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Original article

# Is intraoperative fluoroscopy necessary in anterior cruciate ligament double-bundle reconstruction? A prospective randomized controlled trial

Ji Hyun Ahn*, Sangwoo Kim, Jaehyun Kim

*Department of Orthopedic Surgery, Dongguk University Ilsan Hospital, 27, Dongguk-ro, Ilsandong-gu, Goyang-si, Gyeonggi-do, 10326, Republic of Korea*

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ABSTRACT

*Introduction:* Properly placed tibial and femoral tunnels in anterior cruciate ligament (ACL) reconstruction are important because tunnel misplacement can cause abnormal changes in graft tension patterns, resulting in postoperative knee laxity. To overcome the inaccuracy of tunnel position in ACL reconstruction, intraoperative fluoroscopy has been proven to be a useful method in previous studies focusing on the tunnel position in single-bundle reconstruction, but few studies are available on the efficacy and necessity of intraoperative fluoroscopy for double-bundle (DB) reconstruction. The purpose of this prospective randomized case-control study was to evaluate the effect of intraoperative fluoroscopy on femoral and tibial tunnel position in anatomic DB ACL reconstruction using a postoperative tunnel position in a three-dimensional computed tomography (3D-CT).
*Hypothesis:* Intraoperative fluoroscopy during ACL DB reconstruction could make an appropriate tunnel position closer to the anatomical center compared to conventional fluoroscopy-free procedure.
*Material and methods:* Sixty patients undergoing ACL DB reconstruction (30 fluoroscopy-free reconstruction group and 30 in fluoroscopy-assisted reconstruction group) were included in this prospective study, and randomly allocated into two groups. Mean values of the percentage distance of femoral and tibial tunnel center in a 3D-CT were compared between the two groups. Knee laxity (the anterior translation and pivot-shift grade) and clinical outcomes were also compared at the last follow-up.
*Results:* There was a significant difference only in femoral anteromedial (AM) bundle tunnel position, but not in femoral posterolateral (PL) bundle, tibial AM, or PL bundle tunnel position between the two groups. Femoral AM bundle tunnel in the fluoroscopy-assisted reconstruction group showed significantly ($p = 0.005$) deeper position compared to that in the fluoroscopy-free reconstruction group. There was no significant difference in anterior translation, pivot-shift grade, or clinical outcomes between the two groups.
*Discussion:* Fluoroscopy-assisted ACL DB reconstruction can make deeper placement of the femoral AM bundle than the conventional ACL DB reconstruction.
*Level of evidence:* II, prospective randomized controlled trial.



## 1. Introduction

To restore native knee kinematics in an anterior cruciate ligament (ACL)-injured knee, accurate position of the femoral and tibial tunnel is a major premise in ACL reconstruction [1–3]. Recently, various studies have suggested that non-anatomical tunnel positions can result in graft failure or postoperative residual laxity [1,3–5]. Seon et al. [6] have reported that patients with low femoral tunnel position in ACL single-bundle (SB) reconstruction show significantly better intraoperative internal rotational stability than those with high femoral tunnel position. Parkinson et al. [7] have suggested that shallow nonanatomic femoral tunnel positioning is one of risk factors for graft failure in SB reconstruction.

In ACL double-bundle (DB) reconstruction, Koga et al. [5] have reported that posterolateral femoral tunnel position in pivot shift-positive cases is significantly deeper than that in pivot shift-negative cases. Ahn et al. [1] have suggested that patients with anatomic femoral tunnel placement show superior graft

* Corresponding author. Department of Orthopedic Surgery, Dongguk University Ilsan Hospital, 814, Siksadong, Ilsandonggu, Goyangsi, 411-773 Gyeonggido, Republic of Korea.
*E-mail address:* drsky7171@gmail.com (J.H. Ahn).

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maturation on second-look arthroscopy along with better clinical outcomes than those in the non-anatomical group. They also reported that there was a significant difference in anteromedial femoral tunnel position, but not in posterolateral tunnel position, between anatomical and non-anatomical groups [1].

