INSTRUCTIONAL REVIEW: KNEE

Does the type of graft affect the outcome of revision anterior cruciate ligament reconstruction?

A META-ANALYSIS OF 32 STUDIES

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Aims

Our aim was to perform a meta-analysis of the outcomes of revision anterior cruciate ligament (ACL) reconstruction, comparing the use of different types of graft.

Materials and Methods

A search was performed of Medline and Pubmed using the terms “Anterior Cruciate Ligament” and “ACL” combined with “revision”, “re-operation” and “failure”. Only studies that reported the outcome at a minimum follow-up of two years were included. Two authors reviewed the papers, and outcomes were subdivided into autograft and allograft. Autograft was subdivided into hamstring (HS) and bone-patellar tendon-bone (BPTB). Subjective and objective outcome measures were analysed and odds ratios with confidence intervals were calculated.

Results

A total of 32 studies met the inclusion criteria. Five studies used HS autografts, eight reported using BPTB autografts, two used quadriceps tendon autografts and eight used various types. Seven studies reported using allografts, while the two remaining used both BPTB autografts and allografts. Overall, 1192 patients with a mean age of 28.7 years (22.5 to 39) and a mean follow-up of 5.4 years (2.0 to 9.6) were treated with autografts, while 269 patients with a mean age of 28.4 years (25 to 34.6) and a mean follow-up of 4.0 years (2.3 to 6.0) were treated with allografts. Regarding allografts, irradiation with 2.5 mrad was used in two studies while the graft was not irradiated in the seven remaining studies.

Reconstructions following the use of autografts had better outcomes than those using allograft with respect to laxity, measured by KT-1000/2000 (MEDmetric Corporation) and the rates of complications and re-operations. Those following the use of allografts had better mean Lysholm and Tegner activity scores compared with autografts. If irradiated allografts were excluded from the analysis, outcomes no longer differed between the use of autografts and allografts. Comparing the types of autograft, all outcomes were similar except for HS grafts which had better International Knee Documentation Committee scores compared with BPTB grafts.

Conclusion

Autografts had better outcomes than allografts in revision ACL reconstruction, with lower post-operative laxity and rates of complications and re-operations. However, after excluding irradiated allografts, outcomes were similar between autografts and allografts. Overall, the choice of graft at revision ACL reconstruction should be on an individual basis considering, for instance, the preferred technique of the surgeon, whether a combined reconstruction is required, the type of graft that was previously used, whether the tunnels are enlarged and the availability of allograft.

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Revision anterior cruciate ligament (ACL) reconstruction is considered to be the optimal treatment after a failed primary reconstruction, based on improved stability and return to sport. However, a recent meta-analysis reported slightly inferior results for revision reconstruction compared with primary reconstruction, particularly regarding patient reported outcome measures (PROMs), the objective assessment of the knee, and the development of osteoarthritis (OA). The choice of graft has been reported to influence clinical outcomes, the progression of OA, complications, and failure after primary reconstruction. Hence,
the appropriate choice of graft could also affect the results of revision reconstruction. In primary reconstruction, hamstring grafts (HS) have been reported to have a higher rate of failure than bone-patellar tendon-bone (BPTB) grafts,7–11 while BPTB grafts have increased complications such as limited range of movement (ROM), anterior knee pain and OA of the knee.12,13 However, unlike primary reconstruction, in revision cases the choice of graft can be determined by the nature of the graft that was previously used, and an allograft may be required.

Types of allograft include BPTB,1,8 Achilles tendon,1,2 the tendons of tibialis anterior or posterior,2 or of peroneus longus or brevis.5 Allografts have been widely used in the United States for primary reconstruction to avoid the morbidity of the harvest of an autograft, to provide shorter operating time and to allow the customisation of the size of graft to each patient.14 The use of an allograft may, however, result in increased laxity and a higher rate of revision compared with autograft,8 due to slower incorporation,15 which has limited their use, particularly in older patients (those requiring multiligament reconstruction and revision procedures). Other disadvantages of the use of an allograft include increased cost, limited availability and potential risk of disease transmission.14,16 Processing an allograft using gamma irradiation has been reported to sterilise the graft and to alter its structural and biomechanical properties.17,18

The purpose of this meta-analysis was to compare the clinical outcomes of using autografts versus allografts for revision ACL reconstruction. The goal was to determine whether the choice of graft could affect the outcome as assessed using PROMs, laxity, objective parameters of function of the knee and the rates of complications and re-operations. The outcomes after the use of an irradiated and a non-irradiated allograft were analysed separately in order to evaluate the effect of irradiation on the outcome. The outcome after the use of allografts, HS and BPTB autografts were also compared. The hypothesis was that the outcome after the use of an allograft was inferior compared with the outcome after the use of an autograft in revision ACL reconstruction, and that there was no difference between the outcome after the use of HS and BPTB autografts.

