Endoscopic anatomic landmarks for tunnel placement in ACL reconstruction and their relationship to 7 year clinical outcome.

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ABSTRACT

The aim of this study was to assess the reproducibility of intra-operative landmarks for tunnel placement in single bundle 4 strand hamstring tendon ACL reconstruction and establish its effect on long term clinical outcome. There is a lack of evidence examining the relationship between anatomical landmarks, radiographic tunnel placement and long term clinical outcome.

200 patients undergoing isolated ACL reconstruction were prospectively followed for 7 years with full IKDC and radiographs.

The femoral tunnel was located at a mean 86% posterior along Blumenstaat's line and the tibial tunnel was 48% posterior along the tibial plateau. In the coronal plane the tibial tunnel was 47% along from the medial border of the tibial plateau. The mean coronal graft inclination was 19 degrees.

Intraoperative landmarks result in reproducible tunnel placement and excellent 7 year clinical outcomes. Vertical graft inclination is associated with increased rotary instability and degenerative radiographic change. Graft rupture is associated with posterior placement of the tibial tunnel (>50%). With correct placement single bundle ACL reconstruction satisfactorily controls both AP and rotary instability.

INTRODUCTION

The accurate placement of the ACL graft is crucial in obtaining a successful outcome of ACL reconstruction[1-3]. Incorrect tunnel placement can result in abnormal graft tension, loss of movement and recurrent instability, and is a common cause of failure in ACL reconstructive surgery [4-9].

There appears to be a consensus in the literature as to the ideal location of the tunnels for ACL reconstruction, however the anatomical landmarks that most accurately create these tunnels in vivo remains unclear[10]. There are few prospective studies that have examined the relationship between tunnel position and clinical outcome[10]. The location of anatomical landmarks that recreate a tunnel position have been suggested[11,12] but those that are associated with the best medium to long term clinical outcome remain unreported. To date no studies have combined the use of consistent anatomical landmarks to enable reproducible tunnel placements, and correlated this with medium term clinical outcome of ACL surgery.

The work of Good et al[13] studied the radiographic location of the native ACL in cadaveric knees. They determined that the centre of the native ACL on lateral radiographs is located on the femur at an average 66% from the anterior edge of Blumenstaat’s line and the tibial attachment is located 33% from the anterior border of the tibial plateau. Based on these landmarks Khalfayan et al[2] determined that a significant relationship existed between the clinical outcome of ACL reconstruction and the tunnel position as assessed by post operative radiographs. It has been shown that placing an ACL graft in the centre of the footprint of the native ACL on the tibial side is associated with impingement in the intercondylar notch[11]. The current consensus is the graft should be positioned in the posteromedial portion of the ACL footprint on the tibial side and posterior portion of the native ACL footprint on the femoral side[11,12,14].

Accuracy of tunnel placement appears to be difficult to achieve. Studies that have shown that 50% or more of patients have poorly placed tunnels[14,15].

The importance of documenting the optimal position for tunnel placement that is both reproducible and associated with good long term clinical outcome is becoming increasingly important with the advent of the recent trend towards multiple bundle ACL reconstruction. It is argued that these techniques are necessary in order to control both rotary instability and anterior translation[16]. Although multiple bundle techniques have been shown to restore kinematics in cadaveric studies[17], there is no evidence to support their superiority over single bundle techniques in clinical series[10,18]. Furthermore if stability can be achieved with a *well placed* single tunnel the added complexity of multiple bundle techniques need to be considered.

The primary aim of this study was to examine the reproducibility of tunnel placement using specific anatomical landmarks in single bundle ACL reconstruction. Secondly to examine the relationship between tunnel placement and clinical outcomes over a seven year period.

PATIENTS AND METHODS

Subjects

The study group consisted of a consecutive series of 200 patients undergoing ACL reconstruction by a single surgeon (LP) between October 1993 and March 1996 with 4 strand hamstring tendon autograft and interference screw fixation. Patients were excluded if any of the following criteria were met; 1) Any associated ligament injury requiring surgical treatment; 2) evidence of chondral damage or degeneration; 3) previous meniscectomy; 4) excision of more than one-third of one meniscus at the time of reconstruction; 5) an abnormal radiograph; 6) any abnormality in the contralateral knee; 7) those patients seeking compensation for their injury; and 8) those who did not wish to participate in a research program. Ethics approval was granted by St Vincent's Hospital Ethical Review Board.

Surgical Technique

All operations were performed by the senior author (LP). All procedures were done under general anaesthesia and tourniquet with a "single incision" endoscopic technique and a single bundle 4-strand hamstring graft. The surgical technique has been previously reported in detail[19], however a detailed description is warranted to emphasise the reproducibility of this technique.

