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Single-incision technique misses the anatomical femoral anterior cruciate ligament insertion: a cadaver study

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Abstract We examined the arthroscopic appearance of the anterior cruciate ligament (ACL) attachment site on the femur in five fresh-frozen cadaver knees. First, the ACL was cut out, leaving a footprint of ligament-fibers with a length of 2 mm intact. The ACL was consistently found to insert on the lateral wall of the notch. No fibers were found to attach high in the roof of the notch at the 12 o'clock position. Secondly, we tried to reach the anatomical attachment site with a femoral aiming guide through a correctly placed tibial tunnel. This proved to be impossible. The closest position that could be reached was at the margin of the anatomical attachment site. Investigation of the distal femur after complete dissection confirmed these arthroscopic findings. Femoral aiming devices for use through the tibial tunnel aim for an isometric placement of the femoral tunnel, they do not aim for an anatomical position of the graft.

Keywords Anterior cruciate ligament · Anatomy · Notch · Aiming device · Arthroscopy

Introduction

Knowledge of the anatomy of the anterior cruciate ligament (ACL) and particularly its anatomical attachment site on the lateral femoral condyle is accepted as mandatory for successful ACL reconstruction. Precise descriptions of the anatomical tibial attachment area of the ACL are available based on landmarks that are visible during arthroscopy [2, 3, 10, 15, 16, 17, 18, 21, 24]. The most important factor in tibial tunnel placement is to avoid graft notch impingement. If the recommendations of recent reports are followed, the tibial tunnel lies in the posterior part of the anatomical tibial ACL footprint.

More controversial is the question of where to place the femoral tunnel. Two different philosophies are presented in the literature. Some surgeons aim for the most isometric location on the femur at about 11–12 o'clock [14, 18]. Others try to place the graft at the original anatomical insertion site at 10 o'clock or lower [4, 7, 9, 12, 23]. Using a technique with transtibial drilling of the femoral tunnel substantially reduces the freedom in choosing a location at which to place the femoral tunnel. Some authors recommend fluoroscopic control during surgery [4, 6, 12, 13] to avoid placing a femoral tunnel too shallow along the Blumensaat line.

The primary aim of this study was to describe the anatomical femoral ACL attachment site in the arthroscopic view using an anterolateral and an anteromedial portal. Secondly, we examined whether, through a correctly placed tibial tunnel, which had to respect the anatomical structures outside and inside of the joint, the guiding pin for a femoral tunnel could be directed through the tibial tunnel into the area of the anatomical ACL attachment site.

Material and methods

Five right fresh-frozen cadaver knees from persons of unknown age and sex were thawed overnight at room temperature. The knees showed no signs of previous surgery or major degenerative changes. Proximal and distal to the joint 20 cm of femur and tibia shaft were intact. The individual notch inclination angle was measured on lateral radiography (Fig. 1). The femora were fixed in a clamp to a table to achieve a maximal knee flexion of about 120°. With the skin intact a regular knee arthroscopy with 0.9% saline was applied, with the arthroscope placed in a high anterolateral portal. The working portal was established as low anteromedial, close to the patellar tendon. The pressure of the arthroscopy pump was set to a sufficient 20 mmHg, and the knees were irrigated through the anterolateral portal.

Every knee was checked for absence of substantial degenerative changes and an intact ACL. The normal anatomy of the ACL was documented with a digitally image-storing device from Sony. The ACL was then cut through with arthroscopic scissors. Care was taken to preserve a footprint of ACL fibers about 2 mm long at the anatomical femoral insertion area. The distal ACL stump was removed with a shaver. Thereafter the femoral attachment site was documented through the anterolateral portal. Every photo was taken with the 30° scope looking in the lateral direction with the knee in 90° flexion. The procedure was repeated through the medial portal to see the posterior most limit of the ACL stump together with the deep/inferior curve of the lateral femoral condyle. The findings were described according to the definitions introduced by Amis et al. [3] (Fig. 2).

