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Evaluation of the Bone Bridge Between the Bone Tunnels After Anatomic Double-Bundle Anterior Cruciate Ligament Reconstruction

A Multidetector Computed Tomography Study

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Background: Double-bundle anterior cruciate ligament (ACL) reconstruction is a technically demanding procedure; it requires drilling 2 tibial and 2 femoral tunnels. Tunnel communication, whether intraoperative or postoperative, is a serious complication: It jeopardizes knee stability and graft function.

Hypothesis: During double-bundle ACL reconstruction, special aimers would be helpful to avoid intraoperative bone bridge fracture. The bone bridge between the bone tunnels would maintain its structural integrity, and no tunnel communication would be observed postoperatively because of tunnel widening.

Study design: Case series; Level of evidence, 4.

Methods: This prospective study included 32 patients undergoing double-bundle ACL reconstruction. A multidetector computed tomography study was performed at a mean of 17 months postoperatively. The thickness of the bone bridge between the bone tunnels was measured in the femoral and tibial sides on an axial and sagittal plane, respectively, at 3 locations: the level of the joint line, the midportion of the bone bridge, and the base of the bone bridge. The bone density of the bone bridge was measured in Hounsfield units in the same locations. Bone density of the anterior tibial cortex and lateral femoral condyle was measured for comparisons.

Results: Tunnel communication occurred intraoperatively in 1 patient on the tibial side at the level of the joint line. In the rest of the patients, a well-defined triangular bone bridge was present between the 2 tunnels in the femoral and tibial sides. The thickness at the apex of the bone bridge was 2.0 and 2.2 mm for the femur and tibia, respectively. In addition, the density of the bone bridge at its apex was similar to that of cortical bone.

Conclusion: This study demonstrated that double-bundle ACL reconstruction, as used with anatomic aimers, produces a low rate of tunnel convergence. The bone bridge remains intact postoperatively, although it is thin at the level of the joint line.

Keywords: double-bundle anterior cruciate ligament reconstruction; 3-dimensional computed tomography; tunnel communication; tunnel enlargement

The anatomy of the anterior cruciate ligament (ACL) was described many years ago by Palmer[18] and later by other authors.[8,11,14,24] According to these studies, the ACL consists of 2 bundles: the anteromedial (AM) and the posterolateral (PL). With the conventional ACL reconstruction (single-bundle technique), the AM bundle is mostly restored, which might explain the 10% to 30% failure

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rate after single-bundle ACL reconstruction.[3,10,15] To replicate the double-bundle anatomy of the ACL, the anatomical double-bundle ACL reconstruction technique has been developed over the past decade.[2,5,27] Biomechanical studies have shown that knee kinematics are better restored with the double-bundle technique when compared with the single-bundle technique.[26] In addition, better clinical results have been reported with the double-bundle versus single-bundle ACL reconstruction.[15,17,23,28] These studies have a short-term follow-up; thus, studies with a long-term follow-up are needed to prove the theoretical superiority of the double-bundle ACL reconstruction.[16]

The double-bundle technique is technically more demanding and has a risk for more complications when compared with the single-bundle technique. One of the complications directly associated with the double-bundle technique is communication of the femoral or tibial tunnels. This complication can occur either intraoperatively (because of a technical error) or postoperatively because of tunnel enlargement. Siebold[22] found tunnel communication on the tibial side in 41% of double-bundle cases using magnetic resonance imaging (MRI) as an evaluation method. The author reported that the results were not influenced by tunnel communication. According to several authors, it is imperative to prevent tunnel convergence for a separate graft-bundle function (AM and PL).[6,20] In addition, revision surgery would be difficult after double-bundle ACL reconstruction in the case of tunnel communication.

The aim of this prospective study was to evaluate if there is any tunnel communication between the AM and PL bundles in both the femoral and tibial sides after double-bundle ACL reconstruction. Our initial hypothesis was that the use of special tools (anatomic aimers) would be helpful for the surgeon to avoid bone bridge fracture. Given that no tunnel communication occurred intraoperatively (because of tunnel drilling), our secondary hypothesis was that the bone bridge between the bone tunnels would maintain its structural integrity over time and no tunnel communication would be observed postoperatively because of tunnel widening or screw contact. A multidetector computed tomography (MDCT) was chosen as the most accurate imaging modality for depicting and measuring the osseous structures[1,21] with additional application of multiplanar reconstructions and quantitative analysis of the cancellous mineral density.

