

Comparison of Rotatory Stability After Anterior Cruciate Ligament Reconstruction Between Single-Bundle and Double-Bundle Techniques

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Abstract

Background: Controversy persists as to whether double-bundle reconstruction of the anterior cruciate ligament (ACL) has any clinical advantage over single-bundle reconstruction. Several studies have utilized subjective and non-quantitative manual tests to evaluate the rotatory stability of the knee. We have developed a method to quantitate the rotatory stability of the ACL-deficient knee using open magnetic resonance imaging (MRI).

Hypothesis: Anatomic double-bundle reconstruction restores rotatory stability significantly better than does single-bundle reconstruction.

Study Design: Cohort study.

Methods: Twenty-three consecutive patients treated with the single-bundle reconstruction and 25 consecutive patients treated with the anatomic double-bundle reconstruction were evaluated. Both reconstruction procedures were performed using hamstring tendon autografts. The Slocum anterolateral rotatory instability (ALRI) test was performed one year after surgery using open MRI. To assess rotatory stability, we measured the difference in anterior tibial translation between medial and lateral compartments in the sagittal plane and defined this difference as the ALRI value. Additionally, clinical examinations consisting of the Lysholm knee score, Tegner activity score, KT-2000 anterior translation examination, and the pivot-shift test were carried out.

Results: The mean side-to-side difference in ALRI values was significantly less ($p < .001$) in

double-bundle reconstruction (mean: 1.2 mm) than in single-bundle reconstruction (mean: 4.1 mm). The mean side-to-side difference in KT-2000 measurements was significantly less ($p = .014$) in double-bundle reconstruction (mean: 1.2 mm) than in single-bundle reconstruction (mean: 2.6 mm). The difference in the incidence of positive pivot-shift tests between Group S (43%) and Group D (16%) did not reach the level of statistical significance ($p = .058$). No significant differences in Lysholm score or Tegner score between the groups were observed.

Conclusions: The rotatory stability of anatomic double-bundle reconstruction was significantly better than the rotatory stability of single-bundle reconstruction.

Key Terms: anterior cruciate ligament; single-bundle reconstruction; anatomic double-bundle reconstruction; rotatory stability; quantitative assessment

"What is known about this subject"

Controversy persists as to whether double-bundle ACL reconstruction is superior to single-bundle reconstruction with respect to rotatory stability.

"What this study adds to existing knowledge"

The rotatory stability of anatomic double-bundle reconstruction was significantly better than the rotatory stability of single-bundle reconstruction.

INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction is recognized as the standard treatment for ACL rupture. Detailed studies of the functional anatomy of the ACL have contributed to progressive improvements in ACL reconstruction surgical techniques.^{3,4,33,34} For instance, the femoral tunnel is now being placed in a more anatomic position rather than in the classical high noon position in the single-bundle technique, now that kinematic studies have proven that an obliquely placed graft tolerates better the rotatory force applied to the tibia than does a graft placed in the high noon femoral tunnel.¹¹

Additionally, multiple kinematic studies examining the function of the anteromedial (AM) and posterolateral (PL) ACL bundles suggest a theoretical advantage to double-bundle ACL reconstruction.^{4,14,29,33} Because the PL bundle reportedly bears approximately 30-40% of the combined rotatory and valgus forces on the ACL at low flexion angles, reconstruction of the PL bundle would be expected to improve the rotatory stability of the knee.^{4,27} Despite the publication of several papers comparing the clinical results of single-bundle and double-bundle reconstruction,^{8,10,15,16,18,19,22,32} controversy persists as to whether double-bundle reconstruction has any clinical advantage over single-bundle reconstruction. Some reports claim improved anterior and rotatory stability with double-bundle reconstruction,^{10,16,19,32} but other reports identify no significant differences.^{8,15,18,22} These studies clinically evaluated rotatory stability by subjective

and non-quantitative manual tests, such as the pivot-shift test. More rigorous assessment would require an objective method of evaluation.

