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Femoral and tibial tunnel positioning on graft isometry in anterior cruciate ligament reconstruction: a cadaveric study

James O Smith, Sam Yasen, Mike J Risebury, Adrian J Wilson
Department of Orthopaedics, Hampshire Hospitals NHS Foundation Trust, Aldermaston Road, Basingstoke, Hampshire, RG24 9NA, United Kingdom

ABSTRACT

Purpose. To assess distance changes between the femoral and tibial attachment points of 3 different anterior cruciate ligament (ACL) tunnel entry positions throughout the range of knee motion in cadaveric knees.
Methods. The ACLs of 11 fresh-frozen cadaveric knees (from 6 men and 5 women) were removed using radiofrequency. Three tibial tunnel placements were made using a cannulated awl, and three 2.4-mm pilot tunnels were drilled on the lateral femoral condyle. One end of an inelastic suture was inserted from each of the 3 femoral holes and fixed on the femoral cortex using a suture button in turn, whereas the other end of the suture was passed through the cannulated awl and fixed on each of the 3 tibial placements in turn, with constant tension. Distance changes of the suture throughout the range of knee movement (0º, 90º, and 135º of knee flexion) were measured for each combination of tibial and femoral positions.
Results. The distance was minimum when the knee was in full extension ($p<0.0001$). Most of the distance changes occurred during initial flexion (0º–90º). The most isometric position (mean±standard deviation [SD] distance change, 2.78±0.93 mm; $p<0.0001$) was noted when the suture was at the anteromedial bundle placement in the femur and anterior in the tibia. The least isometric position (mean±SD distance change, 10.37±2.08 mm; $p<0.0001$) was noted when the suture was at the mid-bundle position in the femur and at the posterolateral bundle insertion in the tibia. The anatomic position resulted in a mean±SD distance change of 7.63±2.01 mm ($p<0.0001$). The femoral position had a greater influence on distance change than the tibial position.
Conclusion. None of the ACL graft positions was isometric. Anatomic ACL positioning resulted in comparable anisometry to the native ACL. The minimum distance for all graft positions was noted in full extension, in which position the graft should be fixed during anatomic ACL reconstruction.

Key words: *anterior cruciate ligament reconstruction; range of motion, articular*

Address correspondence and reprint requests to: Mr Adrian J Wilson, Department of Orthopaedics, Hampshire Hospitals NHS Foundation Trust, Aldermaston Road, Basingstoke, Hampshire, RG24 9NA, United Kingdom. Email: wilsonortho@gmail.com

INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction can restore stability of ACL-deficient knees.[1] Despite improvements in graft selection and preparation, surgical technique, and instrumentation, ACL reconstruction cannot replicate the native ACL anatomy or function,[2,3] or prevent accelerated degeneration of the knee.[4,5] Poor long-term outcome is attributed to concomitant damage and / or inadequate restoration of normal knee kinematics.[6] Anatomic single-bundle ACL reconstruction is preferred because it restores the obliquity of the native ACL by centrally placing a single graft within the tibial and femoral footprints.[2,7–10] The distance between the tibial and femoral graft attachment points remains unaltered (isometric) throughout the range of knee movement, leading to a constant graft tension.[11–15] However, the native ACL is 'anisometric' and its length and tension change throughout the range of knee movement.[16–18] Such length changes after ACL reconstruction have been assessed using computer-modelling,[19] cadaveric intact ACLs,[20,21] or various reconstructive positioning.[22,23] Although small length change may replicate the native ACL, large length change may result in instability, restriction of movement, and graft failure.

This study assessed distance changes between the femoral and tibial attachment points of 3 different ACL tunnel entry positions throughout the range of knee motion in cadaveric knees. It was hypothesised that none of the graft placement positions was isometric (distance change=0).

MATERIALS AND METHODS

11 fresh-frozen cadaveric knees from 6 men and 5 women were used; all knees were absent of previous surgery or ligamentous injury, although early degenerative changes were allowed. The knees were mounted in jigs with unrestricted range of knee motion. Standard anteromedial (AM) and anterolateral (AL) arthroscopic portals were made. The ACL was removed using radiofrequency, and bony landmarks on the lateral femoral condyle (intercondylar and bifurcate ridges) and the tibia (anterior edge of the tibial plateau, posterior tibial condyle, and the intermeniscal ligament) were defined. The posterior cruciate ligament and all other intra-articular structures were preserved.

