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Review Article

Review of Graft Choices for Anterior Cruciate Ligament

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The question of which graft to use for anterior cruciate ligament (ACL) reconstruction continues to be debated at meetings around the world. The overall choice of grafts consists of autografts, allografts, and synthetic grafts [(1)]. By far the two most commonly used grafts are central third bone-patellar tendon-bone and hamstring tendon, either semitendinosus alone or semitendinosus combined with gracilis. The next most popular graft was quadriceps tendon, followed by allograft tendon. It is worth noting that there may be considerable geographic variation in the choice of graft for ACL reconstruction.

In selecting a graft for ACL reconstruction there are a number of factors that need to be considered [(2)]. These factors need to be evaluated in regard to the patient's occupation, the type of sport in which they are involved, their skeletal age, associated ligamentous pathology, the chronicity of the injury, and their inherent degree of ligamentous laxity. The reconstruction of an ACL is crucial to the longevity of any given athlete due to it's importance in maintaining the stability of the knee, particularly in activities involving cutting, pivoting or kicking. People with ruptured ACL's have unstable knees that generally become more damaged over time. Therefore, surgical reconstruction is vital for the athlete in order to get back to regular sport activity.

As a result of the increased interest in hamstring tendons, largely due to the development of new fixation methods, there have been a number of randomized controlled trials (RCTs) published in the past few years comparing patellar tendon and hamstring tendon grafts. Both grafts have been shown to produce satisfactory functional outcomes. In general hamstring tendon grafts have been associated with less morbidity, particularly in terms of anterior knee pain and more specifically pain on kneeling. Patellar tendon grafts seem to be associated with an increased risk of extension deficit but in many studies have been associated with slightly less anterior knee laxity as measured by arthrometer. Some studies have shown a higher rate of return to preinjury sport with patellar tendon grafts. In those studies that have looked at radiographic bone tunnel enlargement, hamstring tendon grafts have generally been shown to be more frequently associated with this phenomenon than patellar

tendon grafts. To date, bone tunnel enlargement has not been associated with clinical sequelae but does remain a potential concern in the longer term and also in the setting of revision surgery.

An autograft is a graft transferred from one part of a patient's body to another, such as one's own patellar or hamstring tendon to replace their torn ACL [3]. An allograft is an organ or tissue transplanted from one member of a species to another genetically dissimilar member of the same species, such as a cadaver's hamstring or patellar tendon to replace the athlete's torn ACL.

For ACL reconstruction, several sources of allograft are available -: BTB (hemi or whole), achilles, hamstrings, tibialis anterior, tibialis posterior and quadriceps tendon.

Allograft offers certain advantages in terms of lesser pain, small incision and lesser subsequent muscle weakness , kneeling pain, and minimal risk of patellar fracture. Large allografts, such as achilles or quadriceps tendon, affords the additional advantage of a large cross-sectional area to fill large tunnels, have favorable time-zero biomechanical strength, and have a bone plug for bone-to-bone healing and fixation in at least a single tunnel. When additional collagen is needed, such as in the multi-ligament injured knee allograft is preferred [4].

Disadvantages of allograft include less favorable healing and a greater risk of failure in the younger age groups. Various studies that have found that allograft takes longer to incorporate the implanted tissue. There is also potential risk of disease transmission as patient screening might not detect transmittable diseases in their window period. Jackson et al found that the allografts heal by the same process as their autograft counterparts. however, they heal at a much slower rate. Various studies have demonstrated an overall retear rate of 9 % in allograft primary reconstructions compared with 4 % when autografts were used [5].

Randomized study by Sun et al [6] comparing 86 knees with a BPTB autograft to 86 knees with a BPTB allograft, with an average follow-up of 5.6 years (range, 4-8 years). With regard to stability, no difference was found for the Lachman test, pivot-shift test, mean laxity with arthrometer testing, or percentage of knees with greater than 3 mm of laxity on arthrometer testing.

Three meta-analyses have been performed to compare the stability of autografts with allografts. Two meta-analyses found no statistically significant differences in knee stability measures (Lachman, pivot-shift, and arthrometer tests).The third found a small but statistically significant difference in mean anterior knee laxity on arthrometer testing, with the mean allograft laxity being 1.4 ± 0.2 and mean autograft laxity being 1.8 ± 0.1 ($P < 0.02$). However, no statistical difference existed between the autograft and allograft groups with regard to percentage of knees with less than 3 mm of laxity.

