Effect of Femoral Tunnel Length on the Safety of Anterior Cruciate Ligament Graft Fixation Using Cross-Pin Technique

A Cadaveric Study

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Background: A more oblique placement of the anterior cruciate ligament (ACL) graft has been related to better control of rotatory knee stability. Femoral fixation with a transverse system might injure its posterolateral structures.

Hypothesis: A cross-pin system, originally developed for transtibial reconstruction of the ACL, can safely be used when creating a lower femoral tunnel through the anteromedial portal. However, a long femoral tunnel must be created to protect the posterolateral structures of the knee.

Study Design: Controlled laboratory study.

Methods: An ACL was arthroscopically reconstructed with a hamstring graft in 22 fresh cadaveric knees. The femoral tunnel was anatomically drilled in all cases. Knee flexion angle was set at 110°. Femoral fixation was performed with a cross-pin system. A 30-mm-long femoral tunnel was created in 11 knees (group A). In the remaining 11 knees, the femoral tunnel was drilled as long as each lateral condyle permitted (group B). For both groups, the relationships were compared between the cross-pin and the lateral collateral ligament (LCL), popliteus tendon, articular cartilage, and peroneal nerve.

Results: In 5 cases of group A, the cross-pin was placed either through the LCL or between the LCL and popliteus tendon, whereas in group B it was always posterior to the LCL ($P = .035$). The cross-pin was closer to the articular cartilage in group A than in group B (7.14 mm versus 16.9 mm; $P < .001$). The minimal distance to the peroneal nerve in all specimens was 23.89 mm.

Conclusion: Hamstring graft fixation with a cross-pin system from the anteromedial portal with a 30-mm femoral tunnel presents a higher risk of injury to the LCL. The femoral tunnel should be drilled as long as possible.

Clinical Relevance: A long femoral tunnel is required for safe transverse femoral fixation in an anatomical ACL reconstruction.

Keywords: posterolateral structures; anatomical single bundle; anterior cruciate ligament reconstruction risk; transverse fixation; hamstring graft

Reconstructions of the anterior cruciate ligament (ACL) are currently among the most frequently performed knee surgery procedures. More than 100 years after A. W. Robson performed the first-known ACL surgery,[28] many aspects of ACL reconstruction still remain somewhat controversial. The ACL is well recognized as the main restraint against anterior tibial displacement. It has been advocated that this function is well reproduced by fixing the ACL graft high in the femoral notch at about the 11-o'clock position,

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The authors declared that they had no conflicts of interests in their authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. 38, No. 9
DOI: 10.1177/0363546510366229

the leading technique during the past 20 years.[5] However, this nonanatomical femoral tunnel placement is not so effective at successfully restoring the original ACL rotatory stability.[18] Recent biomechanical studies have demonstrated that lowering the femoral tunnel to a more horizontal and anatomical position is more effective at preserving this property.[21,24,31]

There are 2 major techniques for creating the femoral tunnel: first, drilling through the tibial tunnel, or the transtibial technique; second, drilling through the anteromedial portal, or the anteromedial portal technique. Placing the graft at the original anatomical insertion site with a transtibial technique is not always easily done.[1,2,11] It requires drilling the tibial tunnel from a more medial and proximal starting point.[2,11] However, there is not only a potential risk of damage to the medial plateau cartilage, owing to the obliquity of the tunnel, but also a risk of partial injury to the medial collateral ligament[2] in taking the aforementioned approach. Moreover, the tibial tunnel obtained might not be long enough to guarantee secure fixation.[11] Drilling the femoral tunnel through a low anteromedial portal would be another option for placing the graft anatomically.[11,14]

