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In vitro and in vivo AM and PL tunnel positioning in anatomical double bundle anterior cruciate ligament reconstruction

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Abstract

Background   There have been few studies investigating the correct anatomical femoral and tibial tunnel placement in double bundle anterior cruciate ligament (ACL) reconstruction.

Objective   To compare anteromedial (AM) and posterolateral (PL) tunnel positions in anatomical double bundle ACL reconstruction in human cadaver and patient knees.

Materials and methods   Fifteen fresh-frozen non-paired adult human knees and 27 patients (27 knees) were evaluated. In the cadaver knees, AM and PL bundles were identified by their difference in tension patterns. Their femoral centers were marked with a K-wire, and cut from the femoral insertion site. After this, each bundle was divided at the tibial side. The center of each bundle insertion was again marked with a K-wire, and 5–7-mm tunnels were drilled with transportal or outside-in technique. In patient knees, each tunnel was made according to the native ACL foot print and bony landmarks using transtibial technique ($n = 5$) and transportal technique ($n = 22$). Tunnel placement was evaluated using a C-arm X-ray device and 3D CT. For the femoral side assessment, Bernard and Hertel's technique was used. For the tibial side assessment, Amis and Jakob's technique was used.

Results   The femoral AM tunnel in the cadaver knees was placed in a significantly deeper position when compared to patient knees. There was no significant difference in the AM vertical placement or in the PL tunnel placement in the femur. No significant differences were observed in the tibial tunnel placements between cadaver and patient knees.

Conclusion   In vivo positioning of the femoral AM bundle differed significantly from the in vitro positioning.

Keywords   Anterior cruciate ligament · Reconstruction · Anatomy · Double bundle · Tunnel · Placement

Abbreviations
ACL   Anterior cruciate ligament
AM   Anteromedial bundle
PL   Posterolateral bundle

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Introduction

The anterior cruciate ligament (ACL) consists of two different bundles, the anteromedial (AM) and the posterolateral (PL) bundles [1–6]. Recently, anatomical double bundle ACL reconstruction has become more common and its biomechanical and short-term clinical advantages, when compared to traditional single bundle reconstruction, have been reported [5, 7–12]. With the increasing use of anatomical double bundle ACL reconstruction, several authors have

reported on the anatomy and biomechanics of AM and PL bundles [2–4, 13–15]. In the normal ACL, when the knee is extended, PL bundle is tightened, and when the knee is flexed, the AM bundle is relatively tightened [11]. As intact ACL, it has been suggested that the anatomical AM and PL reconstructed grafts share the load during the knee range of motion and the presence of the PL bundle can better restore the normal knee rotation [12, 15].

Previous studies have shown that the tunnel placement is an important factor in obtaining optimal clinical results [12, 14]. Tunnel misplacement can cause graft impingement, leading to changes in graft tension patterns, which results in knee instability [16, 17]. Zantop et al.[18] reported that non-anatomically placed PL tunnel could not restore the normal knee rotation and anterior to posterior stability after ACL reconstruction. To make accurate anatomical tunnels in double bundle ACL reconstruction, better understanding of tunnel placement is essential. However, there are few studies that have evaluated AM and PL tunnel positions in human cadaver knees [15]. To the best of our knowledge, no study has compared in vitro and in vivo tunnel positioning in anatomical double bundle ACL reconstruction.

The objective of this study was to compare AM and PL tunnel positions in anatomical double bundle ACL reconstruction between the human cadaver knees and the patient knees. Our hypothesis was that the tunnel position in the cadaver knees and the patient knees would be the same.