Gracilis and semitendinosus, hamstring tendon autografts were harvested and prepared to produce a four-strand graft.

High anterolateral and low anteromedial arthroscopic portals were used. The knee joint was arthroscopically assessed and associated injuries treated as required. The ligamentum mucosum was divided allowing the fat pad to retract. The ACL stump was excised, and the lateral wall of the notch was cleared of soft tissue to the posterior capsular attachment.

The femoral tunnel was placed 5mm anterior to the posterior capsular insertion into the lateral femoral condyle, or of deficient, at the 01h30 position in the left and 10h30 position in the right knee, with respect to the apex of the notch. The probe was placed over the posterior rim of the notch, in the "over the top position", and a visual assessment of the 5mm point was made using the laser markings on the probe. It is difficult to assess depth on 2 dimensional monitors. As an adjunct to the visual assessment, with the probe in the over the top position, the surgeon held the probe with a finger on the skin, by withdrawing the probe to the spot 5mm more anterior the surgeon then double checked the distance with reference to his finger tip and the skin. The probe tip then lay exactly 5mm from the posterior cortex. This point was marked with a Stedman Pick.

A 4.5mm drill was passed through the antero-medial portal for an inside out drill technique. Then the knee was maximally flexed and the tunnel was drilled through both cortices (the trajectory is approximately 30º lateral and 45º anterior to the long axis of the femur). A 2.4mm beath pin was inserted and the hole over drilled with a stepped router (S&N Endoscopy) to a depth of 30mm. The router had a diameter equivalent to that measured for the graft plus 0.5mm. A pull out suture was then passed through the tunnel with the Beath pin.

A tibial jig was passed through the antero-medial portal. The tip was placed such that the centre of the drill hole lay on a line between the apex of the medial tibial spine and the posterior border of the anterior horn of the lateral meniscus. It was centred 50% of the graft diameter along this line from the medial tibial spine (so that the most medial part of the tunnel lay immediately next to the medial tibial spine). The tunnel was first drilled with a 4.5mm pilot drill and correct placement was confirmed. Fine adjustments were made as required. A 2.4mm beath pin was inserted into the pilot hole, and over drilled to the appropriate diameter with a router, equal to graft diameter. The pull through suture was retrieved through the tibial tunnel; the lead graft suture was then pulled through the tibial tunnel into the blind femoral tunnel. The graft was then pulled into position.

The knee was fully flexed and a guide pin inserted into the femoral tunnel to allow placement of a 7 x 25mm round headed, soft threaded, cannulated, titanium interference screw (RCI titanium screw, Smith and Nephew Acufex, Mansfield, MA). A reverse threaded screw was used for femoral fixation in right knees. The knee was put through a full range of motion. Correct placement precluded impingement in the notch without notchplasty.

The graft was tensioned at 70° flexion, a guide pin inserted into the tibial tunnel, and an appropriately sized RCI screw partially inserted. The knee was then fully extended and screw insertion was completed. A final assessment of antero-posterior knee stability and range of motion was performed. The knee was irrigated, local anaesthetic instilled, and skin incisions sutured.

Postoperative Rehabilitation

Patients were permitted to weight bear as tolerated on crutches immediately after surgery. They were given oral analgesics for pain control and daily physiotherapy to reduce postoperative swelling and to allow active exercises aiming for full extension by 14 days. No brace was used. The intensive rehabilitation programme included closed chain exercises and an emphasis on proprioceptive training. At 6 weeks patients began jogging in straight lines and swimming. From 12 weeks general strengthening exercises were continued with agility work and sports training activities encouraged. Return to competitive sport involving jumping, pivoting or side stepping was prohibited until 6 months after the reconstruction, and only after rehabilitation goals had been met.

Assessment

Radiological assessment

Before surgery and at 2 and 7 years after surgery, weight-bearing anteroposterior (AP), 30° flexion posteroanterior (PA), lateral, patellofemoral view radiographs were taken. Measurement of tunnel position was performed by 2 orthopaedic fellows from the best available postoperative radiograph for each patient.

The femoral tunnel was assessed on the lateral AP radiograph as follows. The length of Blumenstaat's line was measured. The intersection between Blumenstaat's line and the anterior and posterior border of the femoral tunnel was identified. From these measurements the centre of the femoral tunnel was calculated and then expressed as a percentage of the total length of Blumenstaat's line. The lateral femoral tunnel placement was assessed from the AP radiographs as follows: the distance between the farthest points of the femoral condyles was measured. The distance from the lateral femoral condyle to the intersection both the lateral and medial walls of the femoral tunnel and the intercondylar notch was identified. From these, the midpoint of the femoral tunnel was calculated and expressed as a percentage of the total condylar width.