A guide wire for a tibial tunnel was then drilled, starting in the corner proximal to the pes anserinus and ventral from the medial collateral ligament. We aimed for a position posterior to the center of the tibial ACL footprint, parallel to the notch roof in the extended knee position, 44% along the total anteroposterior length of the tibia, according to the recommendations of Stäubli and Rauschning [24]. An Acufex aiming device was used. The position of the guidewire was documented with a second lateral and an anteroposterior radiograph. A 10-mm tibial tunnel was drilled over the guidewire. Through this tibial tunnel we tried, with the help of a 6-mm offset aiming device (Acufex), to place the guidewire for the femoral tunnel within the femoral ACL attachment site. The resulting 2-mm hole was photographed, and the distance between the hole and the margin of the anatomical attachment site was measured with a probe.

Finally, the knees were dissected. The femurs with the ACL attachment site and the drill hole of the femoral guiding pin were examined. The shortest distance between the margin of the femoral attachment site and the drill hole was measured and photographed with a conventional camera.

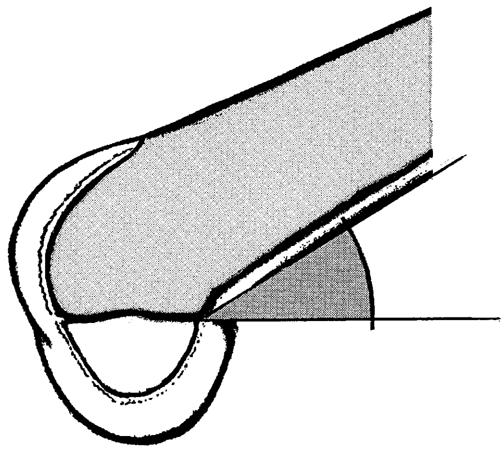

Fig. 1 Notch-inclination angle measurement

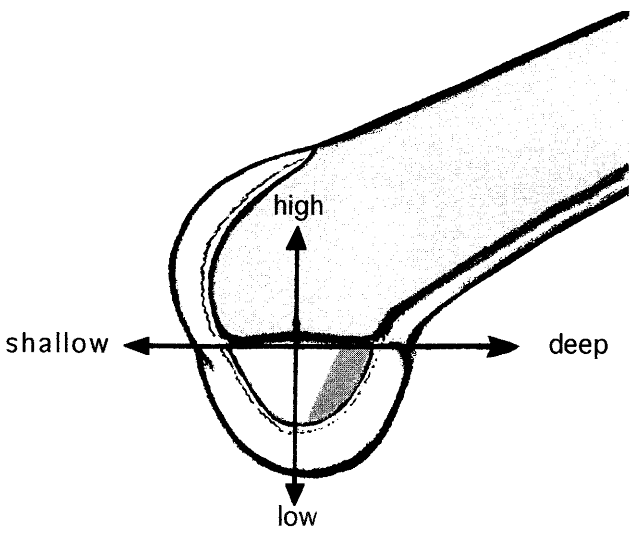

Fig. 2 Notch-navigation according to Amis et al. [2]

Results

Description of the femoral ACL attachment site through the lateral portal

The view through the lateral portal allows the high-low extension of the femoral ACL attachment site (FAAS) to be defined. The FAAS, indicating the femoral insertion of the ACL, was found to be in the same area in all five knees. In relation to bony landmarks the FAAS begins high in the notch at the transition area between notch roof and medial wall of the lateral femur condyle and then covers the entire height of the lateral notch wall to end in the lowest region at the bone-cartilage boundary, which often is found to coincide with the medial edge of the lateral condyle. This means a highest end between the 11 o'clock and the 10 o'clock position, with a lowest end between 8 o'clock and halfway between 7 and 8 o'clock (Fig. 3a, b).

Description of the femoral ACL attachment site through the medial portal

The view through the medial portal also allows the deep-shallow extension of the FAAS to be defined. The deepest end of the FAAS follows the bone/cartilage boundary all along the posterior curvature of the lateral femoral condyle. The most shallow and highest corner of the FAAS is easily distinguishable high in the notch. Measurement with the tip of the probe revealed an expansion of the FAAS in the deep-shallow direction of 6–8 mm (Fig. 4a, b), which gives the footprint a rounded triangular shape.