Materials and methods

Surgery in cadaver knees

Fifteen (15) fresh-frozen non-paired adult human knees were used [3 males, 12 females, median age 60 (49–93) years]. The knees were stored at−20°C and thawed overnight at room temperature before testing. The specimens were prepared to include the distal 20 cm of the femur and the proximal 20 cm of the tibia, and all soft tissue structures. During the tests, the specimen was kept moist with saline solution. Knee joints were opened using a subvastus approach. AM and PL bundles were identified by the differences in tension patterns during the complete knee range of motion. All soft tissues were carefully dissected. First, with the knee at 90° of flexion, relaxed fibers of the ACL were regarded as the PL bundle. The femoral PL bundle insertion was defined and cut from the femur and the center point was visually defined and marked with a 1.2-mm K-wire. Next, the remaining fibers (taut at 90° of knee flexion) were regarded as the AM bundle. The femoral insertion site of the AM bundle was defined and the center point was marked as described for the PL bundle. After marking the center points of each bundle on the femur, the AM and PL

bundles were separated on the tibial side, and each tibial insertion was again defined and their center points were visually marked with a K-wire. Tunnel diameters were selected according to the graft diameter and were 5–7 mm. No tunnel connection was observed in any case. After the tunnels were drilled, their positions were evaluated using a C-arm X-ray device (BV Libra, Koninklijke Philips Electronics N.V., Eindhoven, Netherlands). True lateral image of the knees were used for the evaluation. Metal wire balls were inserted to the femoral tunnels to clearly visualize the tunnel placement. Cannulated drills and K-wires were left within the tibial tunnels where the tibial side radiographic evaluation was performed.

Anatomical double bundle ACL reconstruction in patients

Patients

All patients gave their informed consent.Twenty seven (27) patients with an average age of 30 ± 11 were included in this study. There were 16 men and 11 women. Patients were included if they had a unilateral ACL injury assessed by a positive result of pivot-shift or anterior tibial laxity.

Surgical procedure

All patients underwent anatomical double bundle ACL reconstruction using a hamstring auto graft at Surugadai Nihon University Hospital (Tokyo, Japan) from 2007 to 2009. When the patients recovered their full range of motion after the initial ACL injury, ACL reconstruction was performed. The surgery was performed arthroscopically. At the beginning of the surgery, intra articular conditions were evaluated through the normal anteromedial and anterolateral portals. Femoral and tibial insertions of the ACL were confirmed, and the remnant was removed with a shaver. The AM and PL tunnels were placed at the native ACL stumps and a transtibial ($n = 5$) or transportal technique ($n = 22$) was used to make femoral tunnels. When femoral tunnels were made, resident's notch and bifurcate ridge [19] were indicated to ensure the accurate anatomical positioning of the tunnel. No aiming device was used to make the femoral tunnels. The tibial tunnel was made using an ACL tip guide (Acufex, Smith and Nephew Inc, Andover, MA, USA). Tunnel size was selected based on the graft or knee size, and was 5–7-mm. After the graft was passed through the tunnels, femoral fixation was performed with a titanium button (Endobutton CL, Smith and Nephew Inc, Andover, MA, USA). After this, 20 cycles of passive flexion and extension for preconditioning were performed. The tibial fixation of the graft was accomplished by applying 30 N of initial tension [12] and tethering the sutures (2.0 ETHILON sutures; Johnson and Johnson Co., Ltd, Piscata-

way, NJ, USA) to a Double spike plate (Meira, Co. Ltd., Nagoya, Japan) and fixing it with a 6.5-mm screw.

At the tibial side, intraoperative radiographic evaluation was performed when the K-wires were inserted to the center of each AM or PL insertion site. Using a complete lateral view of the knee, each tunnel position was evaluated. At the femoral side, tunnel position measurement was performed with 3D computed tomography (3D CT), using a complete lateral view of the femoral lateral condyle. As we could not use metal wire balls to evaluate the femoral tunnels in the real operation, 3D CT evaluation was selected.

Evaluation of tunnel placement

The location of the tibial AM and PL tunnels was determined using the line described by Staubli et al. [20]. The lines, parallel to the tibial plateau were marked on lateral tibial radiographs. The centers of the tibial AM and PL tunnels were orthogonally projected onto the line, percentage lengths were calculated on the line from 0 (anterior cortex) to 100% (posterior cortex). To determine the location of the femoral tunnels, the quadrant grid method described by Bernad et al. [21] was used on the lateral femoral radiographs. The position of the center of each tunnel was defined as a percentage ratio of the sagittal diameter of the lateral condyle measured along Blumensaat's line.

