In-vivo Force Changes within the Anteromedial and Posterolateral Bundles of the ACL

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INTRODUCTION

Earlier studies have differentiated between the action of the anteromedial (AM) and posterolateral (PL) bundles of the ACL with a reciprocal tightening and slackening of the anterior and posterior fibers of the ACL in flexion and extension of the knee [1]. However, the in-vivo elongation patterns of the AM and PL bundles of the ACL have been found to be similar [2]. This implies that under physiological loading conditions, the ACL bundles might function in a different way compared to passive knee motion. The objective of this study was to estimate the in-vivo forces of the anteromedial and posterolateral bundles of the ACL under controlled weightbearing using a non-invasive technique.

METHODS

Elongation of the AM/PL Bundles In-Vivo: Ten healthy subjects were recruited under the approval of the IRB and consent forms were collected. The kinematics of one knee of each subject (randomly selected, 5R/5L) were determined using a previously described dual fluoroscopic system (DFIS) [3]. This kinematics data was collected during a single-legged quasi-static lunge activity (at 15°, 30° and 45° of flexion) under two different controlled weightbearing conditions: zero weightbearing (<10N), and full body weight (BW). The length of each bundle at each position was measured as the length of a straight line connecting the corresponding insertion centroids on tibial and femoral sides. At each flexion angle, the elongation of each bundle with respect to its length under zero weightbearing was measured. The elongation-weightbearing curves of the AM and PL were created for each subject.

Force-Elongation Relation of the AM/PL Bundles In-Situ: Force-elongation curves of each bundle were determined at the same flexion angles in six cadaveric human knees using a robotic testing system. All the soft tissues of the knee were dissected away, except for the ACL. The AM and PL bundles were identified and separated. At each given flexion angle, the knee was stretched along the long axis of the ACL and the force-elongation curves of the bundles were determined.

Increase in In-Vivo Bundle Forces: The in-vivo elongation data was mapped to force-elongation curves at the corresponding flexion angles and the in-vivo forces within AM and PL bundles were estimated. Since, the initial tension in each bundle under minimum load (non-weightbearing) was unknown, the force estimation process was done based on different assumed initial bundle tensions (0, 10, 20, 30, 40 and 50 N). The in-vivo weightbearing-elongation curve of each bundle of each living subject at each flexion angle was matched with the corresponding force-elongation curve and the increase in in-vivo bundle tension under full weightbearing condition was statistically determined by a mean value $F_i$ and a standard deviation $\sigma_i$ ($i=1..10$, the number of living subject).

Finally, a weighted mean statistical method was used to estimate the increase in in-vivo forces of the bundles. Under the same weightbearing condition at a selected flexion angle, the weighted mean of the increase in in-vivo force and standard error of the mean ($F \pm \sigma$), was calculated using the following equations:

$$F = \left( \sum_{i=1}^{10} \frac{F_i}{\sigma_i^2} \right)^{-1} \left( \sum_{i=1}^{10} \frac{1}{\sigma_i^2} \right)^{-1} \quad \text{and} \quad \sigma^2 = \left( \sum_{i=1}^{10} \frac{1}{\sigma_i^2} \right)^{-1}$$

RESULTS

In general, the mean values of the AM and PL bundle force increases were the highest at 30° and 15° of flexion, respectively. The patterns of the increase in the forces showed that by increasing the assumed initial tension under no weightbearing, the increase in in-vivo force approached an asymptote at each flexion angle (beyond 40 N of initial tension). Assuming the AM tension was 0 N under zero weightbearing, the increase in in-vivo AM forces caused by full body weight were 94.6 ± 44.2 N at 15°, 107.0 ± 31.0 N at 30°, and 36.8 ± 13.7 N at 45° of flexion (Fig. 1A). The increase in the in-vivo AM forces due to full body weight were 145.3 ± 81.8, 167.3 ± 47.4 and 109.6 ± 29.2 N, respectively at 15°, 30° and 45° of flexion with an assumed tension of 40 N under zero weightbearing (Fig. 1A). However, the changes in AM force at 15°, 30° and 45° of flexion were not significantly different ($p=0.45$).

Assuming the PL tension was 0 N under zero weightbearing, the increase in in-vivo PL forces caused by full body weight were 81.3 ± 62.3 N at 15°, 45.4 ± 36.5 N at 30°, and 14.0 ± 14.9 N at 45° of flexion (Fig. 1B). The increase in the in-vivo PL forces due to full body weight were 82.2 ± 107.0, 38.9 ± 69.2 and 23.7 ± 58.6 N, respectively at 15°, 30° and 45° of flexion with an assumed PL tension of 40 N under zero weightbearing (Fig. 1B). The effect of bundle was statistically significant different ($p=0.008$) with higher force increase in the AM bundle.

DISCUSSION

In order to develop optimal ACL reconstruction techniques that adequately reproduce the natural behavior of the two functional bundles of the ACL, it is substantial to understand the contributions of the AM and PL bundles under physiological loads. The in-vivo force increases of the ACL bundles in response to a change in weightbearing from zero to full body weight were non-invasively investigated utilizing a combined MR and dual fluoroscopic imaging system and a robotic testing system. The findings support this concept that both bundles function in a complementary manner. The results demonstrated that the AM bundle carried greater portion of the tension within the ACL in response to full body weightbearing at all tested flexion angles. This is in agreement with our recent in-situ study in which the load sharing patterns of both bundles were complementary rather than reciprocal under simulated muscle loads [4]. These results suggested that the ACL bundles function in a different way under physiological loading conditions compared to passive knee motion.

REFERENCES


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