyglycolic Acid Dacron (PGA-Dacron) grafts. Earlier generation synthetic grafts include the LAD and LK while newer ones include the LARS and PGA-Dacron. With the implementation of a new generation of synthetic grafts the LAD and LK have fallen out of favor as options for ACL reconstruction. The indications for the use of a synthetic graft is slightly different from traditional graft choices. The rational with synthetic grafts is that they are used to help the healing process of a freshly injured ACL and surgery should take place as soon as possible after the episode of injury. Along with having a quick follow up of reconstruction the existing ACL stump should be preserved so the synthetic graft can augment healing and not act solely as a substitute graft.[26]

The LK graft came about in the 1980's and sparked interest due to the claim that this graft promoted natural ingrowth of collagen fibers leading to generation of a new ligament. With this in mind, it was the hope that a synthetic graft would overcome the problems of donor site

morbidity that is heavily documented in literature surrounding autografts as well as the risk of cross-infection associated with allografts.[12] A study showing the reasons why the LK graft option has fallen out of favor comes from Murray et all. This was a follow up conducted of 18 patients who had undergone ACL reconstruction with the LK graft 10-16 years prior. Of the 18 patients, six needed a subsequent surgical intervention, which five of the six had a complete rupture of the LK ligament, another five required partial medial menisectomy. Two of the 18 people were not working because of chronic knee pain. Other complications of the LK included were increased graft laxity, 10 patients had greater than 3mm of side-to-side difference with 4 of them being over 5mm of difference, as well as concerns of degenerative changes seen in the knee joint. All patients had some degree of degenerative changes seen, 12 patients had moderate changes in the operated knee and no degenerative changes seen in the contralateral knee. Along with the degenerative changes seen there was worry that exposure of the polyester fibers that make up the LK graft could lead to a granulomatous reaction within the knee, which in turn, could then lead to degenerative arthritis. This data was concerning to the authors due to the age of the participants being so young with an average ages of 28 at time of surgery and age 40 at follow up. A few reports prior to this study documented fairly reasonable results in the short to medium term with the LK graft, but this study showed the long-term consequences of the use of the LK graft.

The LAD graft is another of the earlier generation synthetic grafts along with the LK that became available in the 1980's. The LAD was designed to provide protection to the healing ACL or the autograft ACL It provided protection to the healing ACL by transferring loads during the initial healing process and protecting the autograft during its early phase of vascularization and maturation.[4] Since the integration of the LAD in the 1980's there has been documented

complications such as effusions, increased risk of infections, reactive synovitis in the knee for provoking inflammatory reactions from the placement of a foreign material into the knee and was found to delay maturation of autografts. The knee laxity measurements and IKDC scores were significantly different from autografts.[17] Despite the intended outcomes for the patients, the LAD and LK synthetic ligaments are not suggested for ACL reconstruction due to worse outcomes in knee laxity and functions compared to autografts as well as documented graft rupture rates.[17]

One of the new synthetic grafts is the LARS. The newer generation of synthetic grafts is hoping to achieve the same results of the loss of donor site morbidity and infection risk for the patient. A 10-year follow up study of the LARS from Tiefenboeck et al. hoped to provide insight to the long-term effectiveness of the LARS, in hopes that results would be improved from the later generation synthetic grafts. The use of the LARS initially had great results in return to sport activity, which was only an average of four months for all 18 patients. After the initial success with return to activity then came the complications from the surgical procedure. There were five documented graft breakages, three occurred from trauma during sporting activity and two cases where the graft needed to be removed due to infection. Infections from the surgery included a case of a superficial infection and a case of a deep infection. One case of the infection led to the removal of the LARS ligament and the other case resulted in multiple revisions due to infections and effusions. In another case a screw needing to be removed in another case due to pain. In four patients who denied any source of trauma following ACL reconstruction there was a positive Lachman test with a side to side difference of greater than 5mm observed, leading to the conclusion that there was an insufficient LARS ligament or a re-rupture. Seven patients showed radiographic evidence of osteoarthritis and nearly half the patients revealed a graft failure at

minimum of 10 years of follow up from reconstruction with the LARS.[25] Earlier studies on the LARS showed no complications at 2.5 years but by the 10 year follow up there was an observed 50% graft failure rate due to.