We have reported on a method of quantitative assessment of rotatory stability using an open magnetic resonance imaging (MRI) system¹⁷ that enables quantitation of the anterolateral rotatory instability (ALRI) of the tibia in 10 degree of flexion with high reproducibility. Tashiro *et al.* reported that this method successfully quantified residual ALRI in ACL-reconstructed knees and demonstrated a strong correlation with the grading of the pivot-shift test with the tester blinded to the results of the ALRI value.²³

In this study, we employed our open MRI assessment method to quantitatively compare postoperative rotatory stability of single-bundle reconstruction *versus* anatomic double-bundle reconstruction. Our study hypothesis was that anatomic double-bundle reconstruction yields significantly better rotatory stability than does single-bundle reconstruction. We first compared rotatory stability over our entire study population and then compared ALRI values in the subset of patients who regained successful anterior stability in order to assess the incidence of residual rotatory instability. We also confirmed that differences in rotatory stability were not affected by the difference in gender distribution between the two study cohorts.

MATERIAL AND METHODS

Subjects

We conducted a prospective cohort study in consecutive patients undergoing ACL reconstruction *via* medial hamstring tendons performed by the same well-trained surgical team (KO, HM, SM) since 2005. Patients with significant preoperative or postoperative injuries to other knee ligaments (*e.g.*, medial collateral ligament, posterior cruciate ligament, posterolateral corner) or to articular cartilage on either side of the knee were excluded from this study. Patients who had undergone previous operations on either side of the knee also were excluded from the study.

Between January 2005 and June 2007, 28 consecutive patients, all females, underwent single-bundle reconstruction with medial hamstring tendons at our institution. The reason this cohort consisted of only female patients is that during this period, we used medial hamstring tendons only in female patients and used patellar tendon grafts in male patients. Among these 28 patients, one patient who later underwent ACL reconstruction in the contralateral knee was excluded from this study and four (15%) were lost to follow-up. Thus a total of 23 patients (85%) comprised the single-bundle reconstruction group (Group S).

After we discovered that some patients treated with single-bundle reconstruction had persistent rotatory instability despite their having regained sufficient anterior stability, we decided to change from single-bundle to double-bundle reconstruction. Between July 2007 and June 2009, 26 consecutive patients underwent anatomic double-bundle reconstruction at our hospital, among whom one (4%) was lost to follow-up. Thus a total of 25 subjects (96%) comprised the anatomic

double-bundle reconstruction group (Group D, male/female ratio: 8/17). Ethical approval was obtained from the Internal Review Board, and all patients gave their informed consent before they entered the study.

In Group S, average time from injury to operation was 6.0 months (range: 1 to 68 months). The group included four (17%) medial meniscal injuries (one partial meniscectomy and three repairs) and four (17%) lateral meniscal injuries (one untreated, one partial meniscectomy, and two repairs). In Group D, average time from injury to operation was 5.6 months (range: 1 to 32 months). The group included four (15%) medial meniscal injuries (two partial meniscectomies and two repairs) and five (20%) lateral meniscal injuries (one untreated, one partial meniscectomy, and three repairs). Table 1 lists patient characteristics.

All patients in both groups underwent the same rehabilitation program, in which they started passive range-of-motion exercises on the first postoperative day. Range-of-motion was restricted to less than 120 degrees of flexion for the first two weeks after surgery. Partial weight-bearing walking was started one week after surgery and increased gradually. Full weight-bearing walking was allowed starting at four weeks. Patients wore a hard brace (DonJoy knee brace, DJO Inc, Vista, CA, USA) while walking for the first three months. Jogging was started at four months and the running speed gradually increased. Full sports activities were allowed after nine months.

Surgical Techniques

Patients first underwent diagnostic arthroscopy through lateral infrapatellar portals with a 30-oblique arthroscope. If the arthroscopy detected meniscal injuries requiring surgery, we performed partial meniscectomy or meniscal repair depending on the type of tear. Next, we harvested the semitendinosus tendon through a 4 cm oblique longitudinal incision at the level of the *pes anserinus*. In single-bundle reconstruction, we quadrupled the semitendinosus tendon to make a graft of at least 7 mm in diameter and 60 mm in length. In anatomic double-bundle reconstruction, we cut the tendon in half to make two double-looped grafts at least 5 mm in diameter and 60 mm in length. In both reconstructions, if the semitendinosus tendon did not provide enough graft material, we also used the gracilis tendon. Among the 23 single-bundle reconstructions, 11 were performed with ST alone and 12 with ST/G. Among the 25 double-bundle reconstructions, 14 were performed with ST alone and 11 with ST/G. In both procedures, we connected an Endo-button CL (Smith & Nephew Endoscopy, Andover, MA, USA) to the proximal loop end and armed the distal free ends of the tendons with No.2 Ethibond sutures using the Krackow suture technique.

