ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION WITH PATELLAR OR HAMSTRING TENDON GRAFTS:
A REVIEW OF THE EVIDENCE

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INTRODUCTION

Rupture of the anterior cruciate ligament (ACL) is a common injury. The management of such injuries has been much debated and surgical reconstruction with an autograft is a popular option. Here the evidence on the use of two popular candidates (the patellar tendon and hamstring tendons) are compared in an attempt to discover the superior or to gain an indication of factors that may influence this choice.

METHOD

After gaining background information from textbooks and internet resources, a methodological database search for articles on this subject was carried out using the Medline search. Particular attention was paid to randomised controlled prospective trials that had demonstrated a clear effort to eliminate bias from their methods.

BACKGROUND

A variety of options are available for management of ruptured ACL’s. Conservative management is appropriate for many patients, especially if quadriceps muscle bulk is maintained. However, this approach is rarely compatible with a return to strenuous physical activity.

It has been proven that reconstruction of the ACL with grafted tissue is superior to primary repair of the ACL. A variety of grafts have been used. Allografts are a popular option due to the avoidance of having to take a graft from the patient. However processes necessary to reduce the risk of disease transmission significantly weaken the graft tissue. Artificial materials have

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been used as grafts but results have been disappointing. Quadriceps tendon grafts and extra-articular constructs using the iliotibial band have also been employed. Patellar tendon grafts and hamstring tendon grafts are the most popular choices for ACL reconstruction.

**PATELLAR GRAFTS**

Use of the patellar bone-tendon-bone (BPTB) graft has been a popular choice for ACL reconstruction for over two decades and it remains widely used. In this procedure, a 9-11mm wide strip of tendon is harvested from the centre of the patellar tendon through a vertical incision, or two small horizontal incisions. During harvesting, 2-2.5cm long bone blocks are retained attached to the harvested tendon. These bone blocks can then be inserted into tunnels drilled in the femur and tibia at the sites where the normal ACL inserts. These are then locked in place, usually by bioresorbable screws.

**HAMSTRING TENDON GRAFTS**

There are several different surgical procedures documented for use of hamstring tendon grafts for ACL reconstruction. In most procedures, the tendon of the semitendinosus muscle is used; either alone, or in addition to the gracilis tendon. In a procedure that is now commonly used, both semitendinosus and gracilis tendons are harvested and are doubled up giving a 4 fibre construct, known as the DSTG.

Harvesting is achieved through a small incision close to pes anserinus on the medial aspect of the proximal tibia. As with the BPTB graft, hamstring grafts are inserted into tunnels drilled in the tibia and femur. There are various methods for attachment of the graft including metal or bioresorbable screws, sutures and the endobutton-RT. This operation is technically more demanding and requires surgical experience as muscle or nerve damage can occur in the harvesting technique and harvested tendons must be prepared and tensioned prior to implantation in the knee.

Double or quadruple hamstring tendon grafts have the added theoretical advantage of forming a multi-band structure to more closely replicate the two bands of the ACL.

**RESULTS AND DISCUSSION**

There have been many clinical trials directly comparing patellar tendon grafts to hamstring tendon grafts for ACL reconstruction. There have been many retrospective and prospective randomised controlled trials, most with a
follow-up period of one to three years, and a few with follow-up periods of 5-7 years.\textsuperscript{2,5}

Whilst some studies are prospective randomised studies, others are retrospective. Variable methods of randomisation have been used and several studies included only small numbers of patients. While some authors excluded patients with concomitant meniscal injuries, others did not making direct comparison difficult. Furthermore, a variety of different surgical techniques have been used.

Studies have used various methods to assess outcomes following ACL reconstruction. These include subjective assessments like the Tegner Activity Scale or Visual Analogue Scale which assess patients' severity of symptoms and degree of handicap.\textsuperscript{1} The Lysholm Knee Score system has been used to assess patients' symptom severity. Objective clinical tests of knee function used include devices such as the KT-1000 arthrometers to test knee laxity, torque and muscle strength. The International Knee Documentation Committee (IKDC) score is applied by most, due to its inclusion of both objective knee function and subjective assessment of patient’s perceived symptoms.\textsuperscript{1}

\section*{GRAFT HEALING}

Both the patellar BTB grafts and the hamstring grafts depend on adequate healing of the grafted material, to its bony insertions so as to provide mechanical strength and stability.

