Introduction
Knee laxity tests are often used clinically as an objective evaluation of the cruciate deficient and reconstructed knee. A known external load is applied to the knee and the resulting anteroposterior (A-P) tibial translation, or knee laxity, is measured [1]. However, it is difficult to separate the anterior from the posterior tibial translation if the ‘resting’ or starting position of the knee is unknown. In addition, this resting position is affected by ligament injuries, e.g., the classic posterior sag of the posterior cruciate ligament (PCL)-deficient knee [2]. Our objective was to investigate the significance of the shift in the resting position in the PCL-deficient and reconstructed knees. We hypothesized that the resting position of the knee shifts posteriorly with PCL-deficiency. We further hypothesized that this position changes with PCL reconstruction, thus affecting laxity measurements of the reconstructed knee.

Materials and Methods
Eight fresh frozen human cadaveric knees (36-65 years) were tested using the robotic / universal force-moment sensor (UFS) test system [3]. The knee joint was kept intact while the surrounding skin and muscles were dissected. The femur was rigidly fixed to the base of the robot, and the tibia was mounted to the end-effector of the robot via the UFS. The resting positions of the intact knee were first determined through the range of passive knee flexion-extension between 0° and 120°. To achieve this, the robotic/UFS test system found the position of the knee which satisfied the condition of zero external force and moment applied to the joint through the range of flexion. The system was then used to determine the 5 degree of freedom (DOF) knee kinematics at 0°, 30°, 60°, 90° and 120° of flexion in response to A-P loads up to ±134 N. The PCL was transected and the new resting position of the PCL-deficient knee was determined. The A-P load of ±134 N was again applied, yielding the 5 DOF kinematics of the PCL-deficient knee. An Achilles tendon graft was then used to reconstruct the anterolateral bundle of the PCL. Two reconstructions were evaluated in each knee: 1) graft fixation performed at full extension and 2) graft fixation performed at 90° of flexion using a jig which enabled the graft to be tensioned and fixed multiple times. For each reconstruction, the new resting position and 5 DOF kinematics in response to the A-P load were determined at each flexion angle. For the PCL-deficient and both PCL-reconstructed knees, the ‘true’ posterior laxity and ‘apparent’ posterior laxity in response to the A-P load were determined. True posterior laxity was defined as the amount of translation with respect to the resting position of the intact knee. Apparent posterior laxity was defined as the amount of translation measured with respect to the new resting position for each condition, as would be observed clinically (Figure 1).

Because all tests were performed on the same specimen, statistical analysis was performed using repeated measures analysis of variance with multiple contrasts to evaluate the effects of PCL deficiency and reconstruction. Significance was set at p<0.05.

Results
PCL-deficiency resulted in a significant posterior shift in the resting position from the intact knee (p<0.05). This change in resting position tended to increase with knee flexion, ranging from 1.1±1.2 mm to 10.8±2.1 mm at 30° and 90° of flexion, respectively. PCL reconstruction also significantly affected the resting position of the knee. For the graft fixed at 90° of flexion, the resting position was restored to within 1.1±1.3 mm of the intact knee, while the graft fixed at full extension resulted in a resting position which was 2.5±3.4 mm anterior to that of the intact knee (p<0.05, Figure 1). The PCL reconstruction with the graft fixed at 90° of flexion resulted in true posterior laxity which was not significantly different from that of the intact knee. However, the apparent posterior laxity for this reconstruction was significantly higher than the intact knee by 1-2 mm (Table 1, p<0.05). The PCL reconstruction with the graft fixed at full extension resulted in a true posterior laxity which was 1-4 mm less than the intact knee at all flexion angles tested, indicating an overconstrained knee (p<0.05). However, the apparent posterior laxity for this reconstruction was not significantly different from the intact knee (p>0.05).

Discussion
In this study, we investigated the effects of PCL deficiency and PCL reconstruction on the resting position of the knee and measurements of knee laxity. Conventional laxity measurements are determined with respect to the resting position of the knee at the time the test is performed. However, our study has shown that this resting position shifts significantly with PCL deficiency and reconstruction, confirming our hypotheses. This change in resting position significantly affects the measurement of knee laxity. In our study, we have shown that an overconstrained PCL reconstructed knee could have a normal apparent knee laxity while its true knee laxity was significantly less than that of the intact knee. Thus, apparent knee laxity measurements can provide clinicians with false information regarding the results of their reconstruction. A more effective method to evaluate the PCL-reconstructed knee may be to measure total A-P laxity, provided that the ACL is intact. The shift in the resting position of the knee should be considered when evaluating patients clinically and when performing knee kinematics studies.

Table 1: True posterior laxity (TPL) and apparent posterior laxity (APL) under a 134 N posterior tibial load for the PCL reconstructed knee (mean±SD)

<table>
<thead>
<tr>
<th>Flexion Angle</th>
<th>Intact (mm)</th>
<th>Graft Fixed at 90° (mm)</th>
<th>Graft Fixed at 0° (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>6.3±1.5</td>
<td>6.0±1.8</td>
<td>5.9±1.5</td>
</tr>
<tr>
<td>60°</td>
<td>6.7±1.3</td>
<td>6.2±1.5</td>
<td>5.5±2.6</td>
</tr>
<tr>
<td>90°</td>
<td>5.7±1.3</td>
<td>5.9±2.6</td>
<td>5.2±2.6</td>
</tr>
</tbody>
</table>

*Significantly different than intact knee p < 0.05

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