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Original article

# Graft quality and clinical outcomes of intraoperative bone tunnel communication in anatomic double-bundle anterior cruciate ligament reconstruction

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## Abstract

*Background/objective*: In anatomic double-bundle anterior cruciate ligament reconstruction, it is crucial to create two separate bone tunnels within the footprints of the anterior cruciate ligament at the femur and tibia. This can occasionally be difficult to accomplish and the adverse effects of bone tunnel communication are unclear. The purpose of this study was to examine the effects of intraoperative bone tunnel communication on graft quality and clinical outcome.
*Methods*: Fifty-two patients (52 knees) who underwent anatomic double-bundle anterior cruciate ligament reconstruction with hamstring tendons were included. The mean age of the patients was 30.7 years. Clinical assessments were performed 1 year after surgery. Bone tunnel communication was evaluated using computed tomography 10 days after surgery. Graft quality was evaluated using magnetic resonance imaging 6 months after surgery and the signal/noise quotient was calculated using the region of interest technique.
*Results*: Bone tunnel communication was observed in the femur of one knee (1.9%) and the tibias of 10 knees (30.8%). The knees with tibial bone communication were classified into Group C ($N = 16$), and the knees without tibial bone tunnel communication were classified into Group N ($N = 36$). No significant differences were observed between Groups C and N in terms of clinical outcome. The signal/noise quotient of the distal portion of the posterolateral graft in Group C was significantly higher than that of Group N.
*Conclusion*: Bone tunnel communication in anatomic double-bundle anterior cruciate ligament reconstruction did not affect clinical outcome, but it did affect posterolateral graft quality.
*Level of evidence*: Level 4, case series, therapeutic studies.


*Keywords:* bone tunnel communication; clinical outcome; double-bundle anterior cruciate ligament reconstruction; magnetic resonance imaging

## Introduction

Endoscopic anterior cruciate ligament (ACL) reconstruction is one of the most commonly performed orthopaedic surgeries, and the concepts and techniques of this surgery have changed drastically over the past 10 years. In particular, the concept of anatomic reconstruction, creating bone tunnels within the anatomic centre of the native footprint, was introduced and is now considered important for both the single-bundle and double-bundle (DB) procedures.[1−3]

In DB ACL reconstruction, it is crucial to create two separate bone tunnels within the ligament's footprints in the femur and tibia, preserving a bony bridge between the tunnels. This can be difficult because of the lack of definite arthroscopic surgical landmarks, small patient body

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constitution,[4,5] and technical errors during surgery. Bone tunnel communication results in excessive graft movement and adverse effects on the remodelling processes of the graft and bone-tendon healing in the bone tunnels. Lehmann et al[6] indicated that a 1-mm bony bridge between the tunnels in the femur results in a reduction of biomechanical strength and that a 2-mm bony bridge is necessary. Peterson et al[7] compared the biomechanical properties of the knees that were reconstructed via one or two tibial tunnels in anatomic DB ACL reconstruction. The results indicated that the knees with two tibial tunnels exhibited better biomechanical outcomes. The cadaveric knees that were reconstructed with one tibial tunnel and two femoral tunnels were equivalent to the cases in which two tibial tunnels completely communicated.

Revision surgery is difficult after DB ACL reconstruction cases of bone tunnel communication. Bone tunnel communication is one of the weak points of DB ACL reconstruction, and surgeons should pay special attention to this issue. There are some reports of bone tunnel communication in DB ACL reconstruction,[6,8–10] but studies on the adverse effects of bone tunnel communication are currently ongoing.

The purpose of this study was to examine the effects of intraoperative bone tunnel communication caused by drilling on the graft quality and clinical outcomes of patients undergoing anatomic DB ACL reconstruction. Three-dimensional computed tomography (CT) was used to investigate whether bone tunnel communication was present, and magnetic resonance imaging (MRI) was used to evaluate graft qualities. Our hypothesis was that bone tunnel communication would affect the graft quality but not the clinical outcome.

## Materials and methods

### *Participants*

All patients were operated on between January 2009 and December 2012. In this period, 78 isolated primary anatomic DB ACL reconstructions with hamstring tendons were performed in our institution. Inclusion criteria were: primary ACL reconstruction, closed growth plates, more than 1 year of follow-up after surgery, CT performed 10 days after surgery, and MRI performed 6 months after surgery with grafts clearly depicted on MRI. Exclusion criteria were also applied: previous knee surgery, additional knee ligament injury (posterior cruciate ligament injury or Grade 3 collateral ligament injury), and contralateral knee injury.