A study of the epidemiology of the Multicenter ACL revision study (MARS) cohort demonstrated that 54% of the surgeons used an allograft at the time of revision compared with 27% of the patients having had an allograft at the time of their primary reconstruction

Allografts can be sterile by radiation techniques or non radiation techniques. It is feared that Radiation might cause decrease in time-zero biomechanical strength and structural changes in the graft . Low dose irradiation < 20 kGy seems to have eliminate only bacteria and radiation greater than 30 kGy seems to have effect on both bacteria and viruses. hence most graft undergo low dose radiation for sterilization and donor screening for elimination of risk of transmission of Hepatitis B, C and HIV.

Edgar, Zimmer in 2008 compared autograft and allograft of hamstring tendon constructs for ACL reconstruction. In their study of 84 patients , 37 were implanted with autografts and 47 with autograft. The follow up of the study revealed equal performance of both the grafts in terms of clinical parameters. However, in terms of adavantages , allograft scored high as there was no donor-site morbidity, short peri perative duration, ease of determination of size of graft etc.

In a study by Kaeding et.al, 2011 [7] showed that age of the patient determined failure of the graft. The study found that failure of graft was 4 times higher with allograft in age group of 10 – 20 years.

For every ten year decrease in age, the probability of graft rupture increased by 2.3 times for allograft. So the study concluded that younger the age, higher is the graft failtre rate with allograft.

In another study by Barrett, Luber in 2011 [8] on young patients found that high activity patients had higher chance (2.6 to 4) of graft failure with allograft compared with low activity patients. Subjects undergoing bone-patellar tendon-bone autograft reconstruction reported significantly lesser issues when assessed on visual analog scale. They also scored significantly better on Tegner activity scale than patients undergoing allograft reconstruction. Hence the study concluded stating that fresh-frozen bone-patellar tendon-bone allografts should not be used in young patients who have a high Tegner activity score because of their higher risk of failure.

In a study by Guo L& Yang L [9] they found there were 3 cases of acute synovitis due to immunologic rejection (fresh-frozen allografts) and 6 cases of failure (γ-irradiated allografts). KT-1000 examination showed more anterior laxity in the γ-irradiated allograft group compared with the autograft and fresh-frozen allograft groups ($P < .05$). The Lysholm, Irrgang, and Larson activity scales showed no difference among the 3 groups ($P > .05$). The study showed a statistically poorer KT-1000 result and higher failure rate in the γ-irradiated allograft group compared with the autograft and fresh-frozen allograft groups.

In their study, Kraeutler MJ and Bravman JT [10] found Outcomes on subjective IKDC, Lysholm, Tegner, single-legged hop, and KT-1000 arthrometer were statistically significantly in favor of autografts. Return to preinjury activity level, overall IKDC, pivot shift, and anterior knee pain were significantly in favor of allografts, although allograft BPTB demonstrated a 3-fold increase in rerupture rates compared with autograft (12.7% vs 4.3%).

In conclusion, allograft has certain merits: No harvest morbidity occurs because the graft is donor tissue. This allow for the fastest return to activities of Daily Living (ADLs). allografts are the least painful post-operatively. allows for a smaller incision on the medial tibia.

Demerits of allograft includes: It carries the potential risk of viral transmission (HIV, hepatitis). The chance of HIV infection from donor graft tissue is 1 in 1.8 million. Usually Return to full athletic activities is generally within 6-7 months. Chances of graft failure in younger age groups.

BONE-PATELLAR TENDON-BONE (B-PT-B) AUTOGRAFTS

The patellar tendon graft has been the most traditional replacement used for anterior cruciate reconstructions. There is approximately a 25 – 30 year history of usage of this graft for ACL reconstructions. The last 20 or so years, the graft has been placed arthroscopically assisted. The patella tendon is an ideal graft for knee ligament reconstruction, especially for ACL reconstruction. The ability to harvest bone attachments on both ends of this graft allows for interference screw fixation within a bone tunnel, as well as bone-to-bone healing within that tunnel [11].

The biggest positive of using a patellar tendon graft is the bone plug on either end of the graft coming from the patella and the tibia. These bone plugs are about 2.5 cm long, 1 cm wide, and about 5 mm thick. The bone plugs are actually placed in the tunnels that are made for the reconstruction of the ligament [12] These bone plugs can be fixed very securely with screws, either metal or plastic. The graft will then heal to the knee in approximately six weeks. The patient can start running at an early point in time, as long as there is no major meniscal damage that would prevent the patient from doing so.

