The Effect of Different Preconditioning Protocols on Anterior Knee Laxity After ACL Reconstruction with Four Commonly Used Grafts

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Introduction: Increased anterior laxity after anterior cruciate ligament (ACL) reconstruction is a clinical concern. A possible source of unwanted laxity is related to viscoelastic properties of the graft tissue after repetitive loading in the initial post-operative period, as stress relaxation and creep can occur during healing and recellularization. To reduce or eliminate these viscoelastic effects, graft preconditioning prior to fixation has been recommended [1-3]. Unfortunately, there is no consensus on the proper preconditioning protocol, and there is limited data directly comparing how different types of graft tissues respond to preconditioning. The objective of this study was to determine the effect of preconditioning on four common graft tissues by measuring anterior knee laxity after ACL reconstruction.

Methods: Ten human cadaveric knee specimens were used to collect baseline laxity data for the native ACL (mean age 34 years, range 21-45). Specimens were potted in PMMA for fixation. The tibia was clamped to a force-moment sensor mounted on the end of a six DOF robot, with the femur secured to a baseplate (Figure 1). Knees were positioned to 30° flexion and the robot then applied 134 N posterior tibial force followed by 134 N anterior tibial force. This was repeated for 250 cycles while recording the AP tibial translation.

A single knee was selected to test all ACL reconstructions. The ACL was excised and reconstruction was performed with one of four allograft tissues: 1) bone-patellar tendon-bone (BTB), 2) bone-Achilles tendon (ACH), 3) semitendinosus and gracilis hamstrings tendons (HAM), 4) tibialis tendons (TIB).

Immediately prior to reconstruction, the graft was subjected to one of four preconditioning protocols: 1) no preconditioning, 2) preconditioning on a tension board (89 N for 20 mins), 3) in situ preconditioning (89 N for 25 flexion-extension cycles), or 4) combined (protocol 2 and 3). Final tibial fixation occurred under 89 N graft tension at 30° of knee flexion. Cyclic AP testing was then repeated on the reconstructed knee.

In total, 160 graft preparations were tested (10 per preconditioning protocol equating to 40 of each tissue type). The testing order for all graft tissues and preconditioning protocols was randomized. A one-way repeated measures ANOVA was used to compare mean ATT increases from cycle 1 to 250 between the four preconditioning protocols (for each graft tissue) and between the four graft tissues (for a given preconditioning protocol). The level of significance was p < 0.05.

Results: Native ACL knees showed a minimal increase in ATT over 250 cycles (0.2 ± 0.1 mm), while grafts without preconditioning had significantly greater increases in ATT of 2.3 ± 0.5 mm, 2.8 ± 0.4 mm, 2.8 ± 0.3 mm, and 2.8 ± 0.5 mm for BTB, ACH, HAM, and TIB, respectively (p < 0.01; Table 1). For a given graft
tissue type, there were no significant differences in increase in ATT between preconditioning protocols. Within a given preconditioning protocol, there were no significant differences in increase in ATT between ACH, HAM, and TIB grafts. However, BTB grafts without preconditioning had 0.5 mm less increase in ATT than each of the other three tissues (p < 0.03), BTB with tension board preconditioning had 1.1 mm less increase in ATT than TIB (p < 0.001), and BTB with in situ preconditioning had 0.7 mm and 1.0 mm less increase in ATT than HAM and TIB, respectively (p < 0.04). When tension board and in situ preconditioning were combined, BTB grafts also showed 0.7 mm and 0.6 mm less increase in ATT than ACH and HAM grafts, respectively (p < 0.01). Throughout all test conditions and specimens, increase in ATT was more prominent in the first half of cycling compared to the last half with 75% of the total measured increase in ATT achieved by cycle 125 (Figure 2).

Discussion: After 250 cycles of AP testing with an applied AP tibial force of ± 134 N, increases in ATT with all grafts were roughly an order of magnitude greater than that of the native ACL. There were no significant differences in ATT between the four graft preconditioning protocols. Within each preconditioning protocol, while significant differences between the BTB grafts and the other three tissue types were noted, there is probably limited clinical significance as the largest observed difference was 1.1 mm.

Viscoelasticity of ACL graft tissues has been examined previously. Howard et al. [2] suggested that without preconditioning, post-operative viscoelastic creep will occur. However, Ejerhed et al. [4] concluded that in vivo there were no differences in laxity or clinical outcome at 2-year follow-up between ACL reconstructions performed with or without preconditioned BTB grafts. Our results can be best compared to those of Arnold et al. [5], whose BTB autografts were preconditioned with 30 N of constant force for 20 mins. Reconstructed knees were then tested for 1500 flexion-extension cycles. They noted that graft tension dropped rapidly within the first 100 cycles (32% reduction) and leveled off after 500 cycles. In our study, 75% of the total increase in anterior laxity occurred within the first 125 cycles and by cycle 250 further cycle-to-cycle increases in ATT were minimal.

The strength of our study design is that it closely replicates the clinical situation. The graft tissues were not simply tested under uniaxial tension, but after fixation in a knee to replicate anatomic factors and stresses that would be experienced in vivo. Anterior laxity is dependent upon more than the inherent material properties of the tissue. The graft must pass around the edges of tibial and femoral bone tunnels, subjecting the intra-articular graft tissues to contact stresses and local deformations at the tunnel edges. Therefore, we believe the current test setup better simulates actual graft loading conditions during the early post-operative rehabilitation period prior to incorporation and ligamentization.

In conclusion, for a given graft tissue, none of the preconditioning protocols significantly affected ATT during cyclic AP loading. This was a common result for all tissues tested.

Significance: Cyclic increases in ATT for preconditioned grafts were not significantly different than those with no preconditioning. The efficacy of current preconditioning protocols for an ACL graft prior to graft fixation is questioned.
Table 1. Increase in anterior tibial translation over after 250 cycles of applied ±134 N AP force.

<table>
<thead>
<tr>
<th>Condition</th>
<th>ACL</th>
<th>BTB</th>
<th>ACH</th>
<th>HAM</th>
<th>TIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0.2 ± 0.1 †</td>
<td>2.3 ± 0.5</td>
<td>2.8 ± 0.4 *</td>
<td>2.8 ± 0.3 *</td>
<td>2.8 ± 0.5 *</td>
</tr>
<tr>
<td>Board</td>
<td>N/A</td>
<td>2.0 ± 0.4</td>
<td>2.7 ± 0.3</td>
<td>2.5 ± 0.2</td>
<td>3.1 ± 1.2 *</td>
</tr>
<tr>
<td>In Situ</td>
<td>N/A</td>
<td>2.0 ± 0.4</td>
<td>2.5 ± 0.3</td>
<td>2.7 ± 0.3 *</td>
<td>3.0 ± 1.0 *</td>
</tr>
<tr>
<td>Combined</td>
<td>N/A</td>
<td>1.9 ± 0.3</td>
<td>2.6 ± 0.4 *</td>
<td>2.5 ± 0.3 *</td>
<td>2.3 ± 0.5</td>
</tr>
</tbody>
</table>

† Native ACL was significantly less than all other conditions (p < 0.001)
* Significantly greater than BTB (within a preconditioning protocol; p < 0.05)

Figure 1. Six degree-of-freedom robot used to apply 250 cycles of ±134 N anteroposterior tibial force while recording anterior tibial translation.
**Figure 2.** For each graft tissue (regardless of preconditioning), 75% of the total increase in anterior tibial translation occurred within the first 125 cycles. Shown are the mean increases of the native ACL and each of the grafts without preconditioning.