Anterior tibial tunnel placement was assessed from lateral radiographs as follows. The total tibial plateau length was determined. The anterior and posterior margins of the tibial tunnel were identified, relative to the anterior margin of the tibial plateau. From these the midpoint of the tibial tunnel was calculated and then expressed as a proportion of the total tibial plateau length. The medial tibial placement was assessed from the AP radiographs as follows: the length of the tibial plateaus was identified. The distance from the medial tibial plateau to both the medial and lateral borders of the tibial tunnel was measured. From these the midpoint of the tibial tunnel was calculated and then expressed as a proportion of the total coronal width of the tibial plateau.

The angle of graft inclination was measured from the PA weight bearing view at 30 degrees of flexion as follows: a line was drawn between the medial wall of the femoral tunnel and the medial wall of the tibial tunnel from the AP radiograph (Line A). The angle formed between line A and a line perpendicular to the tibial plateau (Line B) was measured as the graft inclination.

The medial, lateral and patellofemoral compartments were examined for evidence of joint space narrowing and the presence of osteophytes at 7 years. Using the IKDC system radiographs were graded as 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 radiographs were interpreted by an independent musculoskeletal radiologist.

Clinical assessment

Patients were assessed preoperatively and at 12, 24 and 84 months after surgery using the International Knee Documentation Committee (IKDC) evaluation form[20]. Assessment was performed by either a physiotherapist or a clinical researcher with extensive experience in knee assessment. Ligament stability was assessed by the Lachman[21] and pivot shift tests[22]. The Lachman test was graded as 0 (less than 3 mm), 1 (3 – 5 mm) and 2 (over 5 mm) and the pivot shift test as 0 (negative), 1 (glide), 2 (clunk), and 3 (gross). Instrumented knee testing was performed using the KT1000 arthrometer (MEDmetric Corporation, San Diego, CA) using the manual maximum test. Patients completed the Lysholm knee score[23] to document subjective symptoms.

Statistical Analysis

The mean and standard deviation of each tunnel placement parameter was calculated. Linear regression analysis was performed to assess the relative contribution of tunnel placement parameters on selected clinical outcomes. Mann Whitney U test was used for comparison of tunnel placement parameters between groups. Statistical significance was set at .05. SPSS 11.0 for Windows (SPSS Science Inc, Chicago, Ill) was used for all statistical analysis. The reliability of radiographic tunnel placement parameters was assessed using intraclass correlations for interrater reliability, and Spearman-Brown coefficient for intrarater reliability.

RESULTS

Two hundred patients were included in a longitudinal prospective study cohort examining the outcome of endoscopic ACL reconstruction with a 4-strand autogenous hamstring tendon graft. Post operative radiographs were available on 184 patients (92%). Rotated or poorly penetrated radiographs where accurate measurement was not possible were excluded.

Reliability of radiographic assessment of tunnel placement

All radiographs were assessed by 2 independent observers (orthopaedic fellows). The results reported represent those of examiner 1. Interrater reliability was assessed using intraclass correlations, and Intra-rater reliability was assessed with the Spearman-Brown coefficient. The mean intrarater Spearman-Brown coefficient was 0.83 and the mean intraclass correlations was 0.73 which Landis and Koch[24] suggest may be interpreted as substantial agreement.

Posterior femoral tunnel placement from lateral radiographs

176 patients had adequate lateral radiographs. The midpoint of the femoral tunnel on the lateral radiographs was located at a mean of 86% posterior along Blumenstaat's line (std dev 5%). The distribution of femoral tunnel placement is represented in Figure 1

Anterior tibial tunnel placement from lateral radiographs

181 patients had radiographs suitable for inclusion. The mean midpoint of the tibial tunnel was 48% along the tibial plateau (std dev 5%). The distribution of tibial tunnel placement is shown in Figure 2.

Medial tibial tunnel placement from AP radiographs

176 patients had radiographs suitable for inclusion. The mean location of the tibial tunnel in the coronal plane was 46% along from the medial border of the medial tibial plateau (sd 3%). The distribution of the location of the medial tibial tunnel is shown in Figure 3.

Lateral femoral tunnel placement from AP radiographs

172 patients had radiographs suitable for inclusion. From the AP radiographs the femoral tunnel was positioned at a mean of 42% lateral to the lateral femoral condyle (std dev 3%). The distribution is shown in Figure 4.

Coronal Graft Inclination

164 patients had radiographs suitable for inclusion. The mean coronal graft inclination from the AP radiograph was 18.6 degrees (std dev 5.5). The distribution is shown in Figure 5.

