Acta Orthopaedica et Traumatologica Turcica 51 (2017) 227–232

Contents lists available at ScienceDirect

Acta Orthopaedica et Traumatologica Turcica

journal homepage: https://www.elsevier.com/locate/aott

Influence of the different anteromedial portal on femoral tunnel orientation during anatomic ACL reconstruction

Dong-Kyu Moon [a], Ho-Seung Jo [b], Dong-Yeong Lee [c], Dong-Geun Kang [c], June-Ho Byun [c], Sun-Chul Hwang [d, *]

[a] Korean Armed Forces Capital Hospital, Republic of Korea
[b] Department of Orthopaedic Surgery, Gyeongsang National University School of Medicine and Gyeongsang National University Hospital, Jinju, Republic of Korea
[c] Orthopaedic Surgery, Gyeongsang National University Hospital, Republic of Korea
[d] Gyeongsang National University Graduate School of Medicine Jinju, Republic of Korea

ARTICLE INFO

Article history:
Received 20 February 2016
Received in revised form
20 June 2016
Accepted 9 July 2016
Available online 31 March 2017

Keywords:
Anterior cruciate ligament
Anteromedial
Portal
Orientation
Reconstruction

ABSTRACT

Objective: The purpose of this study was to evaluate the effect of femoral tunnel orientation, drilled through the accessory anteromedial (AAM) portal or the high AM portal in anatomic anterior cruciate ligament (ACL) reconstruction.

Methods: In 16 cadaver knees, using o'clock method, centers of the ACL femoral footprint were drilled with an 8-mm reamer via an AAM portal (eight knees) or a high AM portal (eight knees). Computed tomography (CT) scans were taken of each knee. Three-dimensional (3D) models were constructed to identify the femoral tunnel orientation and to create femoral tunnel virtual cylinders for measuring tunnel angles and length.

Results: In two of the 16 specimens, we observed a posterior femoral cortex blowout (PFCB) when drilling through a high AM portal. When drilled through the high AM portal, the femoral tunnel length was significantly shorter than when using an AAM portal (30.3 ± 3.8 mm and 38.2 ± 3.1 mm, $p < 0.001$). The femoral tunnel length was significantly shorter in the group with PFCB compared to the group with no PFCB (25.9 ± 0.6 mm and 35.5 ± 4.5 mm, $p = 0.011$). The axial obliquity of the high AM portal was significantly higher than that of the AAM portal (52.2 ± 5.9° and 43.0 ± 2.3°, $p = 0.003$).

Conclusions: In anatomic ACL reconstruction, a mal-positioned AM portal can cause abnormal tunnel orientation, which may lead to mechanical failure during ACL reconstruction. Therefore, it is important to select accurate AM portal positioning, and possibly using an AAM portal by measuring an accurate position when drilling a femoral tunnel in anatomic ACL reconstruction.

Over the years, many authors have reported various surgical techniques for anatomic anterior cruciate ligament (ACL) reconstruction, including tunnel position, tunnel drilling, single-bundle, double-bundle, graft type, and graft fixation. However, no consensus has been developed to date regarding the superiority of one technique over the other.[1–3] Despite the fact that variable factors can affect the surgical outcomes, the most common preventable error, resulting in ACL reconstruction failure, is poor surgical technique with inaccurate tunnel placement.[4,5]

The debate regarding which surgical technique is best for drilling of the femoral tunnel in anatomic ACL reconstruction continues. In the past, transtibial (TT) techniques were used, in which the femoral tunnel was predetermined by the position of the tibial tunnel. However, this technique results in a high and medial femoral tunnel position, which leads to a non-anatomic femoral tunnel position causing residual rotational instability and a persistent pivot shift.[6] To

*Corresponding author. Department of Orthopaedic Surgery, Gyeongsang National University School of Medicine and Gyeongsang National University Hospital and Institute of Health Sciences, 79 Gangnam-ro, Jinju, 52727, Republic of Korea. Fax: +82 55 7619477.

E-mail address: hscspine@hanmail.net (S.-C. Hwang).