Material and Methods
A meta-analysis was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.19

A search of MEDLINE and PubMed was performed on 01 April 2016 using the terms “Anterior Cruciate Ligament” and “ACL” combined with “revision”, “re-operation” and “failure”. Only studies in the English language were considered. No limitations based on the date of publication were applied and further review of the reference lists was performed to identify additional relevant studies.

The inclusion criteria were: randomised controlled trials (RCTs), prospective or retrospective studies with level of evidence I to IV, outcomes of both first or several revision ACL procedures, a minimum follow-up of two years, homogeneous groups of patients based on the choice of autograft or allograft, and the use of one of the following outcomes: side-to-side difference using KT-1000/2000 (MEDmetric Corporation, San Diego, California), Lysholm score,20 Tegner activity score,21 International Knee Documentation Committee (IKDC) score,22 pivot-shift test, and the rates of complications and re-operations. Studies using many types of graft were only included if different subgroups based on the type of graft were presented and analysed separately.

Two authors (AG and GMMM) independently reviewed the studies and screened them for eligibility based on a review of the title and abstract. Any disagreement was resolved by discussion between these two reviewers and a third reviewer (SZ). When the eligibility was unclear from the title and abstract, the full-text was obtained and assessed.

Exclusion criteria included: biomechanical studies, in vitro and in vivo studies, review articles, descriptions of surgical technique, case reports, letters to the editor, editorials, and abstracts from conferences.

The following were recorded: the authors, year of publication, number of patients treated, length of follow-up and the choice of graft for the primary and revision procedure. The use of gamma radiation and the dose was noted in studies using an allograft. The studies were divided into two groups based on the choice of graft, those using exclusively autografts and those using exclusively allografts. The autograft group was further divided based on the exclusive use of the specific BPTB, HS or quadriceps tendon graft (if used in more than two studies), while the allograft group was analysed considering all studies involving allografts. A secondary analysis was performed considering only the studies that used exclusively non-irradiated allografts.

The outcome measures included the Lysholm score,20 the Tegner activity score,21 the objective IKDC score,22 the pivot-shift test and the rate of complications and re-operations. The laxity of the knee was measured with KT-1000/2000 arthrometer, evaluating the side-to-side difference at 134 N or the manual maximum displacement test. The absolute value measured in millimetres and the number of patients with a value of < 3 mm, 3 mm to 5 mm and > 5 mm was recorded. The pivot-shift test was categorised as normal (negative), nearly normal (1+), abnormal (2+) and severely abnormal (3+). All complications, anterior knee pain, infection and loss of movement according to each author’s definition, were recorded. Re-operations, such as revision or further revision, arthroscopy with meniscal treatment or arthrolysis, and removal of hardware were noted.

The outcomes were evaluated according to Grassi et al.6 The Lysholm score, the Tegner activity scale and the absolute values for laxity were evaluated as continuous variables. The measurement of laxity was also evaluated in two ways, based on different cutoffs: patients with 0 mm to 3 mm side-to-side difference or > 3 mm, and those with
0 mm to 5 mm side-to-side difference or > 5 mm. The IKDC results were also analysed in two ways. First, all knees classified as A were separated in order to evaluate the number of normal knees. Secondly, the classification was separated into two groups represented by normal and nearly normal knees (A+B) and fair and poor knees (C+D), and the C/D results were analysed to record the failures as determined by the IKDC classification. The pivot-shift results were divided into two groups represented by normal or nearly normal test (0 and 1+), and abnormal or severely abnormal test (2+ and 3+). Patients who had a complication or underwent a further surgical procedure were included in the analysis.

The study was exempt from institutional review board approval, as it did not require direct involvement of the patients.