### *Clinical assessments*

Clinical assessments were performed before surgery and 1 year after surgery by the same experienced orthopaedic doctor, and included the Lysholm knee scoring scale, the International Knee Document Committee objective scoring system, anterior laxity measured with a KT-1000 arthrometre (MEDmetric Corp., San Diego, CA, USA; a side-to-side difference at 134 N of stress was adopted), and a pivot-shift test.

### *Surgical technique*

All operations were performed by the same experienced surgeon. Anatomic DB ACL reconstructions with hamstring tendons were performed in all patients. The footprint of the ACL on the femur was identified, and the ACL remnant was resected to observe the lateral intercondylar ridge on the lateral femoral condyle.[1] The ACL remnant of the tibial insertion was resected, which left a remnant of 1–2 cm. Femoral tunnels were created. Two 2.4-mm guide pins were inserted using the outside-in method with an anterolateral-entry femoral aimer (Smith & Nephew, Andover, MA, USA) at the centres of the footprints of the anteromedial (AM) and posterolateral (PL) bundles. Next, bone tunnels with diameters of 5.5–6.0 mm and 5.0–6.0 mm were created for the AM and PL grafts, respectively. After creating the femoral tunnels, tibial tunnels were created. Two 2.4-mm guide pins were inserted into the centres of the footprints of the AM and PL bundles. Then, bone tunnels with diameters of 5.5–6.5 mm and 5.0–6.0 mm were created for the AM graft and the PL graft, respectively. The grafts were fixed with two Endobutton CLs (Smith & Nephew) on the femoral side and two Double-Spike Plates (Smith & Nephew) on the tibia. The AM graft was set at 30 N and the PL graft at 20 N at 10° of knee flexion as determined with a ligament tensioner (Smith & Nephew).

### *Evaluation of bone tunnel communication on CT*

Evaluations of bone tunnel communication were performed with a three-dimensional CT scanner (Aquilion 64, Toshiba Medical Systems, Tochigi, Japan) 10 days after surgery. In the femur and tibia, the presence of bone tunnel communication was determined based on coronal, sagittal, and axial sections. If bone tunnel communication was identified, the length of the communication was measured with CT, and the measurements were performed on the Digital Imaging and Communications in Medicine files using the manufacturer's software (Toshiba Medical Systems; Figure 1).

### *Evaluation of the reconstructed ACLs on MRI*

Grafts were performed by MRI 6 months after surgery. Patients were scanned using a Vantage XGV with 1.5 T (Toshiba Medical Systems). All images were obtained with the patient in the supine position and affected knee extended. The standard sequences were sagittal proton density-weighted spin-echo (TR/TE, 1,300/12) sagittal and coronal T2-weighted gradient-echo (TR/TE 532/15) with a 25º flip angle, and axial proton-density spin-echo fat-suppressed (TR/TE 4,000/102). T2-weighted sagittal oblique images were used for evaluation. The slice thickness was 3 mm with a gap of 0.6 mm. The field of view was 16 cm, and the matrix size was 224 pixels $\times$ 352 pixels. The graft evaluations were performed by an experienced orthopaedic doctor. To analyse the graft quality, the signal/noise quotient (SNQ) was calculated using the region of interest (ROI) technique (with the diameter of a 3.0 $mm^2$ circle) with the following equation[11]:

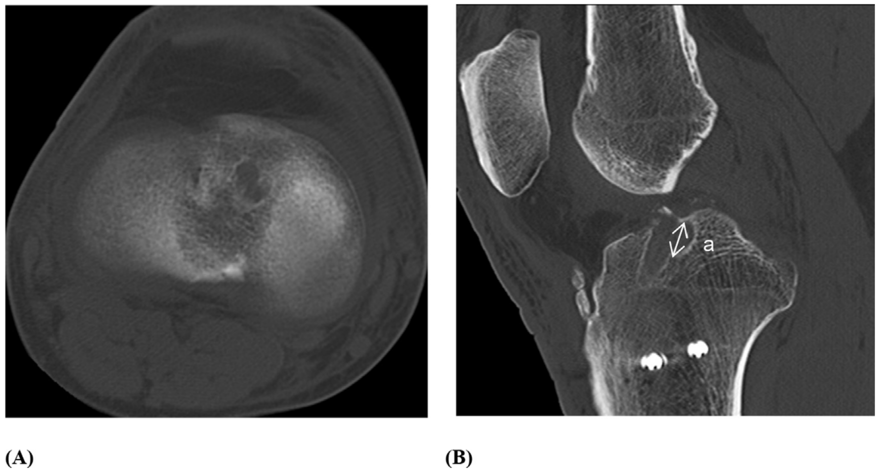


Figure 1. Measurement of length of bone tunnel communication at the tibia on computed tomography. The length of the bone tunnel communication "a" was measured in reference to the: (A) axial, (B) sagittal, and coronal section on computed tomography.