To overcome the inaccuracy of tunnel position in ACL reconstruction, intraoperative fluoroscopy has been proven to be a useful method in previous studies [8–14]. These previous studies have focused on tunnel position in SB reconstruction [8,9,11,13] or tibial tunnel position [10,12,14]. Studies that estimate the efficacy and necessity of intraoperative fluoroscopy for femoral tunnel position in ACL DB reconstruction are lacking. Therefore, the purpose of this prospective randomized case-control study was to evaluate the effect of intraoperative fluoroscopy on femoral and tibial tunnel position in anatomic DB ACL reconstruction using a postoperative tunnel position in a three-dimensional computed tomography (3D-CT). We hypothesized that intraoperative fluoroscopy could make an anteromedial femoral tunnel position closer to the anatomical center compared to conventional fluoroscopy-free procedure.

## 2. Material and methods

### 2.1. Patients and inclusion/exclusion criteria

From December 2014 to June 2016, a total of 73 patients underwent consecutive ACL DB reconstructions at our institution. During the same period, 13 SB reconstructions were performed. The inclusion criteria of this study were ACL DB reconstruction for ACL complete tear. Exclusion criteria were as follows:

- revision surgery (3 cases);
- delay in surgery from initial injury for more than 6 months (3 cases);
- contralateral knee pathology (2 cases);
- multiple ligament surgeries (2 cases);
- meniscus allograft transplantation after ACL reconstruction (2 cases);
- consent declined due to the follow-up difficulty for more than 2 years (1 case).

Patients who met the inclusion criteria without meeting the exclusion criteria were randomized in the operation room on the day of surgery using closed envelopes (Fig. 1). They were assigned into either fluoroscopy-free reconstruction group or fluoroscopy-assisted reconstruction group. A total of 60 patients (30 in each group) were included in this study (Appendix 1). The sample size for the present study was calculated based on data from a pilot study with 5 cases in each group. This prospective trial was approved by our Institutional Review Board (DUIH IRB 2014-92, Issue Date: December 11, 2014).

### 2.2. Surgical Technique

All enrolled patients had DB ACL reconstruction performed by the same surgeon at a single center. For all cases, semitendinosus and gracilis tendons were harvested and used to make anteromedial (AM) and posterolateral (PL) bundle grafts, respectively. Triple strands were used for each bundle.

#### 2.2.1. Double-bundle ACL reconstruction with conventional fluoroscopy-free technique

Centers of femoral footprints of both AM and PL bundles were identified and marked with a thermal device. If it was difficult to define the margin of the footprint with too scarce remnants of ACL, osseous landmarks at the femoral origin such as lateral intercondylar ridge and lateral bifurcate ridge were used to determine anatomical insertion sites of the two bundles. To create femoral tunnels, a 70-degree arthroscope was inserted through the anterolateral viewing portal (Fig. 2). Without notchplasty, femoral tunnels were created with transportal technique through the anteromedial portal using divergent direction between both AM and PL tunnels to avoid femoral tunnel communication. Tibial tunnels were then made with the knee flexed at 90 degrees. An ACL tip-guide set at 50 degrees was inserted through the AM portal to create PL tibial tunnel. A 3.2-mm guide pin was inserted through the drill sleeve and advanced to the center of the footprint of the PL bundle. Tunnel drilling was performed with the drill bit matched to the graft size. A similar procedure was repeated to create AM tibial tunnel. After the tendon graft was passed through tunnels, suspensory fixation devices were used for femoral side fixation of AM and PL bundles (Fig. 3). Each bundle graft was fixed to the tibia using a bioabsorbable interference screw, an additional cancellous screw, and a washer. During fixation of tibial bioabsorbable interference screws, a 20-lb load was placed on each bundle graft at approximately 15 degrees of knee flexion.