Table 1
Femoral and tibial placement points for the anterior cruciate ligament (ACL) tunnels

Position		
Femoral placements		
1	Traditional ACL reconstruction position: high anteromedial bundle footprint position ('over the top' position with a 7-mm offset guide at 2 and 10 o'clock)[39]	
2	Mid-bundle position: at 50% along the lateral intercondylar ridge by direct measurement, as per the anatomic single bundle ACL reconstruction technique[2,8,9]	
3	Shallow posterolateral bundle footprint position: defined by the intercondylar and bifurcate ridges, and direct measurement 3 mm shallow to position 2[24]	
Tibial placements		
1	Posterior, corresponding to the posterolateral bundle footprint: just anterior to the posterior cruciate ligament, 50.1% anteroposterior (measured from anterior) and 51.2% mediolateral (measured from medial)[25]	
2	Midway between posterior and anterior footprints, corresponding to mid-bundle position[7]	
3	Anterior, corresponding to the anteromedial bundle footprint: just posterior to the insertion of the intermeniscal ligament, 37.6% anteroposterior (measured from anterior) and 46.5% mediolateral (measured from medial)[25]	

According to previously defined positions (Table 1),[2,7–9,15,24,25] three tibial tunnel placement points were made using a cannulated awl through the AM portal without impinging the femoral articular surface, and three 2.4-mm pilot tunnels were drilled on the medial face of the lateral femoral condyle (Fig. 1). One end of an inelastic suture (no. 5 FiberWire; Arthrex, Naples, FL, USA) was inserted from each of the 3 femoral holes and fixed on the femoral cortex using a suture button in turn, whereas the other end of the suture was passed through the cannulated awl and fixed on each of the 3 tibial placement points in turn, with constant tension (Fig. 2). Direct measurement has been validated as an accurate technique,[8,25] whereas measurement using radiography results in significant inter- and intra-observer variability.[26]

Distance changes of the suture throughout the range of knee movement (0°, 90°, and 135° of knee flexion) were measured for each combination of tibial and femoral positions. The suture was marked at the exit point of the awl. Each experiment was performed in triplicate. Following measurements, metal markers were added to the tibial and femoral insertion points, and radiographs were taken (Fig. 3).

Comparison of distance changes within each position was made using the Mann-Whitney *U* test. Comparison of distance changes in different graft positions was made using one-way analysis of variance with a *post hoc* Tukey multiple test. A p value of <0.05 was considered statistically significant.