$$\mathrm{SNQ} = \frac{signal(g)\ -signal\ (qt)}{signal\ (bg)} \quad (1)$$

*signal (g)*: signal of graft, *signal (qt)*: signal of quadriceps tendon, *signal (bg)*: signal of background.

The graft evaluation was performed at the intra-articular portions of the AM and PL bundles. The graft was divided into proximal, middle, and distal regions. The signal from the quadriceps tendon was measured with the ROI in the distal part of the quadriceps tendon. For the background measurements, the ROI was placed 2 cm anterior to the patellar tendon (Figure 2). A subset of 15 MR images were randomly selected and reviewed to determine the intraobserver reliability on intra-articular portion of the grafts [Intraclass correlation, ICC $_{(1,\ \ 3)}$]. To assess the intraobserver reliability, three measurements were performed by a single observer at intervals of 1 week. Based on the CT results, the group with bone tunnel communication was defined as Group C, and the group without bone tunnel communication was defined as Group N. Clinical outcomes and graft evaluations on MRI were compared between the two groups.

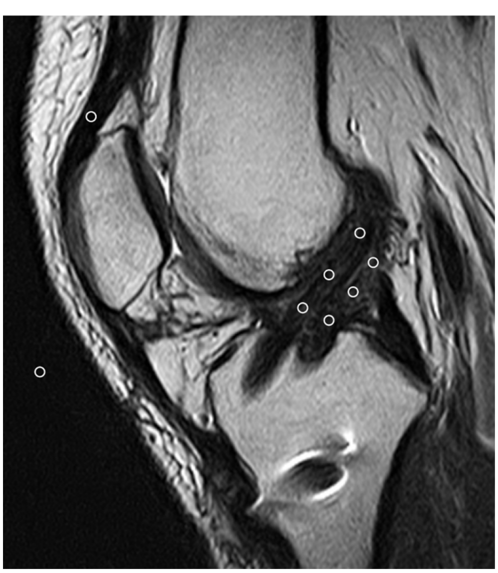

Figure 2. Evaluation of the graft on magnetic resonance imaging. Magnetic resonance image showing the positions of the five regions of interest (white circles) that include the distal third, middle third, proximal third, quadriceps tendon, and 2 cm anterior to the patellar tendon.

*Postoperative management*

The postoperative rehabilitation protocols were similar for all patients. After surgery, the knee was immobilised with a brace for the $1^{st}$ week. Full-weight bearing was allowed after 4 weeks and running was allowed after 12 weeks. Return to competitive sports that involved jumping, sidestepping, or pivoting was allowed after 8 months.

*Statistical analysis*

The statistical analyses were performed using SPSS (version 15.0; SPSS Inc., Chicago, IL, USA). Student *t* tests were used to evaluate continuous valuables like clinical outcome. $\chi^2$ tests were used to evaluate the categorical variables like the presence of bone tunnel communication and the results of the pivot-shift test. The results are reported as mean ± standard deviation. The level of significance was set at $p < 0.05$. Power analysis was performed using G*Power 3 (Heinrich-Heine Universität, Düsseldorf, Germany)[12] with 80% power, an alpha of 0.05, an effect size 0.8, and a 1:1 allocation of the patients. The results indicated that 26 patients per group were needed.

## Results

*Participants*

Fifty-two patients (52 knees) were enrolled. The patients comprised 34 men and 18 women, with a mean age of 30.7 ± 11.9 years (range, 13−60 years) at the time of surgery.

The injuries were acute in 37 knees (i.e., surgeries were performed < 4 months after injury) and chronic in 15. The average interval between injury and surgery was 28 months (range: 21 days–25 years). The most common causes of injury were accidents while playing soccer (12 knees), volleyball (9 knees), and basketball (5 knees). Overall, 46 of the 52 injuries were classified as sports-related. Grade 1 or 2 medial collateral ligament injuries were associated with five knees.

### *Results of the clinical assessments*

The clinical outcomes of all patients are shown in Table 1. In terms of International Knee Documentation Committee classification, all patients were classified into Groups C and D before surgery, but at 1 year follow-up, 94% patients were classified into Groups A and B. The anterior laxity measured with a KT-1000 arthrometre improved at 1 year after surgery. Most of the patients showed good results at the 1-year evaluation.

