ORIGINAL PAPER
PŮVODNÍ PRÁCE

How the Aperture of Femoral Tunnel Affected in ACL Reconstruction Performed with AM Portal Technique?

Jak ústí femorálního tunelu ovlivnilo rekonstrukci PZV prováděnou AM portální technikou

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ABSTRACT

PURPOSE OF THE STUDY
The purpose of this study was to evaluate the position of tibial tunnel (TT) and femoral tunnels (FT) performed by using the anteromedial (AM) portal technique and its effect on the aperture of FT.

MATERIAL AND METHODS
A total 44 patients operated for anterior cruciate ligament (ACL) rupture by AM portal technique between January 2013 and July 2015, were included in this study. They were subjected to a magnetic resonance imaging of the knee to assess the FT, dimensions of the FT aperture and TT. The location of the ACL graft within the joint was compared with the intact ACL of healthy individuals. The patients were also evaluated using Lysholm and IKDC subjective scores for functional outcome.

RESULTS
The mean FT angle on both the coronal plane (42.88°±5.83°) and the sagittal plane (68.47°±9.57°) was significantly different from the intra-articular part of the hamstring autograft angles (74.93°±7.27° and 58.74°±4.88°, respectively) ($p<0.0001$). The mean distance of the FT aperture was 13.18 (±2.49) mm on vertical axis, 10.97 (±1.50) mm on the sagittal axis ($p<0.0001$). The difference between TT axis and the axis of the intra-articular part of autograft on both coronal (72.78°±4.67° and 74.93°±7.27°, respectively) and sagittal planes (60.12°±5.53° and 58.74°±4.88°, respectively) were not significant ($p>0.05$).

DISCUSSION
Ilingrowth et al. claimed that the FT were scattered in the very large distance and some of them were placed outside of anatomical range in the series included the cases performed with transtibial and transtibial independent techniques. In this series, in which we used a femoral guide to drill the FT at lateral femoral condyle at 2 or 10 o'clock position depended upon the site of operation, we obtained a consistent FT which is comparable with the intra-articular part of native ACL. Amano et al. found that the FT aperture enlargement was significant in the series when hamstring tendons were used as autograft, over a 6-month period. We also found a significant difference between the narrowest part of the FT (7.01 ± 1.05 mm) and its aperture (10.97 ± 1.50 mm in sagittal, 13.18 ± 2.49 mm in vertical direction). The enlargement was mainly in the vertical direction, due to the fact that the loads resulting from daily life are mostly on the horizontal plane.

CONCLUSIONS
The direction of intra-articular part of the ACL graft in the cases operated with the AM portal technique is significantly different from the FT direction in both the coronal and sagittal planes. The enlargement of the FT aperture is larger in the vertical axis compared to the sagittal axis. Although the long-term clinical consequences of asymmetrical enlargement of the FT aperture are not known yet, to avoid this potential risk, a technique to approximate the direction of FT to the intra-articular part of the ACL without changing the FT entry site, can be used.

Key words: knee, anterior cruciate ligament reconstruction, femoral tunnel, tibial tunnel, anteromedial portal.

INTRODUCTION

The most important advantage of the anteromedial (AM) portal technique is allowing of placement of the femoral tunnel (FT) independent of the tibial tunnel (TT) in the more horizontal position (2, 4, 13, 20). However, there have been some infrequent reports of posterior wall breakage of the FT (12, 16). The other technical challenges are a short FT, possibility of injury around the lateral epicondyle (i.e. popliteus tendon) and iatrogenic injury to the cartilage of the medial femoral condyle (14).

Furthermore, the angle between the FT and the anterior cruciate ligament (ACL) graft is another crucial issue. Because bending angle of the graft determines the