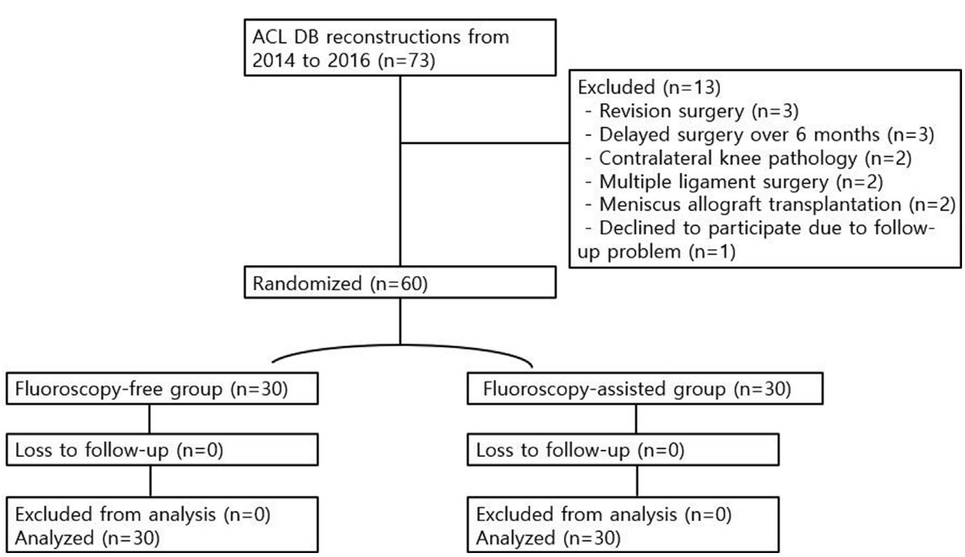


**Fig. 1.** Participant flow diagram.

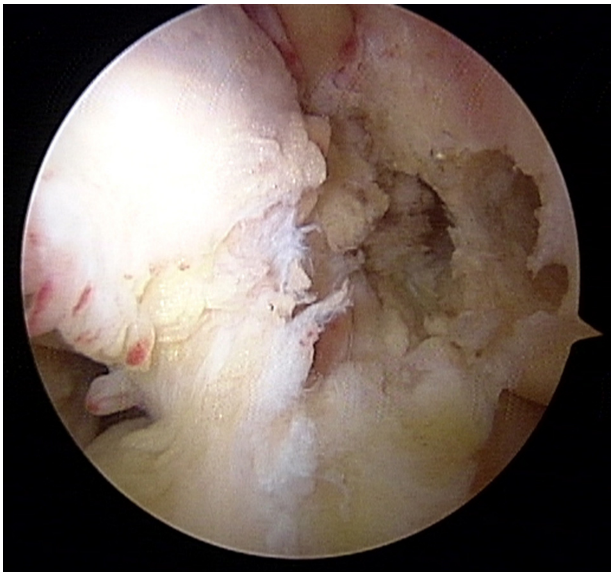

**Fig. 2.** Arthroscopic view of a left knee, using the 70 degree arthroscope from the anterolateral portal for femoral anteromedial and posterolateral tunnels during anterior cruciate ligament reconstruction.

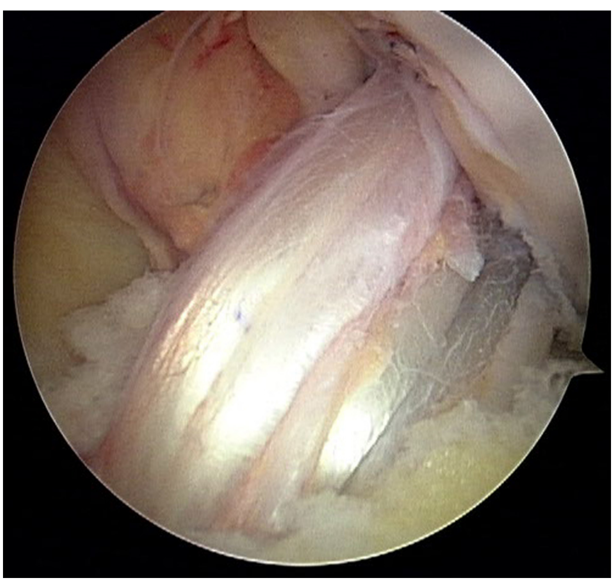

**Fig. 3.** Arthroscopic view of a left knee, using the 30 degree arthroscope from the anterolateral portal. Arthroscopic findings showed a reconstructed anteromedial and posterolateral bundle grafts after double-bundle anterior cruciate ligament reconstruction.

#### 2.2.2. Double-bundle ACL reconstruction with intraoperative fluoroscopy assistance

Fluoroscopy-assisted reconstruction was performed using a lateral fluoroscopic image of the knee. Before creating bone tunnel, the fluoroscopy unit was positioned to obtain a true lateral image of the knee with the posterior femoral condyle superimposed directly (Fig. 4). The femoral tunnel position was based on the method originally described by Bernard et al. [15]. It was defined by drawing a line along the Blumensaat line followed by a perpendicular line extended to the edge of the femoral condyle. A rectangular coordinate system was applied with the origin as the most posterior and proximal point of each axis (the Blumensaat line as the x-axis and its perpendicular line as the y-axis). For the placement of the femoral tunnels, we considered the reported percentage along each axis in a previous study by Forsythe et al. [16]. The tibial tunnel position


**Fig. 4.** An intraoperative lateral fluoroscopic image of the knee during the fluoroscopy-assisted reconstruction. Before creating bone tunnel, the fluoroscopy unit was positioned to obtain a true lateral image of the knee with the posterior femoral condyle superimposed directly.

was also based on previous data using anterior-to-posterior tibial plateau depth and the medial-to-lateral tibial plateau width [16]. Similar surgical procedure to conventional fluoroscopy-free technique was performed for femoral and tibial side fixation.