LARS reconstruction has shown faster rehabilitation rates allowing quicker return to sport activity (Pivoting activity).[25] Some were able to return to sports as quick as three months which is vastly quicker than the autograft and allograft groups which can take up to 12 months or longer to return to activity. There is decreased donor site morbidity and a quicker reconstruction can take place since there is no need for graft harvest as is the case for Autograft reconstruction. Short-term follow up showed increased activity and knee stability within guidelines to return to activity. Long term follow-up at 10 years showed an increase in graft rupture rate of nearly 50%, either due to infections, chronic pain form hardware placed during surgery as well as traumatic injury during sport.[25,26]

PGA-Dacron, like the LARS, is a newer generation synthetic ACL graft. The PGA-Dacron is composed of 75% degradable Polyglycolic acid filaments and 25% non-degradable 6.5mm Dacron thread wrapped in a free synovial graft. The PGA-Dacron was created with the goal of protecting the newly placed partially biodegradable ligament graft with a free synovial graft. The thought behind the PGA-Dacron is to create an environment where the torn ACL could regain its function and potentially heal in a way that is comparable to a torn collateral ligament.[3] The PGA-Dacron graft can only be placed with a preserved ACL remnant. The graft is then placed in continuity with the remnant ACL and the synovial wrap around the graft serves the purpose as a source of healing fibroblasts[3] (Figure 4[3]) The synovial graft used to cover the synthetic ligament can be harvested from the suprapatellar area using a medial arthrotomy approach without dislocating the patellofemoral joint. The intra-articular side of the graft is then

placed outward and sutured around the synthetic graft with absorbable suture. A study by Pritchett consisted of 70 patients split evenly into two groups that compared the PGA-Dacron graft wrapped with a synovial graft (experimental group) to BPTB autografts (autograft group). They had a mean follow up of 12 years where the postoperatively reported data was obtained. All 70 patients underwent the same postoperative protocol and were evaluated by the both the IKDC and KOOS scores as well as through the use of the KT-1000. Through the protocol in place all patients were allowed to return to sports-specific training at four months and competitive athletics at eight months. Postoperatively the experimental group scored statically better in the KOOS and IKDC scores, as well as measurement with the KT-1000. The experimental group showed more stable measurements postoperatively with the KT-1000. 71% of the experimental group showed 0-2mm of side to side difference where the autograft group only showed 54% side to side difference postoperatively. There were two graft failures in the experimental group and three graft failures in the autograft group. The studies reported a main finding that satisfactory stability and functional results after covering an ACL ligament prosthesis with a synovial graft are possible. The results were statistically better than those for autografts as well as complications being infrequent.[3] PGA-Dacron with synovial graft covering showed a satisfied result compared to autograft including knee laxity, range of motion, degenerative changes of knee and rate of failure and complications.[17] The PGA-Dacron graft option is lacking in current research. The Pritchett study showed that the PGA-Dacron may have potential as a top synthetic graft option but will need more research with larger patient populations to confirm the findings Pritchett expressed. The PGA-Dacron is the first synthetic graft to show positive long term results, whereas the others have shown great initial results with poor results in the long term.

Surgical Technique

With the various graft options that one can use for ACL reconstruction there also comes with it various techniques that can be performed by the surgeon to best align the new ACL graft with the previous ACL in anatomical position. Single bundle and Double bundle tunneling can be used to anchor the new graft in place. A single bundle technique uses only one tunnel in the femur and one tunnel in the tibial to anchor the graft. A double bundle technique uses two tunnels placed in the femur and two tunnels placed in the tibia (Figure 2)[7]. A complication that can arise from these two techniques is a phenomenon of tunnel widening. Tunnel widening occurs when the drilled tunnels in the femur or tibia widen thus leading to a loss in surrounding bone. This loss of surrounding bone may lead to need for revision surgery on the reconstructed ACL or an additional surgery with bone grafting prior to the revision surgery. In a study by Aga et al. they found, through the use of CT imaging, that all the tunnels exhibited widening during the first year following the ACL reconstruction. Of the widened tunnels the single bundle technique showed significantly more widening than the double bundle technique. This was the first study to identify tunnel widening in double bundle-reconstructed knees. The concern for a double bundle reconstructed knee that experiences tunnel widening is the convergence of the two tunnels leading to the appearance of a single bundle reconstructed knee.[7]

When looking at single bundle and double bundle surgical techniques in terms of graft revision surgery, it was found, according to Svantesson et al., that the double bundle technique was associated with a significant lower risk of revision surgery compared with a single bundle reconstruction technique.[16] This was a study of 22,460 patients from the Swedish National Knee

Ligament Register and was one of the first to compare revision rates of single bundle and double bundle reconstruction in such a large population.