### *CT results*

One knee (1.9%) had bone tunnel communication at the femur and 16 (30.8%) at the tibia ($p < 0.001$). Additional analyses were performed on the tibial tunnels because femoral bone tunnel communication was observed in only one case. The mean length of bone tunnel communication at the tibia was 9.3 ± 8.2 mm (range, 5.0–18.6 mm). The majority of the lengths of bone tunnel communication were < 10 mm. The distributions of the lengths of the tibial bone tunnel communications are shown in Figure 3. Based on the CT evaluation results, 16 cases were classified into Group C and 36 cases were classified into Group N. The demographic information of the two groups is shown in Table 2. There were no significant differences in patient demographics between the two groups.

### *MRI results*

The intraobserver reliability of the MRI graft valuations was good or excellent (Table 3). The results of the evaluations are shown in Table 4. For the AM grafts, there were no

Table 1
Pre- and postoperative clinical outcomes.

| | Preoperation | Postoperation |
|---|---|---|
| Lysholm score | 69.5 ± 34.2 | 94.8 ± 8.5 |
| Tegner activity score | 6.1 ± 2.6 | 5.8 ± 2.7 |
| IKDC | | |
| A | 0 | 37 |
| B | 0 | 12 |
| C | 40 | 3 |
| D | 12 | 0 |
| Anterior laxity [a] | 6.7 ± 2.2 | 0.78 ± 1.7 |
| Pivot shift test (+), *n* | 47 | 4 |

Data are presented as mean ± standard deviation.
IKDC = International Knee Documentation Committee (objective).
[a] Anterior laxity: side-to-side differences measured with a KT-1000 arthrometer (mm).

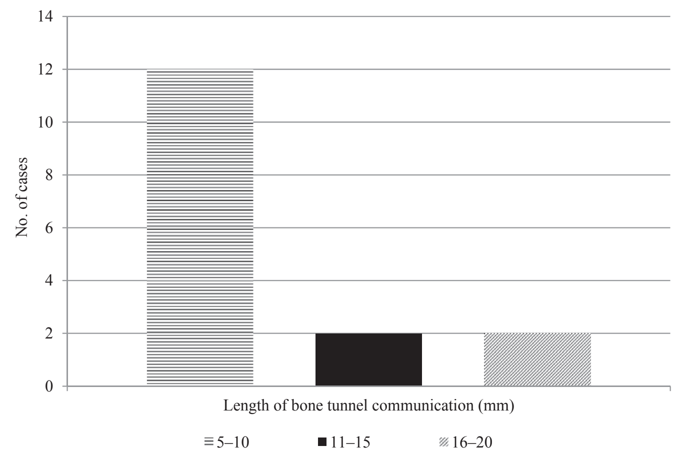


Figure 3. Length of bone tunnel communications at the tibia as measured on computed tomography.

Table 2
Demographics of the patients in Groups C and N.

| | Group C (*n* = 16) | Group N (*n* = 36) | *p* |
|---|---|---|---|
| Sex | | | 0.83 |
| Female | 5 | 13 | |
| Male | 11 | 25 | |
| Age (y) | 32.6 ± 14.3 | 29.9 ± 10.9 | 0.45 |
| BMI, kg/m$^2$ | 25.1 ± 6.0 | 22.8 ± 3.0 | 0.074 |
| Time from injury to surgery (mo) | 9.3 | 12.4 | 0.13 |
| Meniscus injury, *n* | | | |
| Non | 6 | 18 | |
| Medial | 4 | 10 | |
| Lateral | 5 | 8 | |
| Medial + lateral | 1 | 0 | |

Data are presented as mean ± standard deviation.
BMI = body mass index.

Table 3
Intraobserver reliability of graft evaluation (signal/noise quotients) of the intra-articular portions on magnetic resonance imaging.

| | Anteromedial bundle | | | Posterolateral bundle | | |
|---|---|---|---|---|---|---|
| Location [a] | Proximal | Middle | Distal | Proximal | Middle | Distal |
| $ICC_{(1,3)}$ | 0.93 | 0.85 | 0.91 | 0.79 | 0.91 | 0.92 |

$ICC_{(1,3)}$ = interclass coefficient.
[a] Location: to analyse the graft quality, the signal/noise quotients were calculated using the region of interest technique at three zones, i.e., proximal, middle, and distal regions of the graft on sagittal-oblique sections.

