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Influences of knee flexion angle and portal position on the location of femoral tunnel outlet in anterior cruciate ligament reconstruction with anteromedial portal technique

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Abstract

Purpose: To evaluate the influences of knee flexion angle and portal position on the location of femoral tunnel outlet in anterior cruciate ligament (ACL) reconstruction with the anteromedial portal technique.

Methods: We recruited 6 volunteers with 12 normal knees. Each knee was flexed 120 or 135 degrees and scanned with an open MRI. A 3D knee model was created. Virtual femoral tunnels were created on the footprint of the anteromedial bundle and the posterolateral bundle of the ACL from three arthroscopic portals: the standard anteromedial (AM) portal, the far medial and low (FML) portal and the far medial and high (FMH) portal. The location of the femoral tunnel outlet was evaluated by comparing to the dissected cadaveric knee.

Results: Both increased flexion angle and lowering the drilling portal have a similar influence on the femoral tunnel outlet by moving them anterior and distally. Medialization of the portal moves them posteriorly and distally. posterolateral tunnels created on the 120-degree knee model are more likely to be located under the lateral head of the gastrocnemius especially when they are drilled through the AM or FMH portals.

Conclusion: If the femoral tunnel outlet is located under the soft tissue such as gastrocunemius attachment, suspension fixation devices may lapse into fixation failure by sitting on the soft tissue rather than the cortex bone surface. It is more desirable to drill in 135 degrees knee flexion rather than 120 degrees, and through a lower portal, to avoid creating the femoral tunnel outlet under soft tissues.

Type of study: Experimental research

Key Words: Double-bundle anterior cruciate ligament reconstruction · Femoral tunnel outlet · Lateral structure · 3-D MRI

Introduction

Anterior cruciate ligament (ACL) reconstruction is recognized as a reliable operative procedure for ACL injury [1, 6, 25]. Placement of tunnels within the anatomical footprint of the ACL is one of the key issues in the surgical procedures. The conventional drilling technique for the femoral tunnel consists of drilling the tunnel through the tibial tunnel, the so-called "trans-tibial technique" [22]. Although this technique is safe and familiar to many surgeons, several studies have indicated that it is difficult to drill the tunnels within the anatomic footprint of the ACL using the trans-tibial technique because the direction of drilling for the femoral tunnel is restricted by the location and direction of the tibial tunnel [10, 11, 19]. Therefore, tibial tunnel-independent techniques such as the trans-anteromedial (AM) portal technique or the outside-in technique have been advocated [9, 13, 14, 15]. Because the AM portal technique allows the surgeon to aim the drilling site freely at the desired location, it is relatively easy to place the tunnel within the ACL footprint. However, many studies suggest several pitfalls of this technique that may affect the outcome.

There have been some studies on the knee flexion angle during femoral drilling to determine how it affects the length of the femoral tunnels. Some authors reported that drilling with a low flexion angle less than 110 degrees has a risk to create a tunnel shorter than 30mm and a risk to blow out the posterior articular cartilage [2, 3, 12, 17, 21, 23]. Another concern is the risk of injury to important structures laterally, including the peroneal nerve, popliteal tendon or lateral collateral ligament [7, 16-18]. Thus, drilling in a deep knee flexion more than 110 degrees is recommended [2, 3, 7, 16-18, 23].