This study also looked at anatomic and non-anatomic surgical techniques as well as transportal and transtibial drilling techniques. Transportal drilling using a more complete anatomic reconstruction reduces the risk of revision surgery considerably[16], but it is noted that transportal and transtibial anatomic placement can be considered equal, in terms of risk of revision reconstruction, due to the closely overlapping confidence intervals they found. Regardless of transportal or transtibial techniques it is noted that double bundle reconstruction more closely resembles the native anatomy, allowing two separately tensioned bundles to provide a more natural and even distribution of forces on the graft during the knees range of motion.[16]

Although the double bundle reconstruction technique has been documented to have fewer revision surgeries it is still a fairly new surgical procedure which has prevented the wide spread use of this technique. Along with it being a new procedure it is also a more difficult one to perform correctly and accurately. If not performed correctly then there is risk to the patient to have revision surgeries and when a revision surgery is needed from a double bundle reconstructed knee it leads to a more complicated revision than that of a single bundle reconstructed knee.[16]

Pediatric Surgical Considerations

When considering options for ACL reconstruction in pediatric patients an important consideration is the opening of epiphyseal plates. ACL reconstruction was traditionally delayed until the child was close to the end of their pre-pubertal growth spurt, though studies have suggested that the incidences of meniscal damage and cartilage destruction are higher when ACL reconstruction was delayed. With these noticed added damages, surgical intervention has been advocated early to improve functional outcomes.[5] With the epiphyseal plates open there can be much harm done to the patient if those epiphyseal plates are damaged whether from physical or iatrogenic trauma. That has led to the development of all-epiphysis surgical tunneling technique (Figure 3[5]) where tunnels are placed in the femur and tibia in the epiphysis while sparing the epiphyseal plates. The all-epiphysis technique is done in a manner that aligns them anatomically but does not disturb the epiphyseal plates With the growing number of ACL reconstruction surgeries that are performed, there has been a rise in pediatric patients needed to undergo these procedures. The peak age of ACL reconstruction in pediatric patients age 3-20 was found to be 17 years old.[6] Male children on average become skeletally mature and epiphyseal plates close between ages 15.6 and 17.1, and for female children between 15.0 and 16.9.[6] Children who are not yet skeletally mature there was debate in the past as to whether delayed surgical intervention was necessary to allow the epiphyseal plates to close to prevent complications from damage to the open plates. A Meta-Analysis conducted by Dunn et al. reported the following finding, Non-operative or delayed operative patients were 33.7 times more likely to report instability than those who underwent early operation to their ACL injury. Surgery shortly after injury reported less knee instability, fewer meniscal tears, higher IKDC scores and a greater rate of return to pre-injury activity level. Leading to the conclusion that results favored early ACL reconstruction in peds athletes rather than delayed or non-operative treatment based on clinical findings as well as

IKDC scores. These ACL reconstructions were performed with the all-epiphysis technique to spare the epiphyseal plates from iatrogenic damage.