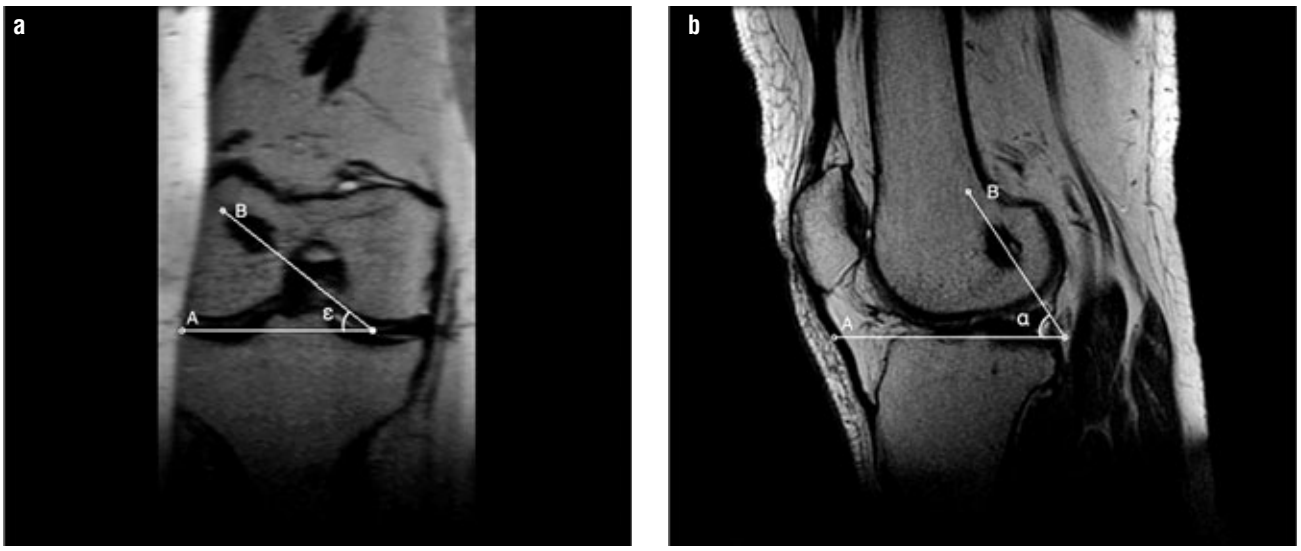

Fig. 1. Method of determining femoral inclination angle on MRI (a) coronal and (b) sagittal planes. A – horizontal articular line of tibial plateau, B –femoral tunnel line. Femoral tunnel inclination angle (a) on the coronal plane is ϵ angle, (b) on the sagittal plane, a angle.

bending stress on the aperture of the FT as expected, subsequently acute angles can cause abrasive forces at most in the aperture of FT and also enlargement of the tunnel (18, 22, 23). Theoretically, to eliminate abnormal stress on the graft-bone contact area, the ideal ACL reconstruction should create a graft similar to the orientation of the intact ACL with correct axial and sagittal obliquity and also be compatible with the FT. However, in the commonly used AM technique, in which the FT is more horizontal, the pressure on the FT aperture is likely to increase. To our knowledge there is no clinical study which compares the position of intra-articular part of native ACL with the position of femoral and tibial tunnels of reconstructed ACL and effects on the intra-articular aperture of tunnels. In the present study, we focused on aperture of the FT, which makes more acute angulation with the intra-articular part of the ACL graft dependent upon a more horizontal FT in the AM portal technique compared to the transtibial technique.

The aim of this study is to evaluate the positions of the FT and the TT compared to the ACL graft performed with AM portal technique and effects on the aperture of FT. The hypothesis is that, the AM portal technique provides an intra-articular graft placement closer to the native ACL axis. However, more acute angulation between the ACL graft and the FT result in greater pressure in the longitudinal axis of the aperture.

MATERIAL AND METHODS

After approval to conduct this study was obtained from the Institutional Ethical Committee, the study was done in agreement with the ethical standards of the Institutional and International Research Committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Between January 2013 and July 2015, 62 patients were operated on using the AM portal technique because of ACL injury. The inclusion criteria were primary single bundle ACL reconstruction, operated by the same surgeon with the AM portal technique, using hamstring autograft in a skeletally mature patient. The exclusion criteria were multi-ligamentous injuries, revision ACL reconstructions, previous fractures in the proximal tibia or distal femur. Forty-four patients, who had undergone an ACL reconstruction consented for a MRI evaluation of the knee or have a MRI which is taken at least 9 months after operation, were included in this study. Of these 44 patients, 40 were male, 4 females. The mean age of the patients was 28.8 (range; 17–48). Follow up was 26.9 (range; 9–72) months. Knee MRIs, which taken for reasons unrelated to the ACL or other knee ligament injury, of 30 patients (27 male, 3 female) were used as a control group. The mean age of the patients in the control group was 28.8 (range; 17–48). The control group was allocated by taking into consideration the male-female ratio and age range in the study group.

