Visualization of torn anterior cruciate ligament using 3-dimensional computed tomography

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Abstract

Recently, a remnant-preserving anterior cruciate ligament (ACL) reconstruction technique has been developed. However, the pre-operative condition of remnant ACL is occasionally difficult to evaluate by magnetic resonance imaging. The purpose of this study is to evaluate the accuracy of pre-operative visualization of remnant ACL using three-dimensional computed tomography (3D-CT). The remnant ACL in 25 patients was examined by 3D-CT before ACL reconstruction surgery. Findings on 3D-CT images and arthroscopy were compared. The 3D-CT images were classified into 4 groups: Group A, remnant fibers attached to the posterior cruciate ligament (PCL); Group B, those located between the PCL and the lateral wall; Group C, those attached to the lateral wall; and Group D, no identifiable remnant fibers on the tibial side. These groups were made up of 4, 3, 9 and 9 patients, respectively. Findings on 3D-CT images were identical to those during arthroscopy in 20 of 25 cases (80%). Remnant ACL can be accurately evaluated using 3D-CT in 80% of cases of torn ACL. This novel method is a useful technique for pre-operative assessment of remnant ACL.

Introduction

Considerable progress has been made in the treatment of the anterior cruciate ligament (ACL)-deficient knee, and many successful outcomes have been reported. Recently, a remnant-preserving technique has been developed. Since remnant tissues contain mechanoreceptors and proprioceptive nerve fibers, this technique may contribute to better recovery in revascularization that may provide better stability recovery and better proprioceptive function recovery for a reconstructed ACL.[1-5] Remnant-preservation may be technically difficult since most of the remnant ACL is usually removed to clearly visualize the femoral entry point and tibial footprint.[6] Special techniques are required for the better visualization of the ACL insertion during remnant-preserving surgery.[3,7] If possible, surgeons want to know the condition of the ACL remnant, and particularly the relationship between the remnant and the ideal bone tunnel position in detail by pre-operative imaging examination. However, the features of remnant fibers as depicted by MRI, which is currently in common use, occasionally differ from those observed during arthroscopic surgery.[8]

Three-dimensional computed tomography (3D-CT) imaging is a useful technique for the evaluation of various soft tissues such as the bronchus, the vasculature, the gastrointestinal tract, and the bladder, and is also valuable for the detection of the relationship between soft tissues and bones.[9,10] In 2002, Irie and Yamada first demonstrated that this technique can allow visualization of the ACL in a 3D form and can accurately detect ACL injuries.[9] Regrettably, details of the pattern of the remnant fibers might not be sufficiently well described by their 3D-CT images. In the present study, we attempted to visualize the features of the tibial side of the remnant ACL fibers using 3D-CT and compared them with the arthroscopic findings. The purpose of this study was to show our results and discuss the possible clinical benefits of 3D-CT on remnant ACL fibers.

Materials and Methods

The study protocol was approved by the ethics committee of our institute (n. 75-2012). Written informed consent for the use of data in the study was obtained from all patients. This study included 25 consecutive patients who underwent ACL reconstruction surgery between July 2011 and August 2012 at our institute. All patients who showed positive Lachmann and pivot-shift were evaluated for study inclusion. MRI was then performed to confirm a torn ACL. If a homogenous low-signal intensity spanning the intercondylar notch continuously from origin to insertion of ACL was absent, variable, non-homogenous, or showed an abnormal origin or insertion,[11] patients were diagnosed as having a torn ACL and they were included in the present study.