Peer review under responsibility of Turkish Association of Orthopaedics and Traumatology.

http://dx.doi.org/10.1016/j.aott.2017.02.004

resolve these issues, some studies have described technical modifications to the TT technique in order to improve the clinical outcomes by placing the tunnel entrance close to the center of the native femoral footprint in anatomic ACL reconstruction.[7] Despite this technical modification, Giron et al reported the inability to restore the anatomic femoral origin of the ACL with TT techniques.[8] A recent systematic review revealed that some studies suggest better results using the anteromedial (AM) technique, while other studies suggested that there is no difference.[9] For those reasons, many studies have recommended independent drilling of the femoral tunnel through a medial arthroscopic portal.[8,10,11]

The advantages of the AM portal technique include its improvement of anatomic accuracy and modifiability over TT procedures.[10,12] Unfortunately, AM portal techniques also have complications, such as femoral articular cartilage damage, posterior femoral cortex blowout (PFCB), fixation failure, and rigid-fix pin protrusion secondary to a short femoral tunnel length.[6,10,11,13–15] Inappropriate AM portal positioning caused by an abnormal entrance angle may also lead to the above stated complications. Therefore, some authors suggest that ACL reconstruction using a low accessory AM (AAM) portal consistently, allows femoral tunnel placement at the center of the ACL footprint and femoral tunnel orientation with low obliquity.[13] Despite the importance of accurate AM portal positioning in obtaining optimal clinical results in anatomic ACL reconstruction, few studies have documented how AM portal positions affect the femoral tunnel orientation angle and the femoral tunnel length.[10,16] Hence, the purpose of the present study was to evaluate the femoral tunnel orientation when drilling through an AAM portal or a high AM portal and to determine how the femoral tunnel length and femoral tunnel orientation angles are affected in anatomic ACL reconstruction. We hypothesized that the different AM portal position (AAM or high AM) of femoral tunnel drilling can affect the length and angle of the femoral tunnel, which may lead to mechanical complications in ACL reconstruction.

Materials and methods

Specimen preparation

This study was approved by our institutional review board. We studied 16 cadaveric knees (8 matched pairs) that had not undergone any previous surgery, did not have gross deformities, without any ACL or posterior cruciate ligament (PCL) injuries, notch stenosis or osteoarthritic changes. Matched pairs were used to minimize anatomic differences between the specimens. The study included six males and two females, and the mean subject age at the time of death was 72.9 ± 11.6 (range: 66–79) years. The proximal femur was clamped in a vise-grip construct. To replicate the clinical situation more closely, all soft tissue structures were carefully preserved. The portals were created with the knee maintained at 90° flexion. First, the anterolateral (AL) portal which was placed approximately 1 cm above the lateral joint line and approximately 1 cm lateral to the margin of the patellar tendon was created. Under arthroscopic visualization through AL portal, an 18-gauge spinal needle was inserted as close as possible along the patellar tendon and above the medial joint line to ensure correct placement of the conventional AM portal, which was placed 1 cm medial to the edge of the patellar tendon, 1 cm above the medial joint line, and just distal to the inferior pole of the patella.[10] To validate our hypothesis, we created two other arthroscopy portals. One was an AAM portal and the other was a high AM portal. The first was the AAM portal, which was placed 1 cm medial and 1 cm inferior to the conventional AM portal. The second was a high AM portal that placed 1 cm medial to the conventional AM portal (Fig. 1). Using these two portals, we compared the femoral tunnel orientation angles and the femoral tunnel lengths.

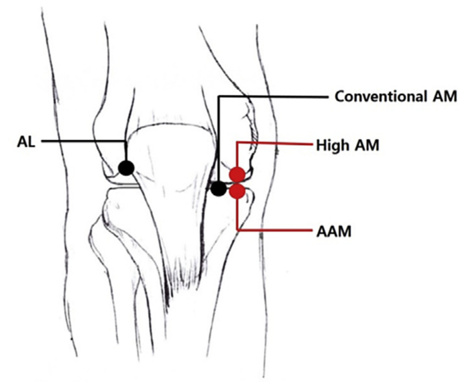

Fig. 1. Illustrative drawing of the portals. AL: anterolateral portal, AM: anteromedial portal, AAM: low accessory anteromedial portal.

