Eccentric Femoral Tunnel Widening in Anatomic Anterior Cruciate Ligament Reconstruction

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**Purpose:** The purpose of this study was to retrospectively evaluate femoral tunnel widening (TW) and migration of the femoral tunnel aperture after anatomic anterior cruciate ligament (ACL) reconstructions with hamstring grafts and bone-patellar tendon-bone (BPTB) grafts. **Methods:** Of the 105 consecutive patients who underwent ACL reconstruction, the 52 patients who underwent isolated ACL reconstruction and in whom tunnel measurement could be obtained by computed tomography were included in this study. In 26 patients, double-bundle reconstruction (DBR) of the ACL using hamstring tendons was performed. These patients were compared with 26 patients in whom rectangular tunnel ACL reconstruction using BPTB grafts (BPTBR) was performed. Femoral tunnel aperture positioning and TW were investigated postoperatively using 3-dimensional computed tomographic images, which were performed a week and a year after surgery in all patients. **Results:** In DBR, the average diameter of the anteromedial (AM) femoral tunnel increased by 34.0% in the horizontal direction and 28.2% in the vertical direction, whereas that of the posterolateral (PL) femoral tunnel increased by 58.2% and 73.4%, respectively, at 1 year after surgery compared with 1 week after surgery. The percentage TW value of the PL tunnel was significantly greater than that of the AM tunnel. In BPTBR, the average diameter increased by 22.0% and 17.1%, respectively. The percentage TW value of the PL tunnel in DBR was significantly greater than that of the femoral tunnel in BPTBR. Each tunnel aperture migrated distally (“shallow”) in the horizontal direction and high in the vertical direction. AM and PL tunnel apertures in DBR migrated in the vertical direction significantly more than they did in BPTBR. No significant differences between the 2 groups were found in clinical outcomes. **Conclusions:** The femoral PL tunnel aperture in DBR showed significantly more widening than did the AM tunnel aperture in DBR and the femoral tunnel aperture in BPTBR. Also, greater migration of the femoral tunnel aperture in the vertical direction because of TW was observed in DBR than in BPTBR. **Level of Evidence:** Level IV, therapeutic case series.

**T**unnel widening (TW) after anterior cruciate ligament (ACL) reconstruction is a well-known phenomenon. Greater TW has been reported in ACL reconstruction using hamstring grafts than in that using bone-patellar tendon-bone (BPTB) grafts. The causes of TW are unclear and are presumed to be multifactorial, with biological and mechanical factors. Biological factors include access of the synovial fluid between the graft and the bone that contains osteolytic cytokines. Mechanical factors include a “bungee effect,” as longitudinal motion of the graft by extracortical femoral fixation, a “windshield-wiper effect,” as transverse motion of the graft, improper graft placement, and accelerated rehabilitation. Although TW does not seem to affect the short-term clinical outcome, a general consensus prevails that the presence of expanded tunnels often severely complicates revision ACL reconstruction.

Recently, ACL reconstruction has focused on anatomically reconstructing the ligament to restore the original footprint and normal kinematics of the knee. During anatomic ACL reconstruction, the lateral intercondylar ridge is an important topographic landmark to identify the femoral attachment of the ACL. In theory, graft placement aligned within native insertion sites, especially the femoral site, could result in the restoration of knee stability and superior clinical outcomes. Nonanatomically positioned femoral bone...
tunnels result in more TW compared with anatomi-
cally positioned tunnels. Although many authors have
discussed TW, most reports in the literature have not
discussed the direction of TW or tunnel aperture
migration. If TW and tunnel aperture migration occur
after an ACL reconstruction procedure in which the
femoral tunnel was placed in the anatomic position,
there is a possibility that the femoral tunnel aperture
extrudes into a nonanatomic position. Therefore, it is
important to know the direction of tunnel aperture
migration if it occurs.

Although there are several studies that describe TW
after anatomic double-bundle reconstruction (DBR) of
the ACL, most of these studies compared DBR with
single-bundle ACL reconstruction. In contrast,
there is no study about TW after anatomic ACL
reconstruction using BPTB grafts. Since 2007, we have
used a 3-dimensional (3D) fluoroscopy-based naviga-
tion system to accurately and reproducibly position
the femoral tunnel during anatomic ACL reconstruction
using hamstring tendon grafts or BPTB grafts. Therefore, we conducted a study comparing femoral
TW after anatomic DBR and anatomic ACL recon-
struction using a BPTB graft with the objective of
placing the femoral tunnel aperture within the native
ACL footprint (i.e., posterosuperior to the lateral
intercondylar ridge of the femur). Knowledge about
TW after anatomic ACL reconstruction using 2 different
graft materials is essential for the selection of a graft.
Furthermore, knowing the direction of TW after ACL
reconstruction could lead to an appropriate tunnel
placement in ACL reconstruction. To the best our
knowledge, this is the first study comparing femoral TW
and migration of the femoral tunnel aperture in
anatomic ACL reconstructions using hamstring tendon
grafts versus those using BPTB grafts.