There were 8 males and 17 females with an average age of 21 years (range 14-58). In all patients, the epiphyseal growth plates of the femur and tibia had already closed. They were examined using a CT scanner (Light Speed Ultra; GE Healthcare, USA) an average 9 weeks (range 1-39 weeks) after the ACL injury. The date of injury in 5 cases was uncertain. The following CT imaging variables were used: 120 kVp, reconstructed slice width of 1.25 mm, helical pitch 15, beam pitch 0.93, and rotation time 1 s. Data were transferred using the Dicom system (Times Medical, USA), and Advantage Workstation version 4.2. (GE Healthcare) was then used to create the 3D-CT images. The threshold was set at 50-105 Hounsfield units (HU) for the ligament tissues, and the ligament and remnant fibers were then described by the automatic object selection program in Advantage Workstation. These images were combined with 3D bone images, allowing visualization of ACL from any direction required. Figure 1 shows ACL and posterior cruciate ligament (PCL) of a normal knee demonstrating the anteromedial and posterolateral ACL bundles separately.

In the present study, the remnant of the tibial side of the ruptured ACL was evaluated using 3D-CT images and was classified into 4 groups: Group A, remnant fibers attached to PCL; Group B, remnant fibers located between PCL and the lateral wall; Group C, remnant fibers attached to the lateral wall; Group D, no identifiable remnant fibers detected on the tibial aspect (Figure 2).

Arthroscopic ACL reconstruction was performed using the semitendinosus tendon with

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or without the gracilis tendon at an average of 12 weeks after ACL injury (range 4-40 weeks) and at an average of 12 days (range 1-39 days) after the 3D-CT examination. During surgery, arthroscopic findings of the remnant ACL on the tibial aspect were observed and classified into 4 groups according to the report by Crain:[12] Group 1, scarring to PCL ligament; Group 2, scar tissue appearing to extend from ACL fibers to the roof of the notch; Group 3, ACL remnants appearing to be adherent to the lateral wall of the notch or the medial aspect of the lateral femoral condyle in a position anterior and distal to ACL anatomic footprint; Group 4, no identifiable ligament tissue remaining (Figure 3). The pre-operative 3D-CT images and arthroscopic findings were then compared in each case.

Results

The 3D-CT images of the tibial remnant of the ruptured ACL were classified into Group A in 3 patients (12%), Group B in 3 (12%), Group C in 8 (32%) and Group D in 11 (44%). All patients in Group C showed that the anteromedial bundle was identifiable but showed decreased tension compared with normal ACL, and the posterolateral bundle was unidentifiable. In Group D, 5 cases showed no remnant ACL on the tibial side, whereas the remaining 5 cases showed isolated remnant fibers with no continuity to either femur or tibia.

Arthroscopic findings revealed that there were 4 patients (16%) in Group 1, 3 (12%) in Group 2, 7 (28%) in Group 3, and 11 (44%) in Group 4.[12] In Group 2, the posterolateral bundle was not detected in all patients whereas in Group 3, the anteromedial bundle was not identifiable and remnant fibers were located anterior to the posterolateral bundle. Mop-ended tears and cyclops-like remnants were