Femoral tunnel creation with transportal techniques

Then, we created two arthroscopy portals, and a guide wire or a Beath pin was inserted at the center of the femoral footprint of the ACL to mark the starting position of the femoral tunnel. The knee was flexed to a 90° angle, since it reproduces an anatomic position that affects normal knee kinematics more closely at this angle.[15,17] All guide wires were advanced through the same entry point on the notch wall of the lateral femoral condyle. The cadaveric knees were held at 110° flexion, since previous studies have recommended this angle while drilling the femoral tunnel through the AM portal.[18,19] To create an entry point for the femoral tunnel, the clock method suggested by Chang et al[15] when drilling femoral tunnel, the aim was to create the tunnel in the center of the native ACL's femoral footprint fibers, which corresponds approximately to the 10 to 10:30 o'clock position for the right knees 2 or 1:30 o'clock for the left knees was used and the footprint center of the ACL femoral attachment was marked using a guide pin. Then, a reamer was passed over the guide wires and the length of the femoral tunnel was measured directly with an ENDOBUTTON depth gauge (Smith & Nephew plc, London, UK). During this process, the native ACL ligament or torn ACL remnants were removed with a shaver in order to accurately identify the footprint center. Eight cases underwent drilling through the AAM portal, and another eight cases underwent drilling through the high AM portal. All these procedures were performed by the senior author. We drilled the tunnels while paying attention to avoid iatrogenic damage to the soft tissue and the cartilage of the femoral condyle. The reamer diameters of the tunnels were defined and set at 8 mm since it is a commonly used parameter for standardization of three-dimensional (3D) simulation.

Tunnel 3D modeling and measurement

After the tunnels were drilled, computed tomography (CT) scans of each knee were taken. From the CT images, landmarks of bony morphology such as; notch width, notch height, and condylar size of each cadaveric knee were measured. Using an axial section image from the CT scan, the posterior femoral wall was identified (Fig. 2). A 3D model of each knee was reconstructed using the Mimics® v.12.3 software (Materialise, Leuven, Belgium) in order to identify femoral tunnel orientation. The Geomagic® software (3D Systems, Rock Hill, SC, USA) was used to create the virtual femoral tunnel

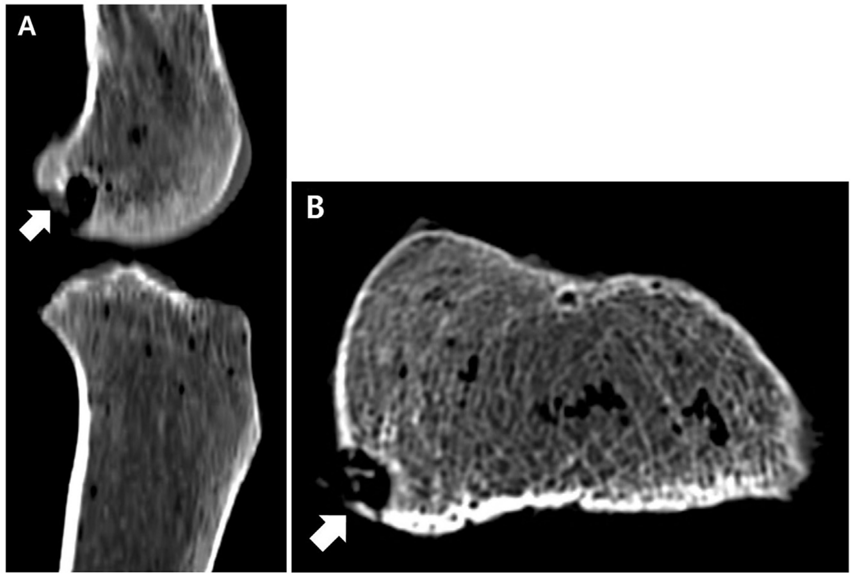

Fig. 2. Computed tomography scans of a posterior femoral cortex blowout (white arrow) in the **(A)** sagittal and **(B)** axial planes.

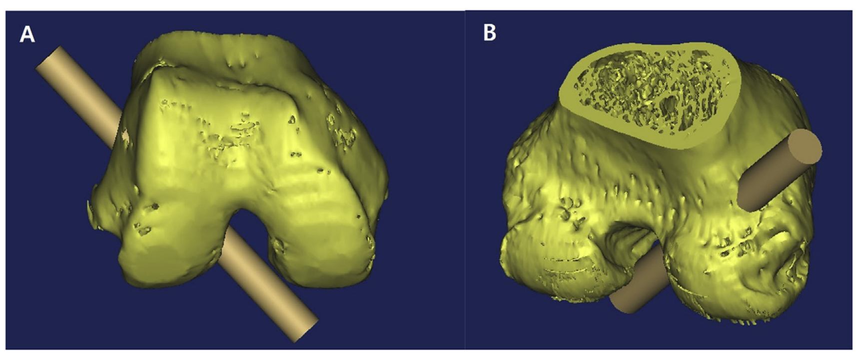

Fig. 3. Three-dimensional reconstructed model of the normally orientated femur tunnel in **(A)** axial and **(B)** posterior views.