Transverse femoral fixation is a popular method for fixation of soft tissue graft. It was originally designed for drilling the femoral tunnel transtibially and placing the tunnel at a higher location.[7] The transverse pins are placed percutaneously through the lateral femoral condyle and have been shown not to damage the surrounding anatomical structures when the femoral tunnel is placed at the high 11-o'clock position (right knee).[22] Lowering the femoral tunnel to the exact anatomical insertion site makes the entry of the cross-pin lower and lateral. It presents a risk of iatrogenic lesion to the posterolateral structures of the knee. Strategies for making transverse pin fixation safer include angling the pins upward[22] and hyperflexing the knee.[3,25] Pujol et al[27] compared performing the femoral tunnel transtibially to performing it through the anteromedial portal at different flexion angles with the Biotransfix cross-pin (Arthrex, Naples, Florida). They concluded that the anteromedial portal technique presents no risk when the knee is flexed at least 130°. Other authors have criticized the degree of knee flexion.[3,26] Pujol et al[27] did not specify the exact position of the starting femoral point; furthermore, they performed the same starting femoral drilling point in the transtibial technique as in the anteromedial portal technique. We can therefore hypothesize that the femoral tunnel was not placed at the anatomical position in either technique.

To evaluate whether the cross-pin system can be safely used when drilling the femoral tunnel through the anteromedial portal, we performed a pilot study on 2 cadaveric knees. We observed that the main difference occurred when we compared the technique with the usual femoral tunnel lengths, 30 mm and longer (Figure 1). On the basis of these findings, we hypothesize that in some knees, a 30-mm femoral tunnel is not long enough and it might damage the posterolateral structures. The aim of this work was to investigate and compare the standard 30-mm tunnel length versus longer tunnels.

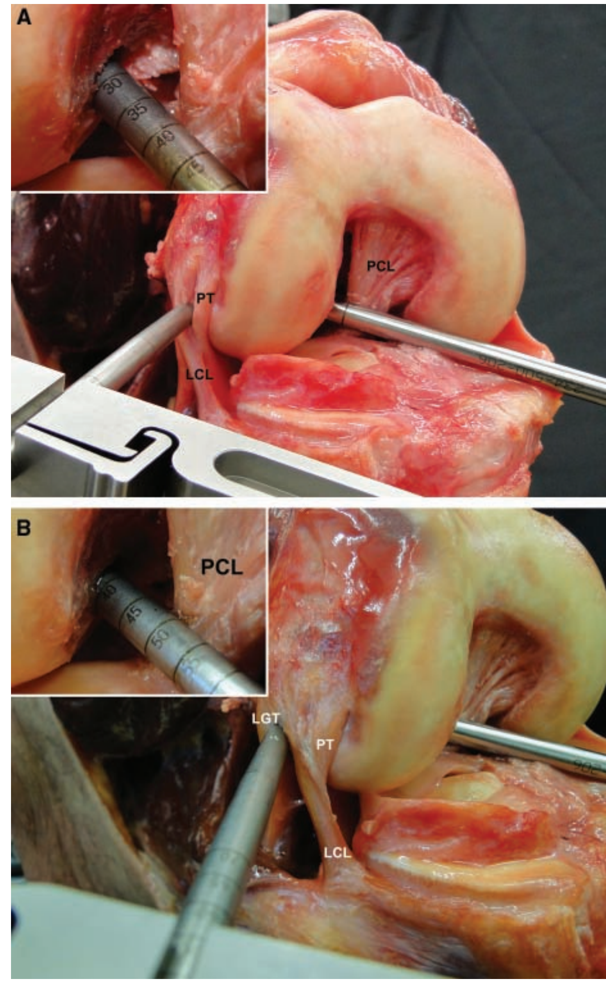

Figure 1. Lateral view of a right knee in the pilot study: A, the femoral tunnel was drilled 30 mm (see the upper left corner), and the transverse system was placed near the lateral stabilizers of the knee; B, in the same knee, the femoral tunnel was drilled 40 mm (see upper left corner), and the system was more posterior and farther away from the lateral stabilizers of the knee. PCL, posterior cruciate ligament; PT, popliteus tendon; LCL, lateral collateral ligament.

MATERIALS AND METHODS

The pilot study used 2 fresh-frozen cadaveric human knees from 2 male donors, one 76 years old and the other 79 years old. The present study used 22 fresh-frozen cadaveric human knees from 14 male donors and 8 female donors whose ages ranged from 62 to 93 years (mean, 76.6). The specimens had been stored at –18°C; they were then thawed at room temperature for 24 to 36 hours before testing. None of the knees showed macroscopic signs of previous surgery. Preoperative mobility, measured with the goniometer, gave maximum flexion ranging from 120° to 135°. Full extension remained possible. Two knees showed remarkable narrowing of the intercondylar notch during the arthroscopic examination and thus had to be excluded from the study and replaced with 2 other knees. The femur and the tibia were cut approximately 30 cm from the joint line, with all the soft tissue around the knee left intact. They were mounted on a knee holder (Extremity Holder, Sawbones, Malmö, Sweden).