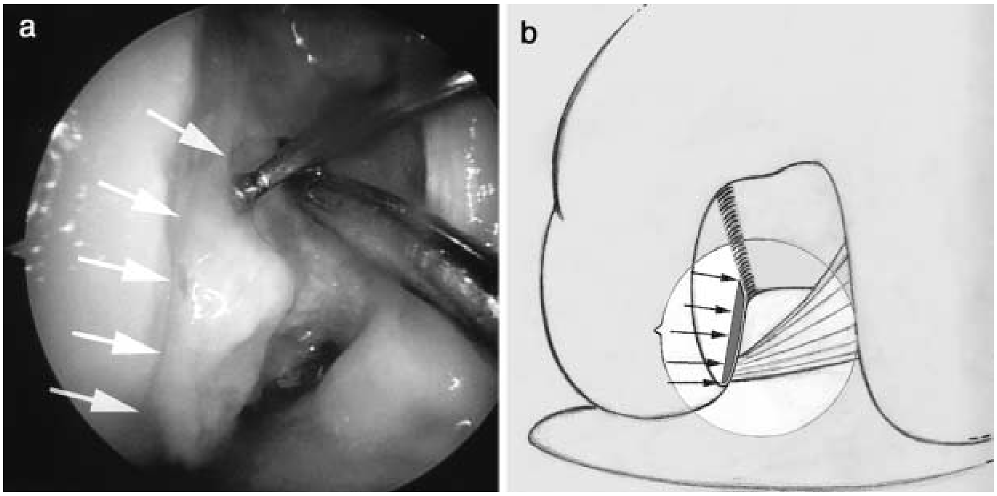

Fig. 3 **a** Notch view, lateral portal, arthroscopic picture of knee no. 3. *Arrows* Extension of the anterior most border of ACL footprint, direction high-low. **b** Schematic drawing of notch view, lateral portal. *Arrows* Extension of the anterior most border of ACL footprint, direction high-low

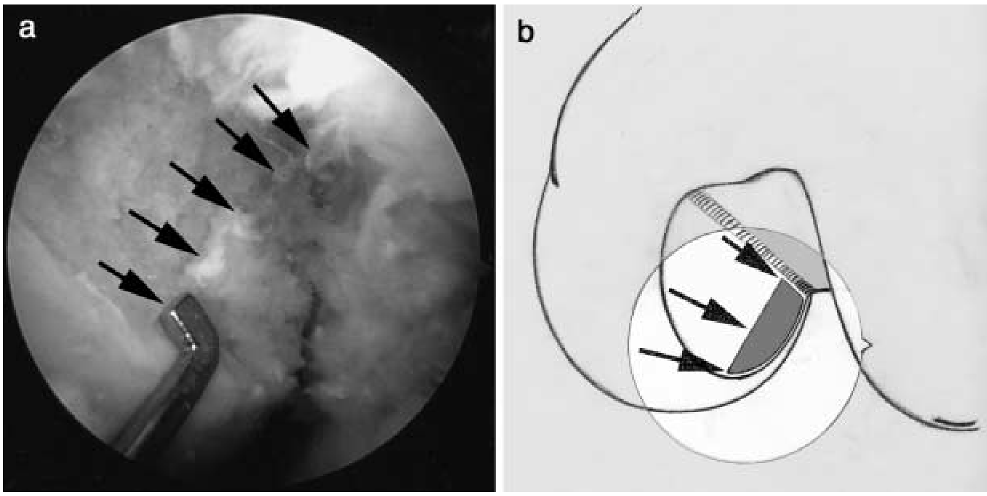

Fig. 4 **a** Notch view, medial portal, arthroscopic picture of knee no. 2. **b** Schematic drawing of notch view, medial portal

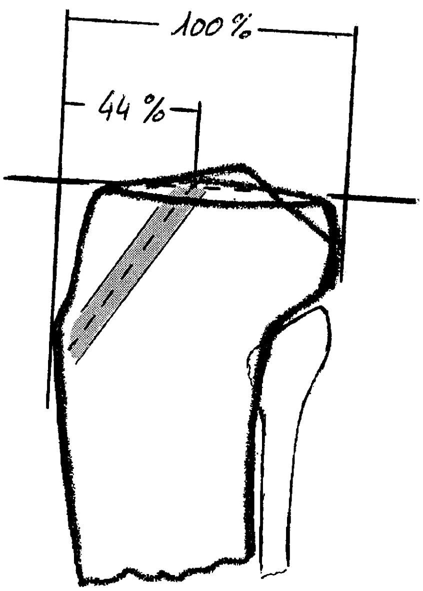

Fig. 5 Tibial tunnel, anteroposterior measurement (percentage)

Tibial tunnel data and femoral notch-inclination angle

In the anteroposterior direction the five tibial tunnels were found to enter the knees at an average of 45% (38–50%) of the entire length of the tibial plateau (Fig. 5). The mean inclination angle in the sagittal plane was 33.8° (30–37°) measured according to the technique shown in Fig. 6; the mean deviation from an axis perpendicular to the tibial plateau in the frontal plane was 11.6° (6–14°; Fig. 7). The notch inclination angles ranged from 36° to 44° (mean 39°), and the tibial tunnels were drilled parallel to the notch roof in the fully extended knee position.