Surgical technique

Semitendinosus and gracilis tendons were harvested, folded in half and passed through ToggleLoc loop (Biomet, USA) to prepare the graft. The ACL tibial guide, which is adjusted to 55°, was inserted through the AM portal. The TT was drilled in the centre of the tibial ACL footprint to appropriate size based on the graft diameter. When the knee was held in 110°–120° of flexion, a guide pin was inserted to lateral femoral condyle from AM portal at 2 or 10 o'clock position depended upon the site of operation. The articular part of the FT was drilled so as to allow at least 20 mm long graft insertion compatible with the diameter of graft already prepared. After passing the grafts, it was secured with a ToggleLoc loop (Biomet, USA) in the femoral side. After tensioning, while the knee was in approximately 20° of flexion, the tibial side was secured with interference screw (PLGA/CompositCP, Biomet, USA). In post-operative rehabilitation, patients were allowed partial weight bearing until

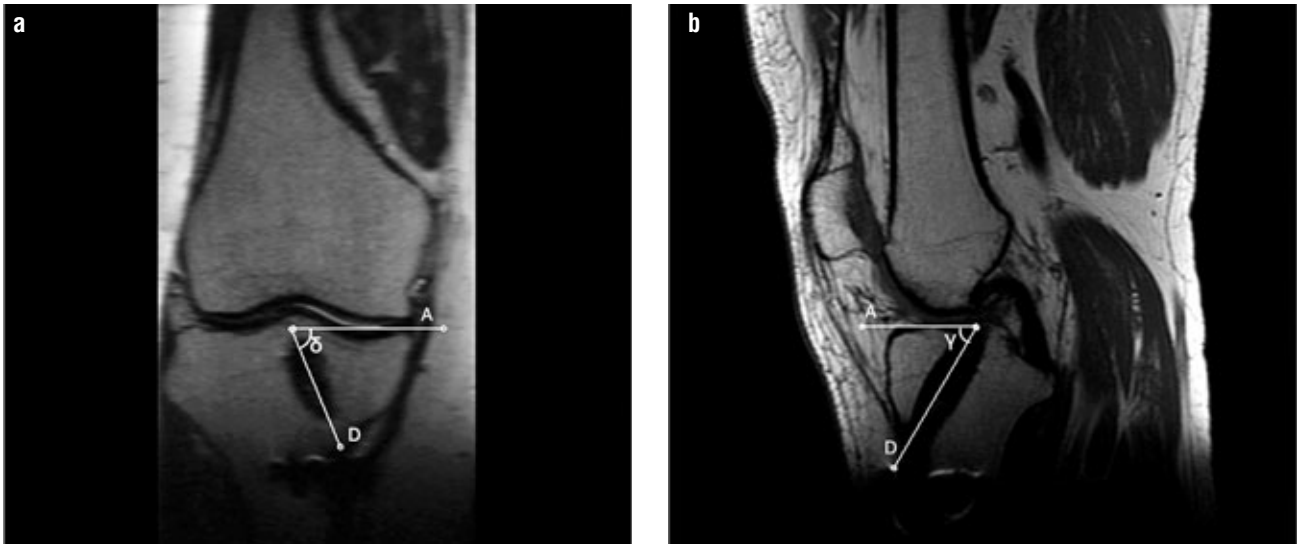

Fig. 2. Inclination angle of tibial tunnel (a) coronal and (b) sagittal planes. A – horizontal articular line of tibial plateau, D – tibial tunnel line. Tibial tunnel inclination angle on the coronal plane is ð angle, on the sagittal plane, γ angle.

active quadriceps control was achieved, for approximately four weeks. In the patients with meniscal repair, post-operative protocol was arranged according to the meniscal tear pattern individually.

MRI evaluation

The MRI was acquired with a GE 1.5 Tesla 32 channel device (General Electronics, 450W Optima with Gem Suite) using dedicated (16 receiver channels) flex knee coil. Patients were placed in the supine position on the table and study performed with the knee positioned in 15° external rotation. Imaging was performed in three standard plans (sagittal PD FSE Fat Sat and T1 SE, coronal PD FSE, axial PD FSE Fat Sat) adding with 3D-FSE-CUBE T1W and T2W sequences for getting high-resolution, contiguous, thin-section isotropic images for viewing complex ACL anatomy more detailed in operated patients. We used CUBE sequences for more detailed visualization with ability of adjusting arbitrary planes but measurements done with standard thin sliced unmodified original images for ensuring standardization. Intra-articular ACL segment was measured with 3D-FSE-CUBE T2W, intra-osseous tunnel angles measured with 3D-FSE-CUBE T1W sequences to achieve the best viewing quality. PDW FS sequence was used for measurement of the intra-articular ACL segment in the control group.