With a long metal ruler and skin pen, the longitudinal axis of the thigh was marked—specifically, the line passing through the middle of the femoral shaft and lateral epicondyle—as was the longitudinal axis of the leg, which passed through the center of the fibular head and shaft. A manual goniometer was used to measure the angle between the 2 lines so that femorotibial flexion could be calculated.

The pilot approach with 2 specimens was carried out first. This was performed with open surgery. The 2 knees were stripped of skin, subcutaneous tissue, facia lata, quadriceps muscle, and the knee capsule. A 9-mm femoral tunnel was then drilled at the femoral stump of the ACL up to the femoral posterior cortex, to avoid breaking through it. The transverse drill guide was then introduced. Two K-wires were then transversally implanted 20° upward with reference to the horizontal plane. One K-wire was introduced 30 mm into the femoral tunnel socket through the transverse drill guide, and the other went as deep as the tunnel allowed.

The gracilis and the semitendinosus tendons were harvested through a 30-mm longitudinal approach medial to the tibial tuberosity. A whipstitch suture was performed on each end of the tendons. The diameter of the double-loop hamstring graft structure was then measured. In those cases with a diameter wider than 9 mm, only the semitendinosus tendon was used for ACL reconstruction.

The experimental protocol was as follows: First, the ACL reconstruction was performed and the transverse fixation implanted. Second, a radiographic evaluation was done of the femoral tunnel. Finally, dissection was performed of the lateral aspect of the knee, and the relationship of the cross-pin device to the surrounding structures was evaluated.

The knees had been randomized into 2 groups: a 30-mm femoral tunnel socket was performed for the 11 knees composing group A; for those 11 knees making up group B, the femoral tunnel was drilled as long as the lateral condyle permitted in each case.

Arthroscopic Procedure

The same author (P.E.G.) performed all the arthroscopic procedures. The knees hung freely at a 90° of flexion, except when the femoral tunnels were being drilled. A high anterolateral portal was established as the viewing portal, then a low anteromedial portal as the working portal. The latter portal was established as inferiorly (ie, close to the tibia) as possible with the help of a spinal needle and under direct visualization to avoid injuring the anterior horn of the medial meniscus. In addition, the portal was as medial as possible without injuring the medial femoral condyle. After complete excision of the ACL, whenever present, the lateral wall of the intercondylar notch was cleared with the help of a shaver. The tibial tunnel position was marked at the center of the ACL stump. A 9-mm hole was made with a conventional step drill guide (ACL System, Stryker Corp, Mahwah, New Jersey). The starting point was always performed 2 cm medial to the tibial tuberosity. The inclination angle on the sagittal plane was set at 55°. The deviation from the axis perpendicular to the tibial plateau in the frontal plane was 20°. The femoral tunnel was subsequently performed. A 7-mm offset femoral tunnel guide was selected to leave 2.5 mm of posterior wall to approach the anatomical deep/shallow position. The high/low position was calculated following the clock-face reference position. The guide was carefully placed at the 10-o'clock (right knees) and 2-o'clock (left knees) positions with the knees at 90° of tibiofemoral flexion, and the starting point was marked—namely, the intermediate point between the anteromedial and posterolateral bundles on the high/low position.[29] The knee was then flexed to 110°, and the femoral tunnel was drilled over the guide pin. Based on the recommendation of the cross-pin technique (Stryker Corp), the femoral tunnel was drilled over the guide pin to a depth of 30 mm in 11 specimens (group A). In the remaining 11 knees (Group B), the tunnel was drilled over the guide pin along the lateral condyle and stopped when the posterior cortex was reached, to not break through it. The transverse drill guide was then introduced into the femoral socket as deeply as the previously determined tunnel length (at 30 mm in group A or at the maximum tunnel length in group B), and a pin was drilled percutaneously into the lateral aspect of the knee, 20° upward with reference to the horizontal plane. The hamstring graft was then introduced and fixed in the femoral side with a 6- × 50-mm Biosteon (HA/PLLA) Cross-Pin (Stryker Corp; hereafter, BCP). Tibial fixation was performed securing the suture's end of the distal part of the hamstring to the periosteum and fat tissue surrounding the entry site of the tibial tunnel.