Distance guiding pin: margin femoral ACL attachment site

In none of the five knees was it possible to place the guiding pin within the margins of the anatomical ACL footprint using the technique described. The closest position that was achievable was at the highest most margin of the attachment area. This was possible in two knees, nos. 2

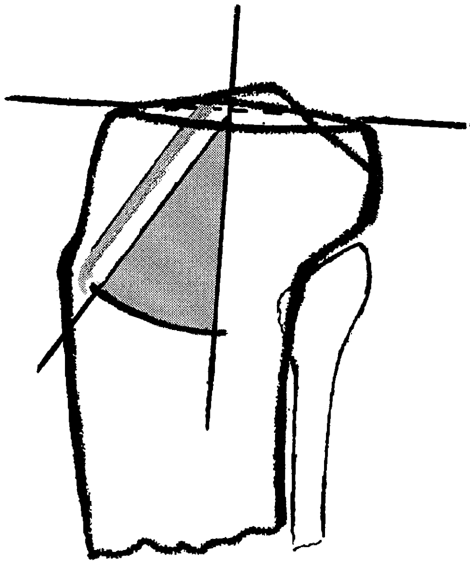

Fig. 6 Tibial tunnel, sagittal plane measurement (degrees)

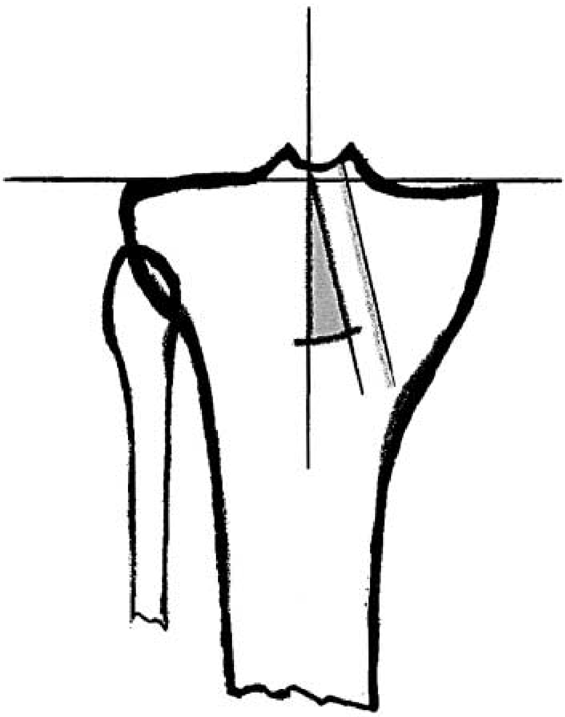

Fig. 7 Tibial tunnel, frontal plane measurement (degrees)

and 4, corresponding to a position halfway between 10 and 11 o'clock. In knees no. 1 and no. 5 the distance of the highest end of the FAAS and the achieved tunnel center was 2 mm, while in knee no. 3 it was 4 mm, corresponding to a position at 11 o'clock and one halfway between 11 and 12 o'clock, respectively (Fig. 8). In four of the five knees the offset of the guiding pin was 6 mm, as planned;