Relationship between tunnel placement parameters and ACL graft rupture

Over the 7 year follow up period 21 patients (11%) had an ACL graft rupture. These patients clinical outcomes were excluded as the majority proceeded to revision ACL reconstruction. However pre-rupture radiographs were available on 19 of the 21 patients. A comparison of the tunnel placement of those patients with ACL graft rupture and those with intact ACL at 7 years is shown in Table 1.

As can be seen in Table 1 the only significant difference between those who sustained an ACL graft rupture and those with an intact ACL graft at 7 years was the position of the tibial tunnel in the sagittal plane. If the tibial tunnel was placed > 50% posterior from the anterior tibial plateau then the incidence of graft rupture was 17% (11/66) versus 7% (8/115) if the graft was placed = or less than 50% anterior to the tibial plateau (p=0.04).

Summary of IKDC examination

The 21 patients who had graft ruptures were excluded from the clinical assessment as the majority had proceeded to revision surgery. Of the remaining 179 full clinical assessment was performed on 148 patients (83%) at 7 years. Of the 31 patients not reviewed at 7 years, 10 were residing outside Australia, 15 were unable or unwilling to attend and 5 patients were unable to be located. A summary of the clinical and subjective results is shown in Figure 6.

Relationship between laxity testing and tunnel placement

Pivot shift testing was significantly associated with the coronal graft inclination on logistic regression analysis (p=0.01), but no other tunnel placement parameter.

The mean coronal graft inclination for those with a Grade 0 pivot shift test was 19.3 compared to 16.8 degrees for those patients with a Grade 1 pivot shift test (p=0.04). That is, patients with a grade 1 pivot shift test had a more vertical graft inclination angle than those with a grade 0 pivot.

In this study group instrumented laxity testing was not significantly associated with any tunnel placement parameters on regression analysis.

The lowest grade for all laxity tests, including instrumented testing, pivot shift and Lachman test, determines the overall IKDC laxity grade. On linear regression analysis overall IKDC laxity grade was not significantly associated with any tunnel placement parameters.

Relationship between range of motion and tunnel placement parameters

Extension loss was not significantly associated with any of the measured tunnel placement parameters in this group. Flexion loss was significantly associated with more posterior placement of the tibial tunnel (p=0.003).

Relationship between degenerative changes on radiographs and tunnel placement parameters

Logistic regression analysis was performed to assess the relative contribution of the tunnel placement variables on the outcome of the IKDC radiological grade for osteoarthritis. Abnormal radiographs at 7 years was significantly associated with more vertical coronal graft angle (p=0.01). No other tunnel placement parameter was significantly associated with abnormal radiological assessment at 7 years.

Tunnel placement parameters and "ideal" clinical outcome

Patients were assigned into 2 groups; those who had an "ideal" clinical outcome at 7 years versus those who did not. The following criteria was applied to define "ideal" clinical outcome at 7 years

- Normal or nearly normal subjective knee function
- Grade A IKDC range of motion (ie <3^0 extension loss and < 5^0 flexion loss)
- Grade A IKDC laxity assessment (ie Grade 0 pivot and <3mm instrumented testing)

- No evidence of degenerative change on radiograph
- No ACL graft rupture

The tunnel placement parameters of the 2 groups are shown in Table 2.

DISCUSSION

Reproducibility can only be achieved when consistent and reliable landmarks are used, even in experienced hands. We have found that using the anatomical landmarks described results in reproducible tunnel placement. Furthermore this placement is successful in achieving excellent clinical outcome over the long term.

In this series we assessed the angle formed between the medial wall of the tibial tunnel and the medial wall of the femoral tunnel from the AP radiograph. This was done to measure the inclination of the ACL graft in the coronal plane. Other authors have studied the effect of variations in *tunnel* angle on the outcome of ACL reconstruction[25], but the influence of the ACL graft angle, which takes into account both the femoral and tibial tunnel location, is unreported. We found that a more vertical graft inclination was associated with a higher incidence of a pivot glide on physical examination at 7 years, and a higher incidence of radiographic osteoarthritis. This is possibly related to some degree of continued rotary instability.

There has been recent increasing interest in double bundle ACL reconstruction. It has been argued that single bundle ACL reconstructions are effective in controlling anterior laxity, but not rotary instability[16]. However the studies that have shown poor rotary control with single bundle techniques have failed to control for tunnel placement or angle of graft inclination[26]. Some proponents of double bundle techniques previously performed single bundle techniques using a trans tibial approach for femoral tunnel placement[27-29]. This may increase the difficulty in obtaining correct femoral tunnel placement and hence graft inclination. We have found that if the tunnels are placed such that the inclination of the ACL graft approximates 19^0 , normal rotary stability on pivot shift testing is achieved with a single bundle technique. We believe that more vertical graft inclination is more likely when drilling femoral tunnels trans-tibially, and would advocate femoral drilling through the anteromedial portal. Future studies will need to determine that multiple bundle techniques are superior to a *well placed* single bundle before the more complex and timely procedure can be supported[30].