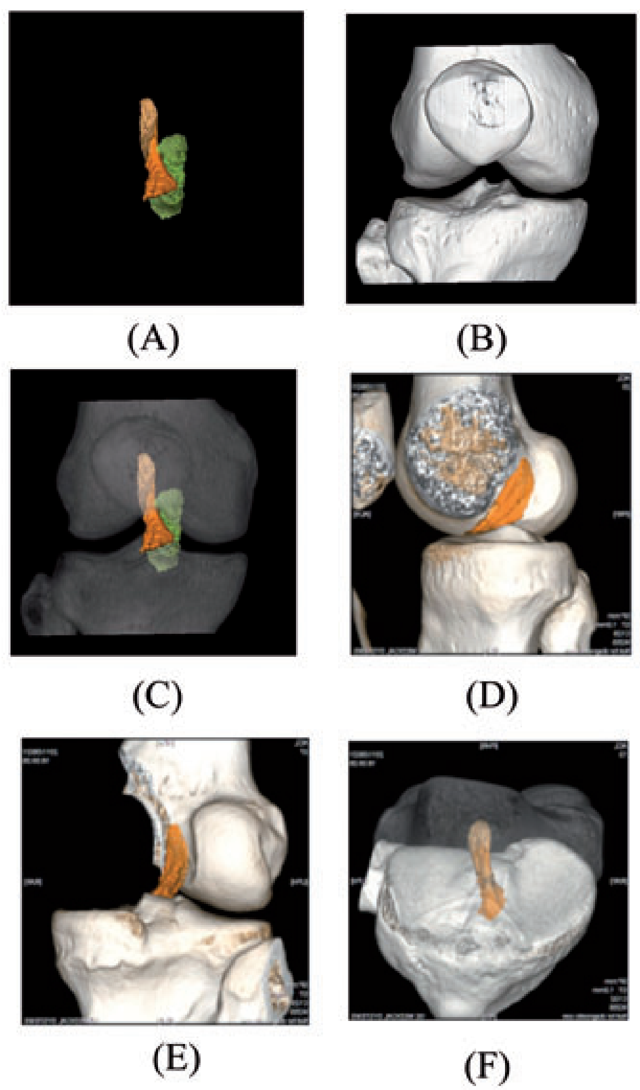

Figure 1. Three-dimensional computed tomography (3D-CT) images of normal anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL). ACL and PCL images described by automatic object selection (A) are combined with 3D bone images (B). ACL and PCL are drawn in the same co-ordinate axes to show their relative positions (C). The 3D-CT technique visualizes ACL from various directions: mediolateral (D), posteroanterior (E), and superoinferior (F).

Table 1. 3D-computed tomography classification and arthroscopic classification.

Arthroscopic classification	3D-computed tomography classification				
	Group A	Group B	Group C	Group D	Total
Group 1	3	-	1	-	4
Group 2	-	3	-	-	3
Group 3	-	-	5	2	7
Group 4	-	-	2	9	11
Total	3	3	8	11	25

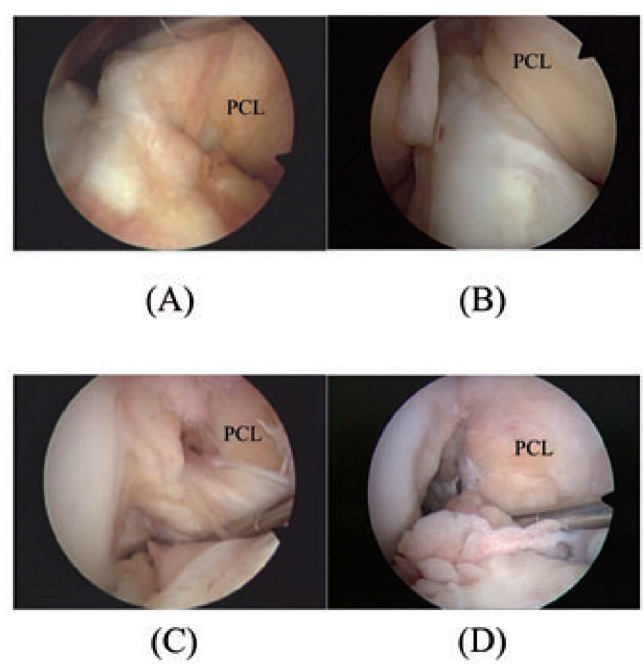

Figure 2. Classification by 3D-computed tomography (3D-CT) images of remnant anterior cruciate ligament (ACL) fibers (tibial aspect). (A) Group A: remnant fibers attached to the posterior cruciate ligament (PCL). (B) Group B: remnant fibers located between PCL and the roof. (C) Group C: remnant fibers attached to the lateral wall of the femur. (D) Group D: no identifiable image of remnant fibers on the tibial aspect.

observed in Group 4.