The downside of using a patellar tendon is that the incision is longer, and there is more pain and

swelling in the knee in the first two weeks. Likewise, the patient has more difficulty regaining control of his quadriceps muscles during the first several weeks, since the extensor mechanism is used for the surgery. Fifteen years down the road 10% to 20% of patients will have patella femoral pain and grinding as a result of the disturbance of the extensor mechanism that occurs with procurement of the graft. In addition, surgeons who do not perform a high volume of ACL reconstructions may not be as comfortable with this graft harvest and its potential pitfalls and complications [13]

Various studies have stated that patellar tendon graft is the best graft choice for teenagers and college athletes that are participating in sports at a very competitive level. The orthopedic literature in the last couple of years has shown that the incidence of reinjury to a patellar tendon graft is less than either a hamstring graft or an allograft in the three to four years after the reconstruction. Teenage girls in particular, in my estimation, have a significantly higher incidence of reinjury to their ACL graft when using a hamstring graft compared to the patellar tendon. Thus, many orthopedic surgeons show a strong preference for a patellar tendon graft choice for teenage and college athletes.

Merits of bone-patellar tendon-bone autograft is that it is one of the strongest grafts concerning the initial fixation. This is due to the fact that there is bone on each end of the graft that is going into a tunnel in the bone. Physicians have the most experience with using this type of graft. Return to full athletic participation is typically quicker, usually within 5-6 months.

Demerits of B-PT-B autografts is that they are generally the most painful of the grafts post-operatively because harvesting the middle third of the patellar tendon along with a bone fragment from the distal pole of the patella and the tibia tubercle. They have an increased chance for patellar tendonitis. Because of the bone fragment harvested from the distal pole of the patella, there is an increased chance for a patella fracture. Initial rehabilitation / activation of quadriceps is more difficult because one third of the connective tissue allowing for quadriceps activation is removed and used. There is an increased incidence of patellar tendon pain and discomfort with kneeling. There is an extra incision where the graft is harvested from.

The ENDOBUTTON BTB Fixation System was developed by Smith & Nephew to assist surgeons performing bone-tendon-bone (BTB) ACL reconstructions. This revised technique, which demonstrates the preferred method of attaching the Endobutton CL BTB Fixation Device (ENDOBUTTON CL BTB) through a longitudinal hole, offers the surgeon many advantages: Bone blocks are fully appositioned in the femoral tunnel. Neither bone block, particularly the tibial bone block, protrudes. The tibial bone block lies flush with the opening of the tibial tunnel, eliminating the need for long grafts. Perforation of the posterior femoral cortex does not compromise fixation and Easier revisions because bone blocks fit existing tunnels, reducing the number of steps required. The ability to “hide” the continuous loop within the femoral bone block allows the bone block to be easily guided and pulled into position, without added bulk or cumbersome sutures. Directly obtaining the length of the needed construct using the endobutton Depth Probe eliminates all calculations and minimizes the potential for error.

This technique delivers strong fixation without the drawbacks of interference fixation such as screw divergence, posterior blow-out, laceration of the graft, the need for long grafts, and screw breakage. In addition, this technique makes it easier for surgeons to apply powerful fixation for interference fixation of the tibial bone block, namely between cortical bone on the tibia and the tibial bone block. These advantages translate into a technique for BTB ACL reconstruction and ACL revisions that is simple, reproducible, and dependable.

HAMSTRING TENDON GRAFTS

The semi-tendinosus tendon along with the gracilis tendon is harvested, from the ipsilateral leg. The intermediate tissue is modified into a four strand graft which is then used for reconstructing anterior cruciate ligament as per selected technique. Most often the tendons are be folded over each other so as to increase the thickness of the donor graft. Folded tendons should act as single unit and hence they are sutured together using a whipstitch technique. The donor graft is subsequently fed through the tibial tunnel and into the femoral tunnel and secured with a various fixation modalities including screws, suspensory apparatus and transfixion devices which might be metallic, polymer or bio-absorbable [14,15,16]

Leiter et al [17] looking at patient outcome scores as well as re-rupture rates. They used the IKDC Score and found that 75% of patients scored normal or nearly normal, however radiographic changes of Kellgren-Lawrence grade 3 were 19% in operated knees compared to 4% in the contra lateral knee, this finding reached significance even after controlling for medial meniscal surgery. They found re-rupture rates of the reconstructed ligament at 9% compared to contra lateral ACL ruptures at 5%.