Case reports conducted by Hoshikawa et al. from Japan listed the findings from three pediatric patients, two males, aged 12 and 14, and one female, aged 13. The three pediatric patients had confirmed wide open physes on imaging prior to surgery. They underwent ACL reconstruction through the use of the all-epiphysis technique. There was no limitation in range of motion found and in one year all participants were able to return to the previous sports activities. The female did have to drop out of her sport of softball because of knee pain at the Patellofemoral joint and graft harvest site at the time of their last follow up in 56 months. Through the use of KT-1000 to measure graft laxity there was found to be on average 1.3mm +/- 0.5mm difference at the one year follow up and 2.5mm +/- 0.2mm at the last follow up. The increase in graft laxity was hypothesized to be from the use of the double bundle all-epiphysis technique. The all-epiphysis technique has tunnels in the femur and tibia that run in the horizontal direction within the epiphysis leading to a greater angle for the graft to bend compared to when the double bundle technique is used in adults. This technique thus requires a thinner size of the graft to compensate for the increased bending angle. Another crucial aspect is the growth of the pediatric patients. Little is known about the behavior of the graft as related to the postoperative growth of patients. Some literature suggests that the graft would be expected to grow along with the patient, a recent study has demonstrated a significant decrease in the graft diameter at one year after ACL reconstruction in patients Tanner stages two through four, thus the newly reconstructed ligament is thought to stretch without hypertrophy.[5] With an already thinner graft used in the ACL reconstruction and the potential for the graft to be stretched with the growth of the child with report of no graft hypertrophy there may be consequences of

increased adverse effects. Hoshikawa et al. also noted that overall complication rate after ACL reconstruction in skeletally immature patients seemed to remain high. Single bundle vs Double bundle techniques remain controversial over which is superior. Although several biomechanical studies have demonstrated the superiority of double bundle reconstruction techniques in the restoration of knee stability, especially with regard to rotation stability.

Important outcomes to measure with pediatric patients include the Fear of Pain questionnaire, which can help address kinesiophobia or fear of movement following a traumatic injury that the patient has not had to overcome before. This questionnaire can help the patient and provider determine areas the patient may be struggling, these areas can be physically, mentally or a combination of both. Other scores that can be used for the pediatric population include the Pediatric versions of the IKDC score and the Pediatric Quality of Life inventory. Patients who experience less knee instability may have a more active lifestyle and a greater chance of returning to sport and not suffering from knee instability. Experiencing negative effects of chronic knee instability can be both physically and mentally taxing, especially for a pediatric patient.[6]

Conclusion

Each graft comes with its pros and cons. Autografts are proven to have the best long-term knee stability but come with added donor site morbidity. Allografts are shown to have higher re-rupture rates as well as other risks such as transmission of disease from donor to patient, but come without donor site morbidity. The likelihood of disease transmission can be greatly diminished through sterilization techniques. The downfall to these techniques is that they can damage the integrity of the graft itself thus leading to an inferior graft overall. Synthetic grafts

have been shown to provide a quicker return to sporting activities without donor site morbidity but also have an increased risk of graft failure as shown in long term follow ups but not necessarily short term follow ups. Older generation synthetic grafts have fallen out of favor for the use of newer generation synthetic grafts which have shown more promising results initially. Long term outcomes with the newer generation synthetic grafts may have a promising future with their role within ACL reconstruction but as of now more research needs to be conducted to prove their ability to have less graft failure rates as well as maintaining knee stability for long term results.

Current literature supports the fact that autograph ACL reconstruction remains the superior option with regards to long-term knee stability findings through the use of IKDC and KOOS scoring as well as measurements taken with the KT-1000 and decreased rates of graft failures. Autografts also have the most research conducted on them helping to support these findings in multiple settings and age groups. Allografts have shown to be a viable option in revision ACL surgeries when autograft options have been exhausted. Allografts are also more expensive than autografts, which adds a piece to the discussion between provider and patient on graft selection.

The goal for surgical management of ACL injuries is to provide a stable knee that will allow return to the highest level of function and, at the same time, minimize the risk for loss of motion. Preoperative, intra-operative, and postoperative factors must be considered to minimize the risk of loss of motion and to optimize results. The pros and cons need to be taken into account as well provider preference and experience as to performing the different procedures. Graft choice, therefore, needs to be made after an educated discussion with the patient re-guarding their requirements and expectations with regards to donor morbidity and speed of

rehabilitation as well as the surgeon's personal experience and the surgical units experience and access to graft options. Certainly, there is no one-size-fits-all graft yet, however, surgeons should offer the differing graft options and inform their patients of the differences as well as their own personal results with each graft suggested.[26] Each patient has individualized goals and outcomes post reconstruction and what they desire to be able to do. Each graft type cannot be chosen without thorough patient-provider dialogue and education to land on the best option for the patient.