This study was focused on the location of the lateral outlet of the femoral tunnels in the anatomic double-bundle ACL reconstruction using the AM portal technique. The posterior area of the lateral wall of the femoral condyle is covered with soft tissues such as the lateral head of the gastrocnemius. When using suspension devices (i.e. Endobutton®) for the fixation of grafts, the devices may sit on the soft tissue rather than directly on the cortex if the outlet of the femoral tunnel is located under soft tissue such as the attachments of muscles, tendons, and ligaments. This could create a risk for fixation failure that could affect the clinical results. We have encountered several cases in which Endobuttons were located on a relatively posterior area of the lateral wall of the femoral condyle with a gap of a few millimeters from the surface of the cortex (Figure 1). Thus we questioned whether a flexion angle of 110 degrees is sufficient for drilling the femoral tunnel with this technique. Although previous studies suggest that the knee should be flexed more than 110 degrees during the drilling to avoid short tunnels or injuries to cartilage, less information is available regarding the influence of a flexion angle greater than 120 degrees on the location of the femoral tunnel outlet on the lateral wall of the femoral condyle. In addition, the location of the AM portal that is used for the drill would also influence the direction of the tunnels. Zantop et.al reported the influence of the portal location and flexion angle, but only on the incidence of cartilage injury [23]. Therefore the following questions were raised. (1) Where is the area that is not covered with thick soft tissues, such as the attachments of muscles, tendons, and ligaments on the lateral wall of femoral condyle? (2) How do a flexion angle greater than 110 degrees and the portal location affect the location of the tunnel outlet? To address these questions, we performed 1) an anatomic evaluation of cadaveric knees, and 2) simulation of femoral tunnel drilling on a 3D knee model made from an MRI of the knee flexed in 120 degrees and 135 degrees from three different medial portals to clarify the influence of these factors on the location of the tunnel outlet. The tested three portals are different in the position in height and the position in horizontal plane. The hypothesis is that it is more desirable to drill in 135 degrees knee flexion than 120 degrees, and through the far medial and lower portal to avoid creating a femoral tunnel with an outlet under the soft tissue.

MATERIALS AND METHODS

Dissection of cadaveric knee

To examine whether there are important soft tissue structures near the femoral tunnel exit, we dissected the lateral structure of the knee using an embalmed cadaveric knee (cadaver of a 72-year-old woman from the 2012 gross anatomy course at Kyushu University School of Medicine). The cadaveric leg did not have any malalignment, varus deformity or flexion contracture of the knee. Following the dissection, we took photos and identified the area that is not covered with thick soft tissues, such as muscle, ligaments or capsule, on the lateral wall of the femoral condyle.

Reconstruction of the three-dimensional knee model from MRI of the knee

Six volunteers (2 males and 4 females) with 6 normal knees were recruited. The median age was 30 years (range; 25 to 35 years). Each knee was flexed 120 or 135 degrees and scanned with MRI at 0.4 Tesla (APERTO, Hitachi Medical Corporation, Tokyo, Japan). The MRI is open in a horizontal direction with a 38 cm vertical gap, enabling it to scan the flexed knee beneath the gantry. A regular goniometer was used to measure the angle between the thigh and the leg and the coil was fitted on the flexed knee. Three-dimensional (3-D) T2-wighted sagittal images (TR/TE = 2,800 ms/100 ms, field of volume = 150 mm, thickness = 1.0 mm) were obtained. A 3-D knee model was reconstructed from the 2-D MRI Digital Imaging and Communications in Medicine (DICOM) data with Mimics software (Materialise NV, Leuven, Belgium). Ethical approval was obtained from the Internal Review Board and all subjects gave their informed consent before they were included.

Simulation of ACL reconstruction on the 3-D knee model reconstructed from the MRI

The femoral footprint of the AM bundle and the posterolateral (PL) bundle of the ACL were identified on the MRI image of each knee and marked on the 3D-knee model. Next, we defined three points on the knee model for arthroscopic portals: the standard AM portal, the far medial and the low (FML) portal and far medial and high (FMH) portal (Figure 2a). The location of the standard AM portal was defined at the level of the lower pole of the patellar and medial edge of the patella tendon. The FML portal is the same as the "accessory anteromedial portal" and "far anteromedial portal", which is commonly used [7,8,12,15,16,17,23,24]. The location of the FML portal was defined as just above the anterior horn of the medial meniscus and 1.5–2.5cm inside the patellar tendon so that a cylinder 6 mm diameter that connects the FML portal and AM bundle footprint did not interfere with the medial femoral condyle in either the 120 or 135 degree flexed knee model. These two portals, the AM portal and the FML portal, are the portals widely used in clinical settings; however, we defined another portal, the FMH portal, which is not used in practice. The location of the FMH portal was defined as being 1 cm above the FML portal. To distinguish these two portals, they were called the FMH portal and FML portal. We defined the FMH portal because it allows examination of the influence of the difference in portal heights by comparing FML and FMH portals. In addition, the influence of medialization of the portal position can be examined by comparing AM and FMH portals because the FMH portal is located about 1.5–2.5cm inside of the AM portal with this setting. Furthermore, a 1 cm difference can occur as a result of surgical variation when deciding the portal height at the time of surgery.

