Dynamic Evaluation of Pivot-Shift Phenomenon in Double-Bundle Anterior Cruciate Ligament Reconstruction Using Triaxial Accelerometer

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Purpose: To evaluate the effect of initial graft tension on rotational stability and to determine the minimum required tension (MRT) based on the pivot-shift phenomenon in isolated anteromedial bundle (AMB), isolated posteromedial bundle (PLB), and double-bundle anterior cruciate ligament (ACL) reconstructions using a triaxial accelerometer during surgery. **Methods:** Primary double-bundle ACL reconstructions were included. The pivot-shift test and N-test were performed before and during surgery with the acceleration measurements using a triaxial accelerometer. The pivot-shift test was also manually graded. The AMB and PLB were fixed to a graft tensioning system during surgery with the following settings: (1) AMB only (AMB), (2) PLB only (PLB), and (3) AMB and PLB (A+P). The total graft tension was first set at 20 N and then was increased in increments of 10 N until the pivot-shift test became negative, which was defined as the MRT in each setting. **Results:** Twenty-five patients were evaluated. The MRT in the AMB setting averaged 26 N (range, 20 to 40 N); in the PLB setting, 28 N (range, 20 to 40 N); and in the A+P setting, 24 N (range, 20 to 40 N). The MRT in the A+P setting was significantly smaller than that in the PLB setting ($P = .008$). The acceleration in the A+P setting was significantly smaller than that in the AMB and PLB settings both in the pivot-shift test (v AMB: $P = .007$, v PLB: $P = .011$) and in the N-test (v AMB: $P < .001$, v PLB: $P < .001$). **Conclusions:** Double-bundle ACL reconstruction better controlled rotational stability with smaller MRT than isolated PLB reconstruction at the time of surgery. In double-bundle reconstruction, the MRT based on the pivot-shift phenomenon could be larger than previously reported MRT based on anteroposterior laxity. **Level of Evidence:** Level IV, therapeutic case series.

Anterior cruciate ligament (ACL) reconstruction was developed to restore knee stability, and the traditional single-bundle reconstruction was considered successful in terms of restoring anterior stability. However, even though anterior stability was successfully restored in the majority of cases, rotatory instability remained after reconstruction in some patients.

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Therefore, anatomic double-bundle ACL reconstruction that replicates both the anteromedial bundle (AMB) and the posteromedial bundle (PLB) was developed in an attempt to better control rotational and dynamic instabilities of the knee,[1] and it has been shown to have some advantages compared with traditional single-bundle reconstruction in both clinical and laboratory settings with regard to rotational stability.[2-8] However, there have still been very few studies that demonstrated the advantages of double-bundle reconstruction by quantitatively and objectively assessing rotational stability, especially a pivot-shift phenomenon such as dynamic rotational stability, in clinical settings.[9,10]

Another concern in double-bundle ACL reconstruction is determination of initial graft tension, as no consensus exists on an optimal setting of initial graft tension in the AMB and PLB.[11-14] Some studies have focused on the laxity match pretension, which is the minimum required tension (MRT) to restore normal laxity compared with the healthy knee, in order to determine the optimal setting of the initial tension.[15,16] In past studies, the MRT has been determined only by anteroposterior laxity; however, the MRT based on rotational stability seems more significant considering the importance of controlling rotational stability, and there has been no study objectively and quantitatively determining the MRT for rotational stability.

Recently, some objective measurements to quantitatively evaluate the pivot-shift phenomenon have been developed.[2,17-26] Among them, a system that measures the acceleration of the tibia during the pivot-shift phenomenon has been introduced: a kinematic rapid assessment (KiRA) triaxial accelerometer (OrthoKey, Lewes, DE). This device is small, easy to apply, noninvasive, reasonable in price, and relatively precise in evaluating the pivot-shift phenomenon.[18,27,28]

The objectives of this study were to evaluate the effect of initial graft tension on rotational stability, as well as to determine the MRT based on the pivot-shift phenomenon in isolated AMB, isolated PLB, and double-bundle ACL reconstructions using a triaxial accelerometer during surgery. The hypotheses underlying this study were that double-bundle ACL reconstruction would obtain better rotational stability (more specifically, smaller acceleration during the pivot-shift phenomenon) compared with isolated AMB or isolated PLB reconstruction and that the pivot shift—based MRT would be lower in double-bundle reconstruction than isolated AMB or isolated PLB reconstruction.