**Statistical analysis.** Continuous variables were extracted as mean and standard deviation (SD). When the SD was not provided, the authors were contacted to obtain this information. If there was no response, the SD was calculated from the data according to the formula: range (higher value - lower value)/4.23 For categorical variables, the total numbers and percentages were used for the meta-analysis. Different comparisons were performed: autografts versus all allografts, autografts versus non-irradiated allografts, HS autografts versus BPTB autografts, non-irradiated allografts versus HS and BPTB autografts.

Statistical analysis was performed according to Kraeutler et al. For dichotomous variables including objective IKDC (A and C/D), KT-1000 arthrometer (0 mm to 3 mm versus > 3 mm, and 0 mm to 5 mm versus > 5 mm), and complications and re-operations, the number of patients in each group was recorded and a summary odds ratio (OR) was calculated using a 2 × 2 contingency table (George Wilson University, Fairfax, Virginia). For continuous variables including mean side-to-side difference using KT-1000/2000, Lysholm and Tegner scores, a mean and a composite SD were calculated for the different groups and subgroups. A standardised mean difference (d) and standardised variance (vd) were calculated from the two means and standard deviation. With the use of the logit method, a summary OR and 95% confidence intervals were calculated from d and vd (George Wilson University, Fairfax, Virginia). A p-value < 0.05 was considered statistically significant.

**Results**
The literature search yielded 812 studies. A flow diagram of the process of selection is shown in Figure 1. After removal of 333 duplicate studies, another 421 were excluded based on their title and review of the abstract. The text of the remaining 58 studies was obtained and reviewed for eligibility. A total of 26 studies were excluded because they did not report the outcome of a specific type of graft. Therefore 32 studies were included in the final analysis.

**The characteristics of the patients.** A total of 23 studies presented the results of autografts: eight with ipsilateral, contralateral or re-harvested BPTB, five with ipsilateral or contralateral HS, two with ipsilateral quadriceps tendon and eight with mixed autografts (see supplementary material). Seven studies reported the results of allografts: one with BPTB and six with mixed allografts (see supplementary material).
The two remaining studies presented outcomes of both BPTB autografts and allografts.38,40 Overall, 1206 patients with a mean age of 28.7 years (22.5 to 39) and a mean follow-up of 5.4 years (2.0 to 9.6) were treated with autografts. Specifically, 466 patients with a mean age of 24.9 years (22.5 to 35) and a mean follow-up of 5.5 years (2.0 to 9.6) received BPTB autografts, while 142 patients with a mean age of 30.4 years (24 to 34) and a mean follow-up of 3.9 years (2.0 to 6.8) received HS autografts. Overall 269 patients with a mean age of 28.4 years (25 to 34.6) and a mean follow-up of 4.0 years (2.3 to 6.0) were treated with allografts. In two studies,34,40 2.5 mrad irradiation was used, including 90 patients with a mean age of 25 years (20 to 30) and a mean follow-up of 5 years (4 to 6). In the remaining seven studies2,24,29,36,38,45,46 the allografts were not irradiated; these included 179 patients with a mean age of 30.5 years (27 to 34.6) and a mean follow-up of 4.4 years (2.7 to 6.0). The pooled outcomes of the patients treated with allografts and autografts are summarised in Tables I and II.

**Table I. Outcomes of revisions with allograft**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Total</th>
<th>Non-irradiated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patients (n)</td>
<td>Studies (n)</td>
</tr>
<tr>
<td>IKDC A</td>
<td>86</td>
<td>4</td>
</tr>
<tr>
<td>IKDC CD</td>
<td>111</td>
<td>5</td>
</tr>
<tr>
<td>KT mean</td>
<td>242</td>
<td>8</td>
</tr>
<tr>
<td>KT &gt; 3 mm</td>
<td>195</td>
<td>6</td>
</tr>
<tr>
<td>KT &gt; 5 mm</td>
<td>138</td>
<td>5</td>
</tr>
<tr>
<td>Pivot-shift II to III grade</td>
<td>252</td>
<td>8</td>
</tr>
<tr>
<td>Lysholm</td>
<td>212</td>
<td>7</td>
</tr>
<tr>
<td>Tegner</td>
<td>76</td>
<td>4</td>
</tr>
<tr>
<td>Complications</td>
<td>269</td>
<td>9</td>
</tr>
<tr>
<td>Re-operations</td>
<td>269</td>
<td>9</td>
</tr>
</tbody>
</table>