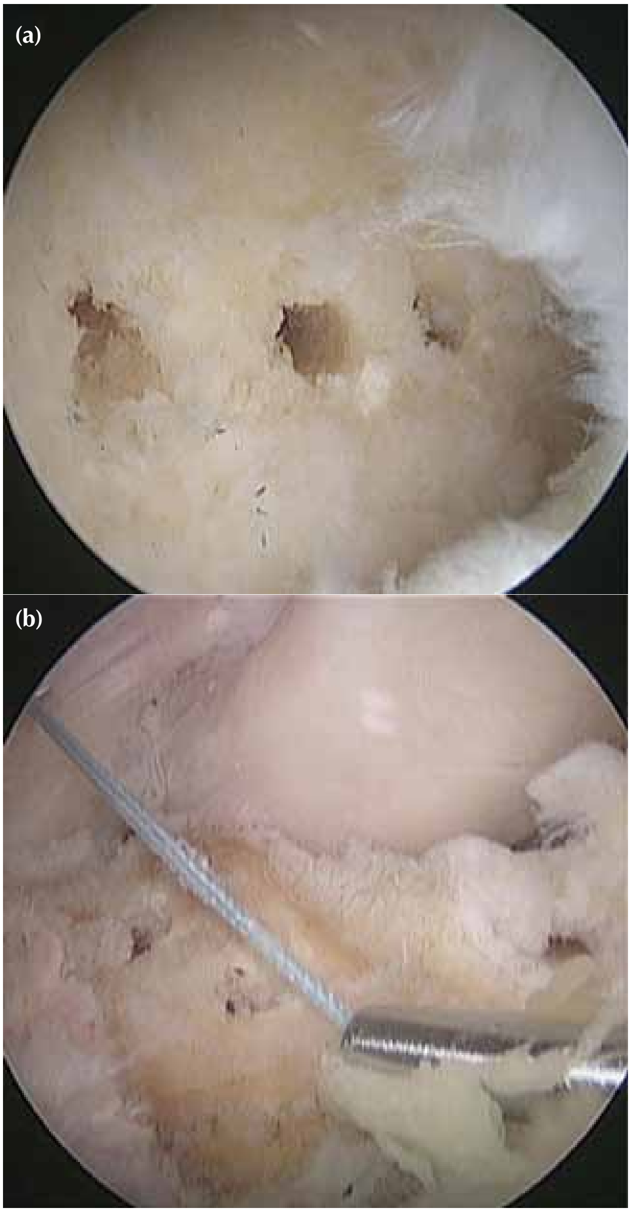

Figure 1 **(a)** Three holes are drilled on the medial face of the lateral femoral condyle, and **(b)** 3 tibial placement points are made with an awl, with the FiberWire suture entering the tip of the awl.

RESULTS

The mean distance change of all graft positions in the

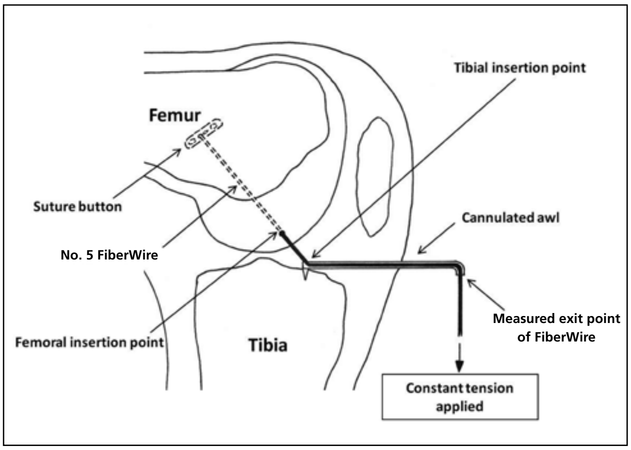

Figure 2 The inelastic no. 5 FiberWire is passed through the femoral pilot hole and fixed on the femoral cortex using a suture button. The tibial placement awl is inserted through the anteromedial portal and fixed into each of the 3 tibial placement points. The inelastic suture is passed from the intra-articular exit point of the femur, through the cannulated awl and out through the anterior portal, and a constant tension was applied to the suture during knee range of movement.

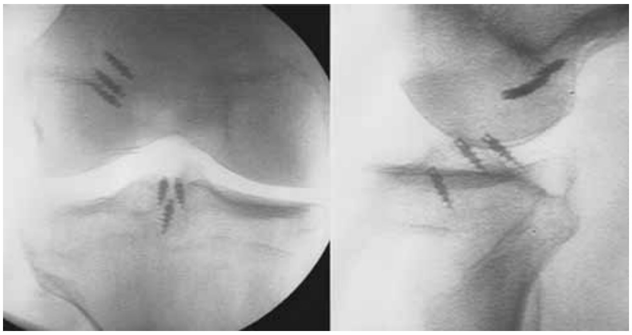

Figure 3 Radiographs showing the 3 femoral and 3 tibial insertion points with metal markers.

11 knees throughout the range of knee motion was 6.40 (range, 2.78–10.37) mm (Fig. 4). The distance was minimum when the knee was in full extension, compared with all other positions (p<0.0001). Most of the distance changes occurred during initial flexion (0º–90º). Comparing all 9 positions, the most isometric position (mean±standard deviation [SD] distance change, 2.78±0.93 mm; p<0.0001) was noted when the suture was at the AM bundle placement i.e. 'over the top' (position 1) in the femur and anterior (position 3) in the tibia, whereas the least isometric position (mean±SD distance change, 10.37±2.08 mm; p<0.0001) was noted when the suture was at the mid-bundle position (position 2) in the femur and at the PL bundle insertion (position 1) in the tibia. The anatomic position (position 2 in the femur and position 2 in the tibia) resulted in a mean±SD distance change of 7.63±2.01 mm.

The femoral position had a greater influence on distance change than the tibial position; the curve was linear when position 1 in the femur was used (Fig. 4). The mid-bundle position (position 2) in the femur resulted in a large reduction in distance during the first 90º of flexion, and then the curve gradient reduced indicating smaller distance reduction during higher flexion. In contrast, position 3 in the femur resulted in an increase in distance beyond 90º of flexion, with the shortest distance at 90º of flexion. This indicated that a non-elastic suture was slack during initial flexion before tightening again beyond 90º.

