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Evaluation of tibial rotational stability of single-bundle vs. anatomical double-bundle anterior cruciate ligament reconstruction during a high-demand activity — A quasi-randomized trial

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ABSTRACT

The purpose of this study was to compare the tibial rotational stability of anatomical double-bundle anterior cruciate ligament reconstructed knees with single-bundle anterior cruciate ligament reconstructed knees during a high-demand activity. Total of 66 subjects, (22 with double-bundle anterior cruciate ligament reconstruction, 22 with single-bundle anterior cruciate ligament reconstruction, and 22 healthy control individuals) were examined in this study. Using a 9-camera motion analysis system, motion subjects were recorded performing during a drop landing and cutting. Using the point cluster technique, the internal-external tibial rotation of both knees was calculated. The mean maximum range of motion for each knee was evaluated for 3 groups (double-bundle group, single-bundle group, and control group). Clinical assessment, including Tegner score, Lysholm score, and knee arthrometric measurement, revealed restoration of the reconstructed knee stability with no differences between the two anterior cruciate ligament reconstruction groups. The results showed that both groups resulted in tibial rotation values that were significantly smaller than those in the intact legs and those in the healthy controls. There were no significant differences in tibial rotation between the DB group and the SB group. Therefore anatomical double-bundle reconstruction restores normal tibial rotation no more than single-bundle reconstruction during this high-demand dynamic activity. These results suggest a trend towards dynamic overcorrection after the ACL reconstruction.

1. Introduction

It is generally recognized that the native anterior cruciate ligament (ACL) does not behave as a simple bundle of fibers, but rather it is composed of two distinct bundles; i.e., the anteromedial (AM) bundle and the posterolateral (PL) bundle [1,2]. The AM bundle, compared to the PL bundle, is relatively isotropic throughout the range of motion. Therefore, the AM bundle has been considered to be the more important structure. Thus, traditional single-bundle (SB) ACL reconstructions have focused on reproduction of the AM bundle. Although many patients can return to their pre-injury activity level after SB reconstruction, some patients still feel instability even when their reconstructed knee is measured as stable according to the Lachman test and the KT-1000 arthrometer [3]. Several *in vitro* studies have revealed that SB reconstruction techniques were insufficient to control rotational loads that mimics the pivot-shift test and recommended reproduction of both the AM and PL bundles [4–7]. Recently, surgical reconstruction of both bundles has been performed with the hopes of producing a better clinical outcome. It is thought that a double-bundle (DB) reconstruction may control dynamic knee stability, especially rotational stability, more effectively than SB reconstruction. While *in vitro* studies have reported that DB reconstruction more effectively restores anterior tibial translation under both anterior and rotational loads [5,7], clinical studies comparing DB and SB reconstruction techniques have been controversial. Some studies have reported better results with the DB technique [8–11], whereas others have reported no differences [12,13]. In all these clinical studies, rotational stability has been evaluated manually, qualitatively, and under non weight-bearing using the pivot-shift test. Although the pivot-shift test can be used to evaluate rotational stability *in vivo*, it has only been validated as a useful test in anesthesized patients. Furthermore, static stability measures have not correlated well with any known measure of functional outcome for ACL-injured subjects before or after reconstruction [14–17]. There are also reports of individuals with statically unstable knees performing asymptomatically at high levels of athletic activity [18]. During functional activities, the knee is subjected to a combination of external forces (such as; gravitational, inertial, and contact forces) and active muscular forces [19,20]. The kinematic

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behavior of the reconstructed knee is cumulatively affected by the combination of those forces, the constraints imposed by passive knee structures (such as; articular surface geometry, ligaments, and meniscus), and the remodeling process of the replacement graft. Therefore, a study that uses only static loads cannot effectively predict the *in vivo* reconstructed knee kinematics during the high-demand activities performed in sports. Thus, it is necessary to quantitatively investigate the dynamic functional stability, especially the rotational stability, after ACL reconstruction using *in vivo* methodology. A few *in vivo* studies using optoelectronic systems have reported that SB-ACL reconstruction does not restore tibial rotation to previous levels during high-demand activities, although anterior tibial translation can be restored [21,22]. Neither of these studies investigated anatomical DB reconstruction techniques. Therefore, the purpose of our study was to compare the rotational stability after anatomical DB reconstruction with that after SB reconstruction during a high-demand activity. Based on the results of previous *in vitro* studies [4–6], we hypothesized that rotational stability in anatomical DB reconstructed knees will be restored more normally than that in SB reconstructed knees when compared to the respective intact contralateral knees.