Leys et al [18] reported results from a cohort study with 15 years follow-up comparing HS to BPTB. Re-rupture rates were 17% in the HS group and 12% in the contra lateral knee. Re-ruptures were more common in men, patients with non-ideal tunnel position. Mean IKDC Subjective symptom scores were 90 (out of 100) and mean functional scores 9.1 (out of 10).

asik et al [19] reported the results of 271 patients with 4 strand HS grafts fixed using a transfix pin. Their follow-up length was a mean of 6.8 years and 86% scored normal or nearly normal on IKDC score. Re-rupture occurred in 1.5% of patients in this shorter follow-up study. Maletis et al reported retrospectively from the prospective Kaiser Permanente ACL Reconstruction Registry revision rates after HS grafts in 3012 patients was 1.56% (1.1% revision rate per 100 years of observation), however follow-up was short at a mean of 1.5 years. No assessment of patient outcome/satisfaction was performed.

Streich et al [20] reported a single blinded evaluation of 40 patients with 4 strand HS grafts at 10 year follow-up. They report 8% re-rupture rate and an IKDC score of 90.3 and all joints were either grade a or B (normal or nearly-normal).

Janssen et [21] alfound that animal and human in vitro and vivo researches have demonstrated three characteristic stages of graft healing after ACL reconstruction: an early graft healing phase with central graft necrosis and hypocellularity and no detectable revascularization of the graft tissue, followed by a phase of proliferation, the time of most intensive remodelling and revascularization and finally, a ligamentization phase with characteristic restructuring of the graft towards the properties of the intact ACL. However, a full restoration of either the biological or biomechanical properties of the intact ACL is not achieved.

In a large systematic review and meta-analysis by CL ardern and NF Taylor [22], With a mean follow-up of 4.0 years, 12,643 primary ACLRs were identified, with 3428 PT and 9215 HT grafts, among which 69 revisions with PT grafts and 362 revisions with HT grafts were performed. Researchers found that the overall 5-year revision rate was 4.2%. a higher revision rate was recorded for HT versus PT grafts at all follow-up times. When adjusted for sex, age, and type of graft, the HR for revision was 2.3 (95% CI, 1.8-3.0) for HT grafts compared with PT grafts. The HR for revision in the youngest age group was 4.0 (95% CI, 3.1-5.2) compared with the oldest age group. Sex had no effect on the revision rate. Patients with HT grafts had twice the risk of revision compared with patients with PT grafts. Younger age was the most important risk factor for revision, and no effect was seen for sex. Further studies should be conducted to identify the cause of the increased revision rate found for HT grafts.

In the nationwide Norwegian Cruciate Ligament Registry, [23] which included 12,643 people

undergoing ACL reconstruction between 2004 and 2012.The revision rates for hamstring tendon grafts were 5.1% at 5 years after surgery, and 2.1% for patellar tendon grafts. This study also looked at different age groups and found this increased rate to be consistent across all age groups. However, the younger group (age 15-19) had a 9.5 revision rate at 5 years using the hamstring graft in comparison to 3.5% using a patellar tendon graft. Together, there was a 2x greater risk of revision overall when using the hamstring graft, but closer to 3x greater risk for younger people. This study suggests that choice of patellar tendon versus hamstring graft should include the type and level of sport played.

Mohtadi NG, Chan DS [(24)] reviewed 19 trials providing outcome data for 1597 young to middle-aged adults were included. Many trials were at high risk of bias reflecting inadequate methods of randomization, lack of blinding and incomplete assessment of outcome. Pooled data for primary outcomes, reported in a minority of trials, showed no statistically significant differences between the two graft choices for functional assessment (single leg hop test), return to activity, Tegner and Lysholm scores, and subjective measures of outcome. There were also no differences found between the two interventions for re-rupture or International Knee Documentation Committee scores. There were inadequate long-term results, such as to assess the development of osteoarthritis. all tests (instrumental, Lachman, pivot shift) for static stability consistently showed that PT reconstruction resulted in a more statically stable knee compared with HT reconstruction.