### 2.3. CT measurement methodology for femoral and tibial tunnel positions

CT scans (Siemens Somatom Definition; Siemens, Forchheim, Germany) of the ACL reconstructed knees were performed at mean 3.25 days (range: 3 to 5 days) postoperatively. Femoral and tibial tunnel positions for AM and PL bundle grafts were measured using 3D-CT images. Positions of the femoral and tibial tunnels were determined using the quadrant method as described by Bernard et al. [15] for lateral radiograph of the knee. Three-dimensional surface models were then produced using Somaris/7 syngo CT 2008G (syngo CT Workplace VA20A; Siemens) as described by Forsythe et al. [16]. All measurements were performed using PiViewSTAR system (version 5.0.9.2; Infinitt, Seoul, South Korea). All statistical analyses were performed with SPSS version 19.0 (SPSS, Chicago, IL, USA).

A true medial view of the femur was established at 90 degrees of knee flexion. To improve visualization of the medial wall of the lateral femoral condyle, the medial condyle was removed from the 3D-CT model at the most anterior aspect of the distal notch. Tunnel positions were determined along the Blumensaat line (the x-axis) followed by a perpendicular line (the y-axis) extending to the edge of the femoral condyle. Center locations of femoral tunnels were quantified from the deepest subchondral contour to the center of the tunnel and the percentage distance from the intercondylar notch roof was determined (Fig. 5).

To measure tibial tunnel position, anterior-to-posterior and medial-to-lateral tunnel positions were determined using a true proximal-to-distal axial view on tibial plateau. Anterior-to-posterior positions were calculated as percentages of the distance from the line running through the anterior border of the tibial plateau to the line running through the most posterior border of the tibial plateau. Medial-to-lateral positions were calculated as percentages of the distance from the line running through the medial

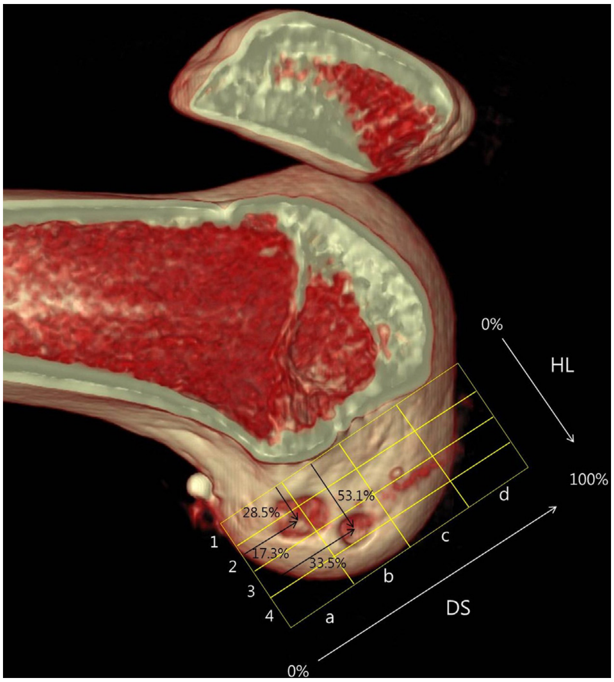


**Fig. 5.** Center locations of the anteromedial and posterolateral femoral tunnels. The percentage distance of each tunnel was measured from the most anterior edge of the femoral notch roof and the most proximal line of posterior femoral condyle on three-dimensional computed tomography, using the quadrant method. The tunnel positions were determined in the anterior-posterior position, perpendicular to the Blumensaat's line, and in the proximal-distal position, parallel to the Blumensaat's line.