In single-bundle reconstruction, we created the tibial tunnel in the center of the ACL footprint using a tibial drill guide system with an angle of 50 degrees to the horizontal plane. We then drilled the femoral tunnel into the lateral femoral condyle at the 1:30 o'clock position for left knees (10:30 o'clock for right knees) with the knee in 90 degrees of flexion, using the transtibial tunnel

technique (Figure 1). After securing the graft onto the femur with Endo-button CL, we fixed the graft onto the tibia with a double-spike plate (Meira, Nagoya, Japan), applying an initial tension of 40 N to the graft at 10 degrees of knee flexion.

In the anatomic double-bundle reconstruction, we drilled two tibial tunnels for the AM and PL bundles at the center of each bundle footprint on the tibia. We first created a tibial tunnel for the PL bundle at the center of the tibial footprint, located at a point approximately 5 mm anterior to the posterior cruciate ligament, using a tibial drill guide system set at an angle of 45 degrees to the horizontal plane. We next drilled a tibial tunnel for the AM bundle at the center of the tibial footprint which was aligned with the anterior horn of the lateral meniscus,³⁵ using a tibial drill guide system set at an angle of 50 degrees to the horizontal plane. We then created two femoral tunnels for the AM and PL bundles at the center of each bundle footprint on the lateral femoral condyle using the transtibial technique (Figure 1). When drilling transtibially at the center of each bundle footprint on the femur was difficult during double-bundle reconstructions, we drilled through the far anteromedial portal. On the tibial side, we fixed the two grafts with two double-spike plates after securing the grafts with Endo-button CL on the femur, applying an initial tension of 20 N to each graft at 10 degrees of knee flexion.

Clinical Evaluations

Patients in Group S underwent clinical evaluations at an average of 13.6 months (range: 8 to 26

months) after surgery *versus* an average of 12.3 months (range: 8 to 14 months) in Group D. The Lysholm knee score¹³ was recorded as a general knee assessment, and the Tegner activity score²⁵ was used to evaluate sports activities. Side-to-side differences in anterior tibial translation were evaluated with a KT-2000 arthrometer (MEDmetric, San Diego, CA, USA) at 30 degrees of knee flexion under an anterior drawer force of 133 N. The pivot-shift test was performed by one well-trained clinician other than the chief surgeon and graded as negative (-), glide (+), clunk (++), or gross (+++). The clinical examiner was blinded to the results of the open MRI studies of rotational stability.

Evaluation of ALRI

To evaluate ALRI, we performed the Slocum ALRI test²⁰ to stress tibial rotation anteriorly and internally, using a horizontal open MRI at 0.4 Tesla (APERIO, Hitachi Medical Corporation, Tokyo, Japan). With the subject lying on the unaffected side in a semilateral recumbent position (Figure 2), we placed a custom-made cushion on the subject's back so that the torso and pelvis were at a 30 degrees angle from the surface of the table. On the affected side, we rested the medial side of the foot on a pad and positioned the knee in 10 degrees of flexion and hanging freely. This external position in turn places the tibia internally at about a 50 degree angle relative to the pelvis and allows the knee to sag into valgus. The hip and knee joints of the unaffected side were flexed slightly to stabilize this posture. The examiner stood behind the subject and

placed his hands on the distal femur and proximal tibia. To increase the stress forcing the tibia to rotate anteriorly and internally, the examiner pushed the fibular head anteriorly with his thumb (Figure 3).

The knee under stress was scanned in the sagittal plane. When scanning the knee under stress, the image plane was adjusted to a sagittal orientation using the Interactive Scan Control (ISC) software.¹⁷ ISC determines the image plane interactively on the basis of fluoroscopy images displayed on a user interface with an update time, including scan time, of 2 seconds. The user is able to change the image plane, oblique angle, phase encoding direction and contrast parameters during the scan. We measured the distance between the tangent lines of the posterior femoral condyle and tibial condyle on the sagittal images at the center of the lateral compartment and medial compartment (Figure 4). The landmarks for the center of the lateral compartment and medial compartment were the medial edge of the fibular head and the attachment of the medial head of the gastrocnemius, respectively. We calculated the difference in anterior tibial translation between lateral and medial compartments (lateral minus medial) and defined this difference as the ALRI value (mm). To assess rotatory stability, we evaluated the side-to-side difference in ALRI values. Although the high reproducibility of this method has been previously published¹⁷, we assessed them in this study again. To analyze the intraobserver reproducibility, the same clinician calculated ALRI values twice at monthly intervals. To evaluate

the interobserver reproducibility, ALRI values were measured by two clinicians blinded to the results of the physical examination.

