Radiological landmarks for placement of the tunnels in single-bundle reconstruction of the anterior cruciate ligament

There is little evidence examining the relationship between anatomical landmarks, radiological placement of the tunnels and long-term clinical outcomes following anterior cruciate ligament (ACL) reconstruction. The aim of this study was to investigate the reproducibility of intra-operative landmarks for placement of the tunnels in single-bundle reconstruction of the ACL using four-strand hamstring tendon autografts.

Isolated reconstruction of the ACL was performed in 200 patients, who were followed prospectively for seven years with use of the International Knee Documentation Committee forms and radiographs. Taking 0% as the anterior and 100% as the posterior extent, the femoral tunnel was a mean of 86% (SD 5) along Blumensaat’s line and the tibial tunnel was 48% (SD 5) along the tibial plateau. Taking 0% as the medial and 100% as the lateral extent, the tibial tunnel was 46% (SD 3) across the tibial plateau and the mean inclination of the graft in the coronal plane was 19° (SD 5.5).

The use of intra-operative landmarks resulted in reproducible placement of the tunnels and an excellent clinical outcome seven years after operation. Vertical inclination was associated with increased rotational instability and degenerative radiological changes, while rupture of the graft was associated with posterior placement of the tibial tunnel. If the osseous tunnels are correctly placed, single-bundle reconstruction of the ACL adequately controls both anteroposterior and rotational instability.

The accurate placement of an anterior cruciate ligament (ACL) graft is crucial in obtaining a successful outcome after reconstruction. Incorrect placement of the tunnels can result in abnormal tension in the graft, loss of movement and recurrent instability; it is a common cause of failure.4,9

There appears to be a consensus in the literature as to the ideal location of the tunnels, but the anatomical landmarks which most accurately create these tunnels in vivo remain unclear. Few prospective studies have examined the relationship between the position of the tunnels and the clinical outcome.10 The location of the anatomical landmarks which recreate the position has been suggested,11,12 but no study has shown which are associated with the best medium- to long-term clinical outcome. To date, no study has combined the use of consistent anatomical landmarks which have enabled reproducible placements of the tunnels and correlated this with clinical outcome.

Good, Odensten and Gillquist13 studied the radiological location of the native ACL in cadaver knees. They determined that the centre of the origin as seen on lateral radiographs was located on the femur at a mean of 66% from the anterior edge of Blumensaat’s line (intercondylar root line). They found that the tibial attachment was located at the junction of the anterior and middle thirds of the tibial plateau. Based on these landmarks, Khalafyan et al determined that a significant relationship existed between the clinical outcome of reconstruction of the ACL and the orientation of the tunnels, as assessed on post-operative radiographs. It has been shown that placing the graft in the centre of the footprint of the native ACL on the tibial side is associated with impingement at the intercondylar notch.11 The current consensus is that the graft should be positioned in the posteromedial portion of the footprint on the tibial side and in its posterior portion on the femoral side.11,12,14

Accurate placement of the tunnels appears difficult to achieve. Studies have shown that in more than 50% of patients the tunnels have been poorly placed.14,15

With the recent trend toward double-bundle reconstruction of the ACL the need for documenting a position of tunnel placement...
that would be both reproducible and associated with good long-term outcomes, is becoming increasingly important. It is argued that the double-bundle techniques are necessary for both rotational and anteroposterior (AP) stability. Although multiple-bundle techniques have been shown to restore the kinematics of the knee in cadaver studies, there is no evidence to support their superiority over single-bundle techniques in a clinical series. If a well-placed single tunnel can be shown to offer adequate stability, the added complexity of multiple-bundle techniques may need to be reconsidered.

The object of this study was to examine the reproducibility of tunnel placement using specific anatomical landmarks in single-bundle reconstruction of the ACL. We also examined the relationship between tunnel placement and clinical outcomes over a period of seven years.

Patients and Methods
The study group consisted of a consecutive series of 200 patients who underwent reconstruction of the ACL by a single surgeon (LAP) between October 1993 and March 1996 using a four-strand hamstring tendon autograft and fixation with interference screws. Patients with associated ligament injury requiring surgical treatment, evidence of chondral damage or degeneration, a history of previous meniscectomy, excision of more than one third of a meniscus at the time of reconstruction, radiographic evidence of degenerative changes or any abnormality in the contralateral knee were excluded. Those seeking worker’s compensation and others who refused to participate in a research study were also excluded. Ethical approval was granted by St Vincent’s Hospital Ethical Review Board.