The association between 3D-CT and arthroscopic classifications is shown in Table 1. Both classifications matched in 20 cases out of 25 (80%). Among 3 cases classified into Group C by 3D-CT findings, one demonstrated that ACL was scarring to PCL with mop-end shape whereas in the other 2 cases, no identifiable ligament tissue remained and the remnants were filled with only synovial tissues. On the other hand, 2 cases with no identifiable remnant on the tibial side according to 3D-CT findings (Group D) were found on arthroscopy to have healed mop-ended tears attached to the medial aspect of the lateral femoral condyle. There was no significant relationship between the types of remnant fibers by both 3D-CT and arthroscopy and the interval from the ACL injury to these examinations.

Discussion

Remnant-preserving ACL reconstruction may have many potential benefits such as the maintenance of proprioceptive function and the promotion of earlier reinnervation, revascularization, and cellular proliferation of the reconstructed ACL.[1,2,4] By conventional ACL reconstruction, however, ACL remnant is removed to visualize its femoral insertion and tibial footprint. For the preservation of ACL remnant fibers, several surgical techniques have been reported.[3,4] Of course, the condition of the remnant fibers can be confirmed during arthroscopic surgery. But if this information can be accurately known before surgery, it may be of great help to knee surgeons. For example, if a torn ACL has Group 4 remnant, surgeons can pre-operatively decide that remnant-preserving ACL reconstruction is not indicated.

MRI is a gold standard radiological examination for the detection of ACL tears. Recent progress in MRI techniques such as sagittal-oblique technique and 3D fast spin echo may make it possible to identify the remnant ACL fibers because they can depict a partial ACL tear,[13,14] but they are not available in every institute. By standard MRI, complete ACL tears can be detected but there may be some difficulty in identifying remnant ACL.[15] In fact, although standard MRI is a useful examination to see whether the ACL is completely torn, it may not be capable of showing the condition of the remnant ACL fibers. The accurate status of the remnant ACL may be evaluated only by arthroscopic examination.[8,16] In the current study, we developed a novel method to evaluate the status of remnant fibers pre-operatively by 3D-CT using the Dicom system and Advantage Workstation only, and we found that this evaluation coincided with arthroscopic findings in 80% of cases. To the best of our knowledge, this is the first study to evaluate the shape and location of the remnant ACL pre-operatively using 3D-CT.

Even today, the diagnosis of a partial ACL tear remains a difficult challenge. It is based on clinical examination, radiological and MRI data, but the real diagnosis is supported by arthroscopic findings.[8] As shown in Figure 1, in this study, the anteromedial and posterolateral ACL bundles can be separately visualized using 3D-CT, on which both the femur and the tibia can be simultaneously shown. Thus, it may be possible to diagnose a partial ACL tear or to evaluate the relationship between the reconstructed 2 bundles and bone tunnels just