Additionally, in order to compare rotatory stability between the patients in each group who successfully regained anterior stability, we evaluated ALRI values in patients with side-to-side differences in anterior tibial displacement less than 2 mm. Furthermore, since the gender distribution was different in the two groups, we also compared ALRI values between only the female patients in both groups.

Statistics

The Mann-Whitney U test was used to compare continuous data between the two groups. The Chi-square test and Fisher exact test were used to analyze categorical variables. The level of statistical significance was set at $p < .05$. To evaluate the intraobserver and interobserver variability of the MRI measurements, an interclass correlation coefficient was used, and values greater than 0.7 were considered to be in good agreement. All analyses were performed using JMP version 7.0.1 (SAS institute Inc. Cary, NC, USA).

RESULTS

No serious intraoperative or postoperative complications occurred in either group, including tunnel malposition, graft fixation failure, iatrogenic cartilage injury, infection, fracture, extension or flexion deficit of knee joint, and deep vein thrombosis.

Mean postoperative Lysholm scores were 96.0 ± 4.3 points (range: 84 to 100) in Group S *versus* 97.1 ± 2.8 points (range, 91 to 100) in Group D ($p = .741$). Mean postoperative Tegner activity scores were 5.7 ± 1.3 points (range: 4 to 9) in Group S *versus* 5.7 ± 1.0 points (range: 4 to 8) in Group D ($p = .942$). Both sets of scores showed no significant difference between the two groups. No significant differences were observed between preinjury and postoperative Tegner scores in both single-bundle ($p = .222$) and double-bundle ($p = .496$) reconstructions (Table 2).

Mean side-to-side differences in anterior tibial translation measured with the KT-2000 arthrometer were 2.6 ± 1.9 mm (range: -0.4 to 7.5 mm) in Group S *versus* 1.2 ± 2.2 mm (range: -2.2 to 8.1 mm) in Group D (Table 2). Anterior stability was significantly better in Group D than in Group S ($p = .014$). The use of ST alone *versus* ST/G for the grafts did not affect the results for anterior stability in either group ($p = .428$ in group S and $p = .592$ in group D).

Results of the pivot-shift test were as follows: 57% negative (-), 39% glide (+), and 4% clunk (++) in Group S *versus* 84% negative (-), 16% glide (+), and 0% clunk (++) in Group D. No patient in either group received a grade of gross (+++) (Table 2). The difference in incidence between the two techniques did not reach statistical significance ($p = .058$).

Mean side-to side differences in ALRI values were 4.1 ± 3.1 mm (range: -1.7 to 9.6 mm) in Group S *versus* 1.2 ± 1.7 mm (range: -1.3 to 6.4 mm) in Group D ($p < .001$), indicating that

group D yielded significantly better rotatory stability than Group S (Table 2, Figure 5). The use of ST alone *versus* ST/G for the grafts did not affect the results for rotatory stability in either group ($p = .612$ in group S and $p = .376$ in group D). The interclass correlation coefficient between two calculations of ALRI values by the same clinician was .94 with a mean difference of 0.6 ± 0.4 mm. The interclass correlation coefficient between two measurements of ALRI values by two different clinicians was .90 with a mean difference of 0.9 ± 0.6 mm.

Additionally, in order to compare rotatory stability between the patients in each group who successfully regained anterior stability, we evaluated ALRI values in patients with side-to-side differences in anterior tibial displacement less than 2 mm: 15 patients in Group S and 19 patients in Group D. Among this patient subset, mean side-to-side differences in ALRI values were 3.6 ± 3.0 mm in Group S *versus* 1.1 ± 1.8 mm in Group D, a significant difference ($p = .003$).

Furthermore, since the gender distribution was different in the two groups, we also compared ALRI values in female patients only: 23 in Group S and 17 in Group D. Among the female patients, mean side-to-side differences in ALRI values were 4.1 ± 3.1 mm in Group S *versus* 1.5 ± 1.9 mm in Group D, again a statistically significant difference ($p = .006$).