Post-operative rehabilitation. Patients were permitted to bear weight as tolerated on crutches immediately after surgery. They were given oral analgesics and attended daily physiotherapy sessions. Active exercises were allowed, aiming for full extension of the knee by 14 days. Braces were not used, and full range of movement was permitted immediately following surgery. The intensive rehabilitation programme included closed-chain exercises and emphasised proprioceptive training. At six weeks, patients began jogging in straight lines and swimming. After 12 weeks, strengthening exercises were continued and an agility programme added. They were encouraged to initiate sports training activities. Return to competitive sports, including jumping, pivoting or side-stepping was prohibited for six months and was allowed after that time only if the goals of rehabilitation had been met.

Radiological assessment. Weight-bearing AP, 30° flexion posteroanterior (PA), lateral and patellofemoral radiographs were obtained before operation and at two and seven years after surgery. The position of the tunnels was independently measured by two orthopaedic fellows (PGH, ST) using the best available post-operative radiograph for each patient.

The position of the femoral tunnel was assessed on the lateral radiographs (Fig. 1). The length of Blumensaat’s line was measured and the points of intersection between it and the anterior and posterior borders of the femoral tunnel were identified. Based on these measurements, the position of the centre of the femoral tunnel was calculated and then expressed as a percentage of the total length of Blumensaat’s line. Placement of the femoral tunnel on the frontal plane was assessed on the AP radiographs (Fig. 2) by measuring the distance between the farthest points of the two femoral condyles. The distances from the lateral femoral condyle to both the lateral and medial walls of the femoral tunnel and the intercondylar notch were also measured. Based on these measurements, the position of the centre of the femoral tunnel was calculated and expressed as a percentage of the total distance between both condyles.

Placement of the tibial tunnel was assessed on the lateral radiographs (Fig. 1) as follows: the length of the tibial plateau was determined and the positions of the anterior and posterior borders of the tibial tunnel were identified relative to the anterior edge of the plateau. This allowed the position of the centre of the tunnel to be calculated and then expressed as a proportion of the total length of the tibial plateau. Placement of the tibial tunnel was assessed on AP radiographs (Fig. 2) by measuring the total width of the tibial plateau. The distances from the medial edge of the medial tibial plateau to both the medial and lateral borders of the tibial tunnel were measured. The position of the midpoint of the tunnel was then calculated and expressed as a proportion of the total width of the plateau in the coronal plane.

The angle of inclination of the graft was measured from the PA weight-bearing view at 30° of flexion (Fig. 3). A line was drawn connecting the medial wall of the femoral tunnel and the medial wall of the tibial tunnel. The angle subtended by this line and a line perpendicular to the tibial plateau was defined as the inclination of the graft.

Radiographs were examined for evidence of narrowing of the joint space and the presence of osteophytes seven years after operation. Using the International Knee Documentation Committee (IKDC) system, radiographs were graded as follows: A, normal; B, minimal changes and barely detectable joint space narrowing; C, moderate changes and joint space narrowing of up to 50%; and D, severe changes and more than 50% joint space narrowing. All the radiographs were interpreted by an independent musculoskeletal radiologist (VL).

Clinical assessment. Patients were assessed pre-operatively and at 12, 24 and 84 months after surgery using the IKDC evaluation form. Assessment was performed by a physiotherapist (LJS) or a clinical researcher (not an author). Ligamentous stability was assessed using the Lachman and pivot shift tests. The Lachman test was graded as 0 (< 3 mm translation), 1 (translation between 3 mm and 5 mm) and 2 (translation > 5 mm). The pivot-shift test was graded as 0 (negative), 1 (glide), 2 (clunk), and 3 (gross).
Instrumented knee testing was performed using the KT1000 Arthrometer (MEDmetric Corporation, San Diego, California) using the manual maximum test. Subjective symptoms were assessed using the Lysholm knee score.\(^{22}\)

**Statistical analysis.** Linear regression analysis was used to assess the relative contribution of each tunnel on selected clinical outcomes. The Mann-Whitney U test was used for comparison of tunnel placement between the groups. The reliability of radiological assessment of tunnel placement was evaluated using intraclass correlations for interobserver reliability, and the Spearman-Brown coefficient for intraobserver reliability. We used SPSS version 11.0 for Windows (SPSS Inc., Chicago, Illinois) for all statistical analyses. Statistical significance was set at \(p < 0.05\).