Radiographic Evaluation

The relative position of the femoral tunnel in the notch was first evaluated with a conventional lateral radiograph, which was obtained for each knee. The posterior femoral condyle outlines should overlap as accurately as possible, and a 6-mm deviation from overlapping was suggested to be the limit of acceptable malalignment.[9] Analysis of the entry placement of the femoral tunnel was performed according to the quadrant method described by Bernard et al.[4] The femoral tunnel was further evaluated with a tunnel view radiograph for each specimen at 30° of knee flexion. Its orientation was measured with reference to a line tangent to the distal aspect of the femoral condyles. A computer software–generated clock face was then superimposed such that 12 o'clock was the highest point of the notch. The center entry of the femoral tunnel was expressed in hours and quarter-hour intervals and normalized for each knee. An experienced radiologist independent to the study made all the measurements.

Dissection and Posterolateral Structures Evaluation

Dissection was performed through a 20- × 15-cm skin incision window centered on the lateral femoral condyle. The skin and subcutaneous tissue were removed. The fascia lata was identified and removed to more easily assess the lateral aspect of the femur. Localization of the cross-pin device and careful dissection of the lateral aspect of the knee were performed to identify the following structures: the lateral collateral ligament (LCL), lateral epicondyle, popliteus tendon (PT), lateral gastrocnemius tendon (LGT), and peroneal nerve (PN). The zone of the lateral aspect of the femur where the bio cross-pin was located was qualified according to its relationship to the LCL. Those cases where the pin was placed posterior to the LCL were classified as being in the safe zone; when the cross-pin device was across or anterior to the LCL, it was classified as being in the unsafe zone. After removal of the lateral soft tissue of the knee, with the exception of the LCL and PT, the distance was evaluated from the pin to the posterior surface of the femur and to the articular cartilage (AC).

The shortest distance from the pin to the corresponding structures was then calculated. All measurements were determined with the help of an electronic digital caliper (ProMax, Fowler, Newton, Massachusetts; range, 0 to 150 mm; resolution, 0.02 mm). Finally, anterior dissection of the knee joint was performed to further certify proper placement of the graft.

Statistical Analysis

Categorical variables are presented as percentages and frequencies. Either the chi-square Pearson or Fisher exact test was used to compare these variables between groups. For each continuous variable, mean and standard deviation as well as median and quartiles were calculated. Because of the small sample number and the difficulty in determining whether the variables were adjusted to a normal distribution, the Mann-Whitney test was used to compare the measurements in both groups. These continuous variables are presented as a median. Statistical analysis was performed using SPSS 15. Statistical significance was set at the .05 level.

RESULTS

In 10 of 11 cases in group A (90.1%), a 30-mm tunnel depth was performed. For the remaining specimen, only a 27-mm tunnel length could be done because of its small lateral condyle. In this case, the posterolateral cortex of the femur was perforated. In the 11 knees in group B, the femoral tunnel length ranged from 28 to 45 mm (median, 38 mm).

Femoral Tunnel Position

Radiographic evaluation revealed the anatomical placement of the femoral tunnel in each knee of both groups. Analysis of the lateral radiograph with the quadrant method showed that the deep/shallow position and high/low position, respectively, had a median of 25.6% and 35.3% for group A and a median of 25.7% and 34.6% for group B (P = .519 and .797, respectively) (Figure 2).

Figure 2. Lateral radiograph of a right knee. According to the quadrant method, the femoral tunnel in this case was performed at the deep/shallow position (white arrow) and the high/low position (black arrow) of 25.6% and 32.7%, respectively.

Analysis of the posteroanterior tunnel view radiograph revealed that the median angle of the femoral tunnel orientation with reference to the bicondylar axis was 53° for group A and 51° for group B (P = .300). The clock-face position reflected a median of 10 o'clock for both groups (P = .898).