DISCUSSION

Our study findings demonstrated that double-bundle reconstruction produced biomechanical results superior to single-bundle reconstruction with respect to anterior and rotatory stability.

Several other research groups have reported similar results.^{10,16,32} Yasuda *et al.*'s 2-year follow-up results showed that anatomic double-bundle reconstruction yielded significantly better anterior stability measured with a KT-1000 arthrometer and significantly better rotatory stability evaluated with the pivot-shift test than single-bundle reconstruction.³² Kondo *et al.* also compared these two procedures, employing the transtibial technique, and had similar findings.¹⁰ Siebold *et al.* reported that double-bundle reconstruction with the transtibial and transportal techniques was superior to single-bundle reconstruction in both anterior and rotatory stability.¹⁹ Aglietti reported on a randomized controlled study comparing the clinical results of these two procedures, employing the outside-in technique. Over a two-year minimum follow-up period, anterior laxity was significantly less after double-bundle reconstruction than after single-bundle reconstruction.² In addition, comparison of the incidence of a residual pivot-shift test following double-bundle reconstruction (14%) *versus* the incidence following single-bundle reconstruction (26%) showed a trend favorable to double-bundle reconstruction ($p = .08$), although the difference in incidence between the two techniques did not reach statistical significance. In these studies, rotatory stability was evaluated by a non-quantitative manual test - the pivot-shift test – which is a subjective test whose outcome may differ between examiners. Our study thus had the advantage that we were able to demonstrate better rotatory stability in the double-bundle group using a quantitative method. Other methods have been proposed for a

rigorous assessment of rotatory stability.^{5-7,24} Yagi *et al.* have performed a quantitative analysis of rotatory stability with three-dimensional electromagnetic sensors.²⁸ They reported that double-bundle reconstruction showed better rotational stability than either single-bundle anteromedial reconstruction or single-bundle posterolateral reconstruction. One difference from our study is that Yagi *et al.* used a novel device that they had developed themselves to measure the acceleration of the femur during the pivot-shift test to evaluate the dynamic motion of an ACL deficient knee, whereas our study evaluated the residual static rotatory translation of the tibia using open MRI, which is widely available. Using a computer navigation system, Song *et al.* found that double-bundle reconstruction produced better intraoperative rotatory stability than single-bundle reconstruction, although they cautioned that intraoperative findings might not correlate with postoperative results.²¹

Our study not only documented more rotatory stability following double-bundle reconstruction than following single-bundle reconstruction, but it also documented significantly less anterior laxity following double-bundle reconstruction. The question then arises whether anterior laxity might influence rotatory instability. A previous study by our research group (Tashiro *et al.*²³) provides an answer: we found that side-to side differences in anterolateral tibial translation had no correlation with the KT-2000 arthrometer measurements, suggesting that the ALRI measured by our method represented a different kind of instability that the KT-2000 arthrometer did not

detect. Furthermore, our analysis of patients who successfully regained anterior stability (*i.e.* a side-to-side difference in anterior tibial displacement < 2.0 mm) revealed that the ALRI values were also significantly smaller following double-bundle reconstruction than following single-bundle reconstruction. Together, these findings demonstrate that the superior rotatory stability which we observed following double-bundle reconstruction compared with single-bundle reconstruction was independent of changes in anterior stability. Therefore, quantitative assessment of rotatory stability is important to evaluating the function of the affected knee, even if the knee has satisfactorily regained anterior stability.

Our determination that anatomic double-bundle reconstruction provides a significant advantage in rotational stability compared with single-bundle reconstruction could possibly be attributed to the existence of a PL graft and an advantage in graft maturation. Several biomechanical studies determined that the PL bundle is important as a stabilizer against internal rotatory loads.^{4,29,33} In particular, Gabriel *et al.*⁴ and Zantop *et al.*³³ both reported that the PL bundle made a significant contribution to rotational stability, especially near full extension. With respect to graft maturation, double-bundle reconstructions are thought to have an advantage over single-bundle reconstructions because of the larger contact area between graft and the bone tunnel wall.