MATERIALS AND METHODS

Study Design

The senior author (M. E. H.) started the procedure of double-bundle ACL reconstruction in our department in January 2005. All patients included in this study were operated on between March 2006 and June 2007. These procedures were therefore performed after surgical experience had been gained and not during the learning period. The inclusion criteria were as follows: rupture of the ACL in the affected knee, no previous knee surgery, no other knee ligament injury, skeletal maturity, and patient's agreement to have a postoperative MDCT of the operated knee. Institutional review board approval was obtained before initiation of the study, and each patient provided informed consent for participation. Forty consecutive patients underwent ACL reconstruction with the double-bundle technique during this period. Eight of them were not included in the study because they refused to undergo a MDCT postoperatively. The remaining 32 patients constitute the sample of this report. Clinically, patients were evaluated preoperatively and postoperatively with the Lysholm and Tegner knee scores and the IKDC (International Knee Documentation Committee) evaluation form; joint laxity was assessed with the KT-1000 arthrometer.

Operative Technique

The double-bundle technique used in this study has been described by Christel et al,[6] using hamstring tendon autografts and anatomic aimers (Smith & Nephew Endoscopy, Andover, Massachusetts) to create 2 femoral and 2 tibial tunnels. Fixation was performed with an EndoButton CL device (Smith & Nephew Endoscopy) on the femoral side and interference screws on the tibial side. A single surgeon operated on all patients. The semitendinosus and gracilis tendons were harvested through a 2.5-cm longitudinal incision 3 cm medial and distal to the tibial tubercle, with the knee flexed to 90°. A standard anterolateral portal was used for diagnostic arthroscopy and an AM portal as a working portal. The ACL stump was removed at the tibial and femoral footprints with arthroscopic scissors and a full radius shaver. The femoral tunnel for the AM bundle was created first through the AM portal (with the knee flexed between 110° and 120°) using an endoscopic femoral guide (Smith & Nephew Endoscopy) with an appropriate offset; a 2.4-mm guide wire was then drilled through both cortices. A cannulated 4.5-mm drill was advanced over the pin, and both cortices were drilled. A drill with the same diameter as the AM bundle was then used to create a socket at a depth that depended on the length of the tunnel. The typical length of the EndoButton for the AM bundle was 20 mm. An accessory AM portal was then created with the aid of a spinal needle, and the arthroscope was inserted through the AM portal. With the knee flexed at 130°, the special PL femoral aimer (ACUFEX Anatomic ACL Guide System, Smith & Nephew Endoscopy) was introduced through the accessory AM portal into the joint. The tip of the aimer carries interchangeable posts with a diameter that ranges between 6 mm and 9 mm. The post with the corresponding diameter (size of the AM tunnel) is adjusted to the aimer (Figure 1). The tip of the aimer, which is 25 mm long and diverges 15° from the shaft, was fully introduced into the AM tunnel. The aimer was rotated until the laser mark was aligned with the center of the PL bundle and a 4.5-mm drill bit was drilled through both cortices. A drill with the same diameter as the PL bundle was then used to create a socket at a depth that depended on the length of the tunnel. A careful inspection of the bone bridge between the 2 tunnels with the arthroscope in the AM portal was carried out to ensure

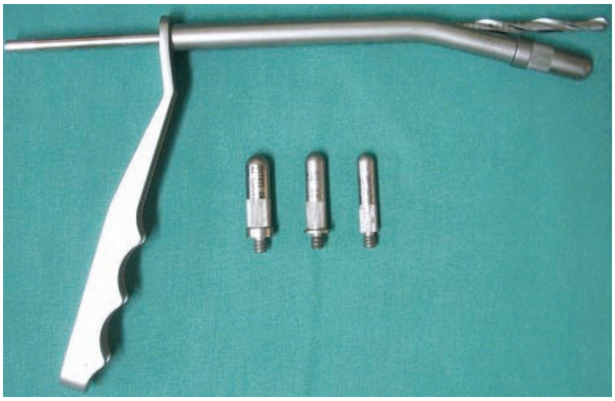

Figure 1. The femoral aimer used for the posterolateral tunnel. The interchangeable posts are shown separately (6 mm, 7 mm, and 8 mm). The 9-mm post is attached to the tip of the aimer. A 4.5-mm solid drill is passed through the cannulated shaft of the aimer to the center of the posterolateral tunnel.