In order to simulate the drilling for femoral tunnels using the trans-portal technique, we placed cylinders of 6mm diameter that connected each portal with the footprint of the AM bundle or the PL bundle (Figure 2b). The cylinders were extended to the lateral femoral cortex, and the point at the intersection of the cylinder and lateral femoral cortex was marked as a femoral tunnel outlet (Figure 2c). The location of femoral tunnel outlet was identified by measuring the anterior-posterior and proximal-distal distances from the lateral epicondyle. The proximal-distal axis was defined as a line parallel to the long axis of the femoral shaft, and the anterior-posterior axis was defined perpendicular to the proximal-distal axis in the lateral epicondyle (Figure 3). To visualize the femoral tunnel outlet positions, approximate position of each outlet point was dotted with the case number on one 3D model by reference to each 3D model.

The anterior-posterior and proximal-distal distances from the lateral epicondyle were conducted by one observer (K.O.) and were repeated in a blinded manner during the course of two sessions at least one month apart. Intraobserver reliabilities, evaluated with the use of the intraclass correlation coefficient, were excellent (0.95). Two observers (K.O. and H.M.) independently measured 24 randomly selected tunnel outlets on 3D MRI models. Interobserver reliabilities, evaluated with the use of the interclass correlation coefficient, were excellent (0.94).

Statistical analysis

A statistical analysis was done using a data analysis system software program (JMP 9.0.2, SAS Institute Inc., Cary,NC). The Wilcoxon signed-rank test was used to compare the anterior-posterior and proximal-distal distances from the lateral epicondyle between 120° flexion and 135° flexion through the each portal. A power analysis indicated that a sample size of 6 participants per group would provide 87.6 % statistical power for detecting a 10mm difference in the distance between the groups. This assumes a probability value of < 0.05 and a standard deviation of 5mm.

Results

Identification of the areas that are not covered with thick soft tissues

After dissection of the lateral wall of the cadaveric femoral condyle, we marked the attachments of the lateral collateral ligament (LCL), popliteal tendon, articular capsule and lateral head of the gastrocnemius (LHG) (Figure 4). When we drew an anterior-posterior axis and a proximal-distal axis on the lateral epicondyle, the posterior-distal quadrant was covered by the LCL and popliteal tendon. The area 45 degrees anterior from the proximal axis was covered by the attachment of the LHG. Thus, the areas that are not covered with thick soft tissues are the anterodistal quadrant and the area 45 degrees proximal from the anterior axis.

Location of the tunnel outlet in the simulation model

The tunnel outlet location of the 3-D MRI simulated model is shown in Figure 5. Each number represents the location of the femoral tunnel outlet for each case number. The color of the numbers represents the portal used for drilling. The distribution of the numbers is because of the differences in morphology of the femoral condyle and ACL footprint among the individuals. However, comparison of the location of each number can indicate the trend of influences of flexion angle and portal position on the location of the tunnel outlet.

Comparison of the location of the same number between the 120-degree and 135-degree cases suggests that increasing the flexion angle moves the tunnel outlet anteriorly and distally by rotating about the lateral epicondyle (Figure 5). The location of AM tunnel outlet in 135-degree was significantly anterior than that of 120-degree ($P<0.05$) (Figure 6a). The PL tunnel outlet in 135-degree tended to be located more anterior than that in 120-degree. The location of PL tunnel in 135-degree was significantly distal compared to that in 120-degree ($P<0.05$) (Figure 6b).

Comparison of the location of the same number among the different colors suggests the influences of portal positions. Comparison between the FML portal and the FMH portal (yellow and blue, respectively) suggests that portal height affects the location of the tunnel outlet in the same way as the flexion angle; changing the portal from high to low moves the outlet anteriorly and distally, just as increasing the flexion angle does (Figure 5). The location of tunnel in FML portal group was significantly anterior and distal than that in FMH portal group for AM tunnel (Figure 6a) and, for PL tunnel (Figure 6b) ($P<0.05$).

In contrast, comparison between the AM portal and the FMH portal (red and blue, respectively) suggests that medialization of the portal moves the tunnel outlet posteriorly and distally (Figure 5). The location of tunnel in FMH portal group was significantly posterior and distal than that in AM portal group for both of AM and PL tunnel ($P<0.05$) (Figure 6a, 6b).