cylinders and make 3D measurements (Fig. 3). The oriented femoral tunnel length and angles (coronal, axial, and sagittal obliquity) were measured. All measurements were evaluated independently by two experienced orthopedic surgeons. To measure the distance of the femoral tunnels, the outline of both the intra-articular tunnel and the extra-articular tunnel was traced and the center of the tunnel apertures was calculated. The tunnel length was defined as the distance between the femoral extra-articular and the intra-articular tunnel apertures (Fig. 4). To determine the association between the femoral tunnel angles and each plane, the virtual femoral tunnel cylinders were projected onto coronal, axial, and sagittal planes, and the cylinder angles were measured (Fig. 5).

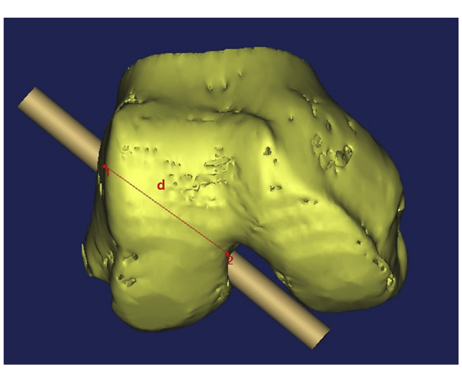

Fig. 4. Tunnel length was defined as the distance (d) between the femoral extra-articular and the intra-articular tunnel apertures.

Statistical analyses

The Mann–Whitney U test was used for the comparison of the cadaveric knee bony morphometry, the femoral tunnel length between the AAM portal and the high AM portal groups and the length between the PFCB and non-PFCB groups. Reliability of the measurements was evaluated by calculating the intraclass correlation coefficients (ICCs) for intraobserver and interobserver reliability (Cronbach's α value). All statistical analyses were performed using the SPSS v.18.0 software (SPSS Inc., Chicago, IL, USA). The significance level was set at $p < 0.05$.

Results

Bony morphometry of cadaveric knees

In our subjects, when comparing bony morphometrics based on the sex of the cadavers, no significant differences were observed. In addition, there was no significant difference in terms of knee bony

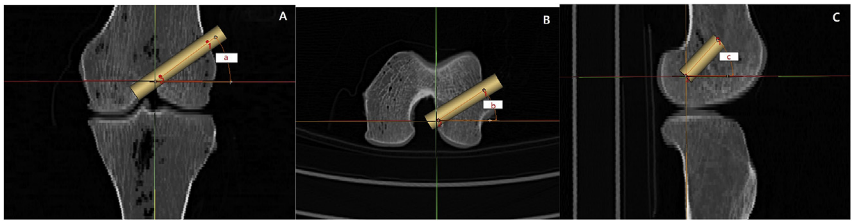

Fig. 5. Femoral tunnel angles were calculated using virtual femoral tunnel cylinders projected on the **(A)** coronal, **(B)** axial, and **(C)** sagittal planes. The angles formed between the virtual cylinders and each plane were measured.

morphometry between the AAM portal and the high AM portal groups (Table 1).

Femoral tunnel length

The average femoral tunnel length was 34.3 ± 5.3 (range: 25.5–42.7) mm. The femoral tunnel length with the high AM portal was significantly shorter in comparison to the AAM portal (Table 2). On the axial CT images, the femoral tunnel length in the PFCB group was significantly shorter compared to that of the non-PFCB group (Table 2). The intraobserver and interobserver reliability of the measurements was relatively high in our study (Table 3).

