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Comparison of anterior cruciate ligament volume after anatomic double-bundle anterior cruciate ligament reconstruction

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ABSTRACT

Backgroud: To determine whether anatomic double-bundle anterior cruciate ligament reconstruction (DB-ACLR) can restore the native ACL volume, and whether the volume change after reconstruction affects clinical outcomes and re-rupture rates following the contemporary techniques.

Methods: Eighty patients undergoing anatomic DB-ACLR using transportal or outside-in technique were prospectively evaluated with magnetic resonance imaging (MRI) before and after surgery. The ACL volumes were determined from 3-D models constructed by applying reverse engineering software. In all participants, measured reconstructed ACL volume were compared with the ACL on the opposite uninjured side. Participants were divided into two groups according to the volume of reconstructed graft; larger volume than native ACL of contra-lateral side (Group 1) or smaller (Group 2).

Results: The mean ACL volume on the reconstructed side (1726.5 mm^3, 982.1 - 2733.8) was significantly smaller than that on the uninjured opposite side (1857.6 mm^3, 958.2 - 2871.5) ($P < 0.001$). A total of 31 patients in Group 1 and 49 in Group 2 showed no significant difference of improvement in the clinical outcome scales at the postoperative two-year follow-up (Lysholm knee score, $P = 0.830$, Tegner activity score, $P = 0.848$). Four patients with ACL re-rupture during the two-year follow-up after reconstruction had smaller reconstructed ACL volumes than native ligament on the opposite site.

Conclusion: Anatomic DB-ACLR technique restored the graft volume rather smaller than the volume of the native ACL. Based on the volumetric consideration, graft reconstructed by anatomic DB-ACLR might have increased probability of re-rupture due to its smaller volume related to native ACL on the contralateral side.

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1. Introduction

The concept of anatomic anterior cruciate ligament (ACL) reconstruction envisions restoration of the native ACL footprint, with the aim of restoring normal ACL caliber, length, and orientation using the contralateral non-injured ACL as a template [1]. Anatomic ACL reconstruction using transportal (TP) and outside-in (OI) techniques results in more accurate restoration of the native ACL footprint [2–4], and closely mimics the native ligament when compared with traditional transtibial techniques [5]. The normal ACL anatomy consists of two bundles – the antero-medial (AM) and postero-lateral (PL) – and each has unique functions in knee kinematics [6–8]. This has increased the popularity of double-bundle ACL reconstruction techniques for restoring stability to ACL-deficient knees. However, persistent high failure rates by re-ruptured grafts after anatomic double-bundle reconstruction have been reported [9].

Several recent studies have addressed the morphological characteristics of native ACL and reconstructed grafts, demonstrating individual diversity of morphological characteristics, including cross-sectional area, size, and volume [10–15]. The finding of anthropometric differences between the knees of subjects with and without ACL injury, using magnetic resonance imaging (MRI), has implicated ACL volume as having a direct role in ACL injury [15].

The present study hypothesized that anatomic double-bundle ACL reconstruction would restore a patient's native ACL volume. It is believed that, to date, there is no available literature regarding the volume of reconstructed grafts.

The present study sought to determine whether there is a difference between the intra-articular volumes of the reconstructed grafts and the native ligaments on the opposite uninjured side, and whether ACL volume change after reconstruction affects clinical outcomes and re-rupture rates following the contemporary anatomic double-bundle ACL reconstruction.

2. Materials and methods

2.1. Patients

This prospective study enrolled patients who met inclusion criteria of a primary ACL reconstruction and who were at least 20 years of age. Enrollment occurred from February 2011 to January 2013. Exclusion criteria included: single-bundle ($n = 11$) and revision ($n = 12$) ACL reconstruction; combined surgeries, including meniscal allograft transplantation ($n = 2$) and multiple ligament injury ($n = 6$); being aged >60 years ($n = 2$); pregnancy ($n = 1$); and other reasons ($n = 10$). Exclusion criteria for the contralateral limb were patients with: previous ACL reconstruction on the opposite side ($n = 6$); ACL degeneration and ACL ganglion cysts; and nonvisualization or poor visualization of the ACL bundles. After exclusion, 86 patients underwent double bundle ACL reconstruction, according to an on-going trial comparing the TP technique and the OI technique. Among the 86 patients, 80 underwent bilateral knee MRI before ACL reconstruction and were randomly assigned using permuted block randomization to the TP group ($n = 40$) or the OI group ($n = 40$) on the day of surgery (Figure 1) [16]. All patients were followed up for >2 years after surgery. The patients were divided into two groups according to the volume of reconstructed graft: larger volume than native ACL on contralateral side (Group 1) and smaller volume (Group 2).

A single surgeon (JHW), who was experienced in ACL reconstruction using both the TP and OI techniques, performed all operations. All patients received MRI scans to both knees two to six days postoperatively, using the same device and protocols. The current study obtained Institutional Review Board approval from the institution (Samsung Medical Center 2010-08-116) before study onset. Informed consent was obtained from all participants.

2.2. Surgical techniques and rehabilitation

Surgical preparation and diagnostic arthroscopic examinations were performed in the usual manner [17]. The hamstring tendon was harvested. A six-stranded graft composed of triple semitendinosus (6.5 to eight millimeters for the AM bundle) and triple gracilis (five to six millimeters for the PL bundle) tendons was created for each group. Tibialis tendon allografts were used for patients who opted for an allograft or for those whose harvested autografts of semitendinosus and gracilis tendon were too short or thin. The grafts were trimmed to retain original size, normally with a length of 26–30 cm. Then it was folded and sutured together using no. 1 absorbable sutures to form two triple-strand grafts. The grafts were fixed with 60–80 N force for a minimum of five minutes. All the allogenic constructs were low dose (1.0–1.2 Mrad) gamma irradiated fresh-frozen grafts that were supplied by a certified tissue bank, which had policies for serological and microbiological testing in accordance with guidelines set forth by the American Association of Tissue Banks and the Food and Drug Administration.

The center of the AM bundle footprint was six to seven millimeters distal (shallow) to the posterior cartilage margin or two millimeters from the posterior bony ridge of the lateral femoral condyle (posterior condylar ridge) and three to four millimeters posterior (low) from the extended line of the posterolateral corner of the intercondylar notch, which was verified at 90° knee flexion. The center of the PL bundle footprint was positioned five millimeters anterior (high) to the edge of the posterior joint cartilage on an imaginary line perpendicular to the tangent at the lowermost portion of the lateral femoral condyle at 90° knee flexion. The required size of the EndoButton (Smith & Nephew Endoscopy, Andover, Massachusetts) for the TP technique or RetroButton (Arthrex, Naples, Florida) for the OI technique was then determined. The anatomic tibial insertion sites of both bundles were marked using a radiofrequency device (Arthrocare, Austin, Texas). The tip of the Pinn-ACL guide (ConMed Linvatec,

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