We recommend that optimal clinical outcome at 7 years is associated with radiological tunnel placement in the following orientation based on those patients who achieved an “ideal” clinical outcome (see Figure 7). The centre of the femoral tunnel should be located 86% posterior along Blumenstaat’s line on the lateral radiograph, and 43% lateral to the lateral femoral condyle on the AP radiograph. It has been suggested that medial placement of the femoral tunnel may cause impingement of the graft against the posterior cruciate ligament, increasing graft tension[31]. Others have shown that more anterior placement of the femoral tunnel is associated with adverse clinical outcomes, as a result of over constraint leading to either loss of motion or graft elongation with cyclic loading[9,15,32].

The tibial tunnel should be 48% posterior along the anterior tibial plateau on the lateral radiograph. This location corresponds to good clinical outcome in this series as well as others[14]. Placement of the tibial tunnel 50% or more posterior was associated with flexion loss and ACL graft rupture. Others have shown that more anterior placement is associated with graft impingement[33], and loss of motion[34]. In the coronal plane the tibial tunnel should be located 47% along the tibial plateau from the medial cortex. Others have shown that more lateral placement is associated with impingement of the graft[34] and more medial placement is associated with loss of flexion[14].

One of the major aims of computer-assisted orthopaedic ACL surgery is an increase in accuracy of tunnel placement[35], however whether this aim is better achieved with computer assisted techniques over standard techniques has yet to be documented adequately in clinical practice. For CAOS, surgeons need to define optimum tunnel placement. This study gives a radiographic position with which an excellent clinical outcome is likely to be achieved.

The use of specific intraoperative landmarks described in this series result in reproducible tunnel placement and excellent clinical outcomes 7 years after surgery. We have determined that even small changes in tunnel position can adversely affect outcome. Vertical graft inclination is associated with increased rotary instability, and radiographic osteoarthritis. Posterior placement of the tibial tunnel beyond 50% of the tibial plateau is associated with increased incidence of ACL graft rupture. We believe that if tunnels are placed using the technique and landmarks described consistent tunnel placement and optimal clinical outcomes can be expected.

FIGURES:

Figure 1: **Distribution of radiographic femoral tunnel placement in the sagittal plane**

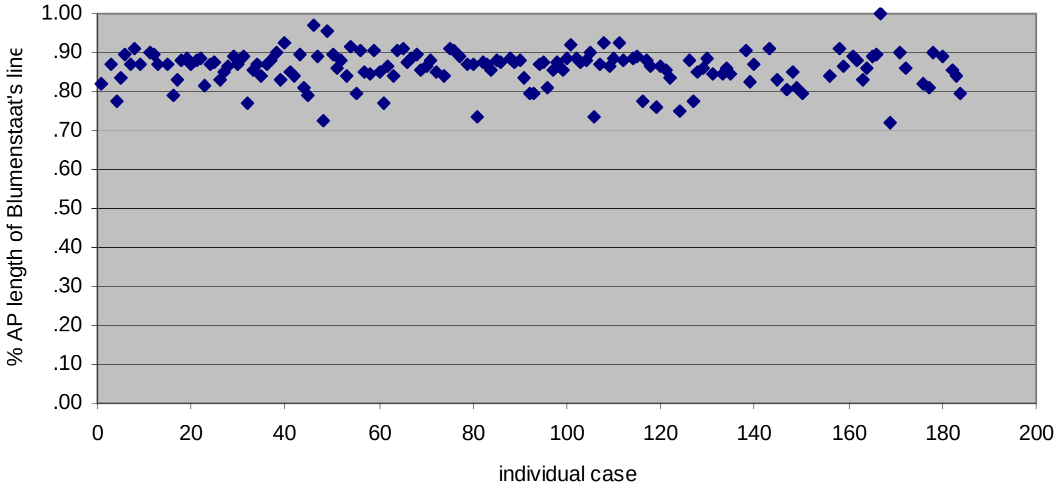


Figure 2: **Distribution of radiographic tibial tunnel placement in the sagittal plane**

