Single-Bundle Anterior Cruciate Ligament Reconstruction Does Not Restore Anterior Tibial Translation During Walking: A Biplanar Fluoroscopy Analysis

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Summary

Six-degree-of-freedom (6-DoF) knee joint kinematics were analyzed using a biplanar fluoroscopic system. During level treadmill walking, significant anterior tibial translation was observed in knees reconstructed with a single-bundle (SB) anterior cruciate ligament (ACL), compared to their contralateral knees and healthy controls. The relatively vertical orientation of the single-bundle graft may have contributed to the observed dynamic anterior tibial laxity.

Introduction

Assessing knee motion in 6-DoF is essential to determine whether ACL reconstructions (ACLR) restore native knee behavior under physiological loading [1]. Excessive anterior tibial translation can lead to knee instability and accelerate degenerative changes. In vivo motion analysis methods, particularly those employing biplanar fluoroscopy, provide precise 6-DoF kinematics during functional activities. The objective of this study was to examine the 6-DoF knee kinematics of SB ACLR patients during in vivo walking to determine whether current SB techniques sufficiently restore native anterior-posterior translational stability.

Methods

IRB approval and informed consent were obtained prior to testing. Ten healthy participants (36.3 ± 9.5 y; 72.5 ± 15.6 kg, 173.1 ± 5.3 cm) and eight SB ACLR patients (24 ± 5.5 y; 77.9 ± 12.2 kg, 172.1 ± 7.1 cm) were enrolled. A custom motorized biplanar fluoroscopic system was used to track both left and right knees during level walking (Fig. 1a). Biplanar fluoroscopic images (75 kVp, 125 mA, 100 Hz) were acquired for two seconds (Fig. 1b). The center of the target knee was tracked using a depth camera, which was used to control the positions and speeds of the X-ray sources and detectors (Fig. 1c). A 2D–3D registration procedure using a statistical shape and intensity model reconstructed the skeletal geometry and provided 6-DoF kinematics. Joint kinematics were analyzed for the operated and non-operated (contralateral) sides, and comparisons were also made to the healthy group. Statistical parametric mapping (SPM) was used for spatiotemporal comparisons. An SPM paired t-test was conducted between the operated (SB) and contralateral sides (SB-CL), while an SPM two-sample t-test compared both knees of the SB group to those of the healthy group. The significance level was set at 0.05.

Results and Discussion

The tibia translated anteriorly with respect to the femur by 2–4 mm immediately after heel strike, continued to increase until mid–stance, and then returned to its initial position by the terminal stance (Fig. 1d). During 20–50% of the stance phase, significantly greater anterior tibial translation was observed in SB group compared with the contralateral knee (Fig. 1e). From 10–90% of the stance phase, the SB knee showed significantly greater translation compared with the healthy knees (Fig. 1e). The contralateral knee also showed differences from the healthy group near 20% of the stance phase. Between 10–20% of the stance phase, the SB group exhibited another sharp increase in anterior translation, which may be attributed to the absence of the native ACL.

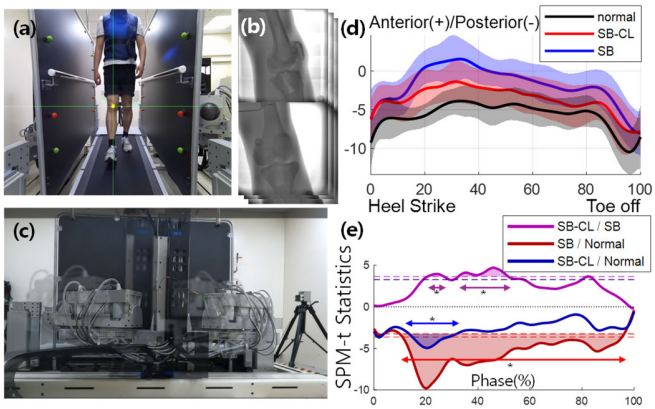

Figure 1: (a-c) Experimental setups, biplanar fluoroscopic images, and motorized operation of the system. (d) Anterior translation of the tibia relative to the femur. (e) SPM-t statistics for between-group comparisons throughout the stance phase.

The increased translation in the early stance phase is consistent with previous studies [2] and persisted until 90% of the stance phase. Tunnel placement, along with the inherent limitations of SB grafts, can lead to residual instability and altered knee mechanics [3]. Conventional SB ACLR often positions the graft more vertically than the native ACL, thereby contributing to increased anterior laxity.

Conclusions

SB ACLR does not fully prevent anterior tibial translation during the stance phase of walking, indicating residual instability and the need for refined techniques.

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References

[1] J. L. Markström, et al. (2018) *Knee Surg., Sports Traumatol., Arthrosc.*, 26:358-367. [2] M. Hofbauer, et al. (2014) *Am. J. Sports Med.*, 42(11):2715-2721. [3] K. Yasuda, et al. (2011) *Am. J. Sports Med.*, 39(8):1789-1800.