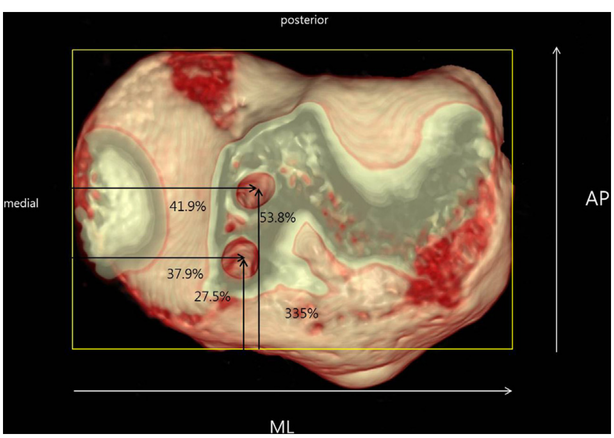


**Fig. 6.** Center locations of the anteromedial and posterolateral tibial tunnels. With use of a true axial view on the tibial plateau, anterior-posterior position and medial-lateral position were measured using anterior and posterior borders and medial and lateral borders of the tibial plateau, respectively.

border of the tibial plateau to the line running through the lateral border of the tibial plateau (Fig. 6). Mean values of percentage distances of femoral and tibial tunnel centers were compared between the two groups.

### 2.4. Assessments of knee laxity, clinical outcomes, and arthroscopic findings

In all enrolled patients, clinical results and knee stability were evaluated using radiographic laxity, pivot-shift-test, and 2000 International Knee Documentation Committee (IKDC) examination form preoperatively and at the last follow-up. Radiographic laxity was evaluated by performing an instrumented laxity test using a Telos device (Telos stress device, Austin & Associates, Fallston, MD, USA) at 30° of knee flexion and with a 30-lb anterior tibial load applied to the proximal tibia. Side to side difference (SSD) in anterior translation between the reconstructed knee and the normal contralateral knee was used to evaluate restoration of normal stability. To evaluate postoperative rotational laxity, pivot-shift grade was repeatedly measured three times by one surgeon. The maximal grade among triple pivot-shift-tests was assessed as rotational laxity. To measure preoperative and postoperative radiologic laxity, the SSD of anterior translation on stress radiographs was performed by two orthopedic surgeons who were blinded to the patient. The mean value of measured SSDs was assessed as radiographic instability. Interobserver reliability in the measurement of radiologic laxity was assessed with the intraclass correlation coefficient (ICC) value. The ICC values for interobserver variability were 0.86 and 0.82 for preoperative and postoperative radiographic laxity, respectively. The characteristics of the cartilage and meniscus injuries observed during ACL reconstruction were documented by a senior surgeon immediately after the surgery. The specific treatments for these injuries were also documented.

### 2.5. Radiographic measurement of Kellgren-Lawrence grade

The standing anteroposterior (AP) radiograph of the whole lower extremity was taken. Preoperative and postoperative Kellgren-Lawrence (KL) grades were assessed in a standing radiograph of the lower extremity in knee extension and 45° flexion. Postoperative KL grade was evaluated at the last follow-up.

### 2.6. Statistical analysis

All statistical analyses of data were performed using SPSS version 19.0.0 (SPSS, Chicago, IL, USA). Normal distribution of measured variables was verified using the Shapiro-Wilk test. Homogeneity of variance was verified using Fisher's f-test and Levene's test to ensure that conditions had been met for parametric testing. Mean, standard deviation (SD), and range were calculated for continuous variables (percentage distance of the femoral and tibial tunnel center, SSD of anterior translation, IKDC subjective functional score, and knee alignment angle) while percentages were calculated for KL grade, Outerbridge grade, meniscal injury, and IKDC objective grade. An independent t-test was applied to compare continuous variables between the two groups. A Fisher's exact-test was used to compare the nominal variables between the two groups.

A pilot study with 5 cases in each group was performed to calculate sample size for the present study. From our pilot study, mean percentage distances of the AM bundle tunnel center of the femur were $40.4 \pm 7.3\%$ and $16.6 \pm 4.7\%$ on the x-axis and y-axis in the fluoroscopy-free reconstruction group and $32.6 \pm 4.5\%$ and $14.2 \pm 3.9\%$ in the fluoroscopy-assisted reconstruction group, respectively. From the pilot study, a standard of 80% power, type I error rate of 5%, and effect size of 0.956 were applied. Using G*Power 3.1 calculation software, the required sample size calculation resulted in a sample size of 30 cases for each group. Interobserver reliability was calculated and assessed with intraclass correlation coefficient (ICC) for measurement of femoral and tibial tunnels.