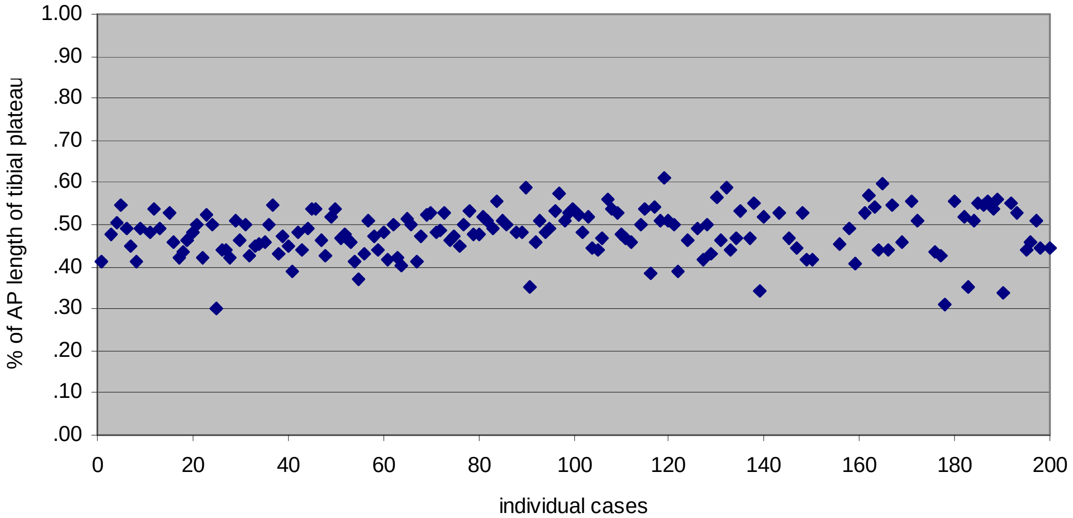


Figure 3: **Distribution of radiographic tibial tunnel placement in the coronal plane**

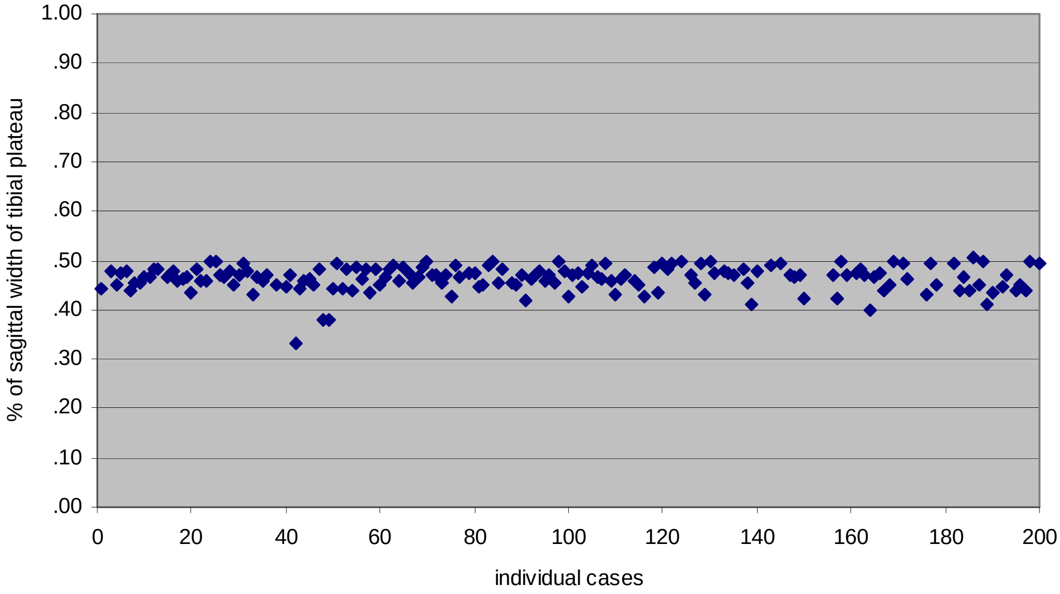


Figure 4: **Distribution of radiographic femoral tunnel placement in the coronal plane**