Table 4
Signal-to-noise quotients of the grafts.

| | Group C | Group N | *p* |
|---|---|---|---|
| AM proximal | 0.87 ± 1.44 | 1.36 ± 1.33 | 0.24 |
| AM central | 1.08 ± 1.53 | 1.1 ± 1.45 | 0.94 |
| AM distal | 1.17 ± 1.92 | 1.87 ± 2.54 | 0.33 |
| PL proximal | 2.68 ± 2.21 | 2.05 ± 2.0 | 0.32 |
| PL central | 2.44 ± 2.2 | 1.91 ± 1.58 | 0.34 |
| PL distal | 3.91 ± 5.81 | 1.33 ± 1.46 | 0.015 |

Data are presented as mean ± standard deviation.
AM = anteromedial bundle; PL = posterolateral bundle.

Table 5
Clinical outcomes of Groups C and N.

| | Group C | Group N | $p$ |
|---|---|---|---|
| | ($n = 16$) | ($n = 36$) | |
| Lysholm score | | | |
| Preoperation | 66.9 ± 3.55 | 69.8 ± 17.8 | 0.57 |
| Postoperation | 95.0 ± 8.5 | 95.9 ± 4.17 | 0.58 |
| Tegner activity score | | | |
| Preoperation | 6.1 ± 1.5 | 6.1 ± 1.3 | 0.84 |
| Postoperation | 6.1 ± 0.91 | 5.6 ± 1.5 | 0.30 |
| IKDC (A + B), $n$ | 14 | 35 | 0.16 |
| Anterior laxity[a], mm | 0.93 ± 1.25 | 0.63 ± 1.78 | 0.54 |
| Pivot-shift test (+), $n$ | 0 | 4 | 0.16 |

Data are presented as mean ± standard deviation.
IKDC = International Knee Documentation Committee (objective).
[a] Anterior laxity: side-to-side differences measured with a KT-1000 arthrometer (mm).

significant differences between Groups C and N. However, SNQs in the distal portions of the PL grafts were significantly higher in Group C than in Group N, and the mean SNQ values in the proximal and central portions tended to be higher in Group C than in Group N.

*Relationship of bone tunnel communication with clinical outcome*

The results of the clinical outcome comparison between Groups C and N are shown in Table 5. There were no significant differences between the groups in any of the evaluations. We performed further analysis of the comparison of SNQ between pivot-shift test (+) cases and (−) cases in Group N. Mean SNQ in the PL graft tended to be higher in pivot-shift test (+) cases, but the numbers in pivot-shift test (+) cases were small (Table 6).

## Discussion

Our study demonstrated that intraoperative bone tunnel communication at the tibia in anatomic DB ACL reconstruction did not affect clinical outcome at 1 year after surgery. However, in the distal portions of the PL grafts, SNQs were significantly higher in Group C than in Group N, which suggests that bone tunnel communication affected the graft remodelling procedures in the PL grafts. These findings confirmed our hypothesis.

In our study, bone tunnel communication was observed in 1.9% of the cases at the femur and in 30.8% of the cases at the tibia. Siebold and Cafaltzis[9] reported that bone tunnel communication that occurred during surgical drilling was observed in 23.8% of cases at the tibia, but in no cases at the femur. This overall incidence was smaller than ours, but bone tunnel communication tended to be more prevalent at the tibia which was consistent with our findings. There are several reasons why bone tunnel communication occurs more frequently at the tibia than at the femur. Firstly, the surgeon is able to observe the femoral bone tunnel position clearly and can reference the lateral intercondylar ridge when creating femoral bone tunnels.[1] Secondly, it is difficult to observe the intra-articular outlet of the PL tunnel through the anterior portal when a remnant of the ACL of the tibial insertion is present. Lastly, in our cases, the anatomic reconstructions that created bone tunnels within the footprints were carefully intended. We speculate that the SNQs of the PL grafts were increased in Group C because in anatomic DB ACL reconstruction, PL graft plays an important role in the nearly extension position[13] to restrict internal rotatory load and PL graft is more stretched. Yasuda et al[14] reported that the length changes of the PL grafts during knee motion were greater than those of the AM grafts. Tanaka et al[15] reported the results of second look arthroscopy after triple-bundle ACL reconstruction. They showed that about 10% of cases showed PL graft rupture. They concluded that the PL graft is under high stress condition. Based on the analysis of the comparison of SNQ in Group N, mean SNQs of pivot-shift test (+) cases were higher than in the pivot-shift (−) cases. This fact also supports that the PL graft is under high stress condition (Table 6).