The FT and TT positions were assessed by measuring the angle of the FT and TT, which appeared at the longest distance in the coronal and sagittal plane images, according to the horizontal base line created by connecting tibial plateau medial and lateral corner points (Fig. 1a,b, 2a,b).

Firstly, the narrowest part of the FT was measured. The diameters of the FT aperture measured in the sagittal plane when the aperture was seen well demarcated at the very first image on the articular surface. Two lines created at the aperture of the FT for measurement; the first line parallel to the femoral shaft axis named "the aperture vertical diameter" and second line intersected with former line at 90° angle named "the aperture sagittal diameter" (Fig. 3).

The position of the intra-articular part of hamstring autograft was measured based on the horizontal line of the tibial plateaus in the coronal plane and horizontal articular line of medial plateau in the sagittal plane in the patients ACL reconstruction were performed. The position of the native ACL was measured by the same method in the control group which included healthy individuals (Fig. 4). The MRI scans were interpreted by two radiologists (O.A. and G.K.). The discordant results of the dimensions of tunnels were decided by referring to the surgical records by the third author (H.B.). These values were compared statistically.

Apart from clinical instability, functional assessment of the patients was evaluated by using Lysholm score and IKDC subjective score preoperatively and postoperatively at the last control.

Statistical methodology

Continuous variables were described using means and standard deviations. We used parametric test to compare results, except for the data which did not pass "the normality test" in which non-parametric tests were used. Statistical evaluations were performed using GraphPad InStat (GraphPad Software Inc., La Jolla, CA, USA). A p value equal to or less than 0.05 was considered to be statistically significant.

RESULTS

The mean FT angle was 42.88° (±5.83°), intra-articular part of the hamstring autograft angle, 74.93° (±7.27°) on the coronal plane ($p<0.0001$). On the sagittal plane these values were 68.47° (±9.57°) and 58.74° (±4.88°), respectively. The difference was significant ($p<0.0001$).

The angle of intra-articular part of the hamstring autograft (74.93° ± 7.27°) was close to the angle of ACL in healthy knee (74.03° ± 5.29°) on the coronal plane in the control group (p>0.05). On the sagittal plane, intra-articular part of the ACL autograft and the healthy ACL were 58.74° (± 4.88°) and 57.81° (± 4.35°), respectively (p>0.05).

The mean distance in the narrowest part of the FT was 7.01 (±1.05) mm. The mean distance of the FT aperture on the vertical axis, which was parallel to femoral axis, was 13.18 (±2.49) mm, on the sagittal axis, which was intersected with former line at 90° angle, 10.97 (±1.50) mm. The difference was significant (p<0.0001).

While the mean TT angle was 72.78° (±4.67°), the intra-articular part of the ACL graft angle was 74.93° (±7.27°) on the coronal plane (p>0,05). The mean TT angle was 60.12° (±5.53°) and intra-articular part of the ACL graft angle was 58.74° (±4.88°) on the sagittal plane (p>0.05).

No patients had clinical instability, positive Lachman test and pivot shift test. The mean pre-operative Lysholm score of 66,45 (±18.00) became 94.00 (±6.16) post-operatively (p<0.0001). The mean pre-operative IKDC subjective score of 53.45 (±13.90) became 84.97 (±9.88) post-operatively (p<0.0001).

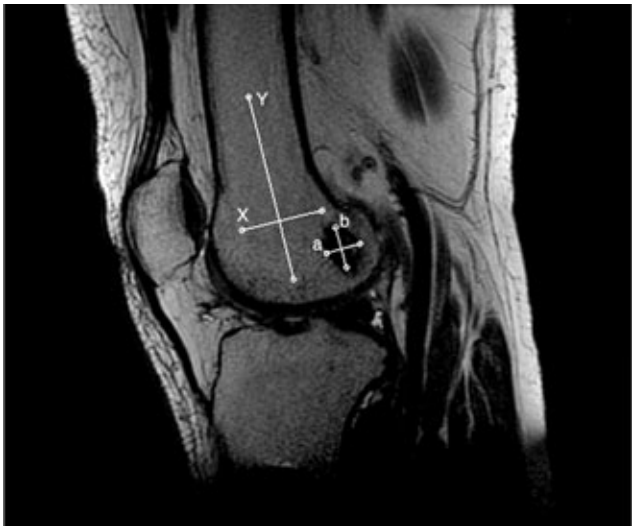

Fig. 3. Method of measuring intra-articular aperture of the femoral tunnel. The diameters of the FT aperture (b) in the vertical axis, which was parallel to (y) the femoral axis and (a) the AP axis, which was intersected with former line at 90° angle.