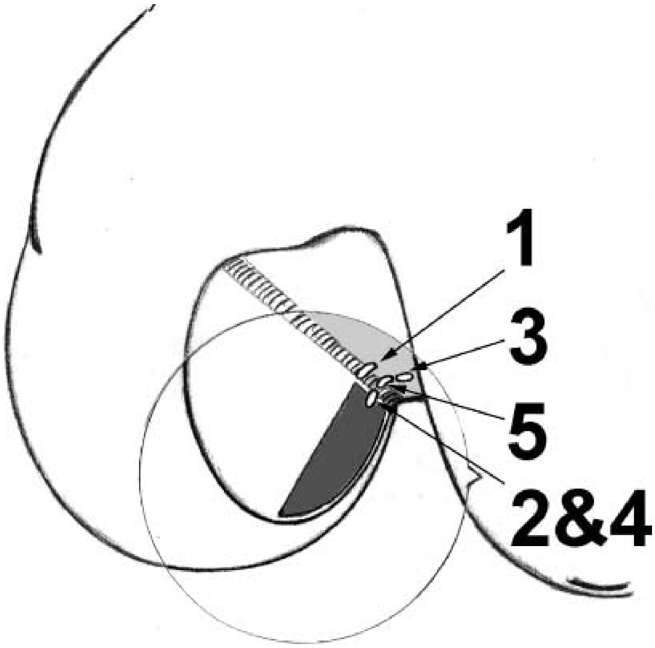

Fig. 8 Notch view, summary guiding pinholes; knees no. 1–5, schematic drawing

in knee no. 1 the distance the posterior femoral edge was about 8–9 mm. These arthroscopic findings were verified after dissection of the knees (Fig. 9).

Discussion

Anatomists, orthopedic surgeons, and engineers know from gross anatomy that the ACL insertion on the femoral side lies deep in the notch, on the medial wall of the lateral femoral condyle, and has a triangular to elliptical shape [1, 2, 10, 11, 22]. The problem is that this information must be translated into the surgeon's arthroscopic view, which differs markedly from the view with which the anatomist is familiar. In contrast to the tibial ACL footprint, some months after the injury the anatomical fibers of the former ACL on the femoral side may have disappeared. Especially if a notchplasty is performed, the last traces of the original ACL stump are lost.

This arthroscopic study was carried out to obtain reproducible data on the anatomical insertion site of the ACL on the lateral femoral condyle. Bony landmarks are hard to define in the notch area by arthroscopy. Apart from the so-called resident's ridge, which was found in all five knees, we identified two bony structures, which may be of some use for the surgeon. One is high in the notch at the transition between the notch roof and the lateral notch wall. It may be surprising for many surgeons who perform ACL reconstructions that the insertion of the anatomical ACL on the femur is found to lie very low in the notch. We found the attachment site to spread between 11 and

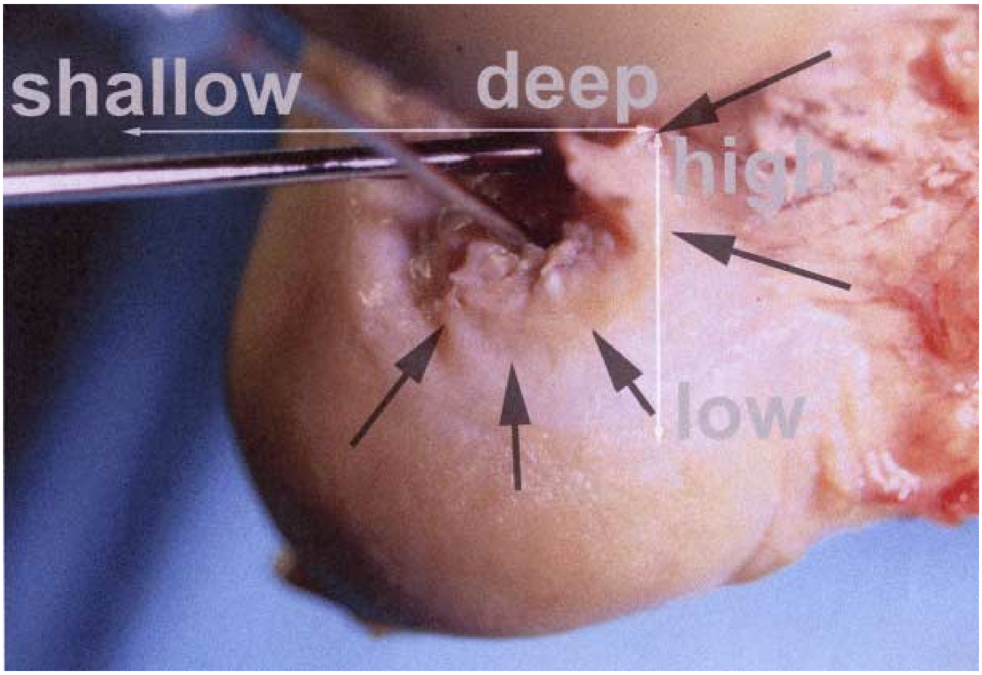

Fig. 9 Example of open dissection of knee no. 3. Distal right femur, view from dorsal/medial into the notch; high in the notch guiding pin for femoral tunnel, low in the notch center of ACL attachment site. *Arrows* Posteriormost margin of ACL footprint