The anatomic position (position 2 in the femur and position 2 in the tibia) did not differ significantly to other positions except for the AM bundle position (position 1 in the femur and position 3 in the tibia), which was the most isometric (p<0.001). The AM bundle position resulted in a significantly smaller change in distance during flexion, compared with the PL bundle position (position 3 in the femur and position 1 in the tibia) [p=0.0065, Fig. 5].

DISCUSSION

The ACL functions as a stabiliser against anterior

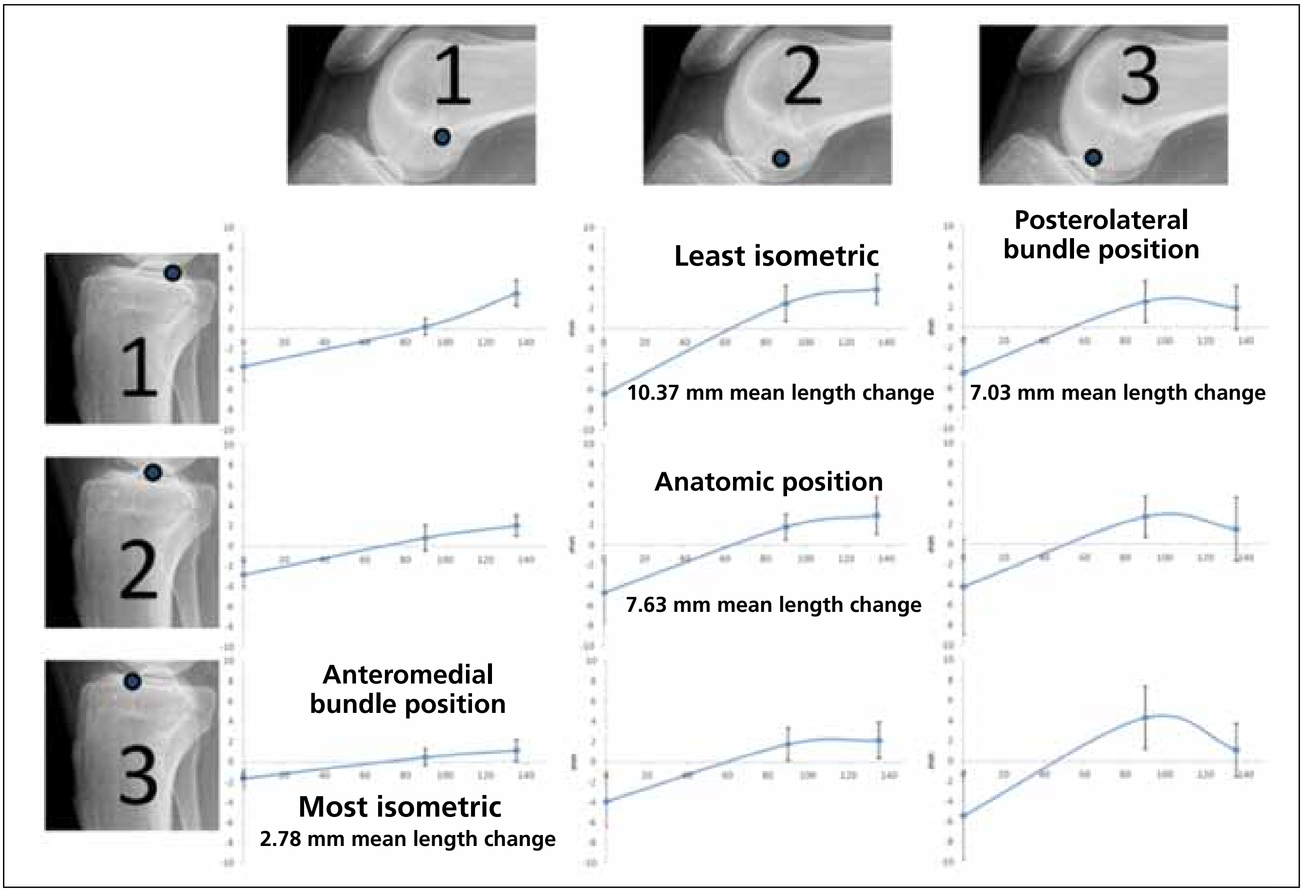

Figure 4 Curves showing the distance changes (anisometry) for each of the 9 graft positions (error bars: ±1 SD).