Conversely, patients experienced more anterior knee problems, especially with kneeling, after PT reconstruction. PT reconstructions resulted in a statistically significant loss of extension range of motion and a trend towards loss of knee extension strength. HT reconstructions demonstrated a trend towards loss of flexion range of motion and a statistically significant loss of knee flexion strength. The clinical importance of the above range of motion losses is unclear. Study found There is insufficient evidence to draw conclusions on differences between the two grafts for long-term functional outcome. While PT reconstr-uctions are more likely to result in statically stable knees, they are also associated with more anterior knee problems [(25,26,27)]

Nomura [(25)] studied 24 post-operative MRI images of the tendon and muscle and strength measurements. They found that the tendon defect regenerated and filled in for 21 of the 24 patients and hamstring muscle was 12% smaller and 25% shorter than the non-operated side. In two strength measurements, the hamstring were >30% weaker as well.

Snow BJ [(28)] in their study on long term effect of hamstring graft found that the mean volume on the operatively treated side was 54.2% of that on the noninvolved side for the gracilis muscle and 58.5% for the semitendinosus muscle. a 7% decrease in quadriceps volume and an 8% increase in the volume of the long head of the biceps on the operatively treated extremity were noted. The semimembranosus muscle and short head of the biceps muscle showed no difference in volume. The gracilis and semitendinosus muscles also showed a decrease in peak cross-sectional area, a decrease in the cross-sectional area 7 cm proximal to the joint line, and evidence of fatty infiltration. There was variable evidence of tendon or scar formation within the tendon bed, with most patients having some tissue that blended into either the sartorius muscle or medial gastrocnemius fasciaat a level proximal to the joint line.

Overall, Hamstring autografts usually have the minimal post-operative pain. Ease of rehabilitation is better with Hamstring grafts. Most patients have a faster return to activities of Daily Living (aDLs).The surgical incision utilized to harvest the hamstring graft (s) is the same incision used to drill and place the fixation hardware. [(29,30,31,32)]

On negative side, the fixation is not very strong in te beginning . hence caution is advised with rehabilitation. It may cause hamstring weakness.

It may cause slower return to full athletic participation .There is no hamstring activation for at least the first four weeks in order to allow the harvest site to scar and heal down. There is also an increase incidence of hamstring strain and tenderness [33,34,35]

QUADRICEPS TENDON GRAFT

Quadriceps tendon as a graft source for anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) reconstruction has recently achieved increased attention. although many knee surgeons have been using the QT as a graft for ACL revision surgery, it has never gained universal acceptance for primary ACL reconstruction. The main reason, is that QT graft harvest is technically more demanding and a scar on the thigh is cosmetically less favorable, despite excellent clinical results in the literature.

In a review by Harris S. Slone [36], Fourteen studies were included in the review of clinical results, including 1,154 ACL reconstructions with quadriceps tendon autograft. Six studies directly compared quadriceps tendon autografts (n = 383) with bone–patellar tendon–bone autografts (n = 484). Stability outcomes (Lachman, pivot-shift, and instrumented laxity testing), functional outcomes (International Knee Documentation Committee and Lysholm scores), overall patient satisfaction, range of motion, and complications were similar between quadriceps tendon and other graft options. Less donor-site morbidity was seen in patients who underwent quadriceps tendon ACL reconstructions.

In a study by Ralph akoto [37], Thirty patients have been evaluated at a 12 months follow-up. The technique achieved in 96.7% normal or nearly normal results for the objective IKDC. The mean subjective IKDC score was 86.1 ± 15.8. In 96.7% the Tegner score was the same as before injury or decreased one category. a negative or 1+ Lachman test was achieved in all cases. Pivot-shift test was negative or (+) glide in 86.7%. The mean side-to-side difference elevated by instrumental laxity measurement was 1.6 ± 1.1 mm. Full ROM has been achieved in 92.3%. The mean single one-leg-hop index was 91.9 ± 8.0 at the follow-up. Potential advantages include minimum bone loss specifically on the femoral side and graft fixation without implants.

SYNTHETIC GRAFTS

Artificial ligaments for ACL started in 1920s. Then silver and stainless wires, nylon and silk strings and various synthetic fibres were used to create artificial grafts. In 1977, Jenkins et al. invented an artificial graft made of carbon fibre (Intergraft, Osteonics Biomaterials, Livermore, CA, USA). In 1981, Dandy et al. first implanted a carbon-fibre reinforced substitute for ACL with an arthroscopic procedure [38]. Subsequent studies showed poor resistance to torsion forces caused an early rupture of the fibres leading to carbon deposits in the liver and inflammatory synovitis in the knee joint .