LCL and Lateral Epicondyle

The position of the BCP with respect to the LCL varied from one specimen to the other. The main finding was relative to the aforementioned zone classification. The pin was introduced in the unsafe zone in 5 specimens of group A (45% of the cases). In every knee corresponding to group B, the pin was always placed in the safe zone (P = .035). In 3 knees of group A where the BCP was in the unsafe zone, it was introduced into the femur just between the LCL and the PT (Figure 3). In the remaining 2 knees with the pin in the unsafe zone, the LCL was partially torn by the BCP. Even so, these partial lesions did not produce varus instability under manual testing in either knee. The median distance from the pin to the LCL was 1.08 mm in group A and 5.57 in group B (P = .002). The median distance from the pin to the lateral epicondyle was similar in both groups (13.63 mm versus 13.62 mm, P = .519).

Popliteus Tendon

As easily deduced from the zone classification results, the cross-pin was considerably closer to the PT in group A

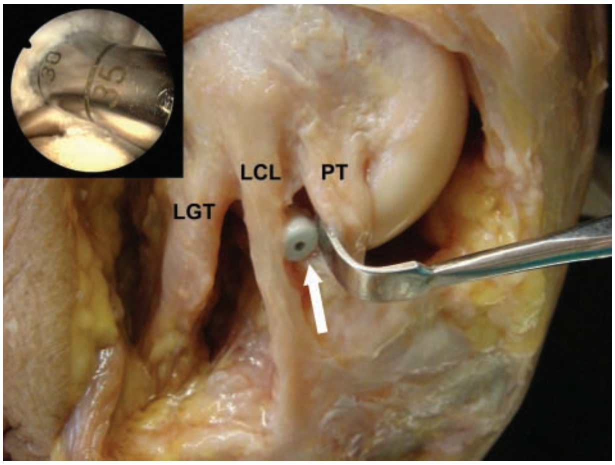

Figure 3. Lateral view of a right knee in group A. The pin (white arrow) is seen placed in the unsafe zone. It was introduced into the femur between the lateral collateral ligament and the popliteus tendon. The popliteus tendon is retracted to show the pin placement. In the upper left corner, arthroscopic picture of the same knee showing a 30-mm femoral tunnel drilling. LGT, lateral gastrocnemius tendon; LCL, lateral collateral ligament; PT, popliteus tendon.

(median, 1.47 mm) than in group B (median, 11.17 mm; $P < .001$).

Lateral Gastrocnemius Tendon

Conversely, the cross-pin was closer to the LGT in group B (median, 0.31 mm) than in group A (median, 5.20 mm; $P = .028$). In 2 specimens in group A and in 3 in group B, the BCP pierced the LGT (Figure 4), in all cases around the origin of the tendon. In most knees of group B, the pin was introduced into the femur just anterior to the LGT.

Peroneal Nerve

The minimal distance from the BCP to the PN was 23.89 mm. The cross-pin was at a considerable distance in all knees in group A (mean, 37.52 mm) and group B (41.19 mm; $P = .27$).

Articular Cartilage and Posterior Femoral Cortex

The AC was closer to the cross-pin in group A. The distance from the pin to the AC in this group had a median of 7.17 mm, whereas the median was 17.18 mm in group B ($P < .001$). The minimal distance was observed in a case in group A, where the pin was 3.57 mm from the AC. As can be deduced from the relationship of the other structures, the BCP was closer to the posterior surface of the femur in group B (median, 1.52 mm) than in group A (median, 4.65 mm ± 4.9; $P = .043$). Table 1 summarizes the most relevant measurement values between the 2 groups. Under direct evaluation of the femoral tunnel, anatomical placement of the graft was confirmed in each knee (Figure 5).