The location of the femoral tunnel outlet in each simulation is compared with the locations of soft tissues on the cadaveric knee. In the simulation with 120-degree flexion, most of the PL tunnel is located within or very close to the attachment of the LHG no matter what portal is used (Figure 5a). When the knee was flexed to 135 degrees, the outlet position of the PL tunnels moved anteriorly. Most of the PL tunnels drilled through the FML portal in 135 degrees flexion were located outside of the attachment of LHG, although drilling through the AM portal or the FMH portal still presents some risk of creating the outlet under the LHG (Figure 5b).

AM tunnels drilled in 120 degrees flexion tend to be located at the postero-lateral area of the femoral epiphysis. Drilling through the FMH portal creates a greater risk to blow out the posterior wall of the femoral epiphysis (Figure 5c). Increasing the flexion angle to 135 degrees moves the tunnel outlet anteriorly resulting in less risk of damage to the posterior wall. However, drilling through the FMH portal still creates a greater risk of placing the outlet under the attachment of the LHG (Figure 5d). Taken together, drilling in 135 degrees of deep knee flexion without using the far medial and high portal is safe to avoid a posterior blowout and to create the tunnel outlet under the soft tissue.

Discussion

The most important finding of this study was to have clarified the influence of knee flexion angle (120 vs 135 degrees) and portal position on the location of the outlet of the femoral tunnel in the ACL reconstruction using the AM portal technique. Increasing the flexion angle moved the tunnel outlet anteriorly and distally with rotation around the lateral epicondyle toward an area that is not covered with thick soft tissues. This is reasonable because the trans-epicondylar axis is known to be an axis of knee flexion [5]. The difference of portal height had a similar influence as the flexion angle. Use of a relatively high portal reduces the impact of the flexion angle, leading to the same result as drilling in a low flexion angle. Zantop et al. reported similar results although they used a bone model that may not represent real knee kinematics [23]. No one has investigated the influence of the horizontal portal position. Medialization of the portal moved the tunnel outlet posteriorly and distally. This would lead the tunnel to exit in the unfavorable area that is covered with the LHG or the LCL. We conclude that (1) 135 degrees deep knee flexion is safer for the PL tunnel to avoid the outlet under the LHG; (2) tunnels should be drilled through the low portal instead of the far medial and high portal because it increases the risk of a blowout of the posterior wall and increases the risk of creating the outlet under the LHG.

There have been some studies on the knee flexion angle during femoral drilling to determine how it affects the length of the femoral tunnels and the risk of a blowout of the posterior femoral cortex [2, 3, 4, 12, 17, 21, 23]. Many authors have warned that drilling in a low flexion angle such as 90 degrees increases the risk of a blowout of the posterior femoral cortex, iatrogenic damage to the peroneal nerve, or short femoral tunnels, and recommended that the knee be flexed more than 110 degrees [2, 3, 7, 17, 23]. However, it is still unclear whether 110 degrees or greater flexion angle is suitable for drilling the femoral tunnel. Basdekis et al. evaluated femoral tunnel orientation drilled through a standard AM arthroscopic portal in 110-, 130-degree, and maximum flexion with cadaveric knees [2, 3]. They found there was no difference in tunnel length and that the distance from the posterior cortex increased with increased knee flexion. They finally recommended drilling at 110 degrees of knee flexion because drilling at 130 degrees of knee flexion increased acuity of the femoral tunnel with respect to the lateral wall of the intercondylar notch. However, the negative impact of tunnel acuity has not been proven and they did not evaluate the lateral structure. Nakamura et al. reported that there was a 20% risk of damage to the cartilage while drilling the PL bundle at 110 degrees of knee flexion [17]. Neven et al. found that no lateral structures were at risk when drilling the PL tunnel in 120 degrees of knee flexion through a low AM portal [18]. These two studies did not investigate a greater flexion angle. Taketomi et al. found that there still be a 6% risk of back wall blowout while drilling the PL bundle at 120～130 degrees of knee flexion [20]. Farrow and Parker evaluated the distance between the lateral structures and the AM or PL tunnel drilled from a point similar to the far medial and lower portal [7]. The PL bundle guide pin lies close to the origin of the LHG tendon at 110 degrees of flexion. At 130 degrees of flexion, the PL bundle guide pin lies closest to the LCL femoral attachment. They recommended that the tunnels be drilled in at least 110 degree of knee flexion but did not conclude which angle is appropriate.