## 3. Results

Demographic and clinical characteristics of each group are shown in Table 1. There was no statistically significant difference in age at surgery, gender, time to surgery from injury, cartilage injury, medial and lateral meniscal injuries, or KL grade between the two groups. The mean follow-up duration was $36.5 \pm 6.5$ months

**Table 1**
Demographics.

| | Fluoroscopy-assisted Reconstruction Group ($n$ = 30) | Fluoroscopy-free Reconstruction Group ($n$ = 30) | $p$-value |
|---|---|---|---|
| Age year; mean ± SD (range) | 35.9 ± 9.9 (17–52) | 38.8 ± 10.6 (15–54) | 0.323 |
| Gender (Female/Male) | 2/28 | 1/29 | 0.554 |
| Body mass index kg/m$^2$; mean ± SD (range) | 26.2 ± 2.6 (22.5–32.3) | 25.2 ± 3.5 (18.7–32.5) | 0.221 |
| Time to surgery from injury week; mean ± SD (range) | 7.9 ± 6.2 (2–23) | 7.7 ± 5.9 (1–20) | 0.932 |
| Follow-up duration month; mean ± SD (range) | 36.5 ± 6.5 (25–45) | 35.1 ± 6.3 (26–46) | 0.812 |
| Preoperative KL grade (Grade 0/1/2/3/4) | Gr 1:27/Gr 2:3 | Gr 1:27/Gr 2:3 | 1.000 |
| Medial meniscus (Intact/Repair/Meniscectomy) | 13/13/4 | 10/10/10 | 0.187 |
| Lateral meniscus (Intact/Repair/Meniscectomy) | 17/11/2 | 17/8/5 | 0.354 |
| Cartilage injury (Outerbridge grade, Grade 0/1/2/3/4) | Gr 1:20/Gr 2:7/Gr 3:3 | Gr 1:20/Gr 2:7/Gr 3:3 | 0.788 |
| Anterior translation (SSD, Preop.); mean ± SD (range) | 8.6 ± 1.5 (6.7–11.3) | 8.8 ± 1.8 (5.7–11.7) | 0.564 |
| Pivot-shift grade (Preop.) (Grade 0/1/2/3/4) | Gr 2:19/Gr3:11 | Gr2:24/Gr3:6 | 0.252 |
| IKDC objective grade (Preop.) (Grade A/B/C/D) | Gr C:14/Gr D:16 | Gr C:13/Gr D:17 | 0.795 |
| Subjective functional IKDC score (Preop.); mean ± SD (range) | 58.4 ± 4.9 (50.9–68.2) | 58.8 ± 5.6 (50.4–70.5) | 0.801 |

SSD: Side to side difference; IDKC: International Knee Documentation Committee.

(range: 25 to 45 months) in the fluoroscopy-assisted reconstruction group and 35.1 ± 6.3 months (range: 26 to 46 months) in the fluoroscopy-free reconstruction group.

Tunnel center positions on 3D-CT were evaluated and measured independently by two orthopedic surgeons who were blinded to patient status. Kappa values for interobserver variability were 0.83 and 8.79 for femoral AM and PL tunnel and 0.86 and 0.77 for tibial AM and PL tunnel, respectively.

There was a significant difference in femoral AM bundle tunnel position, but not in femoral PL bundle, tibial AM, or PL bundle tunnel position between the two groups (Table 2). The femoral AM bundle tunnel in the fluoroscopy-assisted reconstruction group showed significantly ($p$ = 0.005) deeper position compared to that in the fluoroscopy-free reconstruction group. Mean percentage distances of the AM bundle tunnel center of the femur on the x-axis and y-axis were 33.8 ± 4.7% and 16.3 ± 9.2% in the fluoroscopy-assisted reconstruction group and 41.2 ± 14.4% and 14.4 ± 8.3% in the fluoroscopy-free reconstruction group, respectively. In the previous reference study by Forsythe et al. [16], mean percentage distance of the AM bundle tunnel center of the femur on the x-axis was 21.7 ± 2.5% after anatomic tunnel drilling in the cadaver knees. Based on these reference data, the fluoroscopy-assisted reconstruction group in our study provided a more accurate anatomical location in the femoral AM bundle tunnel than the fluoroscopy-free reconstruction group. However, there was no significant difference in anterior translation, pivot-shift grade, KL grade, or clinical outcomes (objective IKDC grade or subjective functional IKDC score) at the last follow-up between the two groups (Table 2).