The purpose of this study was to retrospectively
evaluate femoral TW and migration of the femoral
tunnel aperture after anatomic ACL reconstructions
using hamstring tendon and BPTB grafts through the
use of a 3D computed tomography (CT) model. Our
hypothesis was that greater TW and migration of the
femoral tunnel aperture would occur in anatomic ACL
reconstructions using hamstring grafts than in those
using BPTB grafts.

Methods

Patients

Of the 105 consecutive patients on whom ACL
reconstruction was performed at our institution be-
tween July 2009 and February 2012, 52 patients were
included in this study. Inclusion criteria for the study
were as follows: (1) history of a DBR ACL reconstruc-
tion using hamstring tendon grafts or a rectangular
tunnel ACL reconstruction using a BPTB graft (BPTBR),
(2) no previous intra-articular ligament reconstruc-
tion or osteotomy around the knee joint, (3) absence
of posterior cruciate ligament insufficiency or abnormal
varus/valgus instability, and (4) existence of a bone
bridge between anteromedial (AM) and posterolateral
(PL) tunnels seen on CT in cases of DBR (i.e., the
tunnels had to be separated by a bridge of bone to allow
measurement of each tunnel). There was one patient
who did not meet the first inclusion criterion, 19 pa-
tients who did not meet the second criterion, one who
did not meet the third criterion, and 18 who did not
meet the fourth criterion; therefore, a total of 39 pa-
tients who did not meet the first criterion; 19 pa-
tients who did not meet the second criterion, one who
did not meet the third criterion, and 18 who did not
meet the fourth criterion; therefore, a total of 39 pa-
tients were excluded. In addition, 2 patients did not give
their consent for CT and 11 patients were lost to follow-
up. An experienced surgeon participated in all pro-
cedures as an operator or first assistant. In 26 of the 52
patients, DBR was performed. These patients were
compared with 26 patients in whom BPTBR was per-
formed. Patients in the study included 14 female pa-
tients and 38 male patients with a median age of 27
years (range, 16 to 50 years). Grafts were selected by a
surgeon who took into consideration the activity of
patients, the types of sports they may be involved in,
and patient preference. BPTB grafts were selected pri-
marily for young male or collision/contact athletes,
whereas hamstring grafts were selected for the others
during the study period. Patient information is sum-
marized in Table 1. The institutional review board at
our institution approved this retrospective study. Pa-
tients and their families were informed that data from
their cases would be submitted for publication, and they
all provided consent.

Surgical Technique of DBR

ACL reconstruction was arthroscopically performed
using a 3D fluoroscopy-based navigation system to
place the 2 femoral tunnels, as described pre-
viously. Briefly, the autologous hamstring tendons
were harvested and the doubled grafts were looped
over EndoButton CLs (Smith & Nephew, Andover,
MA). The distal free ends of the grafts were armed with
No. 3 Ethibond (Somerville, NJ) sutures using a whip-
stick technique. The femoral insertion site for each

Table 1. Preoperative Patient Information

<table>
<thead>
<tr>
<th></th>
<th>DBR</th>
<th>BPTBR</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>26</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Gender (female/male)</td>
<td>12/14</td>
<td>2/24</td>
<td>.002*</td>
</tr>
<tr>
<td>Age (years)</td>
<td>31 (18-50)</td>
<td>26 (16-47)</td>
<td>.012*</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>167 ± 9</td>
<td>171 ± 5</td>
<td>.015*</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>64 ± 12</td>
<td>70 ± 15</td>
<td>.047*</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>22.8 ± 2.9</td>
<td>23.7 ± 4.2</td>
<td>.191</td>
</tr>
<tr>
<td>Tegner activity scale</td>
<td>7 (3-9)</td>
<td>8 (5-10)</td>
<td>.053</td>
</tr>
</tbody>
</table>

NOTE. Data are given as means ± standard deviations or medians
(range).