2. Materials and methods

2.1. Subjects

In a comparison of the DB group and the SB group, a power analysis conducted during a pilot study revealed that at least 44 subjects were necessary to achieve 80% statistical power with an α level of 0.05. 44 patients, whose ACL were reconstructed using either a SB or DB method, and 22 healthy control individuals were included in this prospective comparative cohort study. Each patients were quasi-randomized into two groups: DB group (11 female and 11 male patients) and SB group (11female and 11 male patients) (Table 1), according to the patient's month of birth. DB group was selected in patients whose month of birth was odd-number, and SB group was selected in those whose month of birth was even-number. Patients were informed that they were going to be in a study, and that they could choose another reconstruction procedure if they did not want to be in this study. The operation was performed in patients between July 2007 and July 2009. 22 healthy subjects (11 female and 11 male subjects), matched with the ACL reconstruction group in terms of sex, age, height, and weight, formed the control group (Table 1). The time interval between operation and data collection was more than 9 months and less than 20 months for all subjects (mean: 12 months). Subjects were excluded from the study if they had concomitant knee injuries (such as a meniscal tear or a combined ligament injury); a previous injury to either the reconstructed or the contralateral knee. All patients underwent the same rehabilitation protocol. The knee joint was immobilized at 20° flexion for 3 days with a removable post-operative brace. Knee range-of-motion exercise began three days after surgery. Weight-bearing with two crutches started seven days after surgery. Walking with full weight-bearing started at four weeks post-operatively. Knee muscle exercise in the closed kinetic fashion was encouraged starting six weeks after surgery. Patients started running at three months; first, slow jogging, and then, the running speed was gradually increased. When eighty percent of full-speed running was achieved, athletic exercises related to the previous sports or desired sporting activities were initiated with detailed instructions. Athletic exercises were specific to each patient, depending on the kinds of sports previously engaged in, as well as the patient's athletic level. Full athletic activities were allowed six months after surgery. At that time, all patients had regained sufficiently symmetry of the quadriceps and hamstrings strength. The acceptable level of these muscle strengths was determined respectively with the Biodex isokinetic dynamometer (System3; Biodex Medical Systems, Shirley, New York). At the time of data collection, all patients had resumed their activities of daily living and returned to their previous sports at a minimum. The study design was approved by the University of Tsukuba's institutional review board. All subjects provided written informed consent before participation. Prior to any data collection, subjects were evaluated clinically with both Tegner and Lysholm scores. In addition, the difference in anterior knee laxity between the reconstructed and contralateral knee was measured with a knee arthrometer (KT 1000, MED metric Corp).

2.2. Surgical technique

A single surgeon (AK) performed an arthroscopically assisted one-incision ACL reconstruction in all patients. A standard arthroscopic examination was performed via anteromedial and anterolateral portals. In both the SB and DB groups, the semitendinous or the semitendinous and gracillis tendons were used as the autograft. If an adequate length (greater than 22 cm before halving) was not obtained with only the semitendinous tendon, the gracillis tendon was also used.

2.3. Double-bundle reconstruction

The technique used for the DB reconstruction followed the procedure described by Yasuda et al. [23]. Two femoral and two tibial tunnels were created under controlled arthroscopic visualization to reproduce anatomically both the AM and PL bundle using the hamstring tendon graft. The distal half of the semitendinous tendon was doubled and used for the AM graft. The proximal half of the semitendinous tendon was doubled and used for the PL graft. The ACL remnant was removed arthroscopically and the footprint of the AM and the PL bundle were identified. First using a tibial guide (Protrac; Smith & Nephew Endoscopy), the two tibial tunnels were created; one at the center of the AM bundle footprint and one at the center of the PL bundle footprint (Fig. 1). The femoral tunnels were then created through a transtibial approach into the femoral anatomic footprints of the AM and PL bundles. Both femoral tunnels for the AM and PL bundles were located behind the resident's ridge (Fig. 1). If we foresaw that two femoral tunnels could not be created separately

Table 1
Subject data.

	Double-bundle group (n = 22)	Single-bundle group (n = 22)	Control group (n = 22)
Age (years)	22 ± 2	22 ± 6	21 ± 5
Height (cm)	166.0 ± 5.0	164.8 ± 10.2	167.2 ± 7.2
Weight(kg)	58.4 ± 6.9	57.4 ± 12.5	59.3 ± 7.5
Follow up (months)	12.4 ± 2.7	12.3 ± 2.7	–
KT-1000 Difference (mm)	1.3 ± 0.5	1.4 ± 0.4	–
Lyscholm score	93.8 ± 2.6	93.1 ± 3.5	–
Tegner scale	7.0 ± 1.0	6.7 ± 0.6	–
Pivot-shift test (positive)	0/22	0/22	–

Values are given as mean ± standard deviation.