## 4. Discussion

The most important finding of this study was that there was a significant difference in tunnel position of the femoral AM bundle, showing deeper placement in the fluoroscopy-assisted reconstruction group. However, there was no significant difference in the position of other tunnels, knee stability, or clinical outcomes between the two groups.

In a previous study, Ahn et al. [1] found that the anatomical femoral AM bundle tunnel position group showed superior outcomes in knee stability and graft maturation on second-look arthroscopy, comparing with the higher and shallower femoral AM bundle tunnel position. Similar to results of our study, there was no statistical difference in the position of femoral PL bundle tunnel between two groups [1]. Seon et al. [6] have reported that the low femoral tunnel group in SB reconstruction shows better internal rotational stability than the high femoral tunnel group. Iriuchishima et al. [17] have investigated the difference of tunnel position in anatomical DB ACL reconstruction between human cadaver and patient knees. They reported that femoral AM bundle tunnel in cadaver knees was placed in a significantly deeper position than that in patient knees. There was no significant difference in femoral PL bundle tunnel and tibial tunnel placements between cadaver and patient knees [17]. Considering results of several previous studies [1,17] and our study, the femoral AM bundle tunnel position may show large variations with risk of shallow and high placement compared to anatomical position. The reason for such mal-positioned femoral AM bundle tunnel might be technical difficulty in tunneling at its deep and low portion due to potential risks such as cartilage injury of the medial femoral condyle or blow out of the lateral femoral condyle's posterior wall.

In our study, although there was a significant difference in femoral AM bundle tunnel placement between the two groups, there was no significant difference in postoperative knee laxity or clinical outcomes between the two groups. Parkinson et al. [7] have reported that meniscal deficiency is the most significant factor to predict graft failure in single-bundle anatomic ACL reconstruction. In their study, shallow nonanatomic femoral tunnel positioning and younger patient age were additional risk factors for failure, although their relative importance was less. Ahn et al. [18] have suggested that high or shallow position of the femoral AM bundle tunnel, partial meniscectomy of the medial or lateral meniscus, and prolonged surgical delay of more than 11.5 weeks from injury are significant risk factors for inferior clinical outcomes after ACL DB reconstruction. In their study, partial meniscectomy of medial meniscus was the strongest predictor for inferior outcomes [18]. In our study, there was no statistically significant difference in meniscal injury or surgical delay from injury between the two groups. These similarities might be the reason why there was no significant difference in postoperative knee laxity or clinical outcomes in our study, despite there was difference in the position of femoral AM bundle tunnel between the two groups.

Three-dimensional CT reconstruction is a good tool to help surgeons detect and learn from their errors in ACL reconstruction [19]. Sirleo et al. [20] have reported that feedback from postoperative 3D-CT is effective in the learning process to improve accuracy and precision of femoral tunnel placement in order to obtain anatomic ACL reconstruction while reducing arthroscopic time and learning curve. They suggested that in the early series, a trend to placing femoral tunnel slightly shallow in the deep-to-shallow distance and slightly high in the high-to-low distance was observed while a progressive improvement in tunnel position was recorded in the

