INTRODUCTION:
Anterior cruciate ligament (ACL) is demonstrated to consist of two functional bundles. Several biomechanical studies elicited that the predominant function of these bundles is both flexion angle and loading condition dependent. Anteromedial bundle (AMB) is shown to tighten with flexion and posterolateral bundle (PLB) with extension. Further, AMB and PLB are demonstrated to provide resistance to anterior and rotational loadings, respectively.

It has been postulated that the flexion angle at which the two graft bundles are fixed can affect the joint laxity and clinical outcomes. Several biomechanical studies have been performed in an attempt to establish appropriate flexion angles for graft fixation to achieve normal joint laxity. However, a consensus is yet to be reached on how to fix the two bundles of ACL. There is conflicting evidence on the improved efficacy of double tunnel double bundle ACL reconstruction compared to the conventional single bundle ACL reconstruction. Innovative surgical techniques such as anatomical single tunnel double bundle (STDB) ACL reconstruction have been proposed as an alternative for both single tunnel single bundle and double tunnel double bundle ACL reconstructions. But the dilemma of graft fixation angles still persists.

Therefore, the objective of this study was to compare the knee kinematics of and graft forces for the following: (1) STDB ACL reconstruction where both AMB and PLB are fixed at the same flexion angle (0°) or at different flexion angles (PLB at 0° and AMB at 45°) using a robotic testing system. We hypothesized that fixing the AMB and PLB independently at different flexion angles can more closely restore the normal knee biomechanics than simultaneously fixing them at 0° flexion.

METHODS:
Kinematic responses and graft forces were evaluated in twelve human cadaveric knees using a robotic testing system under four different knee conditions: intact, ACL deficient, STDB ACL reconstruction with both AMB and PLB fixed at 0° flexion (protocol 1), and STDB ACL reconstruction with PLB fixed at 0° flexion and AMB fixed at 45° flexion (protocol 2). Each graft bundle was fixed with 20 N of initial tension. In both protocols 1 & 2, femoral graft fixation was achieved by a femoral INTRAFIX system (DePuy Mitek, Raynham, MA). The tibial end of the graft for protocol 1 was fixed at 0° flexion with femoral INTRAFIX system and spiked washer and screw (DePuy Mitek, Raynham, MA). For protocol 2, first the PLB was temporarily fixed at 0° flexion with a spiked washer and screw. Then the knee was flexed to 45° and both AMB and PLB were fixed by a femoral INTRAFIX system. After this fixation, the AMB was further fixed along with PLB by the spiked washer and screw fixation. Knee kinematics and forces of the ACL or ACL graft in each knee were measured under 2 loading conditions: an anterior tibial load of 134 N and simulated quadriceps muscle load of 400 N, at 0°, 30°, 60°, 90°, and 120° of knee flexion.

RESULTS:
STDB ACL reconstruction using protocol 1 closely restored the normal anterior tibial translation (ATT) at 0° and 120° of flexion but could not do so at 30°, 60° and 90° of flexion (P < 0.05) under anterior tibial load (Figure 1). When protocol 2 was used for STDB ACL reconstruction, ATT was closely restored to the normal ATT at 0°, 30° and 120° of flexion but not at 60° and 90° of flexion (Figure 1; P < 0.05).

Under anterior tibial load, graft forces in both protocols were significantly lower than the ACL forces at 30°, 60°, 90°, and 120° of flexion (Table 1; P < 0.05). AMB graft forces in both protocols were significantly lower than the intact AMB at 30° and 60° of flexion. However, PLB graft force in protocol 1 was significantly higher than the intact PLB at 30° and 60° of flexion (Table 1; P < 0.05). In protocol 2 PLB graft force was significantly higher than the intact PLB at 30° of flexion (Table 1; P < 0.05).

This study supports our hypothesis that fixing the AMB and PLB independently at different flexion angles can more closely restore the normal knee biomechanics than simultaneously fixing them at 0° flexion in STDB ACL reconstruction. However, none of these graft fixation protocols can restore the normal knee biomechanics than simultaneously fixing them at 0° flexion in STDB ACL reconstruction. We found that AMB graft forces to be less than the native AMB force and PLB graft forces to be higher than the native PLB force in both protocols. Therefore, increasing the initial tension (> 20N) of AMB bundle graft and decreasing the initial tension (< 20N) of PLB graft may be necessary to restore the normal force distribution in the two bundles.

DISCUSSION:
This study supports our hypothesis that fixing the AMB and PLB independently at different flexion angles can more closely restore the normal knee biomechanics than simultaneously fixing them at 0° flexion in STDB ACL reconstruction. However, none of these graft fixation protocols can restore the native ACL and ACL bundles forces. Therefore, increasing the initial tension (> 20N) of AMB bundle graft and decreasing the initial tension (< 20N) of PLB graft may be necessary to restore the normal force distribution in the two bundles.

Table 1. Anterior cruciate ligament and graft forces (mean ± standard deviation (N)) under the 2 loading conditions at select flexion angles

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Figure 1: Anterior tibial translations under anterior tibial load, I, signifies statistically significant difference compared to the intact knee; D, signifies statistically significant difference compared to the ACL deficient knee; P1, signifies statistically significant difference compared to the protocol 1.

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