that no tunnel communication occurred. The typical length of the EndoButton loop for the PL bundle was 15 mm. The tibial tunnels were then created with the knee flexed at 90°. An endoscopic aimer (ACUFEX Director ACL Drill Guide, Smith & Nephew Endoscopy) was inserted into the knee through the AM portal and adjusted to 50° with the tip of the guide positioned on the center of the AM bundle. A 2.4-mm drill-bit guide wire was advanced into the joint, and a cannulated drill bit corresponding to the diameter of the AM bundle was used to create the AM tibial tunnel. For the PL tunnel, the anatomic PL tibial guide (ACUFEX Anatomic ACL Guide System, Smith & Nephew Endoscopy) was used to place the guide pin in the center of the PL bundle. The guide consists of a handle on which interchangeable posts can be fixed (with diameters ranging from 6 mm to 9 mm) and a lateral flange with a guide pin sleeve (Figure 2). The post with the corresponding diameter (size of the AM tunnel) was then introduced into the AM tunnel. The tip of the guide pin sleeve was placed at the anterior edge of the superficial fibers of the medial collateral ligament. A 2.4-mm guide wire was then inserted through the guide pin sleeve into the joint in the center of the PL bundle. Finally, a cannulated drill bit corresponding to the diameter of the PL bundle was used to create the PL tibial tunnel. Before graft insertion, the arthroscope was introduced in the AM and PL tunnels to ensure that no tunnel communication was present. The 2 grafts were inserted into the joint, and femoral fixation was achieved by flipping the EndoButtons and tibial fixation with interference screws (BIORCI-HA, Smith & Nephew Endoscopy).

Rehabilitation

Rehabilitation protocol was the same for all patients. Free active knee motion without limitation of flexion was permitted after surgery. The patients were recommended to use crutches for 2-3 weeks postoperatively. Weightbearing

Figure 2. The tibial aimer used for the posterolateral tunnel. The interchangeable posts (6 mm, 8 mm, and 9 mm) are shown separately. The 7-mm post is attached to the handle of the aimer. A 2.4-mm guide wire is inserted through the guide pin sleeve into the joint to the center of the posterolateral bundle.

was allowed as tolerated. Intensive physiotherapy including isotonic and closed chain exercises was started after 2 weeks. Running was permitted after 3 months and contact sports after 6 months.

Computed Tomography Protocol and Measurements

For all examinations, we used a 16-row multislice computed tomography (CT) scanner (Light Speed GE Medical Systems, Milwaukee, Wisconsin). The knee was placed in full extension. A continuous scan was obtained from the top of the patella down to the tibial proximal metaphysis with a small field of view restricted to the area to be examined, a collimation of 16 × 0.625 mm and a short pitch of 0.562 (5.62 mm per rotation). The tube parameters were 120 kVp and 200 mA. The acquisition matrix was 512 × 512. The 0.625-mm sections were secondarily reconstructed with a bony algorithm (increment, 0.3 mm) to allow multiplanar reconstructions (1-mm thickness per 2-mm interval) from the axial data set. Coronal reconstructions were performed to a level parallel to a line joining the posterior femoral condyles; sagittal reconstructions were performed to a level parallel to the outer rim of the lateral femoral condyle. Three-dimensional images were also reconstructed in soft tissue algorithm using the volume-rendering technique.