Least isometric

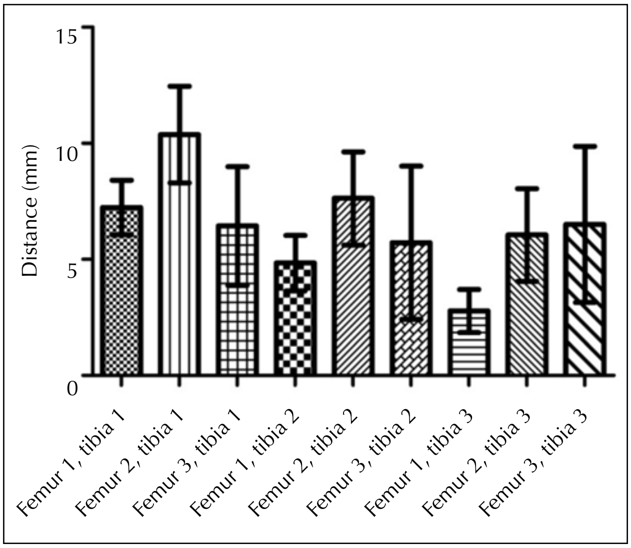

Figure 5 The mean distance changes of 11 knees for each of the 9 positions during the range of knee movement (error bars: ±1 SD) show that only the anteromedial bundle graft position (position 1 in the femur and position 3 in the tibia) significantly differs from the anatomic position (position 2 in the femur and position 2 in the tibia) [p<0.001]. The anteromedial position results in significantly shorter distances than the posterolateral bundle position (position 3 in the femur and position 1 in the tibia) [p=0.0065].

tibial translation and rotation.[1] The ACL is composed of multiple fibres, each with its own tibial and femoral insertion, the sum of which is an envelope of sagittal and rotational stability.[16,27] These fibres condense into 2 bundles: the AM bundle that is tighter in flexion and controls sagittal movement, and the PL bundle that is tighter in extension and controls rotational laxity.[17]

ACL reconstruction using a single bundle graft through a transtibial approach results in excellent initial clinical outcomes.[28] However, the femoral tunnel position is dictated by the tibial tunnel and cannot be placed in an anatomic position.[29–31] This leads to vertical orientation of the graft with little obliquity and results in residual anterior laxity and poor rotational stability,[32] and early degenerative arthrosis.[5,30] Graft alignment in the coronal plane is also important in restoring obliquity (as in the native ACL) and hence rotational stability.[33,34] For both single and double bundle 'anatomic' ACL reconstructions,[2,8,9,35] the knee is tight in extension, but becomes lax in flexion (similar to the native ACL).[15] In traditional (non-anatomic) arthroscopic ACL reconstruction, isometry for femoral and tibial graft placement may not be a key requirement for a well-functioning knee.[11–15] Indeed, the native ACL was not isometric in cadaveric studies.[17,20,21]

Anisometric positioning has important impacts on the surgical technique and graft materials used in anatomic single bundle ACL reconstruction. In particular, once appropriately tensioned, the graft should be fixed with the knee in the optimal position to avoid capturing the knee and limiting full extension or causing excessive strain on the graft. In our study, femoral positioning of the graft had a greater effect on isometry than tibial positioning. This finding is supported by a computed tomography analysis of ACL tunnel positioning.[36] To increase stability throughout the range of motion, a graft with one tibial attachment and more than one femoral attachment may be used to compensate for the loss of tension in anatomic positioning as the knee goes into flexion. For reconstruction of the posterior cruciate ligament[37] and medial collateral ligament,[38] the use of multiple bundles is preferred in order to accommodate isometry changes and load sharing at different angles of flexion and with varying rotational torques.

Limitations of this study were that cadaveric specimens were heterogeneous in size and tissue quality and did not simulate intra-operative conditions. The suture material used exhibited a small amount of intrinsic elasticity. Despite applying a constant tension, the natural constraining behaviour of the native ACL or graft could not be replicated. The suture was smaller in diameter than a graft, and its exact intra-articular course would not be replicated. These effects may have led to underestimation of true isometric changes.

CONCLUSION

None of the ACL graft positions was isometric. Anatomic ACL positioning resulted in comparable anisometry to the native ACL. The minimum distance for all graft positions was noted in full extension, in which position the graft should be fixed during anatomic ACL reconstruction.

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