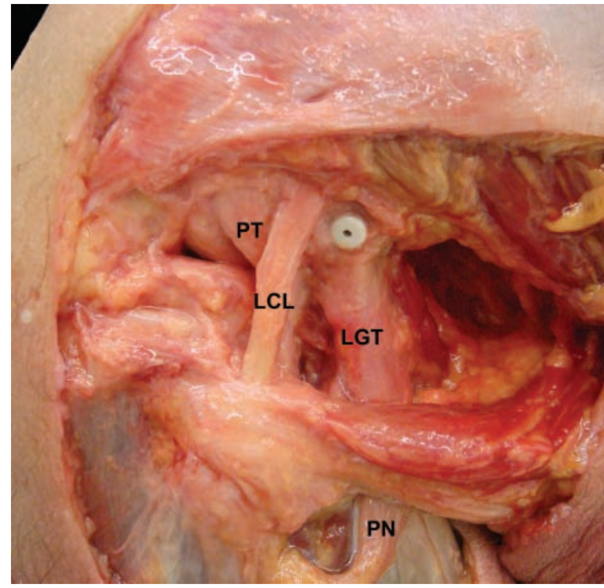

Figure 4. Lateral view of a left knee in group B. The cross-pin is inserted in the safe zone, near the origin of the lateral gastrocnemius tendon. Note the considerable distance to the peroneal nerve. LCL, lateral collateral ligament; LGT, lateral gastrocnemius tendon; PT, popliteus tendon; PN, peroneal nerve.

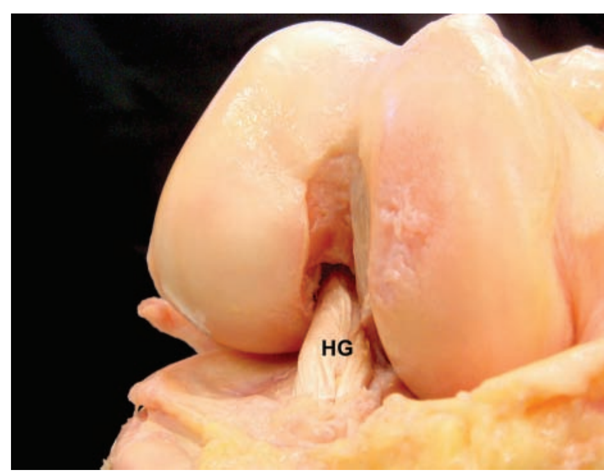

Figure 5. Anteromedial view of a right knee. The hamstring graft (HG) is seen running obliquely from the tibial tunnel, placed in the anterior cruciate ligament stump, to the anatomical insertion site in the medial wall of the lateral condyle.

DISCUSSION

This study demonstrated that securing a hamstring graft with a transverse femoral fixation system can be safely done when drilling the femoral tunnel at its anatomical insertion site. A longer femoral socket appears to have reduced the risk of iatrogenic injury to the LCL.

This finding is in partial agreement with the work performed by Hantes et al.[13] In their report of more than 30 ACL reconstructions using the anteromedial portal and

TABLE 1
Distances From the Cross-Pin to the Anatomic Structures[a]

	Mean	SD	Min	Max	Percentiles			*P*
					25	50	75	
Lateral collateral ligament								
Group A	1.5	2.7	0.0	8.0	0.0	1.1	2.0	.002
Group B	5.5	2.9	1.5	9.6	2.9	5.8	8.2	
Popliteus tendon								
Group A	2.8	3.3	0.0	9.5	0.0	1.5	4.5	< .001
Group B	11.8	2.9	7.9	17.5	8.9	11.2	14.1	
Lateral gastrocnemius tendon								
Group A	5.4	5.4	0.0	15.9	0.0	5.2	8.3	.028
Group B	0.47	1.4	0.0	4.9	0.0	0.3	0.7	
Peroneal nerve								
Group A	38.5	8.7	23.9	51.8	31.4	37.5	46.4	.27
Group B	42.1	7.2	32.9	52.9	34.7	41.2	51.2	
Articular cartilage								
Group A	7.1	1.9	3.6	9.2	6.3	7.2	8.8	< .001
Group B	16.9	3.9	9.3	22.8	14.9	17.2	19.2	

[a]All data expressed in millimeters.