There are some published reports regarding the size of the ACL footprint.[16] Assuming that the diameter of the tunnel for an AM graft is 6 mm, the diameter of the tunnel for a PL graft is 5 mm, and a 2-mm bony bridge is included between the tunnels, the necessary total anteroposterior diameter for a successful procedure should be ≥13 mm. Kopf et al[4] and Hussein et al[17] reported that when the anteroposterior diameter of the insertion of the ACL is < 14 mm, a single-bundle ACL reconstruction should be performed rather than a DB procedure. This may be a good decision to prevent bone tunnel communication.

In DB ACL reconstruction, the use of interference screws also causes bone tunnel communication during surgery because the bone tunnels are in close proximity and their diameters are smaller than that of a single-bundle procedure. In our procedure, we did not use an interference screw. Surgeons should take care with the use of interference screws in DB ACL reconstruction.

Hantes et al[8] reported that bone tunnel communication at the tibia was observed in only one of 32 cases and was not

Table 6
Signal-to-noise quotients of anteromedial and posterolateral graft in pivot-shift test (+) and (−) cases in Group N.

| Portion of the graft | AM | | | PL | | |
|---|---|---|---|---|---|---|
| | Proximal | Central | Distal | Proximal | Central | Distal |
| PS (−) cases ($n = 32$) | 1.39 ± 1.43 | 1.14 ± 1.52 | 1.53 ± 2.13 | 1.81 ± 1.99 | 1.8 ± 1.65 | 1.2 ± 1.39 |
| PS (+) cases ($n = 4$) | 0.86 ± 1.03 | 0.96 ± 0.99 | 2.11 ± 1.64 | 3.0 ± 0.73 | 2.41 ± 1.34 | 2.3 ± 1.02 |

AM = anteromedial; PL = posterolateral; PS = pivot-shift test.

observed in any cases at the femur. In their study, CT was performed 17 months after surgery, and bone tunnel communications included those that occurred during surgery and those that occurred owing to tunnel enlargement after surgery. The frequency of bone tunnel communication reported by Hantes et al[8] was very small. They used special tools (anatomic aimers) to create bone tunnels, and based on the low rate of communication, concluded that the tools were useful. However, based on a postoperative three-dimensional CT figure in that article, the bone tunnels were placed at nonanatomic positions.

Kiekara et al[10] observed bone tunnel communication in 10% of patients at the femur and in 15% of patients at the tibia. These authors also reported on the relationship between MRI bone tunnel communication findings and clinical outcome. These authors found no relationship between the signal intensity of the graft and the clinical outcome. In their report, grafts were evaluated subjectively by examiners on MRI. By contrast, in our study, we used the SNQ to more objectively evaluate the grafts.[18] Although the methods of evaluation were different, their results indicated that bone tunnel communication did not affect clinical outcome and were congruent with ours.

Evaluating the ACL graft by using MRI has been controversial.[18–24] However, evaluation with MRI is noninvasive and convenient. In some reports on the ACL graft evaluation by MRI,[21,23,25] the grafts were evaluated subjectively by examiners. To evaluate the graft more objectively, some researchers reported usefulness of SNQ.[10,18,19,26] Weilar et al[18] demonstrated that SNQ of the graft on MRI had a negative correlation with biomechanical parameters.

The bone tunnel enlargement that occurs after ACL reconstruction is one of the causes of bone tunnel communication. In our study, only bone tunnel communication that occurred during surgery was investigated. Siebold[27] reported that the ratios of bone tunnel enlargement were 43% for each individual tibial bone tunnel and 35% and 48% for the AM and PL femoral bone tunnels, respectively. In our study, the ratio of bone tunnel communication increased when bone enlargement was considered.

There are several limitations to our study. Firstly, the number of patients was small as indicated by the statistical power by *post hoc* test of 0.74. Secondly, we were not able to evaluate the interobserver reliability concerning MRI graft evaluations. Thirdly, MRI evaluations were performed 6 months after surgery, whereas the clinical assessments were performed 1 year after surgery, resulting in a gap between the times of the evaluations. We believe that despite these limitations, the results of our study reveal important information on the clinical effects of bone tunnel communication that should be considered in plans for the future direction of ACL surgery.

In conclusion, bone tunnel communication did not affect clinical outcome 1 year after surgery but bone tunnel communication affected the remodelling procedure of the PL graft.

## Conflicts of interest

The authors declare that they have no conflicts of interest.

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