DISCUSSION

The main finding of this study is that the direction of intra-articular part of the ACL graft in the cases operated with the AM portal technique is significantly different from the FT direction in both the coronal and sagittal planes. The enlargement of the FT aperture is larger in the vertical axis compared to the sagittal axis.

Ilingrowth et al. found that FT were scattered in the very large distance and some of them were placed outside of anatomical range in the series included the cases performed with transtibial and transtibial independent techniques (11). The authors added that a FT angle of less than 32.7° on AP radiograph is likely when an ACL reconstruction is placed outside of anatomic range (10). In this series, in which we used a femoral guide to drill the FT, we obtained a FT with mean 42.88° (±5.83°) angulation on the coronal plane and 68.47° (±9.57°) on the sagittal plane. When we compared these values with the intra-articular part of native ACL, which measured as 74.03° (±5.29°) and 57.81° (±4.35°) respectively, the difference was not significant (p>0.05). However, when we compared the direction of intra-articular part of the graft with the FT, it revealed significant differences on the both coronal (42.88° ± 5.83° versus 74.93° ± 7.27°) and sagittal planes (68.47° ± 9.57° versus 58.74° ± 4.88°) (p<0.0001). We speculate that, although the AM portal technique seems to provide a graft similar to the

Fig. 4. The intra-articular part of (a) the hamstring autograft (line C) and (b) the native ACL (line X) were measured based to the horizontal line (line A, Y). The inclination angle of the autograft is ß angle and the native ACL is "a" angle.

intra-articular orientation of the intact ACL with proper coronal and sagittal obliquity, it might result in a possible increased edge pressure at the FT aperture related to the acute angle between the ACL graft and the FT compared to the transtibial technique.

Celik and Lee reported in the meta-analyses that there was no significant difference in FT widening between the aperture and the mid-portion in patients who underwent ACL reconstruction (5). In the biomechanical study, which anatomic double bundle technique through far AM portal was used, Nishimato et al. found that, the stress on the FT aperture in the AM portal technique, was not increased as much as transtibial technique (18). On the other hand, Amano et al. found that the FT aperture enlargement was significant in the series when hamstring tendons were used as autograft, over a 6-month period (1). Our results support Amano's findings (1). We found a significant difference between the narrowest part of the FT (7.01 ± 1.05 mm) and its aperture (10.97 ± 1.50 mm in sagittal, 13.18 ± 2.49 mm in vertical direction). Amano et al. stated that enlargement was anteriorly and inferiorly in their study performed through far AM portal (1). Our results are compatible with these findings, as enlargement was mainly in the vertical direction, because the difference between the aperture distances in vertical direction 13.41 (± 2.44) mm and sagittal direction 11.06 (± 1.50) mm were significant ($p<0.0001$). The common point of Amano's and our series is the use of AM portal technique, which allows a more horizontal FT drilling (1). Indeed, we found that the direction of the intra-articular part of ACL graft (74.93° ± 7.27°) is quite different from the FT (42.88° ± 5.83°) in the coronal plane. Segawa et al. stated that contact pressure of the graft, particularly in the cases with acute FT angle, was maximum on the anterior aspect of the FT (19).

We speculate that in the early period of ACL healing, before biologic incorporation was completed, in the range of functional angle in daily activities, the high edge pressure of the graft on the aperture of the FT causes enlargement of aperture effected by the forces of movement. Therefore, the distance of the vertical direction at the FT aperture might be longer than the sagittal direction due to the fact that the loads resulting from daily life are mostly on the horizontal plane.