Generally, these studies showed that iatrogenic damage to the lateral structures could be avoided by knee flexion more than 110 degrees from the low portal. With our results, 120 degrees of flexion can be used as long as the low portal is employed. However, considering the possibility for some variance in the portal position due to the morphology of the condyle or the surgeon's error, we conclude that 135 degrees of flexion is safer. We employed the FMH portal because we consider the potential risk of surgical variation or error by which the FML portal or AM portal is created at higher or more medial position, respectively. Nakamae et al. suggested an increased risk for the PL tunnel to be too close to the LCL in deep knee flexion of more than 110 degrees [16]. It is suggested from our results that medialization of the portal shifts the tunnel outlet distally and posteriorly, which may result in a position too close to the LCL. When ACL reconstruction is performed using the AM portal technique with the far medial portal as a working portal, the portal is often positioned as the guide pin is passed into the intercondylar notch just lateral to the medial femoral condyle. Therefore, in a case with a wide intercondylar notch, the working portal may be positioned more medially, and the risk of creating the tunnel outlet too close to the LCL may increase. Vigilance against placing the portal too medially in a case with a wide intercondylar notch is recommended.

There are some limitations in our study. First is the small sample size. However, as the purpose of this study was to clarify the influences of increasing flexion angle and portal position on the location of the tunnel outlet, we consider this sample size sufficient. Second, we used natural knees without ACL injury. The knee flexion position may be different to that of an ACL injury. Third, the knee flexion angle was measured manually. Angle measurement accuracy might be improved by the use of an electric goniometer or navigation system. But, in a clinical situation, we estimate the angle by a manual measurement, and so this procedure seems warranted. Fourth, this simulation study did not exactly reproduce the arthroscopic technique. However, when comparing similar studies using cadaveric knees, the advantage of using the 3-D image model is that we can simulate many different settings in the same model without interfering with each other.

The clinical relevance of this study is the following. The location of femoral tunnel outlet is important not only to avoid an iatrogenic damage of joint structures but also to avoid placing the fixation button on a thick soft tissue. If the femoral tunnel outlet is located under the thick soft tissue such as LHG, suspension fixation devices may lapse into fixation failure by sitting on the soft tissue rather than the cortex bone surface. This study investigated the influence of flexion angle and portal position from this viewpoint.

Conclusion

It was investigated how the flexion angle and portal location affect the location of the tunnel outlet. It is more desirable to drill in 135 degrees knee flexion rather than 120 degrees and through a lower portal from the viewpoint of avoiding a femoral tunnel outlet under the soft tissue. Medialization of working portal would increase the risk to move the outlet closer to LCL.

Conflict of interest The authors declare that they have no conflict of interest.

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Figure legends

Figure 1

Gap between the surface of the cortex and the Endobutton.

Figure 2

a: Portal position. Red: AM portal. Blue: FMH portal. Yellow: FML portal. The purple object is the medial meniscus.

b: Simulation of PL tunnel drilling in the 135 degree flexion model.

Red: from AM portal. Blue: from FMH portal. Yellow: from FML portal.

c: The image from the lateral side.

Figure 3

The proximal-distal axis was defined as a line parallel to the long axis of the femoral shaft, and the anterior-posterior axis was defined perpendicular to the proximal-distal axis in the lateral epicondyle.

Figure 4

Photograph of the lateral aspect of the knee. LHG: the attachment of the lateral head of the gastrocnemius tendon. LCL: the attachment of the lateral collateral ligament. PT: the attachment of the popliteal tendon. CAP: the attachment of the articular capsule. The red point is the lateral epicondyle.

Figure 5

The tunnel outlet location of the 3-D MRI simulated model. Each number represents the location of the femoral tunnel outlet for each case number. The color of the numbers represents the portal used for drilling. Red: AM portal. Blue: FMH portal. Yellow: FML portal.

a: PL tunnel outlet of the 120 degree flexion model.

b: PL tunnel outlet of the 135 degree flexion model.

c: AM tunnel outlet of the 120 degree flexion model.

d: AM tunnel outlet of the 135 degree flexion model.

Figure 6

Anterioposterior and proximodistal location of femoral tunnel outlet relative to the lateral epicondyle.

*Significant difference ($P<0.05$).

a: AM tunnel.

b: PL tunnel.