Several published studies have found in double-bundle reconstructions that the surface of the graft was anchored to the bone tunnel wall by collagen fibers and that revascularization occurred

more rapidly.^{12,26,30,31} In addition, double-bundle reconstructions may prevent excessive stress from being place on one bundle by dividing the stress load between two bundles. For these reasons, double-bundle reconstructions are better with respect to graft maturation than single-bundle reconstructions.

Our study did include several limitations. The first limitation is the difference in the male-to-female ratio between the two groups that arose because we performed single-bundle reconstruction *via* medial hamstring tendons only for women, whereas the reconstruction in men was *via* the bone-patellar tendon-bone. In contrast, we performed anatomic double-bundle reconstruction *via* medial hamstring tendons in both men and women. We therefore performed a separate females-only comparison of ALRI values in order to compensate for the substantial difference in gender distribution between the two study groups. As described earlier, mean ALRI values for the females of Group D were significantly smaller than those for the females of Group S. Moreover, several published studies have also reported no significant difference between male and female patients with respect to side-to-side differences in anterior tibial translation and in the pivot-shift test. Muneta *et al.* reported no gender differences with respect to KT-1000 arthrometer measurements and the pivot-shift test within the single-bundle and double-bundle reconstruction groups separately, or when both groups were combined into a single group.¹⁶ Aglietti *et al.* reported that they had found no differences between men and women in any of the

subjective or objective outcome measurements that they analyzed.¹ Therefore, despite the difference in gender distribution between our study groups, we would maintain that our findings still indicate that rotatory stability was significantly better following anatomic double-bundle reconstruction than following single-bundle reconstruction.

A second limitation of our study finding relates to the reliability of our ALRI measurements.

Okazaki *et al.* examined the reproducibility of ALRI measurements under the manual stress and obtained high intraobserver reproducibility and high interobserver reproducibility.¹⁷ In our study, we also evaluated the intraobserver and interobserver reproducibility of our calculation of ALRI values and demonstrated a high interclass correlation coefficient.

A third limitation relates to the follow-up periods for the two groups. The 1-year mean follow-up period among our study patients was too short to be able to make a final determination of clinical outcomes. Additionally, the range of follow-up periods in the single-bundle reconstruction group was wider (8 to 26 months) than the range in the double-bundle group (8 to 14 months). This difference in ranges may influence the observed clinical results and scores.

The last limitation of our study is that our single-bundle reconstruction technique involved placing the femoral tunnel close to the center of the AM bundle using the transtibial technique, which has been widely used in the last decade. However, the most current single-bundle technique is to create the femoral tunnel at the center of the femoral ACL footprint using a tibial

tunnel-independent technique. A more anatomical graft placement may improve rotatory stability even with the single-bundle technique.^{9,11} Our study thus demonstrates the advantage of double-bundle reconstruction only in comparison with conventional single-bundle reconstruction using the transtibial technique.

CONCLUSION

We quantitatively compared rotatory stability between single-bundle reconstruction and anatomic double-bundle reconstruction using open MRI. Our study analysis demonstrated by quantitative evaluation using open MRI that anatomic double-bundle reconstruction was significantly better than single-bundle reconstruction with respect to both rotatory stability and anterior stability.

Although the clinical scoring methods, specifically the Lysholm score and the Tegner score, did not show significant differences between the techniques, the physical measurements of our study suggest that the more normal stability obtained by double-bundle reconstruction results in more normal functioning of the affected knees, which in turn should help prevent subsequent complications, such as recurrence of knee instability, secondary meniscus tear, articular cartilage damage, or osteoarthritis.

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Legends

Figure 1. CT images of femoral tunnel (A) single-bundle reconstruction (B) double-bundle reconstruction

Figure 2. With the subject lying on the table on the unaffected side, the torso and pelvis are maintained at a 30 degrees angle from the surface of the table, and the medial side of the foot in the affected side is placed on a pad so that the tibia rotates internally with the knee positioned in 10 degrees of flexion and allowed to sag into valgus.

Figure 3. The examiner places his hands on the distal femur and proximal tibia and pushes the fibular head anteriorly with his thumb to stress the tibia rotating anteriorly and internally.

Figure 4. (A) MRI image of the lateral compartment in the sagittal plane. (B) MRI image of the medial compartment in the sagittal plane. The distance between the tangent lines on the posterior aspect of the femoral and tibial condyle was calculated. The medial edge of the fibular head is used as a landmark for the center of the lateral compartment. The attachment of the medial head of the gastrocnemius is used as a landmark for the center of the medial compartment.