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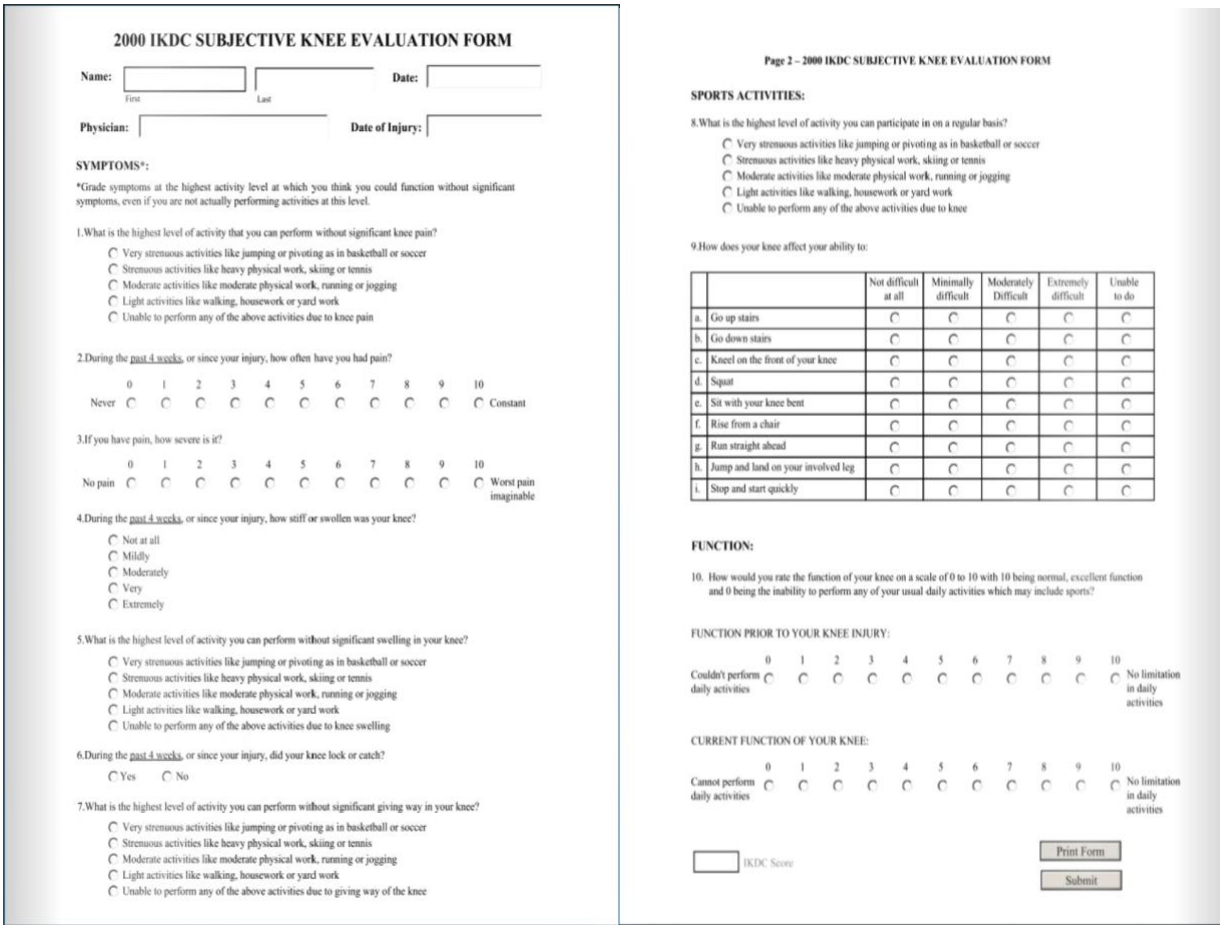
Appendices



2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

Name: First Last **Date:**

Physician: **Date of Injury:**

SYMPTOMS*:

*Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you are not actually performing activities at this level.

1.What is the highest level of activity that you can perform without significant knee pain?

- Very strenuous activities like jumping or pivoting as in basketball or soccer
- Strenuous activities like heavy physical work, skiing or tennis
- Moderate activities like moderate physical work, running or jogging
- Light activities like walking, housework or yard work
- Unable to perform any of the above activities due to knee pain

2.During the past 4 weeks, or since your injury, how often have you had pain?