Comparison of tunnel placement in cadaver knees and patient knees

Data are presented as the mean $\pm$ SD. Comparison of data was made between cadaver knees and patient knees. Collected data were analyzed using SPSS for Windows, Version 12.0 (SPSS Inc., Chicago, IL) software. Comparison of data was performed using Mann–Whitney's U test. Values were considered significantly different at $p < 0.05$.

Results

Tunnel placement in cadaver knees

No triple bundle case was observed in this study. In the radiographic evaluation, the center of the femoral AM tunnel was placed at $15 \pm 6\%$ in a shallow–deep direction (from the posterior) and at $26 \pm 8\%$ in a high–low direction (from Blumensaat's line). The center of the PL bundle was found at $32 \pm 9\%$ in a shallow–deep direction and $52 \pm 5\%$ in a high–low direction (Fig. 1).
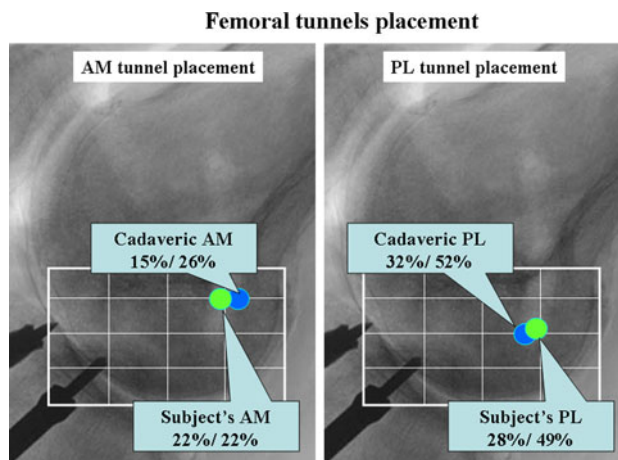

Fig. 1 Femoral tunnel placement in cadaver knees and patient knees
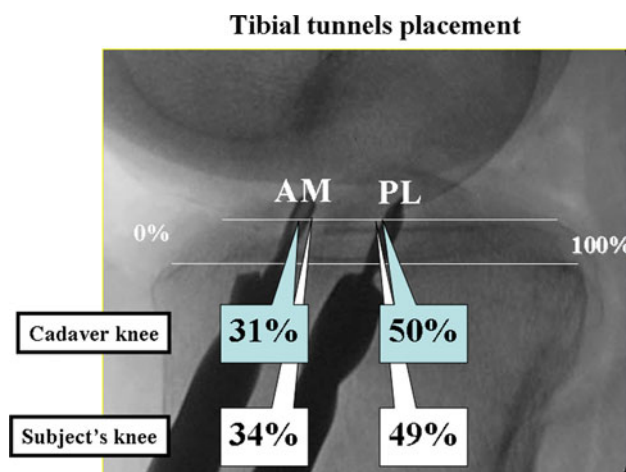

Fig. 2 Tibial tunnel placement in cadaver knees and patient knees

On the tibial side, the center of the AM tunnel was placed at $31 \pm 3\%$ from the anterior edge of the tibia, and the PL tunnel at $50 \pm 3\%$ (Fig. 2).

Tunnels placement in patient knees

In the 3D CT evaluation, the center of the femoral AM tunnel was placed at $22 \pm 7\%$ in a shallow–deep direction and at $23 \pm 12\%$ in a high–low direction. The center of the PL bundle was found at $28 \pm 8\%$ in a shallow–deep direction and $49 \pm 10\%$ in a high–low direction (Fig. 1).

On the tibial side, the center of the AM tunnel was placed at $34 \pm 4\%$ from the anterior edge of the tibia, and the PL tunnel at $49 \pm 5\%$ (Fig. 2).

Femoral and tibial tunnels placement in transtibial technique ($n = 5$) and transportal technique ($n = 22$) are described in Table 1.