*Indicates a statistical significance between the 2 groups with P < .05.
The tibial tunnels were placed in the center of the intermeniscal ligament, and the posterior cruciate ligament, the anterior horn of the lateral meniscus, the reference to the ACL remnant, the medial tibial insertion site was arthroscopically determined in the same manner as in the DBR procedure. After creating a femoral tunnel and a tibial tunnel, the BPTB graft was passed through, and the EndoButton loop was flipped outside the femoral cortex in the usual manner. The bone plug was set far enough into the femoral tunnel that the ligament end of the graft was inset 1 mm into the femoral tunnel to avoid protrusion of the bone plug from the femoral tunnel. Tibial fixation of the BPTB graft was accomplished in the same manner as in the DBR procedure, and the BPTB graft was fixed at full knee extension.

**Postoperative Rehabilitation**

The knee was not immobilized but was protected for 5 weeks with a functional brace. Active and assisted range of motion exercises were started immediately after surgery. Partial weight bearing was allowed 2 days after surgery and full weight bearing was allowed at 1 week. Running was allowed at 4 months followed by a return to previous sporting activity at an average of 8 to 9 months after surgery.

**Computed Tomographic Evaluation**

A 3D computed tomographic scan of the operated knee was obtained a week and a year after surgery for all patients, using a helical high-speed Aquilion 64 or Aquilion ONE (Toshiba Medical Systems, Tochigi, Japan) CT machine. The ZIOSTATION software package (Ziosoft, Tokyo, Japan) was used for 3D reconstruction of the operated knee. The tibia, patella, and medial femoral condyle were removed from the 3D model because it was necessary to visualize the lateral wall of the intercondylar notch. A true medial view of the femur was established by superimposing the posterior aspects of the femoral condyles. All measurements were made on the surface of the lateral wall of the intercondylar notch completely from an orthogonal projection to the angle of the surface being measured to ensure accuracy. An orthopaedic surgeon (S.T.) conducted the CT measurement.

**Measurement of the Femoral Tunnel Diameter**

The horizontal diameter ($D_h$) of the femoral tunnel was defined as the width of the femoral tunnel aperture along the Blumensaat line and the vertical diameter ($D_v$) was defined as the height of the femoral tunnel aperture perpendicular to the Blumensaat line (Fig 1). The tunnel diameter measured 1 week after surgery was used as the baseline measurement, which was compared with the diameter measured at the 1-year postoperative follow-up. A percentage change in the diameter between the 2 periods was defined as the percentage TW value.

**Measurement of the Femoral Tunnel Aperture Positioning**

Morphometric assessment of femoral tunnel positioning was performed according to the quadrant...
technique as described by Bernard et al. The total sagittal diameter of the lateral condyle along the Blumensaat line (D) and the maximum lateral intercondylar notch height (H) were measured using the 3D computed tomographic image. The distance from the center of the femoral tunnel aperture to the most posterior subchondral contour of the lateral femoral condyle (d), and the distance from the center of each tunnel for hamstring tendon graft to Blumensaat’s line (h) was measured (Fig 2A). For the rectangular tunnel for the BPTB grafts, the center of the ellipse by which the rectangular tunnel aperture was approximated was defined as the center of the femoral tunnel for the BPTB graft (Fig 2B). The length of distance d as a partial distance of D and the height of the distance h as a partial distance of H were expressed in percentages, such as d/D% and h/H%, respectively.

Clinical Evaluation
Clinical assessment was performed 1 year after surgery, corresponding to the period of computed tomographic assessment. All patients were subjectively evaluated using the Lysholm score. Anterior knee stability was quantitatively assessed using a KT-2000 arthrometer (MEDmetric, San Diego, CA). Reconstructed and contralateral knees were measured with a 134-N anterior force applied to the proximal tibia at 20° of knee flexion. The side-to-side difference in anterior translation was used as a representative indicator of restored knee stability. The pivot shift test was graded as negative, glide, clunk, or gross to determine rotational stability. The range of motion of the reconstructed and contralateral knees were evaluated.

Statistical Analysis
Statistical analysis was performed using the EXCEL statistics 2012 software package for Microsoft Windows (SSRI, Tokyo, Japan). Patient parameters were compared using the Student t test and the Mann-Whitney U test. Radiographic parameters were compared using the Student t test. Clinical outcomes were compared with the Student t test and the \( \chi^2 \) square test. The statistical significance level was set at \( P < .05 \). One orthopaedic surgeon (S.T.) previously performed a
Results