Femoral tunnel orientation angles

The coronal, axial, and sagittal obliquity of the orientated femoral tunnel was accurately measured by using 3D reconstructed simulation (Table 4). The coronal obliquity of the high AM portal group was significantly lower in comparison to that of the AAM portal group (41.4° ± 3.2° and 44.3° ± 1.9°, respectively; $p = 0.041$). The axial obliquity of the high AM portal group was significantly greater compared to that of the AAM portal group (52.2° ± 5.9° and 43.0° ± 2.3°, respectively; $p = 0.003$). However, the sagittal obliquity of the two portal groups was not significantly different (high AM: 49.6° ± 4.2° and AAM: 48.1° ± 2.4°; $p = 0.389$).

Table 1
Knee morphology differences in cadaveric knees.

	Male (n = 12)	Female (n = 4)	p
Medial condyle width (mm)	26.6 ± 1.8	26.6 ± 1.5	0.806
Lateral condyle width (mm)	28.8 ± 2.6	27.4 ± 5.9	0.625
Notch width (mm)	19.2 ± 4.3	17.8 ± 2.8	0.584
Notch height (mm)	31.6 ± 3.6	29.8 ± 1.7	0.426
	AAM portal (n = 8)	High AM portal (n = 8)	p
Medial condyle width (mm)	26.3 ± 1.5	26.9 ± 2.0	0.531
Lateral condyle width (mm)	27.9 ± 3.0	29.1 ± 4.0	0.516
Notch width (mm)	19.9 ± 3.6	17.8 ± 4.1	0.278
Notch height (mm)	31.4 ± 3.6	30.9 ± 3.1	0.772

AAM: low accessory anteromedial portal, AM: anteromedial portal.

Table 2
The mean femoral tunnel length based on (a) different anteromedial portal positions and (b) the presence of posterior femoral cortex blowout.

(a)	AAM (n = 8)	High AM (n = 8)	p
Tunnel length (mm)	38.2 ± 3.1	30.3 ± 3.8	<0.001
(b)	Blowout (n = 2)	Intact (n = 14)	p
Tunnel length (mm)	25.9 ± 0.6	35.5 ± 4.5	0.011

AAM: low accessory anteromedial portal, AM: anteromedial portal.

Table 3
The intraobserver and interobserver reliability of measurements.

	Observer 1	Observer 2	Mean	Observer 1 vs Observer 2
ICC	0.970 ($p < 0.001$)	0.962 ($p < 0.001$)	0.966	0.943 ($p < 0.001$)

ICC: interclass correlation coefficient.

Table 4
The characteristics of femoral tunnel orientation according to the type of entry portal.

Specimen no.	AM portal position	Tunnel length (mm)	3D entrance angle (coronal/axial/sagittal)	Posterior cortex blowout
1	AAM	37.5	44.5°/42.3°/42.5°	No
2	AAM	35.2	42.4°/41.2°/48.1°	No
3	AAM	38.6	45.3°/40.6°/50.1°	No
4	AAM	38.2	40.7°/44.5°/48.4°	No
5	AAM	40.4	44.6°/47.3°/48.2°	No
6	AAM	42.7	45.6°/44.5°/48.3°	No
7	AAM	32.9	46.4°/40.8°/50.4°	No
8	AAM	40.2	44.9°/42.4°/48.6°	No
Mean		38.2°±3.1°	44.3° ± 1.9°/43.0°±2.3°/48.1° ± 2.4°	
9	High	26.3	43.5°/60.7°/52.3°	Yes
10	High	27.4	45.8°/50.2°/40.4°	No
11	High	30.7	40.8°/47.6°/48.7°	No
12	High	25.5	34.8°/62.2°/50.8°	Yes
13	High	31.1	42.4°/50.9°/48.2°	No
14	High	34.0	40.8°/46.5°/53.8°	No
15	High	30.9	42.1°/50.4°/52.2°	No
16	High	36.6	40.9°/48.7°/50.3°	No
Mean		*30.3°±3.8°	*41.4° ± 3.2°/*52.2° ± 5.9°/49.6°±4.2°	

AAM: low accessory anteromedial portal, AM: anteromedial portal.
*Denotes a significant value ($p < 0.05$).

