FUNCTIONAL BEHAVIOR OF RECONSTRUCTED ANTERIOR CRUCIATE LIGAMENT INSERTIONS COMPARED TO NORMAL INSERTIONS

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INTRODUCTION

In the United States, approximately sixty to seventy-five thousand individuals require anterior cruciate ligament (ACL) reconstruction annually [1], typically using a patellar tendon (PT) autograft as the replacement tissue. Current reconstruction methods may not completely restore knee function [2], however, possibly contributing to future joint problems for the patient.

Previous studies [3,4,5] have established the pull-out test as the standard method of evaluating the mechanical function of reconstructed soft-tissue insertions, however, as this method tests mechanical response at a single orientation, it may not capture the overall function of normal or reconstructed soft-tissue insertions.

In light of this, the complete functional characterizations of normal ACLs and PT reconstructions may be necessary to show differences or similarities. In this paper, the tibial insertion of both tissues will be examined.

MATERIALS AND METHODS

Six PTs, with bony ends, were dissected from the right knee of pigs (80-100 lbs). To simulate the tibial end of an anterior cruciate ligament (ACL) reconstruction, expanded polyurethane foam (Sawbones, Vashon, WA) was used as a substitute for cortical bone, and the central third of each PT used for the reconstruction.

The tibial end of the simulated reconstruction was manufactured by coring a 28.6 mm cylinder from a slab of the raw foam. An 8 mm hole was drilled along the axis of each cylinder to mimic the reconstruction tunnel, and a 30° angle cut at the top of each cylinder, approximating the angle the normal ACL makes with the tibial plateau. The bone blocks at either end of the PT reconstruction were trimmed, the tibial end inserted into the tunnel, and fixed with a titanium interference screw, similar to those used in human ACL reconstructions (Figure 1). The patellar end of the tissue was embedded in epoxy to facilitate gripping.

Six ACLs were also studied for comparison. The tissues, with bony ends, were dissected from the right knee of pigs (80-100 lbs). The ends were embedded in epoxy to facilitate gripping.

The tibial ends of each specimen were characterized by measuring the sub-failure load-elongation behavior of the tissue at 49

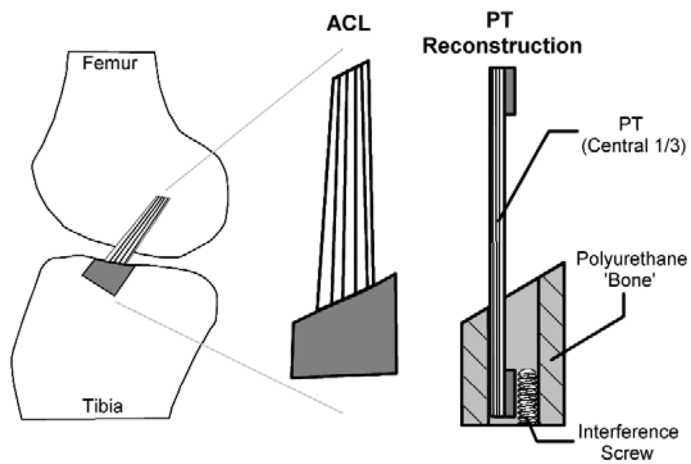

Figure 1. Schematic of the simulated ACL reconstruction, and comparison to normal tissue

different combinations of anterior / posterior and lateral / medial tilts, up to 30°, in increments of 10° (including combined tilts) [6]. Tests were performed at an elongation rate of 200 mm/min, and the testing order was randomized to reduce viscoelastic effects. The linear stiffness at each of the 49 orientations was computed using a least-squares approximation, stiffness variation as a function of orientation was assessed, and the maximum stiffness determined for each specimen. The stiffness at each orientation for each specimen was normalized on the maximum stiffness of that specimen, and the resulting normalized stiffness values were averaged at each orientation over all specimens of that tissue type. Comparisons were then drawn between the two types of tissue.

RESULTS

All six specimens in each group were successfully tested and characterized. Repeat testing at specific orientations verified that no tissue damage was induced by these tests.

The maximum stiffnesses for the six ACLs are shown in Table 1, and for the six PT reconstructions in Table 2. The average maximum ACL stiffness is 59.59±12.50 N/mm, and the average maximum PT reconstruction stiffness is 48.44±10.24 N/mm. Note that there is some variability in the direction of maximum stiffness in both tissue types.