Figure 5. Comparison of side-to-side differences in ALRI values between Groups S and D. The mean side-to-side differences in ALRI values in Group S were significantly larger than those in Group D ($p < .001$). Error bars represent standard deviation.

TABLE 1.**Patient data**

	Group S (n=23)	Group D (n=25)	Significance
Age at surgery (years, range)	26 (15-41)	27 (14-37)	$p = .591$
Male/female ratio	0/23	8/17	$p = .004$
Side (right/left)	9/14	10/15	$p = .951$
Time from injury to operation (months, standard deviation)	6.0 (5.6)	5.6 (3.1)	$p = .741$
Time from operation to follow-up (months, standard deviation)	13.6 (4.5)	12.3 (1.9)	$p = .587$
Meniscal surgery			
number of partial meniscectomies	2 (9%)	3 (12%)	$p = .708$
number of meniscal repairs	5 (22%)	5 (20%)	$p = .882$

TABLE 2.

Comparisons of Clinical Outcomes between Group S and Group D

	Group S (n=23)	Group D (n=25)	Significance
Lysholm knee score			
preoperative	64.8 ± 9.6	66.9 ± 8.4	<i>p</i> = .426
postoperative	96.0 ± 4.3	97.1 ± 2.8	<i>p</i> = .741
Tegner activity score			
preinjury	6.3 ± 1.0	6.1 ± 0.9	<i>p</i> = .898
postoperative	5.7 ± 1.3	5.7 ± 1.0	<i>p</i> = .942
Anterior side-to side difference	2.6 ± 1.9 mm	1.2 ± 2.2 mm	<i>p</i> = .014
Pivot-shift test			<i>p</i> = .058
(-)	13 patients (57%)	21 patients (84%)	
(+)	9 patients (39%)	4 patients (16%)	
(++)	1 patient (4%)	0 patient (0%)	
(+++)	0 patient (0%)	0 patient (0%)	
Mean side-to-side difference in	4.1 ± 3.1 mm	1.2 ± 1.7 mm	<i>p</i> < .001
ALRI values			