**Table II. Outcomes of revisions with autograft**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Hamstrings</th>
<th>Bone-patellar tendon-bone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patients (n)</td>
<td>Studies (n)</td>
</tr>
<tr>
<td>IKDC A</td>
<td>657</td>
<td>16</td>
</tr>
<tr>
<td>IKDC CD</td>
<td>687</td>
<td>17</td>
</tr>
<tr>
<td>KT mean</td>
<td>850</td>
<td>20</td>
</tr>
<tr>
<td>KT &gt; 3 mm</td>
<td>343</td>
<td>13</td>
</tr>
<tr>
<td>KT &gt; 5 mm</td>
<td>284</td>
<td>10</td>
</tr>
<tr>
<td>Pivot-shift II to III grade</td>
<td>422</td>
<td>12</td>
</tr>
<tr>
<td>Lysholm</td>
<td>664</td>
<td>18</td>
</tr>
<tr>
<td>Tegner</td>
<td>385</td>
<td>12</td>
</tr>
<tr>
<td>Complications</td>
<td>1206</td>
<td>25</td>
</tr>
<tr>
<td>Re-operations</td>
<td>1206</td>
<td>25</td>
</tr>
</tbody>
</table>

IKDC, International Knee Documentation Committee score; KT mean, mean values of KT-1000/2000; SD, standard deviation

Total allografts versus autografts. The outcomes after the use of autograft were better when compared with allografts with respect to the mean KT-1000/2000 values of laxity, the percentage of patients with laxity of > 3 mm, and the rates of complications and re-operations (Table III). The outcomes after the use of allograft were better compared with autografts with respect to the mean Lysholm and Tegner activity scores. There was no statistical difference between allografts and autografts with respect to IKDC grade, KT-1000/2000 values > 5 mm or pivot-shift grade ≥ II.

**Effect of irradiation of the allograft.** When the 90 patients that received irradiated grafts were excluded from the analysis, there was a noticeable change in outcomes (Fig. 2, Table III). There was then found to be no difference between allografts and autografts with respect to the mean KT-1000/2000 values and the percentage of patients with a side-to-side difference of > 3 mm. Non-irradiated allografts had a significantly smaller rate of re-operation compared with autografts. Finally, there was no significant difference in Lysholm score between non-irradiated allografts and
autografts. The outcomes which were not affected by excluding irradiated allografts included the IKDC grades, side-to-side differences of > 5 mm, pivot-shift, and Tegner activity scores.

Comparisons of the types of graft. Due to the heterogeneity of the studies, graft-specific subgroup analysis of autografts was only possible for HS and BPTB (Table IV). Conversely, a similar analysis was not possible for allografts. Similar outcomes between HS and BPTB were present for all side-to-side KT-1000/2000 measurements and pivot-shift. HS autografts had better IKDC grades, Lysholm and Tegner activity scores and rates of complications and re-operations. No outcome was better in the BPTB autograft group than in the HS autograft group (Fig. 3).

Similar performances between non-irradiated allograft and HS autograft were found for IKDC grades, side-to-side KT-1000/2000 measurements, pivot-shift, Tegner activity scores and rates of complications and re-operations. HS autografts only had better Lysholm scores compared with non-irradiated allografts. Non-irradiated allografts had no better outcomes compared with HS autografts (Fig. 4). Similar performances between non-irradiated allograft and

### Table III. Odds ratios of the comparisons between allografts and total autografts

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Allograft vs autograft</th>
<th>Non-irradiated allograft vs autograft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR 95% CI</td>
<td>Better performance OR 95% CI</td>
</tr>
<tr>
<td>IKDC A</td>
<td>1.4621 (0.9112 to 2.2875)</td>
<td>=</td>
</tr>
<tr>
<td>IKDC CD</td>
<td>0.7003 (0.4046 to 1.2123)</td>
<td>=</td>
</tr>
<tr>
<td>KT mean</td>
<td>1.7933 (1.3810 to 2.3286)</td>
<td>Autograft 1.3208 (0.9728 to 1.7933)</td>
</tr>
<tr>
<td>KT &gt; 3 mm</td>
<td>1.5395 (1.0594 to 2.3727)</td>
<td>Autograft 0.7689 (0.4676 to 1.2645)</td>
</tr>
<tr>
<td>KT &gt; 5 mm</td>
<td>1.5618 (0.7922 to 3.0794)</td>
<td>=</td>
</tr>
<tr>
<td>Pivot-shift II to III grade</td>
<td>1.4625 (0.8541 to 2.5042)</td>
<td>=</td>
</tr>
<tr>
<td>Lysholm</td>
<td>1.4120 (1.0672 to 1.8681)</td>
<td>Allograft 1.1861 (0.8630 to 1.6301)</td>
</tr>
<tr>
<td>Complications</td>
<td>2.9161 (1.8877 to 4.5049)</td>
<td>Autograft 0.3107 (0.0965 to 1.0044)</td>
</tr>
<tr>
<td>Re-operations</td>
<td>3.4215 (2.3359 to 5.0117)</td>
<td>Autograft 0.3220 (0.1165 to 0.8904)</td>
</tr>
</tbody>
</table>