Methods

Patients

This was a retrospective study, which was prospectively designed to objectively evaluate the pivot-shift phenomenon during ACL reconstruction surgery. Collection of the data was made in our institution between June 2014 and February 2015. Inclusion criteria were primary double-bundle ACL reconstruction with an autologous semitendinosus tendon. Exclusion criteria were knees with osteoarthritis, concomitant ligament tears, history of injuries in contralateral and ipsilateral knees, and bone too brittle to set a graft tensioning system as described later. In addition, we had only one graft tensioning system, which needed to be sterilized for use during surgery; if there was more than one ACL reconstruction that met the inclusion criteria per day, we randomly included one patient who agreed to be included in this study. This study was approved by our Institutional Review Board, and all the patients provided written informed consent.

Surgical Technique

The ACL reconstruction procedure was performed by 2 attending surgeons (surgeons 1 and 2) or under their supervision. A ruptured ACL was confirmed arthroscopically, and meniscal injury was managed according to the injury status. Only the semitendinosus tendon was harvested and cut into halves and folded, creating 2 double-stranded bundles of 5.5 cm or more in length looped with EndoButton CL-BTB (Smith & Nephew Endoscopy, Andover, MA). The open end of each graft was closed with 2 Krackow sutures and a Bunnell suture using no. 2 strong sutures. Use of the EndoButton CL-BTB made it possible to close the open end of the graft before femoral tunnel creation, allowing shorter surgical time. Prior to graft passage, the grafts were pretensioned by Suture Vise with Tensiometer (Smith & Nephew Endoscopy) for at least 10 minutes on Graftmaster (Smith & Nephew Endoscopy). Both femoral and tibial tunnels were created at the anatomic position of the insertion sites of each bundle. Femoral tunnel creation was made via the outside-in approach, and tibial tunnel creation was made from the anteromedial surface of the tibia. The femoral sides of the AMB and PLB grafts were fixed with the EndoButton (Smith & Nephew Endoscopy). Each graft was then provisionally fixed to the Stress Equalization (SE) Graft Tensioning System (Linvatec, Largo, FL) with sutures at the tibial site for further evaluation. After all the measurements were finished, the AMB graft was definitively fixed to an anchor staple with sutures at the tibial site at 20° of flexion at the tension of the MRT (determined by the following measurements) plus 5 N considering graft relaxation. The PLB graft was then fixed to another anchor staple at 20° of flexion in the same manner.

Preoperative Measurements

The triaxial accelerometer system KiRA was attached to the lateral aspect of the proximal shank between the tibial tuberosity and Gerdy's tubercle by a belt. It was placed in a sterile plastic bag and used during surgery. This system was wirelessly connected to a tablet with Bluetooth where the knee movement analysis was conducted. This tool measures the acceleration of the tibia on the femur during the tests for pivot-shift phenomenon (in m/s^2) and extracts the difference between maximum value (a_{max}) and minimum value of acceleration (a_{range}: $a_{max} - a_{min}$), which indicates the magnitude of subluxation during the pivot-shift phenomenon, and the acceleration range was defined as "acceleration" in the following analyses (Fig 1).[18,29]

The tests for the pivot-shift phenomenon were performed preoperatively by an attending surgeon for both injured and uninjured legs under anesthesia, and both the pivot-shift test and N-test were performed. For the pivot-shift test, the extended leg was picked up at the ankle with the examiner's ipsilateral hand, and this hand internally rotated the knee and flexed the knee from full extension, while applying valgus stress with the contralateral hand on the lateral side of the proximal tibia.[30] For the N-test, with the patient lying supine on a bed, the examined extremity was lifted