Bio-TransFix femoral fixation device, they concluded that the technique was safe and effective. However, they did not evaluate the placement of the cross-pin device with respect to the posterolateral structures, nor did they evaluate the effect of differing femoral tunnel depths, given that they always drilled a 35-mm tunnel socket. Furthermore, they did not specify the degree of knee flexion or the angulation of the transverse drill with respect to the horizontal plane. Similarly, a study by Pujol et al[27] lacked some critical technical details. They concluded that there is no risk with the anteromedial portal technique when the knee is flexed at least 130°, but they did not specify technical factors that might aid the surgeon—namely, the exact positioning of the starting femoral point. They performed the same femoral starting point in both the transtibial and the anteromedial portal technique, as shown in their drawings. Drilling the femoral tunnel at the low anatomical position is not easily accomplished with the standard transtibial technique.[1,2,11] In the current study, a low femoral tunnel, which could not have been reached with a transtibial technique, was rigorously performed in all the specimens. We can therefore speculate that what Pujol et al[27] performed was a high femoral tunnel near the high-noon point, rather than an anatomical reconstruction.

In the present study, the evaluation of the lateral and notch view radiographs and, most important, the direct evaluation of the intercondylar notch during the final dissection confirmed that the grafts were properly oriented around the anatomical insertion site. We also observed that the femoral tunnel angulations with reference to a line tangent to the distal aspect of the femoral condyles coincided with the results described in a previous study.[3] The clock-face reference method used for the femoral tunnel position has been criticized as a simple but inaccurate method of tunnel referencing[10]—specifically, that it only considers the high/low position but misses the shallow/deep reference. This might be more important at the time of radiographic evaluation of the femoral tunnel position or when a double-bundle reconstruction is being performed. In the case of single-bundle reconstruction, the step femoral guide always lies below the posterior wall at the same degree of flexion; as such, we believe that the cephalad/caudad orientation is the important one when creating the tunnel in a clinical setting. In this sense, the clock-face reference position might still be valid. It is at the time of evaluation of the lateral radiography when the high/low and shallow/deep references are most important in the setting of anatomical single-bundle ACL reconstruction. The method described by Bernard et al[4] has been demonstrated to better localize the femoral tunnel in both planes. This quadrant method was described to define the center of the femoral insertion site of the ACL on conventional lateral radiographs. Four distances are measured on a lateral radiograph: The relationship between the total sagittal diameter of the lateral condyle measured along the Blumensaat line and the distance from the center of the ACL to the most dorsal subchondral contour of the lateral femoral condyle allows for the calculation of the deep/shallow reference. The relationship between the maximum intercondylar notch height and the distance from the center of the ACL to the Blumensaat line are used to calculate the high/low reference. With this quadrant method, the center of the ACL attachment at the lateral femur condyle was originally described as being located at 25% (high/low) and 25% (deep/shallow). Later on, it was shown that the high position is around 8% (high/low) and 38% (deep/shallow) whereas the anatomical site is localized at 40% (high/low) and 25% (deep/shallow),[24,33] which is similar to our findings. In the current study, a notch view radiograph was included in the protocol because it has been suggested that performing only lateral radiographs is insufficient to verify 3-dimensional placement of the tunnel and that an anteroposterior radiograph may help in further evaluation of its position.[8]

The degree of knee flexion during drilling of the femoral tunnel is controversial. Pujol et al[27] suggested that there is no risk with the anteromedial portal technique when the knee is flexed at least 130°. Basdekis et al[3] recently demonstrated that the tunnel acuity increases with 130° or more of flexion. In such a case, the graft might increase pressure on the anterior tunnel wall and produce a subsequent widening of the femoral tunnel. Therefore, they recommended 110° of knee flexion. This finding is supported by the recent work performed by Nishimoto et al,[26] who suggested that the abrasive force by the sharp edge of the bone tunnel aperture when the graft is acutely bent and stretched might lead to graft failure. Nevertheless, this has not been proven clinically. Furthermore, flexing the knee more than 110° is sometimes difficult when the patient is positioned supine, with both legs hanging free at 90° flexion, one of the most common positions for knee surgery. These reasons support the use of a 110° flexion angle for performing the femoral tunnel in the present study. The knee flexion angle used while determining graft placement has been demonstrated to have some effect on positional accuracy. It has been shown that 90° of knee flexion provided the best results in terms of minimizing displacement from the appropriate location.[16] In the present study, placement of the graft was first determined with the knee at 90° of flexion. The starting point was marked; the knee was flexed to 110°; and the femoral tunnel was drilled.