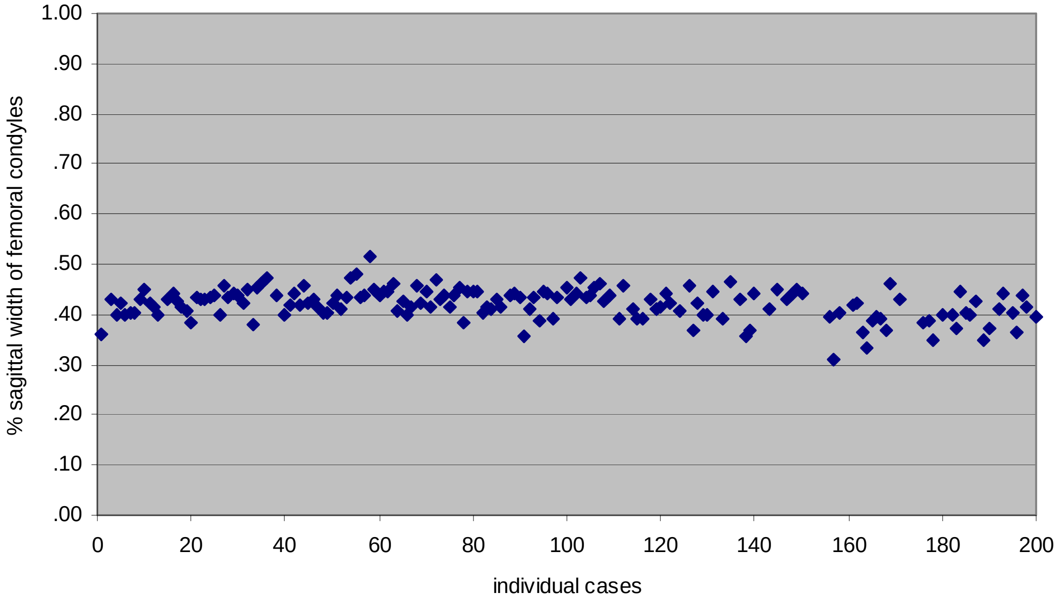


Figure 5: **Distribution of radiographic coronal graft inclination angle**

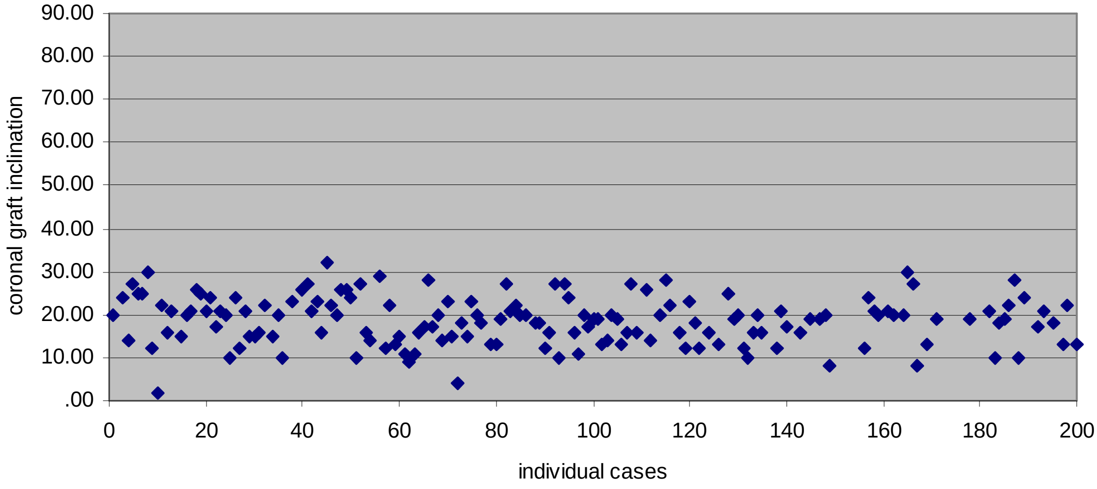


Figure 6: **Summary of the clinical and subjective results at 7 years after surgery**