One of the major advantages of the BPTB graft is that it requires bone-to-bone healing to fix the graft in place. This type of healing is stronger and occurs faster than soft tissue-to-bone healing.\textsuperscript{4} It is thought the bone blocks heal to the bone of the tunnel walls within 6-8 weeks.\textsuperscript{1}

Hamstring grafts depend on soft tissue-to-bone healing. Soft tissue-to-bone healing is thought to be weaker and takes longer to provide sufficient mechanical stability than bone-to-bone healing.\textsuperscript{4} The healing process following implantation of tendon within osseous tunnels involves the laying down of fibrous tissue fibres orientated along the load axis. One to three months after implantation, partial breakdown and replacement of the graft by scar-like tissue appears to occur.\textsuperscript{4} The use of growth factors and gene therapy to accelerate tendon to bone healing has become the focus of much research. In recent years there have been advances in fixation techniques, including the use of the endobutton-RT device.

The process of soft tissue-to-bone healing remains less understood. Some studies have identified the phenomenon of “tunnel widening” in x-rays of patients following ACL reconstruction with DSTG.\textsuperscript{6,7} However, the clinical
significance of this remains unclear as radiographic evidence does not correlate with functional or objective testing of knee kinematics.

ANATOMICAL AND BIOMECHANICAL CONSIDERATIONS

Fixation techniques have been developed so that grafted tendons do not advance too far into bone tunnels in the femur and tibia as the effects of stretching of the grafted tendons can cause a “bungee cord” effect which can lead to graft rupture and intra-articular damage.\textsuperscript{3,4} This criticises of some of the fixation techniques used with hamstring tendon grafts as they are thought to predispose to graft stretching. Development of surgical techniques, such as the use of bioresorbable screws and endobutton-RT devices to fix grafts has an important effect on the success of grafts.

Cylindrical tendon grafts cannot truly mimic the ACL as it has a thicker diameter at its bony attachments compared to in the centre. Furthermore, the ACL has proprioceptive functions and contains blood vessels, nerves, and unique populations of fibroblasts.\textsuperscript{7} The ACL is not isometric and is capable of stretching and shortening in response to differences in load distribution and strains placed on it. Graft material appears to be incapable of such behaviour, because it is composed of avascular collagen, is devoid of a nerve supply, and effectively acts as a tether within the joint.

Grafted tendons cannot fully restore the functions of the ACL. The aims of reconstructive surgery are therefore to provide sufficient joint stability for patients to return to a reasonable level of activity without severe pain.

SUCCESS RATES OF BPTB AND HAMSTRING TENDON GRAFTS

Studies comparing patellar bone-tendon-bone grafts to four-strand (DSTG) grafts have found each type of graft to be approximately equally successful in restoring knees to a functional state and returning patients to their pre-injury level of activity.\textsuperscript{2,8-11} Indeed, several prospective studies and review articles have concluded that there is no proven difference between the two graft types in terms of Lysholm scores, IKDC scores, clinical ligament evaluation or anterior knee pain.\textsuperscript{2,8-12} Table 1 summarises the results of 4 prospective randomised trials. For most outcomes no differences were found between patellar and hamstring grafts. Furthermore, Feller et al. (2003) found no statistically significant difference between the two grafts in terms of IKDC scores, Cincinnati scores or rates of return to pre-injury levels of activity.

ACL reconstruction operations with both BPTB grafts and hamstring tendon grafts have been shown to have 90-95% success rates in terms of achieving “good” or “excellent” outcomes and returning patients to pre-injury
levels of sporting activity.\textsuperscript{3} Other authors claim that 15% to 25% of patients have less than satisfactory results.\textsuperscript{1}

A randomised prospective trial by Shaieb \textit{et al.} (2002) found that there was a greater tendency for patients in the hamstring tendon group to rate their surgery result as excellent (80% versus 61%), although this difference was not statistically significantly.\textsuperscript{14} Differences in patient satisfaction are often related to anterior knee pain and extension deficits (discussed below). Aglietti \textit{et al.} (1994) found a greater percentage of patients returned to pre-injury levels of activity with patellar grafts,\textsuperscript{13} but most studies found no such difference. A meta-analysis by Freedman \textit{et al.} concluded that patellar tendon autografts resulted in better static knee stability and increased patient satisfaction compared with hamstring tendon autografts.