Table 1 In vivo tunnel positioning in the anatomical double bundle ACL reconstruction

Technique to make femoral tunnels	Femoral side		Tibial side	
	AM (shallow–deep/high–low)	PL (shallow–deep/high–low)	AM	PL
Trans-tibial (n = 5)	30.4 ± 2.6%/13 ± 4.1%	31.4 ± 6.8%/43.3 ± 8.8%	32.9 ± 3%	47.4 ± 5%
Trans-portal (n = 22)	17.9 ± 4%/27 ± 11.6%	25.7 ± 7.8%/5.2 ± 10.6%	33.7 ± 4.1%	49.1 ± 5.3%

The tunnels made with transtibial technique were placed relatively shallow and high in the condyle
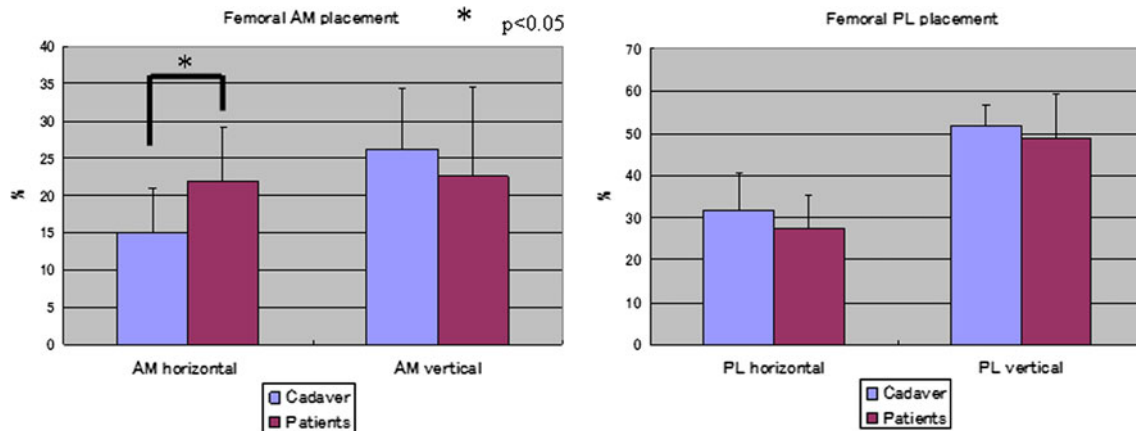

Fig. 3 Statistical analysis showed significant difference of femoral AM tunnel positioning between cadaver knees and patient knees. No significant difference in femoral PL tunnel positioning was observed between the two groups
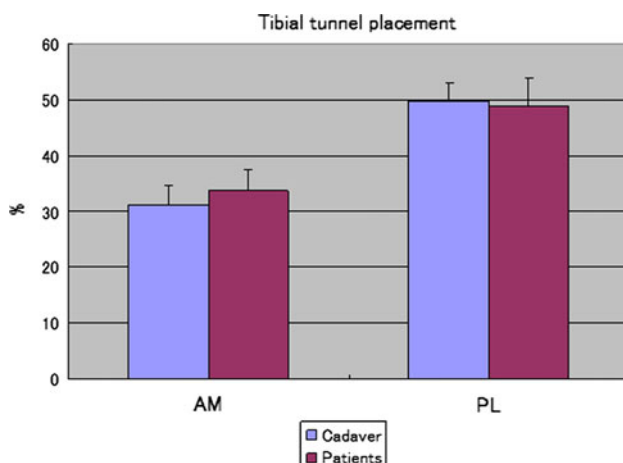

Fig. 4 No significant difference in tibial tunnel placement was observed between cadaver knees and patient knees

Statistical analysis of tunnel placement between cadaver knees and patient knees

The femoral AM tunnel in cadaver knees was placed in a significantly deeper position when compared to patient knees. There was no significant difference in the AM vertical placement or in the PL tunnel placement in the femur (Fig. 3). No significant difference was observed in tibial tunnel placement between cadaver and patient knees (Fig. 4).

Discussion

Different from our hypothesis, tunnel placement in the cadaver knee and patient's knee showed significant difference in this study. To our best knowledge, this is the first study to evaluate in vitro and in vivo tunnel placement in anatomical double bundle ACL reconstruction, which has become a common orthopaedic procedure [2, 5, 6, 9]. In anatomical double bundle ACL reconstruction, surgeons have to make two femoral and two tibial tunnels within the narrow ACL foot print. In spite of the presence of bony landmarks [19, 22], defining the ACL footprint accurately during arthroscopy can be difficult, especially in knees with chronic ACL tear. Consequently, a good understanding of ACL anatomy and correct tunnel placement is a necessity for surgeons [5, 19, 23–25].