**Table 2**
Comparison between the fluoroscopy-assisted and -free reconstruction groups.

| | Fluoroscopy-assisted Reconstruction Group ($n = 30$) | Fluoroscopy-free Reconstruction Group ($n = 30$) | $p$-value |
|---|---|---|---|
| Femoral tunnel position (AM bundle, deep-shallow direction); % mean ± SD (range) | 33.8 ± 4.7 (19.5–43.8) | 41.2 ± 14.4 (17.4–76.1) | 0.005 |
| Femoral tunnel position (AM bundle, high-low direction); % mean ± SD (range) | 16.3 ± 9.2 (10.2–31.9) | 14.4 ± 8.3 (10.2–33.3) | 0.416 |
| Femoral tunnel position (PL bundle, deep-shallow direction); % mean ± SD (range) | 36.1 ± 9.4 (21.5–58.8) | 37.1 ± 17.1 (21.1–65.7) | 0.792 |
| Femoral tunnel position (PL bundle, high-low direction); % mean ± SD (range) | 49.1 ± 11.9 (15.5–67.7) | 48.2 ± 11.2 (13.0–63.4) | 0.780 |
| Tibial tunnel position (AM bundle, anterior-posterior direction); % mean ± SD (range) | 37.8 ± 10.3 (19.1–58.1) | 33.1 ± 5.9 (18.3–50.4) | 0.063 |
| Tibial tunnel position (AM bundle, medial-lateral direction); % mean ± SD (range) | 40.7 ± 4.4 (30.3–47.9) | 41.9 ± 4.9 (32.8–50.7) | 0.297 |
| Tibial tunnel position (PL bundle, anterior-posterior direction); % mean ± SD (range) | 54.9 ± 7.6 (38.6–72.4) | 53.6 ± 9.3 (33.3–69.7) | 0.579 |
| Tibial tunnel position (PL bundle, medial-lateral direction); % mean ± SD (range) | 43.3 ± 3.4 (34.3–48.3) | 43.9 ± 4.1 (35.5–52.1) | 0.496 |
| Anterior translation (SSD); mm mean ± SD (range) | 2.4 ± 1.4 (0.2–4.5) | 3.0 ± 1.8 (0.1–6.2) | 0.101 |
| Pivot-shift grade (Grade 0/1/2/3/4) | Gr 0:24/Gr1:5/Gr 2:1 | Gr 0:19/Gr1:8/Gr 2:3 | 0.321 |
| Postoperative KL grade (Grade 0/1/2/3/4) | Gr 1:24/Gr 2:5/Gr 3:1 | Gr 1:22/Gr 2:7/Gr 3:1 | 0.872 |
| IKDC objective grade (Grade A/B/C/D) | Gr A:21/Gr B:9 | Gr A:15/Gr B:10/Gr C:5 | 0.101 |
| Subjective functional IKDC score; mean ± SD (range) | 92.3 ± 5.2 (78.3–98.9) | 89.7 ± 6.4 (75.2–97.3) | 0.083 |

PL: posterolateral; SSD: Side to side difference; IDKC: International Knee Documentation Committee.

late series with feedback from 3D-CT. Their results were similar to results of our study showing that the fluoroscopy-free reconstruction group had shallower position of the femoral AM bundle tunnel than the fluoroscopy-assisted reconstruction group.

Inderhaug et al. [8] have suggested that intraoperative fluoroscopy is effective as an aid for placing femoral tunnel in a more accurate position compared to a desired anatomic center in ACL SB reconstruction. In a cadaveric study, Moloney et al. [11] have reported that surgeons can be successfully guided by fluoroscopy to create more consistent femoral and tibial tunnels during ACL reconstruction. In our present study, the senior surgeon who performed all ACL surgeries had already done a large number of ACL DB reconstructions (more than 300 cases) prior to this present study. Nevertheless, there was a significant difference in femoral AM bundle tunnel position according to the use of fluoroscopy during ACL surgery. This noteworthy finding may suggest that intraoperative fluoroscopy can be also a useful method for expert surgeons during ACL DB reconstruction.

Regarding the strength of our study, we suggested efficacy of intraoperative fluoroscopy during ACL DB reconstruction as clinical relevance of this study using a prospective randomized study design.

Several limitations are noted. First, although our study was performed with prospective randomized data collection and analysis, there might be variations such as difference in exercise intensity during rehabilitation period and other additional confounders. In addition, we did not confirm the healing of repaired meniscal tear for all cases, although there was no statistical difference in meniscal injury or its treatment between the two groups. The second limitation was that, although we proved the difference in tunnel position according to the use of intraoperative fluoroscopy, we did not reveal the optimal placement for each femoral and tibial tunnel during ACL DB reconstruction. Third, we did not prove the detail effect of the position of each tunnel on postoperative knee stability or clinical outcomes. In addition, all ACL reconstructions and the assessment of pivot-shift grade in our present study were performed by only one surgeon. This could be another limitation of our study.

## 5. Conclusion

In conclusion, fluoroscopy-assisted ACL DB reconstruction can make deeper placement of the femoral AM bundle than the conventional ACL DB reconstruction.

## Disclosure of interest

The authors declare that they have no competing interest.


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This study was supported by the research fund from Dongguk University. The funding sources had no role in the design or conduct of the study; collection, management, analysis, or interpretation of the data; or preparation, review, or approval of the manuscript.


## Authors' contributions

J.H.A.: original idea, performed the statistical analysis and drafted the article.

S.K.: measured the data and performed the statistical analysis.

J.K.: measured the data and performed the statistical analysis.


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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.otsr.2019.04.011.

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