A minimum length of 25 mm for the femoral tunnel is currently recommended.[3] Lowering the femoral tunnel is performed at the expense of a significantly shortened femoral tunnel.[12] To compensate for this, high-degree knee flexion angles have been advocated. It has been demonstrated that the greater the knee flexion, the longer the tunnel obtained.[3] As shown in the work of Basdekis et al[3] and this study, a femoral tunnel of at least 25 mm can be systematically achieved at 110° of knee flexion. Persistent rotatory instability has been shown to result in an inferior subjective functional outcome and earlier articular degeneration.[17] Therefore, looking for a technique that could reduce this stability deficit might be mandatory. Several studies have recently compared the clinical results between ACL double-bundle reconstruction and single-bundle reconstruction.[23,32] These researchers have concluded that the double-bundle reconstruction was more effective at successfully restoring the original ACL rotatory stability. Nevertheless, in these studies, the ACL in the single-bundle group was reconstructed at the high 11-o'clock position. It has also been demonstrated, biomechanically, that placing the femoral tunnel in a single-bundle technique at the center of the anatomical origin of the ACL more closely restores rotational stability to the knee than does the standard tunnel reconstruction at the 11-o'clock position.[21,24,31] It has more recently been shown that an anatomical femoral tunnel–placed single-bundle reconstruction reproduced anteroposterior and rotational stability as effectively as double-bundle reconstruction in biomechanical[15] as well as clinical studies.[19,30]

In the McKeon et al[22] study, the safe zone for cross-pin fixation consisted of placing the guide facing 20° to 40° upward. They warned of a high risk of vascular injury if the pin is introduced angling downward. Similarly, Castoldi et al[6] demonstrated the high risk of femoral chondral injury if the pin is introduced in a caudad direction. In considerations of these recommendations, the cross-pin was introduced in a 20°-of-cephalad direction in the current study.

There are a few limitations to the present study. First, we performed the technique at only 110° of knee flexion, although some reports have suggested that higher degrees of flexion might be safer. However, one purpose of the present study was to determine if the technique could be safely performed at a lower angle of knee flexion. Second, although varying the drill angles for the cross-pin insertion could affect the results, the femoral transverse drill angle was fixed at 20° cephalad; as such, the effect was not studied.

Fixation of the graft in the femoral side with a cross-pin system device, initially designed for use with an upper transtibially drilled femoral tunnel, may lead to iatrogenic injury when the femoral tunnel is lowered. In the present study, we compared 2 femoral tunnel lengths. In group A, we followed the recommendations given when the tunnel is drilled at the 11-o'clock position. This 30-mm femoral tunnel demonstrated a high risk of injury to the LCL and the PT. Conversely, when the femoral tunnel was drilled as deep as the lateral condyle allowed, the technique was shown to be safe and reproducible for transverse fixation. Although some risk of injury to the LGT was observed in these cases, piercing this big tendon–belly muscle should not have any remarkable clinical consequence. A windshield wiper effect may be one deleterious consequence of these longer tunnels secondary to moving the fixation point further from the aperture.[20] Pujol et al[27] suggested that the solution is not to increase the depth of the femoral tunnel but to flex the knee at least 130°. Although we did not evaluate degrees of knee flexion other than 110°, it has been shown that the system can be safely used at this degree following the technique performed in group B. In some of the specimens studied in both groups, the cross-pin directly pierced the LGT. Nevertheless, this may have no clinical relevance. However, this technique proved to be safe with respect to the PN, leaving a minimum distance of 24 mm, and to the AC, particularly when the femoral socket is drilled longer than 30 mm.

The current study shows that fixation of hamstring graft with a cross-pin system is safe when drilling the femoral tunnel anatomically from the anteromedial portal at 110° of knee flexion and with the longest possible tunnel. Conversely, if the femoral tunnel socket is drilled only 30 mm, it might lead to injury to the LCL and the PT. Our hypothesis is confirmed. Therefore, the former technique is recommended for safe transverse femoral fixation in anatomic ACL reconstruction.

ACKNOWLEDGMENT

We thank Cynthia Scheidt, Pau Rigol, and Felix Vilches for their help in the arthroscopic procedures and anatomical dissections. We are also grateful to Sergi Mojal for assisting in the statistical analysis.

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