On all 3 plane data sets, the following measurements were performed: The bony bridge between the tunnels in the femoral and tibial sides was measured regarding its thickness using 2-dimensional images. Assessment was performed on coronal images for the femur and on sagittal images for the tibia at 3 locations: level of the joint line,

Figure 3. Appearance of the bone bridge at the femoral side after double-bundle anterior cruciate ligament reconstruction. Measurement of the thickness of the bone bridge was performed at 3 locations.

midportion as shown on either coronal or sagittal reconstructions, and base of the bone bridge (Figures 3 and 4). In addition, the thickness of the bone bridge at its apex was measured using the volume-rendering technique (3-dimensional; Figure 5). The bone density of the bone bridge was measured in Hounsfield units (HU) in the same locations. Bone density of the anterior tibial cortex, lateral femoral condylar cortex, and adjacent cancellous area were measured for comparison. Finally, the length of the AM and PL tunnels was measured in the coronal and sagittal reconstructions for the femur and tibia, respectively. All measurements were performed by an experienced musculoskeletal radiologist (A.H.K). A subset of 15 CT images was randomly selected and reviewed by a second observer to determine interobserver variability.

Statistics

Analysis of variance was used to compare the density among areas of the bone bridge, cortical bone, and adjacent cancellous bone in the femur and the tibia. The paired *t* test was used for comparison of the preoperative and postoperative Lysholm and Tegner scores and KT-1000 arthrometer measurements. Finally, the Wilcoxon signed rank test was used for comparison of the preoperative and postoperative IKDC classification and pivot-shift results. Significance was set at $P < .05$.

RESULTS

All patients were men, with a mean age of 23.5 years (range, 18 to 28 years). Mean height was 181 ± 8 cm and

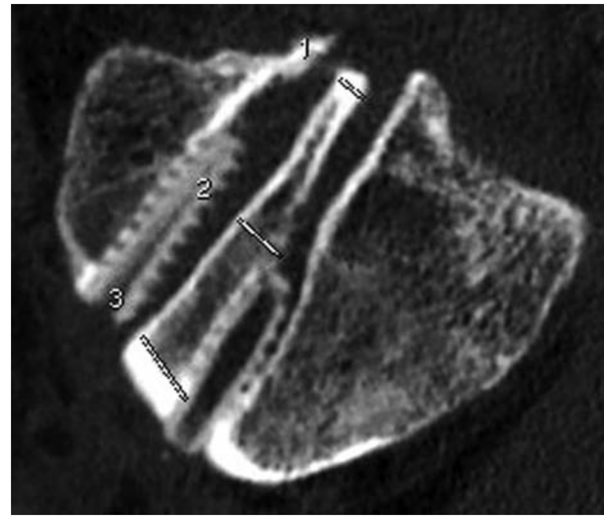

Figure 4. Appearance of the bone bridge at the tibial side after double-bundle anterior cruciate ligament reconstruction. As with the femoral side, measurement of the thickness of the bone bridge was performed at 3 locations.

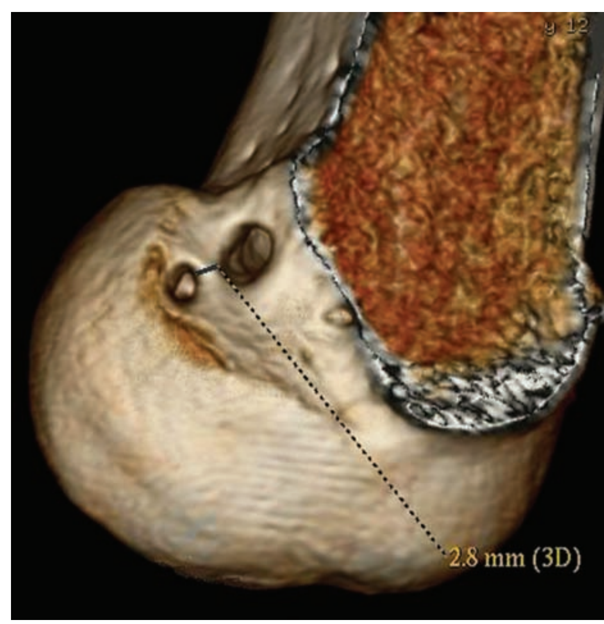

Figure 5. Measurement of the bone bridge at the femoral side using the volume-rendering technique (3-dimensional). In this case, the thickness of the bone bridge was 2.8 mm.

mean weight was 83 ± 13 kg. The mean body mass index of our study population was 25.3 ± 2.6. The mean follow-up period from the date of surgery to the CT study was 17.3 months (range, 14 to 26 months). No tunnel communication was observed on the femoral side in any patient. In 1 patient, tunnel communication caused by intraoperative error (bone tunnel drilling) was observed on the tibial side at the level of the joint line. Computed tomography measurements were not performed in this patient in the