9–8 o'clock; the center lies definitely lower than at the 11 o'clock position. The other anatomical landmark deep and low in the notch is the transition between the bony lateral notch wall and the cartilage of the lateral femoral condyle. These findings might help to place the ACL graft in a more anatomical position.

The optimal position of the femoral tunnel for ACL grafts has yet to be determined. Generally two philosophies can be derived from the literature. There are surgeons aiming for the most isometric place on the femur at 11 o'clock [14, 18] while others try to place the graft at the original anatomical insertion site at 10 o'clock or lower, according to our findings [4, 7, 9, 12, 23].

Assuming an anatomical tunnel placement to result in more natural knee kinematics [2, 8, 20], we tried to reach the center of the femoral anatomical ACL attachment site through a correctly placed tibial tunnel according to Stäubli and Rauschning [24]. This tunnel placement technique respects anatomical structures, starts in the corner medial to the patellar ligament, at the proximal border of the pes anserinus and ventral from the medial collateral ligament, directing the tibial tunnel into the posterior part of the tibial ACL footprint. The orientation of this tibial tunnel obviously determines the placement of the femoral tunnel. Considering also a 10-mm tunnel about 4 cm long and a very stable and bulky aiming device, it is clear that the freedom to maneuver the guiding pin into the ideal spot is markedly reduced. It therefore was not surprising that it was impossible to place the femoral guiding pin within the anatomical footprint. Although the guidewires in two knees reached the high margin of the anatomical area, the ultimate femoral tunnel would have lain in the high and deep part of the natural ACL attachment site.

We chose to measure the distance from the resulting pinhole to the margin of the ACL attachment site instead of the center of the area. This distance could be measured quite precisely under arthroscopic control, in contrast to the distance between the hole and the center of the attachment area, because the center itself is arthroscopically difficult to define.

In the natural ACL various fibers are recruited under defined circumstances, ingeniously fitting into the overall knee kinematics [5]. It is possible to divide the ACL into several functionally different bundles. Bundles attaching deep and high in the attachment site bear load in 90° of knee flexion, whereas the bundles attaching low in the attachment site are recruited between extension and 30° of knee flexion [19]. If an ACL graft is placed on the lateral notch wall, the changes in its position in the deep-shallow direction are the primary determinant of whether the tibiofemoral distance increases or decreases with flexion; changes in the position on the high-low axes are of less effect [13].

According to our data, most of the femoral tunnels tend to be placed deep and high in the notch, far from the center of the anatomical attachment site. If we wish to reach a tunnel position that is lower and more anatomical, one possibility would be to drill the tibial tunnel from a starting point more medially. With this solution new problems could arise: if anatomical structures are not be harmed, it is unacceptable to cause any damage to the medial collateral ligament. Another possibility for reaching a more anatomical femoral tunnel position would be to use the anteromedial portal instead of the transtibial portal and to flex the knee to 130°.

The femoral aiming devices on which the single-incision technique depend aim for an isometric placement of the femoral tunnel. Simultaneously they guarantee a femoral tunnel deep in the notch, avoiding a posterior blow-out. In other words, surgeons aiming for an anatomical position of the graft at the femoral side instead of an isometric placement should realize that the use of an aiming device through a tibial tunnel may lead to a nonanatomical position of the graft on the femoral side, partially due to the aiming devices themselves.

Is this merely an academic discussion? The ACL is the primary restraint against anterior tibial translation [22]. The more horizontally or anatomically it is placed, the more efficiently it can act against this anterior displacing force, and the better it can serve its purpose. The second most obvious reason for an anatomical placement is that if an anatomical placement and orientation of the graft are achieved, the graft will not impinge on the notch roof or on the posterior cruciate ligament, as the natural ACL did not impinge under physiological circumstances. For those reasons we prefer the anatomical graft placement.

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