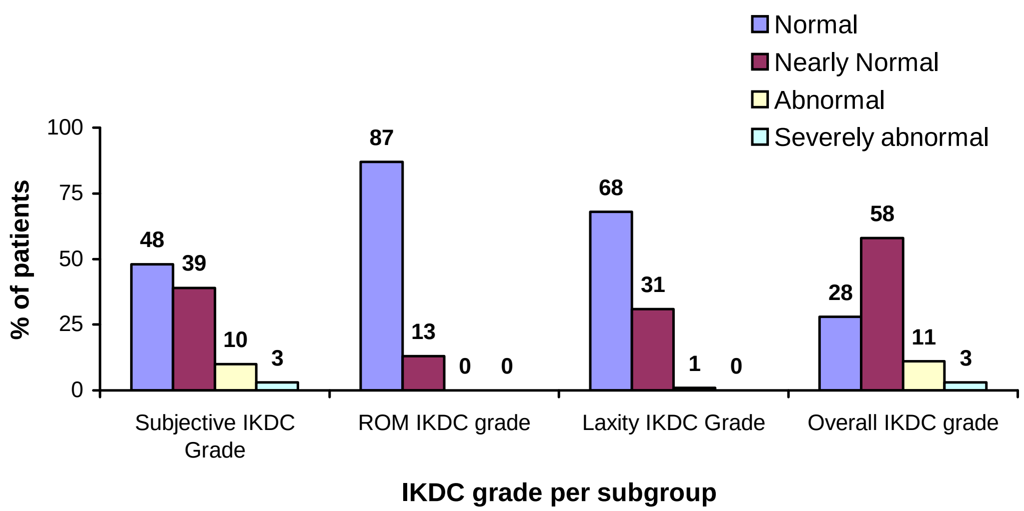
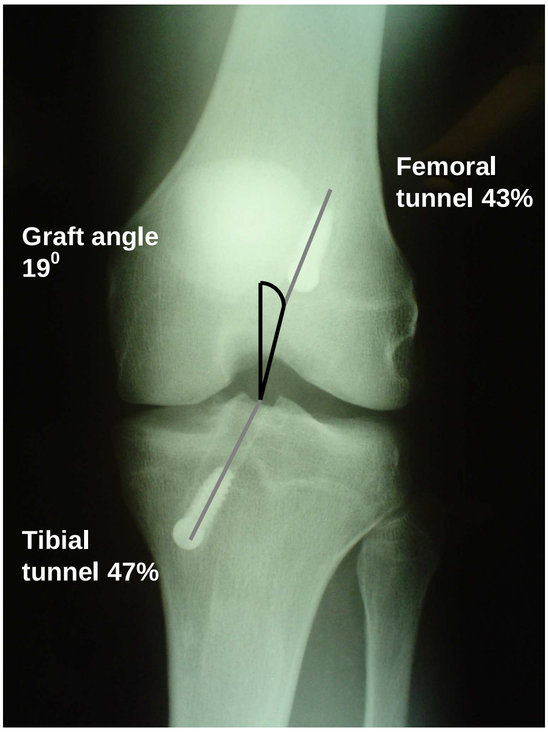
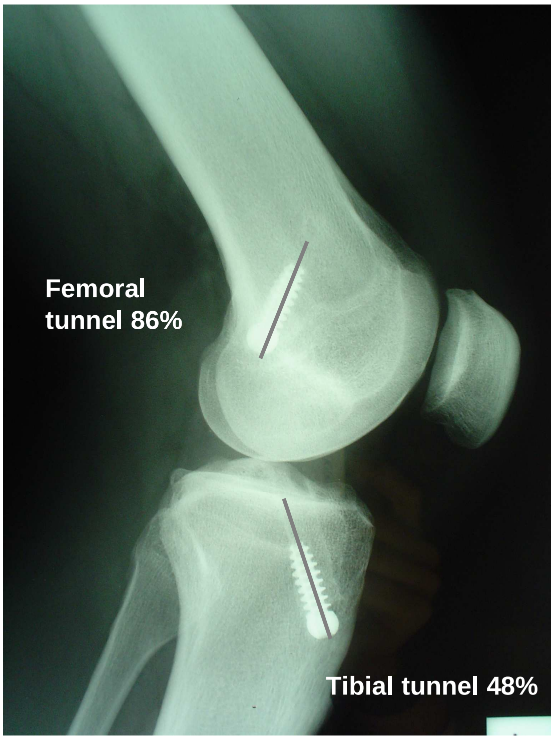


Figure 7: Recommended radiological tunnel position after ACL reconstruction

a) Coronal view



b) Sagittal view



TABLES

Table 1: **Comparison of tunnel placement parameters between patients who had an ACL graft rupture and those with intact ACL grafts at 7 years.**

		ACL graft intact	ACL graft rupture	p
Number of patients		165	19	
Posterior femoral tunnel placement	Mean	85.6	86.8	0.29
Anterior tibial tunnel placement	Mean	47.8	51.5	0.005
Medial tibial tunnel placement	Mean	46.5	45.9	0.38
Lateral femoral tunnel placement	Mean	42.1	41.8	0.75
Graft inclination	Mean	18.7	17.9	0.61

Table 2 **Comparison of tunnel placement between patients with “ideal” clinical outcome and those with non-ideal outcome**

		“ideal” outcome*	Not “ideal” outcome	p
Number of patients		68	88	
Posterior femoral tunnel placement	Mean	85.8	86.3	0.31
Anterior tibial tunnel placement	Mean	48.4	49.5	0.19
Medial tibial tunnel placement	Mean	46.6	46.7	0.76
Lateral femoral tunnel placement	Mean	43.1	42.4	0.10
Graft inclination	Mean	18.8	18.8	0.93

* Ideal outcome defined as normal or nearly normal knee function, Grade 0 pivot test, <3mm instrumented testing, full range of motion, no evidence degenerative changes on radiograph and no ACL graft rupture

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