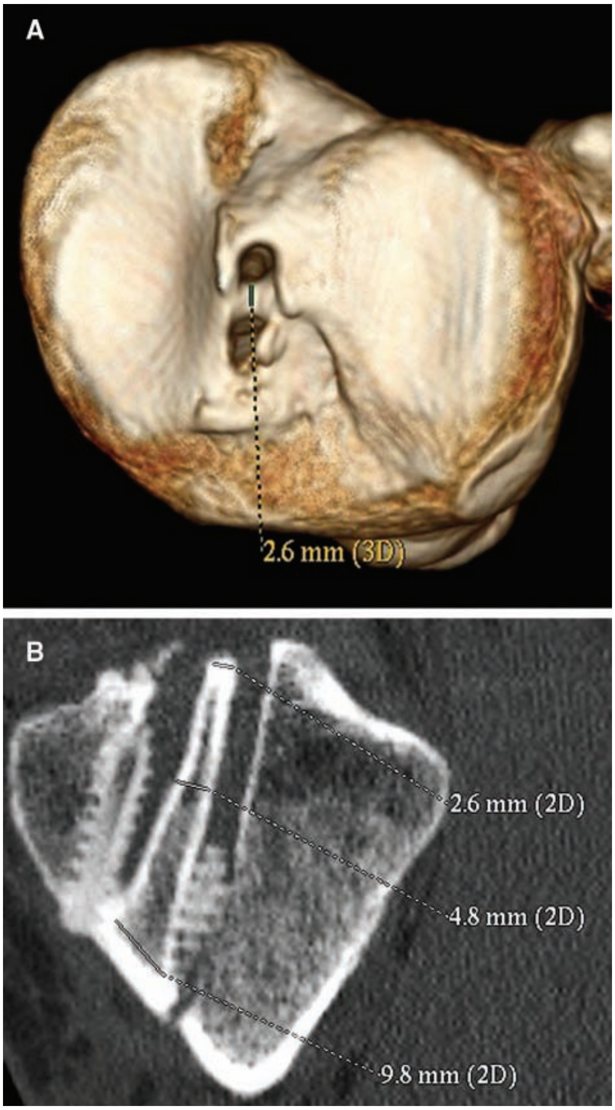

Figure 6. A, measurement of the bone bridge at the tibial side using the volume-rendering technique (3-dimensional). B, measurement with the 2-dimensional technique (same patient). In this case, the thickness of the bone bridge measured 2.6 mm with both techniques.

tibial side. The CT confirmed that the bone bridge between the AM and PL bundles was triangular on the femoral and tibial sides. On the femoral side, the mean thickness of the bone bridge at the level of joint line was 2.2 ± 0.9 mm, whereas on the tibial side, the mean thickness of the bone bridge at the level of joint was 2.0 ± 1.2 mm (Figure 6). There were no differences between the volume-rendering technique and the 2-dimensional technique. As expected, the bone bridge was thicker at its base on the femoral and tibial sides (Table 1).

The bone bridge at the level of the joint (ie, the apex of the bone bridge) was significantly thicker (more dense) than the midportion and base of the bone bridge in both the femur and the tibia (Figures 7 and 8). The density of the bone bridge apex on the tibia and the femur was close to that of the anterior tibial cortex and the lateral femoral condyle cortex, respectively (Table 2). In contrast, the bone density at the level of the midportion and base of the bone bridge of both the femur and tibia was close to the density of the adjacent cancellous bone. The mean length of the AM femoral tunnel was 44.2 mm (38.6 to 49.2) whereas the mean length of the PL femoral tunnel was 37.7 mm (33.1 to 41.3). The mean length of the AM tibial tunnel was 40.6 mm (39.5 to 49.2) whereas the mean length of the PL tibial tunnel was 44.1 (41.3 to 51.6). Finally, the interobserver variability for measurements was excellent, and intraclass correlation coefficient was .90, with a confidence interval of 0.85 to 0.93.