0 1 2 3 4 5 6 7 8 9 10

Never ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Constant

3.If you have pain, how severe is it?

0 1 2 3 4 5 6 7 8 9 10

No pain ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Worst pain imaginable

4.During the past 4 weeks, or since your injury, how stiff or swollen was your knee?

- Not at all
- Mildly
- Moderately
- Very
- Extremely

5.What is the highest level of activity you can perform without significant swelling in your knee?

- Very strenuous activities like jumping or pivoting as in basketball or soccer
- Strenuous activities like heavy physical work, skiing or tennis
- Moderate activities like moderate physical work, running or jogging
- Light activities like walking, housework or yard work
- Unable to perform any of the above activities due to knee swelling

6.During the past 4 weeks, or since your injury, did your knee lock or catch?

○ Yes ○ No

7.What is the highest level of activity you can perform without significant giving way in your knee?

- Very strenuous activities like jumping or pivoting as in basketball or soccer
- Strenuous activities like heavy physical work, skiing or tennis
- Moderate activities like moderate physical work, running or jogging
- Light activities like walking, housework or yard work
- Unable to perform any of the above activities due to giving way of the knee

Page 2 – 2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

SPORTS ACTIVITIES:

8.What is the highest level of activity you can participate in on a regular basis?

- Very strenuous activities like jumping or pivoting as in basketball or soccer
- Strenuous activities like heavy physical work, skiing or tennis
- Moderate activities like moderate physical work, running or jogging
- Light activities like walking, housework or yard work
- Unable to perform any of the above activities due to knee

9.How does your knee affect your ability to:

		Not difficult at all	Minimally difficult	Moderately Difficult	Extremely difficult	Unable to do
a.	Go up stairs	○	○	○	○	○
b.	Go down stairs	○	○	○	○	○
c.	Kneel on the front of your knee	○	○	○	○	○
d.	Squat	○	○	○	○	○
e.	Sit with your knee bent	○	○	○	○	○
f.	Rise from a chair	○	○	○	○	○
g.	Run straight ahead	○	○	○	○	○
h.	Jump and land on your involved leg	○	○	○	○	○
i.	Stop and start quickly	○	○	○	○	○

FUNCTION:

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function and 0 being the inability to perform any of your usual daily activities which may include sports?

FUNCTION PRIOR TO YOUR KNEE INJURY:

0 1 2 3 4 5 6 7 8 9 10

Couldn't perform daily activities ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ No limitation in daily activities

CURRENT FUNCTION OF YOUR KNEE:

0 1 2 3 4 5 6 7 8 9 10

Cannot perform daily activities ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ No limitation in daily activities

IKDC Score

Print Form

Submit

Figure 1. IKDC Knee Evaluation Form[10]

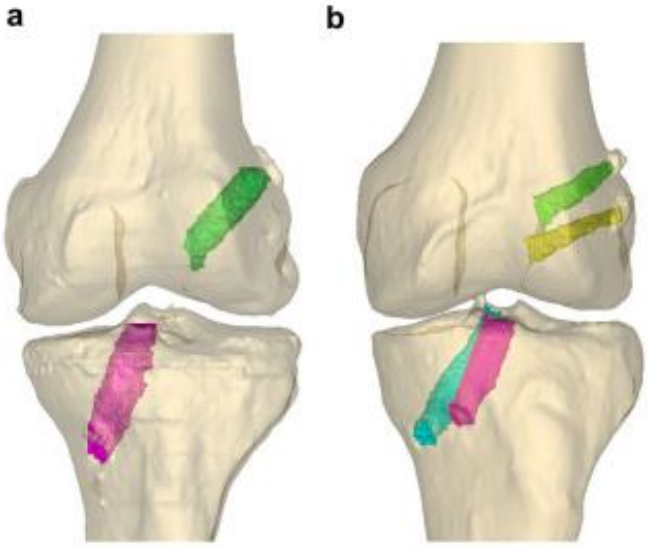


Figure 2. **a** Single-bundle ACL reconstruction knee in a 3D CT model with one tunnel on each side of the joint. **b** Double-bundle ACL reconstruction knee in a 3D CT model with 2 tunnels in the femur AM (green) and femur PL (yellow) and two tunnels in the tibia AM (fuchsia) and tibia PL (cyan)[7]