On the other hand, in this series we found that the intra-articular direction of ACL in healthy individuals (74.03° ± 5.29°) is very similar to that of patients who underwent ACL reconstruction (74.93° ± 7.27°). However, the lack of transition zone of mineralized fibrocartilage makes abnormal loading inevitable on the aperture of FT in relation to the flexion angle of the knee during daily life and the angle of the FT. Less enlargement of the FT in the cases which bone-tendon-bone (BTB) graft is used, might be due to this (9). Unlike the BTB graft, the hamstring graft makes an acute angle in the aperture of the FT and a large amount of graft-tunnel movement occurs. In addition, we believe that in the early period before the graft healing completed, a longer distance between the fixation point of the graft and the tunnel entry, compared to the BTB technique, can also be effective on this situation in the ToggleLoc loop (Biomet, USA) fixation technique.

Although the literature extensively focuses on the FT, the TT has come to attention recently. In the transtibial technique the TT starting point moved to the medial side, in this way more horizontal FT was obtained (21). However, although there is no such requirement in the AM portal technique, increased obliquity and posteriorization of the TT is hardly desired. This is because increased obliquity may result in a shortened TT and a widened aperture of the TT (4, 10, 14). While shortened TT might lead to weakened TT fixation, the more posterior TT might lead to insufficient restraint against the anterior translation of the lateral compartment (3, 9). In the present study, in which the AM portal technique was used, TT opened on the ACL footprint on the tibia with a mean angle of 72.78° (±4.67°) without need of excessive coronal plan angulation. Mehta et al. stated that AM portal technique might cause more edge pressure on the TT aperture compared to the transtibial tunnel technique (15). However, we found that in the present series, in which the AM portal technique was used, the direction of intra-articular part of the ACL graft is quite similar with the direction of TT in both horizontal and sagittal planes ($p>0.05$). Although we focused on the FT aperture in this study, we can speculate that a pressure increase at the TT aperture is not expected to be as high as at the FT aperture in daily knee activities.

Chalmers et al. found in a systemic review that the AM portal technique for ACL reconstruction might be more likely to obtain improved clinical and biomechanical outcomes compared to the TT technique (6). It has been claimed that a FT position inside the anatomic footprint of the ACL restores knee kinematics closer to the normal knee (17). This depends on the placement of the FT in the anatomic footprint owing to the increased freedom in the AM portal technique. Chang et al. reported in the meta-analysis that the AM portal technique was 3.7-times more likely to produce a negative post-operative pivot shift test compared to the transtibial technique (7). Chen et al. found that the odds of normal post-operative functions are 2.2-times higher in the AM portal technique than the transtibial technique (8). The authors concluded that the functional outcome of the AM portal technique is at least comparable with the transtibial technique (8). Our findings support these results. Both Lysholm (pre-operative 66.45 ± 18.00 versus post-operative 94.00 ± 6.16) and IKDC subjective scores (pre-operative 53.45 ± 13.90 versus post-operative 84.97 ± 9.88) improved significantly at the mean 26,9 months follow up.

In the present study, MRI, due to several advantages, was chosen for evaluation. Firstly, patients are not exposed to X-ray. Secondly, the MRI gave the opportunity to evaluate the intra-articular portion of the graft aside from position of the tunnels. Unlike the other studies, we used the MRI to analyse the both the positions of the FT and TT. In this way, we had the advantage of comparing the intra-articular part of the graft with the intra-osseous part in terms of directional changes. This gave us the provision to predict the edge loading forces

on the aperture of the FT. This study is also valuable because it is one of the very limited number of studies which considers the graft throughout (i.e. intra-articular and intra-osseous components of the graft).

However, this study has several limitations. In this retrospective study only, a small number of patients were available for MRI examination. Using the MRI to calculate the length of the femoral and tibial tunnels, which extend in 3 planes may have resulted in bias. However, the angle of the tunnels in either plane gives very accurate results which is the main data in this study. Furthermore, MR is the unique method that shows the ACL graft both within the bone and joint space.

CONCLUSIONS

We found that the direction of intra-articular part of the ACL graft in the cases operated with the AM portal technique is significantly different from the FT direction in both the coronal and sagittal planes. The enlargement of the FT aperture is larger in the vertical axis compared to the sagittal axis. This asymmetrical enlargement of the FT aperture has a further potential risk to increase in the knees with aggressive post-operative rehabilitation protocols after ACL reconstruction through AM portal. Although the long-term clinical consequences of asymmetrical enlargement of the FT aperture are not known yet, this potential risk can be reduced by approximating the direction of FT to the intra-articular part of the ACL, as in the all-inside ACL reconstruction technique, without changing the FT entry site.

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