TABLE 1
Thickness of the Bone Bridge of the Femur and Tibia at 3 Locations (in mm)

	Femur		Tibia	
	Mean ± SD	Range	Mean ± SD	Range
Joint line	2.2 ± 0.9	1.6-3.3	2.0 ± 1.2	1.4-3.1
Midportion	5.2 ± 2.3	3.5-7.1	4.2 ± 1.9	2.9-5.7
Base	11.4 ± 4.5	7.3-14.6	9.4 ± 3.9	5.9-12.1

From a clinical point of view, patients improved significantly according to KT-1000 arthrometer results and the Lysholm and Tegner knee scores (Table 3). The median IKDC classification significantly improved from a preoperative C to a postoperative A ($P < .001$, Wilcoxon). Similarly, the median pivot-shift test significantly improved from a preoperative 2 (clunk) to a postoperative 0 (absent; $P < .001$, Wilcoxon).

DISCUSSION

The most difficult part of the double-bundle ACL reconstruction technique is to create 2 tunnels in the femur and tibia and keep an intact bone bridge between them. We agree with Christel et al[6] that the use of anatomic aimers is of great help to avoid a bone bridge fracture and tunnel communication. In our study, an intact bone bridge was always present in the femoral side of all patients and in the tibia side of all but one patient. Our initial hypothesis was therefore confirmed: The use of special tools is helpful to avoid bone bridge fracture. According to the manufacturer, the design of the aimers is such that the thickness of the bone bridge is between 2 mm to 3 mm, as confirmed by our results in the femoral and tibial sides. We believe that even for experienced surgeons the use of aimers is helpful because it makes the procedure easy and reproducible.

A common finding after ACL reconstruction with hamstring tendons is that of tunnel enlargement. An increase of 40% to 100% of the initial tunnel diameter has been reported because of tunnel widening in single-bundle ACL reconstruction.[9,12,19,25] As such, tunnel widening after a properly performed double-bundle ACL procedure with hamstring tendons could cause tunnel communication

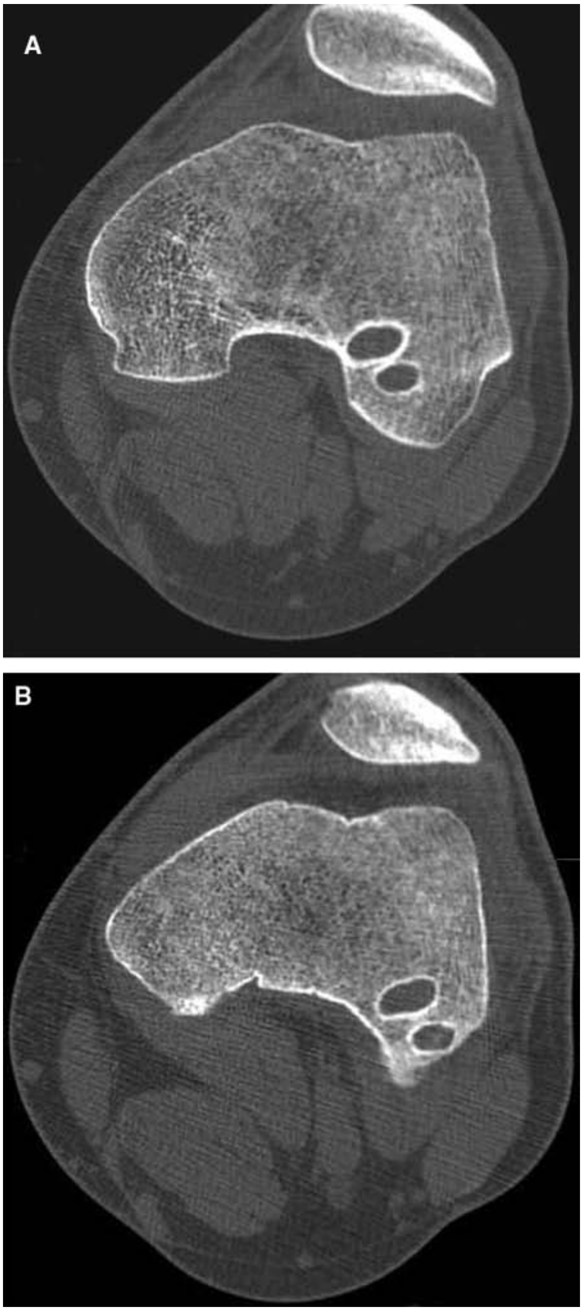

Figure 7. A, axial cut of the femur at the level of the joint line, which shows the 2 tunnels abutting each other with sclerotic borders. B, in contrast, the bone density between the tunnels at the level at the midportion of the bone bridge is similar to that of the surrounding cancellous bone.

