IN-VIVO KINEMATICS OF THE ACL DURING WEIGHT-BEARING KNEE FLEXION

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INTRODUCTION
Research on the ACL has focused on measuring the ligament tension in-vitro as well as relative elongation or surface strain in-vivo. Few studies have observed the morphological change of the ACL during functional activities. The purpose of this study was to analyze the elongation, rotation (twist) and orientation of the ACL during in-vivo weight-bearing flexion in living human subjects using a orthogonal fluoroscopic images and MR image-based 3D computer models.

MATERIALS AND METHODS
Five human knees of living subjects (age 21-41, 4 male, 1 female) were scanned using MR with a 1.5-T magnet using the 3D FIESTA pulse sequence (Fig. 1A). A 3D anatomic model of each knee, including the tibia, femur and ACL insertion areas, was constructed (Fig. 1B). The knee was then imaged during a single leg lunge at 0°, 30°, 60°, and 90° of flexion using an orthogonal fluoroscopic imaging technique [1]. The MR image-based models and the dual-orthogonal fluoroscopic images were then used to reproduce the kinematics of the knee using an image matching process [1]. The relative position and orientation of the ACL insertions during the in-vivo flexion were then measured from the models, representing 3D in-vivo ACL kinematics (Fig. 1C).

In this study, we analyzed the elongation (represented by the distance between the center points of the tibiofemoral insertion areas), twist angle along ACL axis, elevation angle with respect to tibial plateau and deviation angle from sagittal plane of the ACL at 0°, 30°, 60°, and 90° of flexion during the weightbearing flexion. A repeated measures ANOVA followed by the Newman-Keuls test was used to analyze the data. Statistical significance was set as P<0.05.

RESULTS
The ACL consistently decreased in length with flexion (Fig. 2A). The ACL was 30.1 ± 3.8 mm long at full extension. At 60° and 90° of flexion, the ACL length decreased by 10% compared with that at the full extension position (p<0.05). The ACL twisted internally with flexion (Fig. 2B). However, the ACL twisted only by 20° at 30° of flexion. There was a statistically significant difference in the twist at 90° of flexion compared to that at full extension and 30°.

The ACL was oriented more vertically at full extension (64.9 ± 10.7°) (Fig. 2C), and decreased significantly with flexion to 52.6 ± 8.2° at 30° of flexion. The ACL deviated laterally by 11.1 ± 7.6° at full extension and by 11.2 ± 11.6° at 30° of flexion (Fig. 2D). Thereafter, the deviation angle decreased to 5.7 ± 7.4° at 60° of flexion and to 2.3 ± 8.6° at 90° of flexion.

DISCUSSION
This study investigated the kinematics of the ACL during an in-vivo weight-bearing flexion of the knee using dual-orthogonal fluoroscopic images and MR image-based 3D computer models. The data demonstrated that the length of the ACL decreased from full extension to 90° of flexion. The percent decrease in length of the ACL from full extension to 60° and 90° was more than 10%. This suggests that the ACL primarily functions at low flexion angles, and with increasing flexion, its role is diminished. The data on the in-vivo ligament elongation demonstrated that the ACL plays a more important role in lower flexion angles than at higher flexion angles during the in-vivo activity. In addition, the ACL was shown to undergo complex deformations during in-vivo knee flexion, including twisting and changes in orientation. These data suggest that only describing the tensile behavior of the ACL might not reveal the true biomechanical role of the ACL during knee motion.

These data may be invaluable for improving contemporary surgical treatment of the ACL injuries. The data on in-vivo ACL deformation suggested that a successful ACL reconstruction after injury should not only be aimed to restore elongation behavior of the ligament, but also the rotational and orientation characters of the ACL, so that the normal knee kinematics can be restored. Future studies should focus on quantifying the ACL graft deformation in ACL reconstructed patients.

Figure 1. A typical MR image (A) used to construct the 3D knee model (B). The relative motion of the ACL insertion sites during in-vivo knee flexion.

Figure 2. ACL elongation (A), twist (B), elevation (C), and deviation (D) as a function of flexion (*p < 0.05).

REFERENCES

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