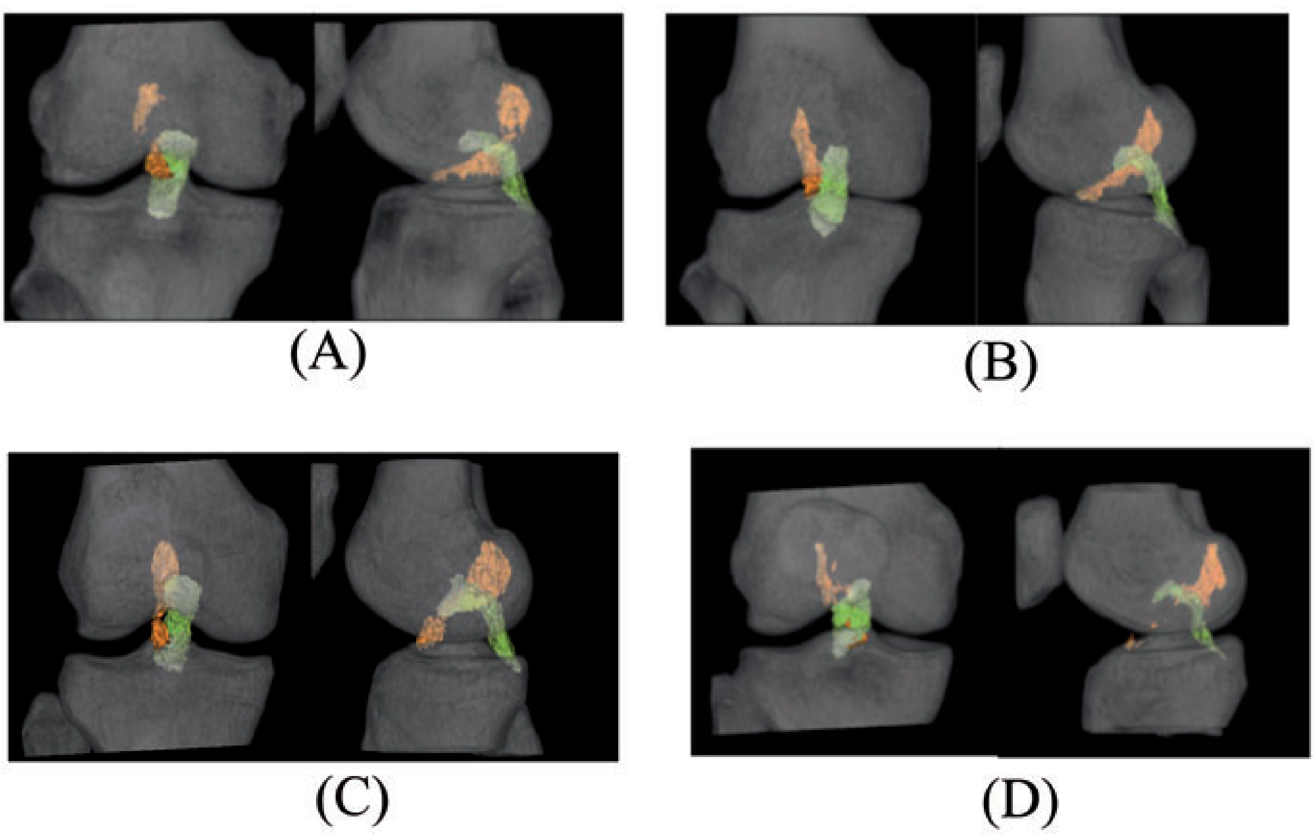

Figure 3. Arthroscopic evaluation of the morphology of the torn anterior cruciate ligament (ACL). (A) Group 1: scarring to the posterior cruciate ligament (PCL). (B) Group 2: ACL healing to the roof of the notch. (C) Group 3: attenuated ACL remnant healing to the lateral wall more anteriorly and distally than its origin. (D) Group 4: resorption of the torn ACL. The lateral wall is completely stripped (based on Crain *et al.*)

as with 3D high-resolution MRI.[17]

In this study, arthroscopic findings did not match the 3D-CT classification in 5 out of 25 cases (20%). In 2 cases, the remnant comprised of synovial tissue with no ligament fibers. Fibrous tissues may not have been accurately depicted within the 50-105-HU range set in this study. In the other 3 cases, the remnant was in the form of the so-called mop-ended tear, which is difficult to classify by either 3D-CT or arthroscopic examination. The status of remnant fibers in such tears may change, till they either adhere to the surrounding tissues or shrink. In addition, the pre-operative time period may have affected the 3D-CT images.

This study had several limitations. First, the sample size was small, including only 25 patients. Second, the quality of 3D-CT images was dependent on various factors, such as the CT scanner, analysis software, and the skill of the engineer. These factors need to be standardized to obtain reproducible images. Third, although this method may be useful, its true value needs to be assessed on the basis of advantages and disadvantages such as cost and radiation exposure. Improvement in medical technology, however, is expected to provide better image quality in the future.

Conclusions

Three-dimensional CT enables us to observe ACL fibers from any desired angle. This study demonstrated that the tibial side of the remnant ACL fibers can be accurately evaluated using ligament-visualizing 3D-CT in 80% of patients with a torn ACL, which indicates that this is a useful technique for pre-operative assessment of remnant ACL fibers.

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