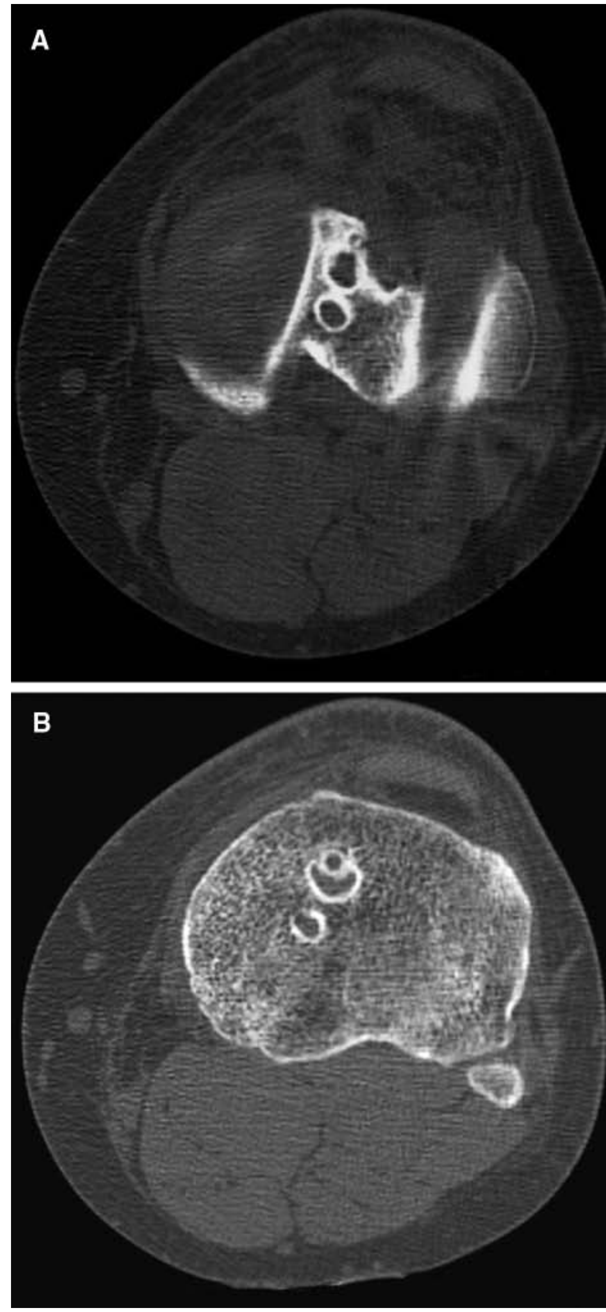

Figure 8. A, axial cut of the tibia at the level of the joint line; note the high density of the bone between the 2 tunnels. B, in contrast, the bone density between the tunnels at the level of the midportion of the bone bridge is similar to the surrounding cancellous bone.

on either the tibial or the femoral side. This complication jeopardizes graft function and knee stability, to which revision surgery would be difficult.[6,20] In our study, the bone bridge between the tunnels on the femoral and tibial sides was intact, except when violated intraoperatively, and no tunnel communication was observed more than 1 year postoperatively. Similarly, Järvelä et al[13] using MRI found no new tunnel communication between the AM and PL bundle tunnels in both the femur and the tibia, although all 4 tunnels had a large amount of tunnel enlargement. In contrast, Siebold[22] using MRI found tunnel communication on the tibial side in 41% of his patients after double-bundle ACL reconstruction. It is not clear from his study if this communication resulted because of postoperative tunnel enlargement or intraoperative tunnel drilling. In contrast to Siebold's study, our study

TABLE 2
Mean Density of the Bone Bridge of the Femur and Tibia (in Hounsfield Units)

	Apex	Midportion	Base	Cortical Bone	Adjacent Cancellous Bone
Tibia					
Mean	910	340	410	980	375
Range	780-1070	240-480	280-510	830-1180	250-460
P^a		.013	.020	.347	.017
Femur					
Mean	880	365	405	1010	390
Range	730-1050	250-500	270-490	880-1250	260-480
P^a		.027	.031	.232	.023

[a] *P* value for each location compared with apex.