Discussion

In this study, we demonstrated that a femoral tunnel drilled through a high AM portal during anatomic ACL reconstruction results in a malpositioned femoral tunnel. In contrast, no specific complications occurred when creating a femoral tunnel through an AAM portal. We hypothesized that the different AM portal positions (AAM or high AM) of femoral tunnel drilling can affect the length and angle of the femoral tunnel, which may lead to mechanical complications in ACL reconstruction. When a femoral tunnel has been created after setting an entry point at the ACL footprint center using a high AM portal instead of the usual AAM portal, different tunnel angles can be created. Different tunnel angles show deviations in the femoral tunnel length and can also affect the position of the extra-articular aperture exiting the femur lateral cortex, and can cause complications such as PFCB. Therefore, this study supports the hypothesis that different AM portal positions of the femoral tunnel are significantly associated with the orientation of the femoral tunnel, which may have important implications for a supplementing technique in anatomic ACL reconstruction.

While a systematic review of anatomic ACL reconstruction showed that the definition of anatomic ACL reconstruction is poorly established,[2] many studies have recommended a 110° of knee flexion when drilling the femoral tunnel through the AM portal. In addition, a femoral tunnel position inside the anatomic footprint of the ACL restores normal knee kinematics to closer resemble the intact knee, and is biomechanically superior to a tunnel position located non-anatomically.[20–22] Therefore, in order to disregard other variables except the AM portal position, we set the fixed knee flexion angle at 110° and the femoral tunnel entrance position in the center of the femoral footprint. Then, we used eight AAM portals and eight high AM portals for drilling the femoral tunnel.

Despite many advantages in the AM portal technique, many authors have also reported complications in this technique.[6,10,11,18] Most of the complications associated with the AM portal technique involved femoral tunnel orientation (tunnel angle, tunnel length, and tunnel entrance position) because there is no accurate guiding system for femoral tunnel drilling. Drilling the femoral tunnel in anatomic ACL reconstruction through an AM portal results in a more oblique and horizontal tunnel in comparison to the conventional techniques.[23–25] These abnormal orientations of the femoral tunnel can cause complications such as articular cartilage damage to the medial femoral condyle, short femoral tunnel length (<25 mm) and PFCB.[6,10,11] Basdekis et al[18] also revealed that shortened femoral tunnel length can compromise graft healing at the femoral tunnel and lead to low fixation strength and failure of ACL reconstruction. Hence, the authors suggested that a minimum length of 25 mm is required for fixation. In the same context, our results reveal that when femoral tunnel drilling is done through the high AM portal, it results in a significantly shorter femoral tunnel when compared to the tunnels resulting from AAM portal drilling; and may lead to mechanical failure. Therefore, a surgeon should be more cautious and precise when creating an AM portal, since a femoral tunnel drilled through a high AM portal caused by technical error may not only create the complications mentioned above, but may also shorten the femoral tunnel length and cause mechanical failure.

A malpositioned high AM portal affects both the femoral tunnel length and the tunnel angle. In general, even though the high AM portal is not commonly used, it could be inadvertently created by the means of a surgical technical error among obese patients or in presence of patella alta. Improperly created high AM portal in such patients would be closely associated with an abnormal femoral tunnel angle, which would lead to the development of mechanical failure in anatomical ACL reconstruction. Despite its importance, previous studies have not focused on the accuracy of AM portal positioning. Hamilton et al only considered the effect of the axial angle when drilling a femoral tunnel through the conventional AM portal.[16] However, in the present study, a 3D femoral tunnel angle was considered using not only the axial angle but the coronal and sagittal planes as well. We also had the important finding that drilling through a high AM portal leads to a femoral tunnel orientation with a lower coronal angle and a higher axial angle. The mean angles of the orientated femoral tunnels with a high AM portal were $41.4° \pm 3.2°/52.2° \pm 5.9°/49.6° \pm 4.2°$ on the coronal, axial and sagittal planes. These angles represent a more horizontal and oblique femoral tunnel compared to the tunnels resulting from the use of an AAM portal. In addition, PFCB occurred in two of the eight cases when drilling a femoral tunnel using a high AM portal. The femoral tunnel length was also significantly shorter in the PFCB group compared to the non-PFCB group. This verifies the fact that a malorientated angle (high axial or high coronal) may cause surgical complications such as short femoral tunnel length and PFCB.