Figure 1 (from Pinczewski \textit{et al.}) shows the percentage of patients with IKDC scores of ‘A’ or ‘B’ with four-strand hamstring tendon grafts and BPTB grafts. As is shown by most trials, both methods produce IKDC ratings of ‘A’ or ‘B’ for the majority of patients and there is no statistically significant difference between the two groups.\textsuperscript{2} Figure 2 displays the results of a randomised controlled trial showing almost identical results for Tegner and Lysholm scores with patellar and hamstring tendons at one year.\textsuperscript{14} Table 2 is taken from another trial comparing patellar and semitendinosus tendon grafts and no significant differences were found between the groups in Lysholm scores, Tegner activity level scores or single-legged hop test scores.

\textbf{Figure 1:}

\textit{Percentage of patients with an overall IKDC score of A or B in a study comparing patellar tendon and four-strand hamstring tendon grafts for ACL reconstruction}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Percentage of patients with an overall IKDC score of A or B in a study comparing patellar tendon and four-strand hamstring tendon grafts for ACL reconstruction.}
\end{figure}
Initial recovery from surgery with hamstring tendon grafts is usually superior and patients are less likely to require crutches for long periods after the operation and are often able to return to work earlier than those who receive patellar grafts. However, it appears that patients can return to demanding exercises marginally earlier with patellar grafts.

Table 1: Comparison of Studies Assessing Hamstring Versus Patellar Tendon Autograft

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Months of follow-up (minimum/average)</td>
<td>24/29</td>
<td>22/28</td>
<td>24/42</td>
<td>60/60</td>
</tr>
<tr>
<td>Study design</td>
<td>Prospective randomized (alternating)</td>
<td>Prospective randomized (alternating)</td>
<td>Prospective randomized (by month of birth)</td>
<td>Prospective sequential (isolated ACL injury only)</td>
</tr>
<tr>
<td>Number of patients (initial/final)</td>
<td>80/72</td>
<td>63/60</td>
<td>129/125</td>
<td>180/170</td>
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<td>Timing of surgery</td>
<td>Chronic</td>
<td>Chronic</td>
<td>Acute and chronic</td>
<td>Acute and chronic</td>
</tr>
<tr>
<td>Rehabilitation equal</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Full weightbearing without aids (weeks)</td>
<td>6</td>
<td>8</td>
<td>1</td>
<td>1–1.5</td>
</tr>
<tr>
<td>Use of brace support</td>
<td>Hinged ROM 0–6 weeks</td>
<td>Hinged ROM</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Closed chain exercises</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>IKDC level I activity</td>
<td>Not tested</td>
<td>Not tested</td>
<td>Not tested</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>Lysholm</td>
<td>Overall IKDC</td>
<td>IKDC symptoms</td>
<td>Range of motion</td>
</tr>
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<td>---------------------------</td>
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<td></td>
<td>Not tested</td>
<td>Not tested</td>
<td>Not significant</td>
<td>Not significant</td>
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<td>Not tested</td>
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<td>Not significant</td>
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<td></td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Hamstring ($P &lt; 0.001$)</td>
</tr>
<tr>
<td></td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
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<td>Not significant</td>
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<td>Not significant</td>
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</tbody>
</table>

(Sources: 2,11,15,16)
Figure 2:
Lysholm and Tegner scores at 12 months following patellar and hamstring graft ACL reconstructions from a randomised controlled trial

POST-OPERATIVE LIGAMENT LAXITY

Although some studies have found no differences in laxity between patellar and hamstring grafts,\textsuperscript{10,11,12,15} other studies have found BPTB grafts to provide greater stability and rigidity than hamstring tendon grafts when knees are assessed clinically or by kinematic devices.\textsuperscript{16-18} Bizzini et al. (2006) found knees grafted with DSGT grafts to have a significantly greater laxity than BPTB grafts at a mean follow-up of 11 months.\textsuperscript{17}

A prospective randomised trial by Beynnon et al. (2002) found that after three years of follow-up, the objective outcomes with bone-patellar tendon-bone autograft were superior to those of replacement with a two-strand semitendinosus-gracilis graft with regard to knee laxity, pivot-shift grade, and strength of the knee flexor muscles. However, the two groups had comparable results in terms of patient satisfaction, activity level, and knee function.\textsuperscript{18}

Some studies have demonstrated significantly greater laxity of women’s knees with ACLs reconstructed with hamstring tendons when compared with men.\textsuperscript{2,17,19} Beynnon et al. (2002) argue that greater laxity seen in women’s knees following ACL reconstruction may have been due to inferior fixation
techniques that were not able to “accommodate for the generalized laxity and the decreased bone mineral density often found in women.”