Figure 1

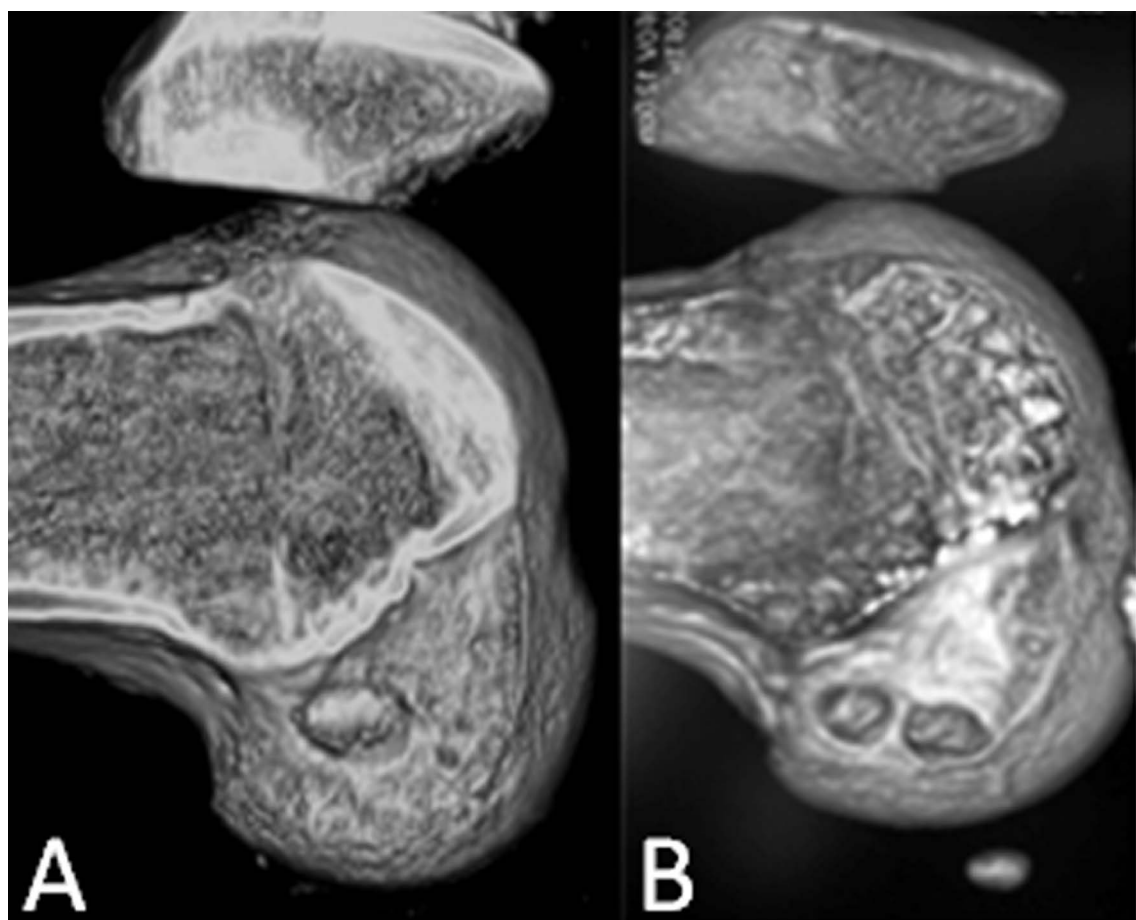


Figure 2



Figure 3



Figure 4

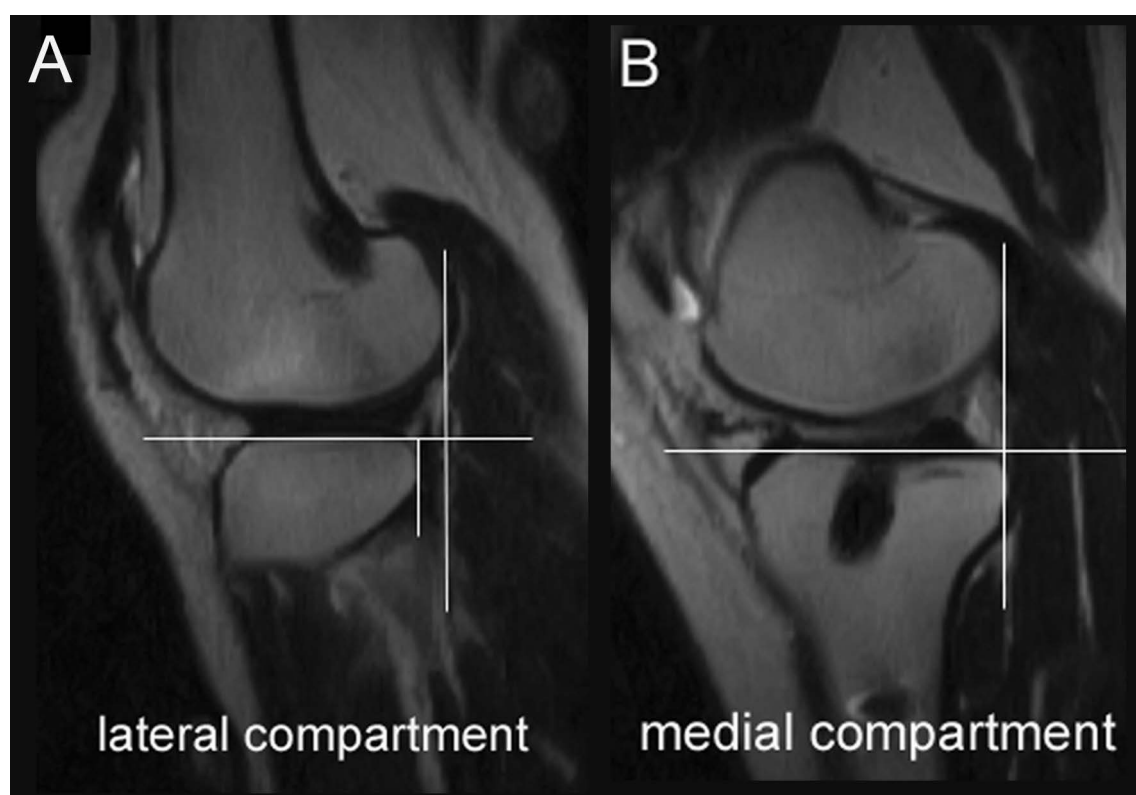


Figure 5