OR, odds ratio; CI, confidence interval; IKDC, International Knee Documentation Committee score; KT mean, mean values of KT-1000/2000

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**The Bone & Joint Journal**
Does the type of graft affect the outcome of revision anterior cruciate ligament reconstruction?

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BPTB autograft were found for side-to-side KT-1000/2000 measurements, pivot-shift, Lysholm scores and rates of complications. Non-irradiated allografts were better than BPTB autografts with respect to IKDC grades, Tegner activity scores and the rates of re-operations (Fig. 4).

Discussion

The most important finding of this meta-analysis was that, following revision ACL reconstruction, autografts performed better than allografts, with lower post-operative laxity and rates of complications and re-operations. However, if only non-irradiated allografts were considered, outcomes were similar to autografts. Additionally HS and BPTB autografts had similar outcomes in terms of laxity and pivot-shift, while HS autografts were better with respect to PROMS and IKDC grades.

Similar findings have been reported for primary ACL reconstruction. A recent systematic review and meta-

Table IV. Odd ratios of the comparisons between types of graft

<table>
<thead>
<tr>
<th>Outcome</th>
<th>HS autograft vs BPTB autograft</th>
<th>Non-irradiated allograft vs HS autograft</th>
<th>Non-irradiated allograft vs BPTB autograft</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR 95% CI</td>
<td>Better performance</td>
<td>OR 95% CI</td>
<td>Better performance</td>
</tr>
<tr>
<td>IKDC A</td>
<td>3.3077 1.4971 to 6.0420</td>
<td>HS</td>
<td>0.8298 0.4589 to 1.5006</td>
</tr>
<tr>
<td>IKDC CD</td>
<td>0.2000 0.0983 to 0.4071</td>
<td>HS</td>
<td>1.6277 0.7394 to 3.5828</td>
</tr>
<tr>
<td>KT mean</td>
<td>1.0894 0.7594 to 1.5627</td>
<td>=</td>
<td>1.1095 0.7253 to 1.6973</td>
</tr>
<tr>
<td>KT &gt; 3 mm</td>
<td>0.9174 0.3852 to 2.1849</td>
<td>=</td>
<td>1.0294 0.4348 to 2.4369</td>
</tr>
<tr>
<td>KT &gt; 5 mm</td>
<td>5.0000 0.5351 to 46.7185</td>
<td>=</td>
<td>0.5047 0.1348 to 1.8898</td>
</tr>
<tr>
<td>Pivot-shift II to III grade</td>
<td>1.1570 0.1252 to 10.6890</td>
<td>=</td>
<td>3.0867 0.9882 to 9.5447</td>
</tr>
<tr>
<td>Lysholm</td>
<td>3.2357 2.1608 to 4.8454</td>
<td>HS</td>
<td>0.4761 0.3127 to 0.7251</td>
</tr>
<tr>
<td>Tegner</td>
<td>4.4116 2.2686 to 8.5789</td>
<td>HS</td>
<td>1.2021 0.6001 to 2.4083</td>
</tr>
<tr>
<td>Complications</td>
<td>0.3659 0.1417 to 0.9444</td>
<td>HS</td>
<td>1.9689 0.6771 to 5.7254</td>
</tr>
<tr>
<td>Re-operations</td>
<td>0.3057 0.1289 to 0.7250</td>
<td>HS</td>
<td>0.5181 0.1434 to 1.8724</td>
</tr>
</tbody>
</table>

HS, hamstring; BPTB, bone-patellar tendon-bone; OR, odds ratio; CI, confidence interval; IKDC, International Knee Documentation Committee score; KT mean, mean values of KT-1000/2000

Fig. 3

Hamstring (HS) autograft versus bone-patellar tendon-bone (BPTB) autograft comparison. Values at the left of the midline are in favour of BPTB autograft, values at the right of midline are in favour of HS autograft. When the confidence intervals (dotted line) cross the midline (value 1) the difference between graft is not significant. Since high numbers of International Knee Documentation Committee (IKDC) grade C/D, grade II to III pivot-shift, complications, re-operations and high KT-1000/2000 values (KT) are negative outcomes, when they are in favour of a given graft it represents a worst performance. Conversely, higher IKDC grade A, Lysholm and Tegner represent a better performance.