In 1986, ligaments made by expanded polytetrafluorethylene (PTFE) were approved in the United States by the Food and Drug Administration (FDA) for the use in patients with previously failed autologous ACL reconstructions. The Gore-Tex ligament is made by a single strand of PTFE wounded into multiple loops. It was designed as a true prosthesis and implanted to permanently replace the natural ACL. It was supposed to promote immediate fixation and early load-bearing capacity. These grafts have an ultimate tensile strength of 5300 N, higher than any other commercial artificial ligament. In a study by Ahlfeld et al, he found one prosthetic breakage [39]. In a study by Glousman et al, noticed an immediate improvement of objective and subjective parameters. Complications included four ruptures, seven major complications (8%) and 14 revision operations (17%) [40]. Studies also found synovial reaction. In a study by Sledge et al , he eported a rupture rate of 29% in their five-year follow-up and discouraged future implantation of these devices [41]. However, in all studies they observed a worsening in knee stability. Mechanical properties of these grafts

were recognised as unsuitable, as failures were related to mechanical fatigue due to the lack of tissue ingrowth and to the presence of wear debris. Hence, Gore-Tex graft was withdrawn from the market in 1993.

Further, Dacron graft was experimented. The graft was composed of an 8-mm diameter sleeve of loosely woven velour with a central core made of four tightly woven tapes. It has a mean ultimate tensile strength of 3,631 N and a mean ultimate elongation of 18.7% . A study by Lukianov et al. [42] reported the results at a mean follow-up of 28 months in 41 patients who underwent ACL reconstruction with a Stryker Dacron ligament prosthesis. In 75% of the patients Lachman, anterior drawer, and pivot shift tests were found negative. However, in 1991, Arnauw et al. [43] studied 57 patients with an ACL Dacron prosthesis and observed a rupture rate of 40% 18 months after surgery. Wilk and Richmond described the five-year results after the implantation of 84 Dacron ligaments in which the failure rate was 35.7%. This represented a dramatic increase compared to the 20% failure rate reported at the two-year follow-up. [44] With the same artificial ligaments, Gillquist and Odensten reported a five-year follow-up of 69 patients [45]. They noticed only two cases of mild synovitis, but a high percentage of revisions (34%) and a high level of anteroposterior (AP) laxity. In 1997, presenting their long-term results, they described an increased rupture rate with 29% of the patients who underwent revision surgery. Hence, product was withdrawn from the market by Striker in 1994.

The introduction of the Kennedy Ligament Augmentation Device (LAD; 3M, St. Paul, MN, USA) in 1975 by Dr. John Kennedy was a mile stone in synthetic grafts. It consisted of an 8-mm diameter ribbon of polypropylene woven with an ultimate tensile strength of 1,730 and a stiffness of 56 N/mm. It was implanted in knee ligament surgery in addition to an autologous ACL reconstruction or after ACL primary repair and was designed to provide protection to the healing ACL or autologous graft. In fact its mechanical profile, much inferior to other artificial ligaments, was conceived to transfer loads during initial healing process and to protect the autologous implant during its early phase of vascularisation and collagen maturation. Roth et al. [46] presented the results of a Marshall-MacIntosh technique reinforced with LAD and documented significant improvements in terms of stability and functional outcome. Del Pizzo [47] in his three-year follow-up paper on patients who underwent ACL reconstruction with LAD, documented negativity to Pivot-shift test in 95% of the patients and AP laxity less than 3 mm in 72%. The rupture rate was 1.4%.

Proflex was conceived by Mansat [48] in France in 1985 and implanted for chronic knee instability with an “over the top” technique. A free transplant of the central third of the patellar tendon is introduced into the femoral tunnel, while the artificial ligament is fixed proximally to the external femoral cortex by a staple. Both components are then introduced and fixed in the tibial tunnel. The implantation through the “over the top” technique demonstrated a reduction of tunnel abrasion and consequently less wear particles in the joint cavity. Nevertheless, follow-ups demonstrated several complications including arthrosynovites, early breakage, and tunnel osteolysis.