**TW of the Femoral Tunnel Apertures**

Postoperative femoral TW is described in Fig 3. Data in text are given as mean ± standard deviation. The actual values of TW (in millimeters) are also described after the percentage increased. In DBR, the average diameter of the AM femoral tunnel aperture increased by 34.0% ± 30.7% (1.8 ± 1.6 mm) in the horizontal direction and 28.2% ± 30.2% (1.3 ± 1.4 mm) in the vertical direction, whereas the average diameter of the PL increased by 58.2% ± 46.0% (2.8 ± 2.2 mm) and 73.4% ± 39.8% (3.1 ± 1.7 mm), respectively, at 1 year after surgery compared with 1 week after surgery. The percentage TW value of PL tunnel apertures was significantly greater than that of AM tunnels (P < .05 in the horizontal direction; P < .001 in the vertical direction). In BPTBR, the average diameter of the femoral tunnel aperture increased by 22.0% ± 26.1% (1.8 ± 2.1 mm) in the horizontal direction and 17.1% ± 23.4% (1.4 ± 1.9 mm) in the vertical direction. The percentage TW value of PL tunnel apertures in DBR was significantly greater than that of the femoral tunnel apertures in BPTBR (P < .001 in the horizontal direction; P < .001 in the vertical direction), whereas there were no significant differences between the percentage TW value of AM tunnel apertures in DBR and that of femoral tunnel apertures in BPTBR (P = .14 in the horizontal direction; P = .15 in the vertical direction).

**Clinical Evaluation**

Data in text are given as means ± standard deviations. The postoperative mean Lysholm score was 97.6 ± 3.4 points in DBR and 97.6 ± 3.3 points in BPTBR. The postoperative side-to-side difference in anterior translation measured with the KT-2000 arthrometer averaged 0.1 ± 1.0 mm in DBR and 0.2 ± 1.6 mm in BPTBR. The postoperative pivot shift test produced negative or glide results in all patients (100%) of both groups. With respect to the range of motion of the knee, loss of extension of greater than 5° compared with the contralateral knee was not observed in either group, whereas loss of flexion of greater than 5° compared with the contralateral knee was observed in 1 patient (4%) from each group. No significant difference between the 2 groups was found in all clinical outcomes.

**Discussion**

This study revealed 3 important findings. First was that the femoral PL tunnel showed significantly greater widening than the AM tunnel in anatomic DBR. Most previous studies describing TW in DBR did not show...
BPTB grafts, there has been no report that compared reconstruction using hamstring grafts than in that using has been reported in conventional single-bundle ACL observed in DBR than in BPTBR. Although greater TW Conversely, greater widening of the PL tunnel was greater than TW in BPTBR, there was no signifi difference between the AM and PL tunnel apertures in DBR. One of the reasons is that the AM and PL bundles have different functions, and the PL bundle is associated with a greater change in tension with knee motion. This resulted in more extensive motion of the PL graft within the tunnel, and a longer time was required for bone-to-graft healing. The other reason is that although the AM tunnel aperture was surrounded by superior and posterior articular hard subchondral bone and the PL graft, the PL tunnel aperture was surrounded by only posterior articular hard subchondral bone and the AM graft. Therefore, the PL graft had space for expansion.

Second was that greater TW was observed in anatomic ACL reconstruction using hamstring tendon grafts than in BPTBR, especially in the PL tunnel. Although widening of the AM tunnel in DBR was greater than TW in BPTBR, there was no significant difference between AM TW in DBR and TW in BPTBR. Conversely, greater widening of the PL tunnel was observed in DBR than in BPTBR. Although greater TW has been reported in conventional single-bundle ACL reconstruction using hamstring grafts than in that using BPTB grafts, there has been no report that compared femoral TW between anatomic ACL reconstructions with hamstring tendon grafts and those using BPTB grafts. We confirmed greater TW in ACL reconstruction using hamstring tendon grafts when anatomic ACL reconstruction was performed with the objective of placing the femoral tunnel aperture within the native ACL footprint (i.e., posterosuperior to the lateral intercondylar ridge). An explanation for smaller TW in BPTBR compared with DBR was simple and clear. In BPTBR, bone-to-graft healing was achieved faster and more securely compared with that achieved with DBR, which resulted in smaller TW in BPTBR. The soft tissue graft length in the tunnel may affect TW. According to a biomechanical study, optimal strength and stiffness of the reconstructed ACL were achieved with 17-mm grafts. In contrast, the relation between the graft length in the tunnel and TW is still unknown. Meanwhile, femoral TW in BPTBR was not so great but did occur because of 2 possible causes. First, a suspension device was used for femoral fixation; consequently, a little motion of the graft within the femoral tunnel occurred. Second, the bone plug was set far enough into the femoral tunnel that the ligament end of the graft was inset 1 mm into the femoral tunnel, and as a result a little “windshield-wiper effect” as transverse motion of the graft might occur.