ACL Specimen #	Maximum Stiffness (N/mm)	Direction of Maximum Stiffness
1	62.85	30° Posterior, 30° Medial
2	73.33	30° Posterior, 30° Lateral
3	64.80	20° Posterior, 0° Medial
4	52.15	30° Posterior, 30° Lateral
5	66.20	10° Posterior, 10° Lateral
6	38.23	30° Posterior, 0° Medial

Table 1. Maximum stiffness, and direction of maximum stiffness, for each ACL

PT Specimen #	Maximum Stiffness (N/mm)	Direction of Maximum Stiffness
1	53.59	30° Anterior, 0° Medial
2	48.58	20° Anterior, 20° Medial
3	41.04	20° Posterior, 10° Medial
4	65.96	10° Posterior, 10° Medial
5	43.73	30° Anterior, 30° Lateral
6	37.76	0° Anterior, 10° Lateral

Table 2. Maximum stiffness, and direction of maximum stiffness, for each PT

In order to examine the differences in orientation-dependent behavior between the two tissues, stiffness were graphed as a function of medial / lateral tilt for all seven anterior / posterior tilts. The two extreme tilts, 30° anterior (Figure 2) and at 30° posterior (Figure 3) are shown.

DISCUSSION

As shown in Figures 2 and 3, the orientation-dependent behavior of the PT reconstruction does not exactly mimic that of the normal ACL; neither as a function of medial / lateral tilt, nor as a function of anterior / posterior tilt. This could indicate that the function of the tibial insertion of PT reconstructions does not completely mimic the function of the tibial insertion of the normal ACL; however further research is necessary to ensure that the reconstruction method and / or simulation of the tibial plateau are not the direct cause of orientation-dependent behavior.

The fixation method used may also directly influence the behavior of the reconstructed insertion. Graft fixation is a topic of great clinical interest [7], and further research may provide valuable data for the evaluation and comparison of different fixation methods.

Statistical methods for drawing comparisons between the two types of tissues are being developed. These methods may ultimately determine whether the differences described are significant, or if the PT reconstructions used here are sufficient replacements for normal ACLs.

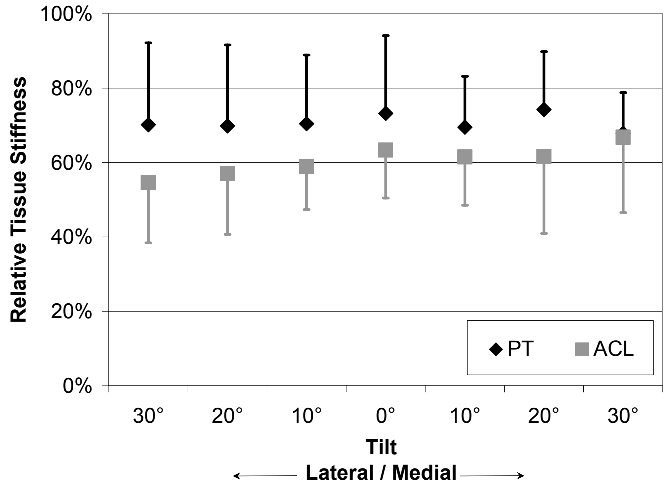

Figure 2. Average normalized stiffness as a function of medial / lateral tilt: 30° anterior

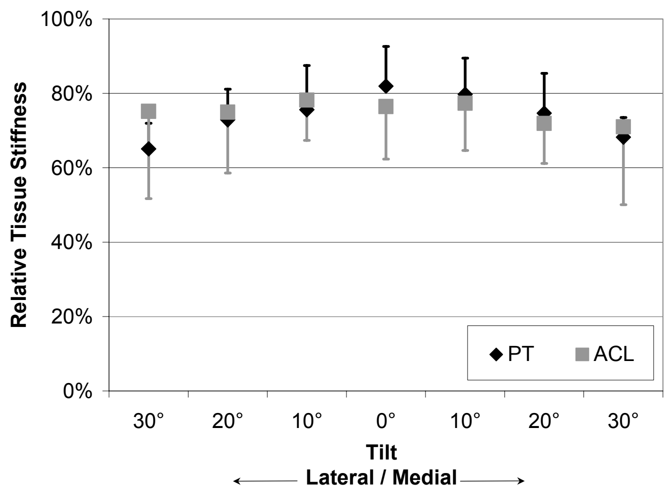

Figure 3. Average normalized stiffness as a function of medial / lateral tilt: 30° posterior

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