In previous anatomical reports, the average position of the center of AM insertion on the femur was 22% in a shallow–deep direction and at 23.9% in a high–low direction [2–4, 15]. The center of the PL bundle was reported at 29.5% in a shallow–deep direction and 52.7% in a high–low direction. Our clinical femoral tunnel placements were similar to previous anatomical reports on ACL. However, a significant difference in AM tunnel placement in a shallow–deep direction was observed when compared to cadaver knees. Although we are uncertain why the femoral AM tunnel in cadaver knees was placed deeper in the condyle than

those in patient knees and those in previous reports, we dissected the ACL with careful attention and believe that our cadaveric results reflect the correct ACL anatomy. One of the possible reasons for the difference of femoral AM tunnel placement is the technique of tunnel drilling. In the cadaver knees, to make the correct anatomical tunnels within the ACL foot print, an outside-in technique or transportal technique was used. In contrast, in 5 cases of patients knee, a transtibial technique was used, and in 22 cases, transportal technique was used. As Yasuda et al. reported [12], it is possible for surgeons to make correct anatomical tunnels using a transtibial technique in anatomical ACL reconstruction. However, the technique requires a great technical skill, and there might have been inaccuracies in our tunnel placement in these cases. In our results, femoral tunnels made with transtibial technique that were placed relatively high and shallow, especially in femoral AM tunnel (Table 1), and this could be the cause of differences in AM tunnel placement between cadaver knees and patient's knees. As Zantop et al. reported [18], even in the double bundle ACL reconstruction, non-anatomical femoral tunnel cannot restore the normal knee stability. Therefore, surgeons have to carefully make anatomical tunnels in the ACL reconstruction. Different from the concept of traditional isometric ACL reconstruction, normally we do not use femoral aimer in the anatomical double bundle ACL reconstruction. However, not to make extremely shallow femoral tunnel, especially in the trans-tibial technique, the use of femoral aimer should be considered again.

The average placement of tibial tunnels in previous reports are AM 32.5% and PL 47.3% from the anterior border of the tibia. At the tibial side, our results were similar to the previous reports [2–4, 15].

Results of previous studies of ACL anatomy vary on both the femoral and tibial side [2–4, 15]. The presence of these ample variations might be explained by the separation of the ACL into two bundles. Because the ACL consists of many small fibers, separating AM and PL bundles can be difficult. Iriuchishima et al. stated that separation should be done according to the tension patterns to achieve a more consistent description of ACL morphology [26].

The main limitations of this study were: (1) In our cadavers, the AM and PL bundles were separated by their tension pattern and the center points were chosen only by macroscopic evaluation and careful dissection. Although this dissection was made by experienced surgeons, this might include human error and bias. (2) The average age of the cadavers used was significantly greater than the average age of patients in this study. Even though no specimens had osteoarthritic changes, the ages of the specimens should be considered in such anatomical studies. Furthermore, gender difference should be evaluated in the future plan. (3) For the femoral tunnel assessment, radiographic evaluation was per-

formed in the cadaver knees, however, 3D CT evaluation was performed in the patient knees. This is because, metal wire balls could not be inserted to the femoral tunnels in the arthroscopic surgery for the patients. This differences of evaluation could be some bias and should be corrected in the future studies. (4) Our sample size of cadavers was not large ($n = 15$) but was similar to previous studies [5, 18]. However, due to anatomical variation, a study with a larger sample size is needed to more accurately define the ACL anatomy.

We believe that this study will contribute to greater accuracy of ACL surgery and provide a reference data for postoperative radiographic evaluation.

Conclusion

In conclusion, we have evaluated the anatomy of the ACL focusing on tunnel placement in double bundle ACL reconstruction, both in cadaver knees and patient knees. In vivo positioning of the femoral AM bundle differed significantly from in vitro positioning. Surgeons have to carefully select the technique to make femoral tunnels and need technical improvement to make correct anatomical tunnels in the anatomical double bundle ACL reconstruction.

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