**Table 2:**
The Lysholm Score, Tegner Activity Level Score, and Single-Legged Hop Test Score Preoperatively and at Follow-Up from a Randomised Controlled Comparison of Patellar (BTB) and Semitendinosus Tendon (ST) Grafts

<table>
<thead>
<tr>
<th>Test</th>
<th>BTB group</th>
<th>ST group</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median (range)</td>
<td>Median (range)</td>
<td></td>
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<tr>
<td>Lysholm score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperatively</td>
<td>70 (14–95)</td>
<td>68 (21–100)</td>
<td>NS(^a)</td>
</tr>
<tr>
<td>At follow-up</td>
<td>95 (46–100)</td>
<td>90 (51–100)</td>
<td>NS</td>
</tr>
<tr>
<td>Significance pre- vs. postoperative</td>
<td>(P &lt; 0.001)</td>
<td>(P &lt; 0.001)</td>
<td></td>
</tr>
<tr>
<td>Tegner activity level score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperatively</td>
<td>3 (1–9)</td>
<td>4 (2–9)</td>
<td>NS</td>
</tr>
<tr>
<td>At follow-up</td>
<td>6 (1–9)</td>
<td>6.5 (3–9)</td>
<td>NS</td>
</tr>
<tr>
<td>Significance pre- vs. postoperative</td>
<td>(P &lt; 0.001)</td>
<td>(P &lt; 0.001)</td>
<td></td>
</tr>
<tr>
<td>Single-legged hop test (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperatively</td>
<td>84 (0–111)</td>
<td>79 (0–108)</td>
<td>NS</td>
</tr>
<tr>
<td>At follow-up</td>
<td>92 (0–123) (one missing)</td>
<td>93 (0–122)</td>
<td>NS</td>
</tr>
<tr>
<td>Significance pre- vs. postoperative</td>
<td>(P = 0.005)</td>
<td>(P = 0.001)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Not significant
(Source: \(^{12}\))
Graft Site Morbidity Following BPTB Graft ACL Reconstruction

Anterior knee pain is a common post-operative complaint, experienced by 10-40% of patients after ACL reconstruction. Several studies have reported a higher incidence of post-operative anterior knee pain and pain on kneeling in the patellar graft groups, although others have not replicated this result. Agletti et al. (2004) found a higher prevalence of postoperative kneeling discomfort in the BPTB group compared to the hamstring tendon group.

This may constitute a profound morbidity for patients who are young adults who wish to return to occupations or recreational activities that require kneeling. Ejerhed et al. (2003) included a ‘knee-walking’ test as an outcome in their study design. Although they found no statistical differences for any other measured outcomes, they found that 53% of BPTB grafted patients found this test difficult or impossible, whereas only 23% of the hamstring tendon graft group had difficulty with this.

Some surgeons, including Steadman, have suggested methods of treating this, including surgical methods such as loose anterior closure of the patellar tendon defect, and altered rehabilitation programmes but there is no strong evidence to support this.

The incidence of patello-femoral pain when patients return to physical activity months after ACL reconstruction with BPTB graft has led to some surgeons now preferring hamstring tendon grafts. Patello-femoral pain has also been noted in patients who undergo conservative management of ACL tears, so processes other than graft related mechanisms may have a significant role.

Quadriceps muscle wasting is more pronounced in patients grafted with patellar tendons. However, Corry et al. (1999) found that although there was notable thigh atrophy seen in the year following surgery, there was no significant difference in thigh muscle bulk between the two groups at 24 months post-surgery. Similarly, Aune et al. (2001) found superior results for single-leg hop and isokinetic knee extension tests in the hamstring tendon group at 6 and 12 months, but there was no advantage over the patellar group at 2 years.

Loss of full extension of the knee is a common complaint following ACL reconstruction. Pinczewski et al. (2002) concluded that there was a greater incidence of loss of full extension of the knee (ie. fixed flexion deformity) in those grafted with patellar tendon.

It is thought that the incidence of post-operative knee stiffness and extension deficit can be reduced by correct timing of surgery (ie surgery not done until the joint is no longer swollen and has an adequate range of motion)
and by adherence to an approved rehabilitation programme. However, a fixed flexion deformity is a recognised adverse effect of BPTB grafts and surgeons must consider what effect such a deformity would have on an individual patient’s life before choosing this graft.