Fig. 4

Non-irradiated allografts versus bone-patellar tendon-bone (BPTB) or hamstrings (HS) autograft comparison. Values at the left of the midline are in favour of BPTB autograft (red line) or hamstrings autograft (blue line), values at the right of midline are in favour of non-irradiated allograft. When the confidence intervals (dotted line) cross the midline (value 1) the difference between grafts is not significant. Since high numbers of International Knee Documentation Committee (IKDC) grade C/D, grade II to III Pivot-Shift, complications, re-operations and high KT-1000/2000 values (KT) are negative outcomes, when they are in favour of a given graft it represents a worst performance. Conversely, higher IKDC grade A, Lysholm and Tegner represent a better performance.
analysis comparing autografts and allografts for primary reconstruction suggested that autografts were better than irradiated allografts with respect to the function of the knee and stability, however non-irradiated allografts gave outcomes which were equal to autografts. This supports the results of Krych et al, who found a higher rate of rupture and inferior hop-test results in patients treated with BPTB allografts, but noted no significant difference when irradiated and chemically treated allografts were excluded from the analysis. Similar results were obtained comparing soft-tissue allografts and HS autografts.

In vitro detrimental effects of radiation on allografts have been demonstrated, even with low-doses of radiation (< 2.5 mrad). Detrimental effects have also been reported in a meta-analysis by Park et al, which included 21 studies and 1453 patients. They found that non-irradiated allograft gave better clinical outcomes than those using even low-dose (< 2.5 mrad) irradiated grafts, in terms of Lysholm score, KT-1000/2000 values and abnormal pivot-shift findings. Therefore, the results of the present meta-analysis support the previous evidence for primary ACL reconstruction in that, for revision reconstruction, irradiated allografts gave worse results than other grafts.

Several authors have investigated the effect of the choice of graft in revision ACL reconstruction. Denti et al reported similar outcomes between HS and BPTB autografts, while Ahn et al and Mayr et al reported comparable subjective and objective results of non-irradiated BPTB or Achilles tendon allografts compared with HS and BPTB autografts. In contrast, the Multicenter ACL Revision Study (MARS) prospectively evaluated 1205 patients and reported a 2.78 times higher risk of rupture of the graft at two-year follow-up when allografts were used. However, no subgroup analysis was performed based on the technique used for processing the graft (aseptically treated, low-dose irradiation or terminal irradiation), thus masking the potential effect of irradiation. In fact, a report by the Kaiser Permanente registry on 5968 primary ACL reconstructions with allografts, indicated that irradiation using > 1.8 mrad and allograft processing with BioCleanse (RTI Surgical Inc., Alachua, Florida) were predictors of a higher risk of failure and subsequent revision.

Despite statistically significant differences among the various types of graft with respect to Lysholm score, the clinical significance should be questioned. While a validated minimal clinical important difference for the Lysholm score has yet to be established, eight to ten points are considered a clinically significant difference. In the present meta-analysis, the difference between allografts and autografts, and their subgroups, did not exceed four points and should be considered comparable in terms of patient-reported subjective knee function.

Another important finding of this meta-analysis was that patients who were treated with a BPTB autograft had inferior objective IKDC grades compared with both HS autografts and non-irradiated allografts. The objective IKDC is a composite four-grade classification that evaluates the overall function of the knee, taking into account several parameters such as laxity, ROM, and swelling. Therefore, if similar stability is assumed, the inferior IKDC outcomes in the BPTB subgroup may be due to the increased morbidity related to harvesting the graft, similar to in primary ACL reconstruction. The BPTB subgroup also had the highest number of complications and re-operations compared with the other types of graft. This is mostly due to loss of movement, anterior knee pain, patello-femoral symptoms or the requirement for arthrolysis and debridement. Patellar fractures and patellar tendon rupture were also reported in some cases of BPTB re-harvesting. It should be noted that BPTB grafts were chosen after a failed primary reconstruction with HS and vice versa. In both cases BPTB harvesting was performed in either the primary or revision reconstruction. Thus, based on these findings, using BPTB after a failed primary reconstruction could lead to sub-optimal results. The detrimental effects may be due to the further surgical insult to an already injured knee, which may have advanced OA, especially after long periods of uncorrected instability.