TABLE 3
Clinical Results

	Preoperative	Postoperative	P
Lysholm knee score	62 ± 14	92 ± 9	.001
KT-1000 arthrometer[a] (mm)	6.3 ± 2.8	1.1 ± 1.9	.003
Pivot-shift			
0, absent	0	27	
1, glide	9	5	
2, clunk	23	0	
IKDC[b]			
A, normal	0	24	
B, nearly normal	1	7	
C, abnormal	28	1	
D, severely abnormal	3	0	
Tegner score	3.1 ± 1.4	7.1 ± 1.8	.001

[a] Measurement with the KT-1000 arthrometer as side-to-side difference at manual maximum.
[b] International Knee Documentation Committee.

observed no postoperative tunnel communication among the 32 patients.

Another possible risk factor for tunnel communication on the tibial side is related to screw insertion. As shown by Buelow et al,[4] insertion of a bioabsorbable interference screw increases the bone tunnel diameter by compressing the cancellous bone. Therefore, a safe distance between the 2 tibial tunnels (base of the bone bridge) should be preserved to withstand these compression forces. The base of the bone bridge in our study was approximately 1 cm, which indicates a safe distance. In addition, with proximal convergence of the bone bridge on the tibial side, it is possible, with long screws, to violate the bone bridge close to the joint line where the bone bridge is thin. According to our results, the length of the AM and PL bone tunnels on the tibial side was 40.6 mm and 44.1 mm, respectively. This means that insertion of a 25-mm screw does not interfere with at least the last 15 mm of the bone bridge, which is the "sensitive" thin area.

According to some studies, tunnel enlargement occurs between the tip of the screws and the joint line on the tibial side.[22] According to our results, this area of the bone bridge is thin (2 mm to 4 mm). We found that the density of the bone bridge at its apex (the level of the joint line) on the femoral and tibial sides was close to that of the cortical bone. The strong bone in this area is probably a preventive factor for tunnel communication.

As has been demonstrated by many studies, the majority (75%) of tunnel widening occurs during the first 3 to 6 months, with no significant change after this period.[9,12,19,25] In the present study, the timing of the CT evaluation was selected to be at least 1 year postoperative, given that tunnel widening is established during this period. The MDCT with isotropic resolution was chosen as the most accurate imaging method to assess the morphology of the bridge lying between the 2 tunnels and to quantitatively measure the density of its osseous structure. Basdekis et al[1] already applied MDCT to evaluate and validate the positions of the femoral tunnels after ACL double-bundle reconstruction. They found that the thickness of the bone bridge at the level of the joint line was 2.9 mm, which is similar to our findings.

A limitation of our study was the lack of a group undergoing the procedure based on a freehand technique for direct comparison. Another limitation is that only male patients were evaluated because at that time the senior author chose to perform this procedure mainly in soccer players. Perhaps the results regarding tunnel communication would be different if female patients with smaller knees were included in our study. A final limitation is related to the CT technique and the quantitative analysis method regarding the quality of the osseous structures of the bone bridge: First, the cortex is a small structure, and reproducibility might be suboptimal. Second, the quantitative CT needs a soft tissue algorithm and a phantom to correct for photon statistical variations.[7] However, to make our technique as simple as possible for other studies to follow, we thought that the error induced from the small region of interest would be the same for the cortex of the bridge as for the cortex of compared structures. In addition, the error of measuring on the bone algorithm images in the order of 5 HU to 10 HU would not be significant if we consider that the average density of the cortical bone was more than 800 HU. This error would be the same for both regions of measurements; thus, it was practically negligible.

CONCLUSION

The technique for double-bundle ACL reconstruction, as used in the present study with anatomic aimers, results in a low rate of intraoperative tunnel communication. Postoperatively, the bone bridge maintains its structural integrity, and although thin, it is dense at the level of the joint line on both the femoral side and the tibial side.

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