**GRAFT SITE MORBIDITY FOLLOWING ACL RECONSTRUCTION WITH HAMSTRING TENDON GRAFTS**

Hamstring tendon grafts are also associated with graft site morbidity. Aune et al. (2001) found significant hamstring muscle weakness at 2 years following hamstring graft ACL reconstruction. There is controversy over semitendinosus and gracilis’s ability to regenerate. Anderson et al. (2001) found there to be no loss of muscle torque following recovery from surgery with either type of graft. A study of muscle strength following surgery with patellar or hamstring grafts found quadriceps strength to be the same in both groups but found deficits of knee flexor torque in the hamstring graft group. Marder et al. (1991) also identified hamstring weakness in the hamstring group. It would seem that following hamstring graft ACL reconstruction, at least some hamstring muscle weakness is to be expected.

With hamstring grafts patients suffer less quadriceps muscle wasting and may feel able to return to sporting activity earlier than with patellar grafts. However, this may be ill-advised as it appears that hamstring tendon grafts do not reach maximum strength until about six months after reconstruction due to the molecular processes of graft healing discussed above.

**ACL RECONSTRUCTION AND OSTEOARTHRITIS OF THE KNEE**

ACL rupture is associated with increased risk of osteoarthritis. It is also thought that risk of developing osteoarthritis of an ACL-deficient knee increases with length of time before surgery is carried out. The progression of degenerative change may also be influenced by the type of graft used. One 7 year follow-up found that whilst 45% of patellar graft patients had radiographic evidence of osteoarthritis in the affected knee, those with hamstring tendon grafts were only 14%.

There are only a few long-term studies to examine trends in this field. Further research is required to investigate whether patellar grafts do increase risk of osteoarthritis or other factors such as meniscal injuries, length of time before surgery or previous knee injuries are more important.
Graft Failures and Rare Complications

Both BPTB grafts and hamstring tendon grafts have excellent success rates, however some grafts will fail. There are six main causes of ACL reconstruction failure are:

1. Drill hole placement in a non-anatomic location
2. Failure of Fixation
3. Graft impingement
4. Intrinsic graft failure
5. Arthrofibrosis
6. Trauma

The correct placement of tunnels to accurately replicate the anatomical arrangement of the ACL is essential. Arthrofibrosis occurs in up to 10% of ACL reconstructed knees and may be prevented by early and full range of motion exercises both before and immediately after surgery.

Traumatic rupture of autograft ACL reconstructions occur in about 2% of cases. Some studies have discovered a slightly higher rate of graft rupture with hamstring tendons (Pinczewski et al. (2002): 3% rupture rate in the patellar group vs 8% rate in the hamstring group; Roe et al. (2005): 4% in patellar group vs. 10% in hamstring group) however these differences were not statistically significant. In a meta-analysis, Freedman et al. found patellar tendon autografts to have a significantly lower rate of graft failure than hamstring grafts (1.9% versus 4.9%). The attachment of hamstring tendon to bone is weaker than that with BPTB grafts in the first few months due to the less efficient soft tissue-to-bone healing. However, most ruptured grafts can be attributed to premature return to strenuous exercise rather than surgical failings.

Graft impingement can occur due to poor graft placement, variations in notch shape and size and from graft hypertrophy. Infection is a very rare occurrence with both grafts, especially with the development of arthroscopic techniques.

Conclusion

On reviewing the evidence from clinical trials comparing the use of BPTB grafts and hamstring tendon grafts for ACL reconstruction, there does not appear to be any evidence to suggest any difference in functional outcomes between the two methods. This is despite evidence that hamstring grafts are associated with greater laxity than BPTB grafts.

The chances of suffering anterior knee pain and pain on kneeling are greater with BPTB grafts than with hamstring tendon grafts. Furthermore, patients with BPTB grafts frequently suffer deficits of knee extension and
quadriceps muscle wasting, although this usually normalises within two years. The incidence of osteoarthritis may be higher with patellar grafts than with hamstring grafts.

Several studies have noticed a slightly higher rate of graft rupture with hamstring tendon grafts. However, this is not true for all studies and both have low rates of post-operative graft failure.

Given the current evidence, it is reasonable for surgeons to make decisions on the choice of graft over a variety of factors for each patient individually. Factors including previous injuries, level of physical activity desired, sex, age, previous knee surgery, concurrent illnesses, and surgeon experience are all relevant. As the two grafts are equally effective, it would be reasonable for a surgeon to use the procedure which he is most skilled at.

Associated meniscus pathology and timing of ACL reconstructive surgery appear to be important factors in influencing outcome, and seem to be more important than the choice of graft. Graft fixation techniques and bony tunnel placement as well as postoperative rehabilitation also influence the outcome.

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