**Results**

Post-operative radiographs were available for 184 (92%) of the 200 patients. Rotated or poorly-penetrated radiographs were excluded.

**Reliability of radiological assessment of tunnel placement.** All radiographs were independently assessed by two observers (PGH, ST). The results reported represent those of observer 1 (ST). The decision to use the results of one examiner was made once reliability was established. Intraobserver Spearman-Brown coefficient was 0.83 and the intraclass correlation was 0.73, which Landis and Koch\(^{23}\) suggest may be interpreted as substantial agreement.

**Posterior femoral tunnel placement.** Lateral radiographs of adequate quality were available for 176 patients (88%). The midpoint of the femoral tunnel was located at a mean...
of 86% (standard deviation (SD) 5) posteriorly along Blumensaat’s line. The distribution of the midpoints of placement of the femoral tunnel is shown in Figure 4a.

**Anterior tibial tunnel placement.** Lateral radiographs suitable for the assessment of placement of the tibial tunnel were available in 181 patients (91%). The midpoint of the tibial tunnel was at a mean of 48% (SD 5) along the length of the tibial plateau. The distribution of midpoints for placement is shown in Figure 4b.

**Medial tibial tunnel placement.** Anteroposterior radiographs suitable for the assessment of placement of the tibial tunnel were available in 176 patients (88%). The location of the tibial tunnel in the coronal plane was at a mean of 46% (SD 3) lateral to the medial border of the medial tibial plateau. The distribution of the location points of the medial tibial tunnel is shown in Figure 4c.

**Lateral femoral tunnel placement.** Anteroposterior radiographs suitable for the assessment of placement of the femoral tunnel
were available in 172 patients (86%). The femoral tunnel was positioned at a mean of 42% (SD 3) lateral to the lateral femoral condyle. The distribution is shown in Figure 4d.

**Graft inclination.** This was measured in 164 patients (82%) who had AP radiographs of adequate quality. The mean inclination of the graft in the coronal plane was 19˚ (SD 5.5) from vertical in the coronal plane. The distribution is shown in Figure 4e.

**Relationship between tunnel placement parameters and rupture of graft.** Rupture of the ACL graft was observed in 21 patients (11%) during the seven-year period of follow-up. The clinical outcomes of those patients were excluded, as the majority had a revision procedure. However, radiographs before the rupture were available for 19 of these 21 patients. A comparison of the placement of the tunnel in the patients with ruptured and those with intact grafts at seven years is shown in Table I.

The only significant difference between those who suffered rupture and those with an intact graft at seven years was the position of the tibial tunnel in the sagittal plane (Mann-Whitney U test, p = 0.003). If the tibial tunnel was placed > 50% posteriorly along the length of the anterior tibial plateau, the incidence of rupture was 17% (11 of 66) vs 7% (8 of 115) if the graft was placed ≤ 50% posteriorly (Mann-Whitney U test, p = 0.04).

**Summary of IKDC examination.** The 21 patients (10.5%) with rupture of the graft were excluded from the clinical assessment because the majority had a revision procedure. Of the remaining 179 patients (89.5%), full clinical assessment was performed on 148 (83%) at seven years. Of the 31 patients not reviewed at seven years, ten were residing outside Australia, 16 were unable or unwilling to attend and five could not be located. A summary of the clinical and subjective results is shown in Figure 5.

**Relationship between laxity and tunnel placement.** Logistic regression analysis showed a significant association between the pivot-shift test and inclination of the graft in the coronal plane (p = 0.01). No other parameter of placement was significantly associated with the pivot-shift test (posterior femoral tunnel, p = 0.28; anterior tibial tunnel, p = 0.19; medial tibial tunnel, p = 0.09; lateral femoral tunnel, p = 0.19).