The other important finding of the current study, which has not been reported previously, was that greater migration of the femoral tunnel aperture because of TW was observed in DBR than was seen in BPTBR. This study revealed that the femoral tunnel aperture did not undergo circumferential widening but expanded in a particular direction after ACL reconstruction. As a result, the center of the femoral tunnel aperture migrated. The results of the current study showed that the AM and PL tunnel apertures in DBR migrated mainly in the vertical direction. Surgeons need to take into account the fact that eccentric TW occurs after DBR. We believe that this phenomenon will contribute to further development of anatomic ACL reconstruction.

Most studies of TW comparing extracortical fixation using the suspensory device and other fixation methods showed that greater TW was associated with the use of the suspensory device. Buelow et al. reported that extracortical fixation using the EndoButton resulted in greater TW compared with aperture fixation using the interference screw. The results of the current study may be associated with the use of the EndoButton. There are very few studies of TW comparing suspensory fixation and other implants in anatomic DBR or BPTBR.
studies are required in the future to address whether aperture fixation decreases TW in anatomic ACL reconstruction.

Clinical outcomes of the current study showed good results after ACL reconstruction and no difference between DBR and BPTBR. It indicated that the grafts in both DBR and BPTBR were clinically functional. However, from the results of this study, it was not known whether TW and tunnel migration affect clinical outcome after anatomic ACL reconstruction. The number of patients involved this study was too small to clarify effects of TW or tunnel migration on clinical outcomes after anatomic ACL reconstruction.

There were some strong points of this study. First, the same surgical method was used for both DBR and BPTBR, such as femoral tunnel positioning and use of fixation devices, whereas in previous studies comparing TW between ACL reconstruction using hamstring tendon grafts and those using BPTB grafts, different surgical methods were used. Second, we used 3D computed tomographic images to evaluate the position of the femoral tunnel aperture. Computed tomographic images are recommended instead of plain radiographs for the postoperative evaluation of tunnel positions in ACL reconstruction procedures. A 3D computed tomographic scan model quadrant method has been reported as reliable in measuring the location of femoral tunnels after ACL reconstruction. We applied this method to evaluate femoral TW and the direction of femoral aperture migration.

Limitations

There were several limitations to this study. First, the current study did not analyze effects of tunnel migration or TW on clinical outcomes after ACL reconstruction, as previously mentioned. Future studies involving a large number of patients are needed to clarify whether these factors influence clinical results after ACL reconstruction. Second, this was a retrospective study with a relatively small number of patients. There were certain dissimilarities between the 2 groups, such as age or sex, because grafts were selected by each surgeon according to patient activity, participation in sports, or patient preference. It is likely that there were differences in bone mineral density (BMD) between the groups because BMD depends on multiple factors such as sex, age, and activity. Differences in BMD between the groups may affect the results of this study. However, according to Meller et al., there was no correlation between TW and BMD in an animal model of ACL reconstruction. We consider that differences in graft choice rather than the dissimilarities in patient profiles impacted the results of this study. Third, we used 3D computed tomographic images to evaluate TW instead of multiplanar reconstruction CT. Multiplanar CT is more suitable to evaluate TW; however, the focus of this study was to evaluate migration of the femoral tunnel aperture. As previously mentioned, a 3D computed tomographic scan model quadrant method has been reported as reliable to measure the location of femoral tunnels after ACL reconstruction. Therefore, we used a 3D computed tomographic scan model to evaluate both TW and migration of femoral tunnel aperture in this study. Another option exists in which measurement of the tunnel diameter along the tunnel aperture axis can be performed to obtain the diameter of the elliptic tunnel. Because evaluation of eccentric TW was a high priority, the use of the same rectangular coordinates was chosen to measure both TW and migration of tunnel aperture. Fourth, tibial TW or tunnel migration was not evaluated in this study, whereas femoral TW and tunnel aperture migration were evaluated. Whether a similar migration phenomenon occurs with tibial tunnels should be clarified in future studies. Fifth, in DBR, patients were excluded if a bone bridge between the AM and PL tunnels could not be identified on 3D CT. It was difficult to evaluate each tunnel diameter when 2 tunnels communicated with each other. Finally, a short follow-up period and large variability in the results were also limitations of this study.

Conclusions

The femoral PL tunnel aperture in DBR showed significantly greater widening than did the AM tunnel aperture in DBR and the femoral tunnel aperture in BPTBR. Also, migration of the femoral tunnel aperture in the vertical direction because of TW was greater in DBR than in BPTBR.

References

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