Unlike in our study, previous studies have only performed two-dimensional (2D) modeling using radiologic data and dissected cadaveric saw bone models. In addition, they have not considered the effect of the soft tissue around the knee and most of them used the conventional AM portal in their experiments. Since these limitations cannot reflect the real clinical situation, we considered the soft tissue effect around the knee by using an undissected knee model. Further, previous studies have tested tunnel orientations based on different drilling angles when generally using only the AM portal. Our study is valuable because it is the first study to consider complications due to a malorientated femoral tunnel using a high AM portal. In addition, femoral tunnels through all AM portals were reconstructed and analyzed by using a 3D multi-plane (coronal/axial/sagittal) simulation for accurate measurement. The 3D simulation outcomes revealed that abnormal angles of a malorientated femoral tunnel can cause many complications that previous studies have reported; therefore, surgeons should carefully consider the position of the AM portal. Three of the eight cases using a high AM portal had a short femoral tunnel length of about 25 mm. These outcomes were due to intraoperative technical errors and graft-tunnel mismatch, which can lead to clinical anatomic ACL reconstruction complications. Surgeons must overcome these technical errors in order to achieve a successful anatomic ACL reconstruction.

Our study had some limitations. First, the study population was limited because our study was a cadaveric one. Therefore, we could not study how other factors such as various knee flexion angles and different femoral tunnel entrance positions may affect the femoral tunnel orientation. However, we minimized our study's limitations by setting the optimal knee flexion angle and the femoral tunnel entrance position based on the previously reported outcomes of anatomic ACL reconstructions. Second, there was a difference between the actual ages of the samples used in this study and the ages of patients who were prone to ACL reconstruction. Therefore, the representativeness may be considered confined. Third, despite the fact that the tibial tunnel position is also important in anatomic ACL reconstruction, we did not take these tunnels into consideration. This issue is critical and it requires future high-standard medical researches with well-established protocols.

In conclusion, the findings in the present study demonstrate the importance of accurate AM portal positioning in anatomic ACL reconstruction. Through this study, we found that the malpositioned AM portal can cause abnormal lengths or angles in femoral tunnel orientation. For these reasons, high AM portal should be avoided due to PFCB and the probability of mechanical failure. Thus, it is important to select accurate AM portal positioning, and possibly use an AAM portal by measuring an accurate position when drilling a femoral tunnel in anatomic ACL reconstruction.

Acknowledgement

This work was supported by Development Fund Foundation Funding number (development-2015–117), Gyeongsang National University, 2015.

References

1. Muller B, Hofbauer M, Wongcharoenwatana J, Fu FH. Indications and contraindications for double-bundle ACL reconstruction. *Int Orthop*. 2013;37(2):239–246.
2. van Eck CF, Samuelsson K, Vyas SM, van Dijk CN, Karlsson J, Fu FH. Systematic review on cadaveric studies of anatomic anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(Suppl 1):S101–S108.