The mean inclination of the graft in the coronal plane for those patients with a grade 0 pivot-shift test was 19˚ (SD 5.3) compared with 16˚ (SD 5.4) for those with a grade 1 test (Mann-Whitney U test, p = 0.04). Patients with a grade 1 pivot test had a more vertical angle of inclination of the graft than those with a grade 0.

Instrumented testing for laxity was not significantly associated with any parameters of tunnel placement on regression analysis (posterior femoral tunnel, p = 0.38; anterior tibial tunnel, p = 0.41; medial tibial tunnel, p = 0.21; lateral femoral tunnel, p = 0.10; graft angle, p = 0.44).

The lowest grade for all laxity tests, including instrumented testing, pivot shift and Lachman tests determines the overall IKDC laxity grade. On linear regression analysis, this grade was not significantly associated with any parameters of tunnel placement (posterior femoral tunnel, p = 0.73; anterior tibial tunnel, p = 0.54; medial tibial tunnel placement (%)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Graft intact</th>
<th>Graft ruptured</th>
<th>p-value (Mann Whitney U test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior femoral</td>
<td>85.6 (4.5)</td>
<td>86.8 (5.8)</td>
<td>0.29 (0.58)</td>
</tr>
<tr>
<td>Anterior tibial</td>
<td>47.8 (5.4)</td>
<td>51.5 (4.4)</td>
<td>0.005 (0.003)</td>
</tr>
<tr>
<td>Medial tibial</td>
<td>46.5 (2.5)</td>
<td>45.9 (2.6)</td>
<td>0.38 (0.27)</td>
</tr>
<tr>
<td>Lateral femoral</td>
<td>42.1 (3.0)</td>
<td>41.8 (3.8)</td>
<td>0.75 (0.45)</td>
</tr>
<tr>
<td>Graft inclination (˚)</td>
<td>19 (5.4)</td>
<td>18</td>
<td>0.61 (0.89)</td>
</tr>
</tbody>
</table>

Summary of the International Knee Documentation Committee (IKDC) results seven years after surgery.
tunnel, p = 0.86; lateral femoral tunnel, p = 0.09; graft angle, p = 0.19).

**Relationship between range of movement and tunnel placement.** Loss of knee extension was not significantly associated with any of the measured parameters on regression analysis (posterior femoral tunnel, p = 0.35; anterior tibial tunnel, p = 0.23; medial tibial tunnel, p = 0.76; lateral femoral tunnel, p = 0.30; graft angle, p = 0.70). Loss of knee flexion was significantly associated with more posterior placement of the tibial tunnel (p = 0.003), but no other tunnel placement parameters on regression analysis (posterior femoral tunnel, p = 0.13; medial tibial tunnel, p = 0.67; lateral femoral tunnel, p = 0.30; graft angle, p = 0.70).

**Relationship between radiological degenerative changes and tunnel placement.** Logistic regression analysis was performed to assess the relative contribution of the variables of tunnel placement on the outcome of the IKDC radiological grade for osteoarthritis (OA). Abnormal radiographs at seven years were significantly associated with a more vertical angle of the graft in the coronal plane (p = 0.01) on regression analysis. No other parameter was significantly associated with abnormal radiological findings (posterior femoral tunnel, p = 0.82; anterior tibial tunnel, p = 0.11; medial tibial tunnel, p = 0.53; lateral femoral tunnel, p = 0.08).

**Tunnel placement parameters and ideal clinical outcome.** Patients were assigned to two groups; those who had an ideal clinical outcome at seven years and those who did not. The following criteria were used to define the ideal clinical outcome: normal or nearly normal subjective knee function; grade A IKDC range of movement (< 3° loss of extension and < 5° loss of flexion); grade A IKDC laxity assessment (grade 0 pivot and < 3 mm laxity on instrumented testing); no evidence of radiological degenerative changes; and an intact graft.

The parameters of tunnel placement of the two groups are shown in Table II.