In 1988 in Milan, a small ligament (30-mm long and 10-mm thick) made of polyethylene terephtalate was developed; it was called Pro-Pivot and implanted as an augment to a BPBT graft with an “over the top” technique .The study conducted in 1991 by Lanzetta et al. on 130 sportsmen who underwent ACL Pro-Pivot replacement showed good results in terms of joint stability. Second-look arthroscopies at six, 12 and 24 months after surgery demonstrated a process of integration of the artificial ligament that appeared complete two years after its implantation [49].

Showing the results eight years after the implantation of 160 artificial Trevira-hochfest devices using an over the top technique, Krudwig

demonstrated good results in terms of patient satisfaction and AP stability (only 16% of the patients showed an anterior sub-luxation >5 mm) [50]. Radiographic signs of osteoarthritis were found only in patients with previous history of meniscal surgery. The author suggested that synthetic prostheses do not invariably induce knee arthritis.

After analysing 33 ruptured ABC grafts (Surgicraft Ltd, Redditch, UK) with scanning electron microscopy, Mowbray et al. correlated the high incidence of early prosthetic ligament failures to the abrasion of the ligament at the tibial tunnel exit. The authors found that artificial implants are particularly vulnerable to rupture if an impingement occurs. Similarly, Amis and Kempson reported the failure mechanisms of Apex ligaments (De Puy International, Leeds, UK) and confirmed the hypothesis that bone impingement at the tibial tunnel exit leads to synthetic fibre damage.

Lavoie et al. reported their results after the implantation of LARS ligaments (Ligament Advanced Reinforcement System, Surgical Implants and Devices, Arc-sur-Tille, France) [51]. These ligaments are made of polyethylene terephtalate and their structure allows tissue in growth in the intra-articular part.

The follow-up made on 47 patients, eight to 45 months after implantation, showed good average results according to subjective parameters (average KOOS score 93), and a satisfying Tegner activity level. A subsequent study from the same scientific group compares two-year results after LARS ligament ACL reconstruction with the BPTB graft technique [52]. Their findings were that the LARS ligament gave better subjective and objective outcomes during the initial years, while no difference with the autologous procedure could be found 24 months after surgery.

In a retrospective study, Liu et al. compared LARS artificial ligaments to four-strand hamstring tendon autografts four years after implantation. They observed excellent functional outcomes, with a higher knee stability in the LARS group. Studies advocate that LARS ligament reconstruction could lead to an early return to high activity levels, although long-term results are still required.

Research in the field of artificial ligaments demonstrates that the ultimate characteristic required for these materials is biocompatibility (chemical stability, degree of polymerization, absence of soluble additives, scarce water adsorption, presence of pores for fibroblasts ingrowth); on the other hand, mechanical characteristics (traction resistance, stiffness, elongation, torsion and abrasion resistance) should be as similar as possible to those of the natural ligament. In order to succeed, tissue engineering should provide a functional and biologically valid ACL, able to promote a continuous tissue remodelling. Despite much effort and many experimental studies, every material has been found to have several drawbacks, and research to find the ideal substitute, mimicking the natural human tissue, is still ongoing.

SUMMARY

All three grafts work quite nicely for ACL reconstruction. The most important consideration is actually putting the graft in the proper position, fixing it securely, and doing proper physical therapy after the reconstruction. These factors are certainly equally as important as the actual graft selection. Obviously the choice of the graft is very dependent on the age of the patient and what sports the patient participates in. Teenage girls in particular have a very high incidence of ACL tears because of their body alignment and they also have a higher incidence of reinjury after reconstruction than adults and teenage males**.**

The surgeon has many choices when it comes to graft selection for ACL reconstruction. There are certain situations in which one graft may be favored over another, such as in the young, athletic population where autograft tissue should be used. However, there is good literature that excellent results can be achieved with each type of graft, and thus the surgeon must inform his or her

patients of the advantages and disadvantages of each graft and help them make an informed decision. In nutshell, BTB autograft is generally accepted as the "gold standard" due to its biomechanical profile and reliable, fast bone-to-bone healing; however, hamstring tendons offer certain theoretical advantages in those that do a lot of kneeling, pre-existing patellofemoral pain, patellaalta, or in those with open physes. Synthetic grafts have been tried in various forms , however with limited success. But more long term, prospective studies must be done to determine its incorporation properties and ensure its long-term survival compared to patellar tendon and hamstring autografts. allograft tissue is an excellent choice in many revision situations, in the older recreational athlete, and in those with low demands but need to return to work faster with less pain and dysfunction immediately post-operatively.

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