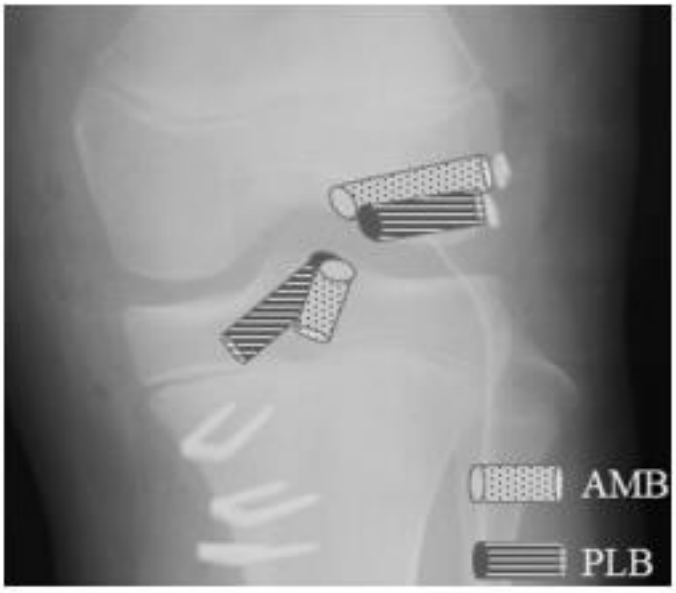


Figure 3. Diagrams of the surgical technique and the 4 drill hole placement. AMB, bone tunnels for anteromedial bundle; PLB, bone tunnels for posterolateral bundle.[5]

Figure 4. AP view of a knee showing the ligament prosthesis in position. The synovial wrap covers the intra-articular portion, and the remnant anterior cruciate ligament serves as a source of fibroblasts. [3]

Time after Reconstruction	Rehabilitation Program
Day 1	Leg splinted at 10° flexion, continuous passive motion (CPM) begun
2–3 days	Ab/adduction straight leg raises (SLR), extension SLR, passive range of motion (ROM) 0°–90°, gluteal sets, ambulation (nonweightbearing), crutches
5–6 days	Discharge from hospital, CPM and exercises continued at home, rigid knee immobilizer (set at 10°) used except during passive knee ROM exercises, hamstring curls, ab/adduction and extension SLR, toe touch weightbearing
3 weeks	Quadriceps exercises, active ROM 60° to 90° gradual light resistance. Note: Patients should have attained passive ROM of 0°–90° assisted by CPM or the well leg. Continue Dobi splint when up. May discontinue for sleep
6 weeks	Passive ROM 0° to 100°, weightbearing as tolerated, wear IKO (functional knee brace) 10° stops, full time when walking
8–10 weeks	Full weightbearing as tolerated, active ROM 0 to 110 degrees, passive stretching to increase ROM, SLR with increased weights, eccentric knee extensions, short arc knee extension 90° to 45°, hamstring curls, swimming, stationary bicycling when patient able to walk without crutches. Note: If patient has not attained full extension, regimen includes lying prone with 1 pound weight on ankle
12–14 weeks	ROM 0° to 120°, full weightbearing, previously described exercises continued, knee bends, step-ups (well leg first; step-down, operated leg first), calf raises
4 months	ROM 0° to 130° (goal), brace discontinued for activities of daily living (ADL) if patient's quadriceps tone is good, exercises increased in intensity with higher weights and more sets and repeats, fast speed isokinetics
5 months	Jumping rope
6 months	Cybex at 180 and 240 deg/sec with a 20° block, KT-1000, lateral shuffles, walking up to 2 miles per day, short arc knee extensions to full knee extensions, squats, use of brace for activities other than ADL
7–8 months	Cybex, KT-1000, walking, progressive running and jogging; weight lifting continued to strengthen quadriceps, hamstrings, and calf muscles; jogging followed by progressive running program, including backward running and hill running; agility drills including large (gentle) figure of eights; lateral shuffles; slow and fast speed isokinetic strengthening exercises
9–12 months	Return to normal activity levels if strength greater than 80% of the nonoperated knee, full ROM, no pain or swelling, successful completion of functional progression

Table 1. Rehabilitation program[8]

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