**Table II.** Comparison of tunnel placement parameters (mean values) between patients with ideal clinical outcome and those without

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ideal outcome</th>
<th>Not ideal outcome</th>
<th>p-value (Mann-Whitney U test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>68</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>Mean (SD) tunnel placement (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior femoral</td>
<td>85.8 (4.1)</td>
<td>86.3 (5.1)</td>
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</tr>
<tr>
<td>Anterior tibial</td>
<td>48.4 (4.8)</td>
<td>49.5 (4.8)</td>
<td>0.19</td>
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<tr>
<td>Medial tibial</td>
<td>46.6 (2.4)</td>
<td>46.7 (2.4)</td>
<td>0.76</td>
</tr>
<tr>
<td>Lateral femoral</td>
<td>43.1 (2.3)</td>
<td>42.4 (2.8)</td>
<td>0.10</td>
</tr>
<tr>
<td>Graft inclination (°)</td>
<td>18.8 (5.2)</td>
<td>18.8 (5.9)</td>
<td>0.93</td>
</tr>
</tbody>
</table>

* ideal outcome was defined as normal or nearly normal knee function, grade 0 pivot test, < 3 mm instrumented testing, full range of movement, absence of degenerative changes on radiographs and intact anterior cruciate ligament graft

**Discussion**

Even in the hands of experienced surgeons, reproducible results can only be achieved when consistent and reliable landmarks are used during surgery. We have found that the use of the anatomical landmarks described resulted in consistent placement of the osseous tunnels and excellent clinical outcomes in the long-term.

We have assessed the angle formed on the AP radiograph by the medial walls of the tibial and femoral tunnels and used this to measure the inclination of the graft in the coronal plane. Other authors have studied the effect of variations in the angle of the tunnel on the outcome of the reconstruction, but the influence of the angle of the graft, taking into account the location of both the femoral and tibial tunnel, has not been described. We found that a more vertical graft was associated with a higher incidence of a pivot glide as assessed on physical examination seven years after operation, and a higher degree of radiological OA. This may be related to some degree of sustained rotational instability.

There has been an increasing interest in double-bundle reconstruction of the ACL. It has been argued that single-bundle reconstructions are effective in controlling anterior laxity, but not rotational instability. However, the studies which have shown poor rotational control with single-bundle techniques have not considered tunnel placement or the angle of inclination of the graft. Some proponents of double-bundle techniques previously performed single-bundle reconstructions, using a transtibial approach for placement of the femoral tunnel. This may increase the difficulty in obtaining correct placement and consequently the inclination of the graft. We have found that if the tunnels are placed so that the inclination of the graft is approximately 19° in the coronal plane, normal rotational stability on the pivot-shift test is achieved with a single-bundle technique. We believe that vertical inclination of the graft is more likely to occur when drilling femoral tunnels through the tibia and therefore would advocate proceeding through the anteromedial portal. Future studies will need to demon-
strate the superiority of multiple-bundle techniques before the use of these more complex procedures can be firmly supported.29

We have shown that optimal results at seven years after operation are associated with the radiological orientation of the tunnels (Fig. 6). The centre of the femoral tunnel should be located 86% posteriorly along Blumensaat's line, and on the AP view, it should be at a distance of 43% lateral to the lateral femoral condyle. Medial placement of the femoral tunnel may cause impingement of the graft against the posterior cruciate ligament, thus increasing the tension of the graft.30 Others have shown that more anterior placement of the femoral tunnel is associated with adverse clinical outcomes as a result of excessive constraint leading to either loss of movement or elongation of the graft with cyclical loading.9,15,31 The tibial tunnel should be located 48% posteriorly along the tibial plateau on the lateral radiograph.14 Placement of the tibial tunnel ≥ 50% posteriorly was associated with loss of knee flexion and rupture of the graft. Others have shown that more anterior placement is associated with graft impingement,32 and decreased range of movement.33 In the coronal plane, the tibial tunnel should be located at 47% across the width of the tibial plateau from the medial cortex. Others have shown that more lateral placement is associated with impingement of the graft,33 while medial placement will result in loss of flexion.14

One of the aims of computer-assisted surgery of the ACL is to increase the accuracy of placement of the tunnels.34 Whether this is feasible with the use of computer-assisted techniques has yet to be described. During such procedures, the surgeon needs to define the optimal points for placement of the tunnels. Our study offers radiological landmarks with which an excellent clinical outcome is likely to be achieved.

Fig. 6a

Recommended radiological position of the tunnels in a) the coronal and b) the sagittal views after reconstruction of the anterior cruciate ligament.

Fig. 6b

References