3. Adachi N, Ochi M, Uchio Y, Iwasa J, Kuriwaka M, Ito Y. Reconstruction of the anterior cruciate ligament. Single- versus double-bundle multistranded hamstring tendons. *J Bone Jt Surg Br*. 2004;86(4):515–520.
4. Getelman MH, Friedman MJ. Revision anterior cruciate ligament reconstruction surgery. *J Am Acad Orthop Surg*. 1999;7(3):189–198.
5. Johnson DL, Swenson TM, Irrgang JJ, Fu FH, Harner CD. Revision anterior cruciate ligament surgery: experience from Pittsburgh. *Clin Orthop Relat Res*. 1996;(325):100–109.
6. Bedi A, Raphael B, Maderazo A, Pavlov H, Williams 3rd RJ. Transtibial versus anteromedial portal drilling for anterior cruciate ligament reconstruction: a cadaveric study of femoral tunnel length and obliquity. *Arthroscopy*. 2010;26(3):342–350.
7. Xu Y, Ao Y, Wang J, Yu J, Cui G. Relation of tunnel enlargement and tunnel placement after single-bundle anterior cruciate ligament reconstruction. *Arthroscopy*. 2011;27(7):923–932.
8. Giron F, Cuomo P, Edwards A, Bull AM, Amis AA, Aglietti P. Double-bundle "anatomic" anterior cruciate ligament reconstruction: a cadaveric study of tunnel positioning with a transtibial technique. *Arthroscopy*. 2007;23(1):7–13.
9. Chalmers PN, Mall NA, Cole BJ, Verma NN, Bush-Joseph CA, Bach Jr BR. Anteromedial versus transtibial tunnel drilling in anterior cruciate ligament reconstructions: a systematic review. *Arthroscopy*. 2013;29(7):1235–1242.
10. Harner CD, Honkamp NJ, Ranawat AS. Anteromedial portal technique for creating the anterior cruciate ligament femoral tunnel. *Arthroscopy*. 2008;24(1):113–115.
11. Lubowitz JH. Anteromedial portal technique for the anterior cruciate ligament femoral socket: pitfalls and solutions. *Arthroscopy*. 2009;25(1):95–101.
12. Chhabra A, Diduch DR, Blessey PB, Miller MD. Recreating an acceptable angle of the tibial tunnel in the coronal plane in anterior cruciate ligament reconstruction using external landmarks. *Arthroscopy*. 2004;20(3):328–330.
13. Ilahi OA, Ventura NJ, Qadeer AA. Femoral tunnel length: accessory anteromedial portal drilling versus transtibial drilling. *Arthroscopy*. 2012;28(4):486–491.
14. Takeda Y, Iwame T, Takasago T, et al. Comparison of tunnel orientation between transtibial and anteromedial portal techniques for anatomic double-bundle anterior cruciate ligament reconstruction using 3-dimensional computed tomography. *Arthroscopy*. 2013;29(2):195–204.
15. Chang CB, Yoo JH, Chung BJ, Seong SC, Kim TK. Oblique femoral tunnel placement can increase risks of short femoral tunnel and cross-pin protrusion in anterior cruciate ligament reconstruction. *Am J Sports Med*. 2010;38(6):1237–1245.
16. Hamilton SC, Jackson 2nd ER, Karas SG. Anterior cruciate ligament femoral tunnel drilling through anteromedial portal: axial plane drill angle affects tunnel length. *Arthroscopy*. 2011;27(4):522–525.
17. Golish SR, Baumfeld JA, Schoderbek RJ, Miller MD. The effect of femoral tunnel starting position on tunnel length in anterior cruciate ligament reconstruction: a cadaveric study. *Arthroscopy*. 2007;23(11):1187–1192.
18. Basdekis G, Abisafi C, Christel P. Influence of knee flexion angle on femoral tunnel characteristics when drilled through the anteromedial portal during anterior cruciate ligament reconstruction. *Arthroscopy*. 2008;24(4):459–464.
19. Zantop T, Haase AK, Fu FH, Petersen W. Potential risk of cartilage damage in double bundle ACL reconstruction: impact of knee flexion angle and portal location on the femoral PL bundle tunnel. *Arch Orthop Trauma Surg*. 2008;128(5):509–513.
20. Musahl V, Plakseychuk A, VanScyoc A, et al. Varying femoral tunnels between the anatomical footprint and isometric positions: effect on kinematics of the anterior cruciate ligament-reconstructed knee. *Am J Sports Med*. 2005;33(5):712–718.
21. Petersen W, Lenschow S, Weimann A, Strobel MJ, Raschke MJ, Zantop T. Importance of femoral tunnel placement in double-bundle posterior cruciate ligament reconstruction: biomechanical analysis using a robotic/universal force-moment sensor testing system. *Am J Sports Med*. 2006;34(3):456–463.
22. Pinczewski LA, Lyman J, Salmon LJ, Russell VJ, Roe J, Linklater J. A 10-year comparison of anterior cruciate ligament reconstructions with hamstring tendon and patellar tendon autograft: a controlled, prospective trial. *Am J Sports Med*. 2007;35(4):564–574.
23. Lee KW, Hwang YS, Chi YJ, Yang DS, Kim HY, Choy WS. Anatomic single bundle anterior cruciate ligament reconstruction by low accessory anteromedial portal technique: an in vivo 3D CT study. *Knee Surg Relat Res*. 2014;26(2):97–105.
24. Loh JC, Fukuda Y, Tsuda E, Steadman RJ, Fu FH, Woo SL. Knee stability and graft function following anterior cruciate ligament reconstruction: comparison between 11 o'clock and 10 o'clock femoral tunnel placement. 2002 Richard O'Connor Award paper. *Arthroscopy*. 2003;19(3):297–304.
25. Simmons R, Howell SM, Hull ML. Effect of the angle of the femoral and tibial tunnels in the coronal plane and incremental excision of the posterior cruciate ligament on tension of an anterior cruciate ligament graft: an in vitro study. *J Bone Jt Surg Am*. 2003;85-A(6):1018–1029.