The rates of complications and re-operations, despite being worse for BPTB autografts, should be interpreted with caution, as the definition of these outcomes varied among the studies. Moreover, the reporting of these rates was inconsistent. Furthermore, the negative outcomes in the re-harvested BPTB subgroup could have contributed to the worse outcomes of the entire BPTB group. Finally, it should be noted that patients who were treated with a BPTB autograft had a mean age of 24.9 years, compared with 30.4 and 30.5 years for those being treated with HS autografts and non-irradiated allografts respectively. As worse results after primary ACL reconstruction have been reported in younger patients, there may also be an age-related effect following revision surgery.

Overall, when irradiated allografts were excluded, there was no difference in the outcome of revision ACL reconstruction between autografts and allografts. Improved stability and PROMS were obtained with HS, BPTB or non-irradiated allografts. Thus, the choice of graft for revision ACL reconstruction should not be dogmatically directed towards a specific type, but determined on an individual basis bearing in mind the preferred surgical technique, the type of graft used at the initial procedure, the presence of enlarged tunnels and the availability of allograft. This supports the trend suggested by the MARS Group, indicating that the preferred technique of the surgeon is the main predictor of the choice of graft in revision ACL reconstruction, after accounting for the type of graft that was previously used and the age of the patient.

The results of this meta-analysis should, however, be interpreted with caution due to the many methodological limitations. First, the lack of RCTs produced a heterogeneous mixture of patients, previous reconstructions, surgical techniques and follow-up. However, the heterogeneity
allowed the inclusion of > 1000 patients in the analysis. The single-armed nature of the studies and the lack of randomised studies made the conclusions and recommendations observational and level IV evidence at best. However, meta-analyses with similar design and aims have been already published for the comparison of grafts used at primary ACL reconstruction. 8,59

A second limitation was the lack of data, with many studies being excluded based on using both allografts and autografts without reporting the outcomes of the graft-specific subgroups. Another limitation was that clinical outcomes were not stratified to the characteristics of the patients or surgical techniques, such as the type of graft which was previously used. This meant that the investigation of an association between these variables and outcomes was not possible. Due to the lack of stratification, it is possible that the effect of irradiation of the graft on the clinical outcomes could have been biased by the difference in mean age between patients receiving irradiated (25 years) and non-irradiated (30.5 years) allografts. Moreover, many other factors that could have influenced the outcomes such as the position of the tunnel, the technique of drilling, enlargement of the tunnels, staged reconstruction and the size of the graft were not evaluated.

Finally, the inconsistent definition of complications and the inconsistent reporting of re-operations could have biased the results, limiting the ability to calculate the pooled rate of failure and re-revision.

In conclusion, we found that autografts had better outcomes than allografts in revision ACL reconstruction, with lower post-operative laxity and rates of complications and re-operations. However, if only non-irradiated allografts were considered, the outcomes were similar to autografts. Furthermore, patients who received BPTB autografts had inferior objective IKDC grades compared both with HS autografts and non-irradiated allografts. Choosing a graft for revision ACL reconstruction should be done on an individual basis based on the preferred surgical technique, whether a combined reconstruction is required, the type of graft that was previously used, whether the tunnels are enlarged, and the availability of allograft.

Take home message:
- There are no differences of outcome after revision ACL reconstruction between autografts and non-irradiated autografts.
- Irradiated allografts show inferior results compared with other grafts.

Supplementary material

Tables showing details of the studies reporting on the revisions performed with autografts and allografts can be found alongside the online version of this article at www.bjbjboneandjoint.org.uk

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M. Nitr: Analysis and interpretation of the data.
S. G. Moulton: Interpretation of the data, Revising the manuscript, Language editing.
G. M. Marcheggianni Mucicoli: Collection and analysis of the data.
A. Bondi: Interpretation of the data, Revising the manuscript.
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