INTRODUCTION: Accounting for the joint geometry of the knee through normalization is important when studying the change in kinematics and the strain in soft tissues when loads are applied [1,4,5]. Since very small deviations in knee kinematics can have profound clinical interpretations, the normalization scheme employed will likely produce a bias in the measured kinematics of each subject. Both rotations and translations of the tibia relative to the femur are coupled to knee flexion angle due to the geometry of the articular surfaces and the soft tissue restraints in the knee [1].

Traditional marker-based in vivo kinematic measurements are commonly referenced to the knee position during a static “neutral” stance trial. Until now, in vivo studies using fluoroscopy [2,3] have referenced tibiofemoral measurements relative to the static position of the tibia and femur acquired during CT or MRI. Conversely, studies based on the mechanical testing of cadaver knees most often report tibiofemoral kinematics relative to an unloaded or passive knee extension [4,5]. Specifically, a “neutral path” is determined in which force and moment profiles are removed or minimized over the entire test range of motion. We propose that applying consistent normalization will help reduce intra-subject variability as well as allow for more meaningful comparisons of the changes in knee kinematics that occur during activity.

The purpose of this study is to compare two proposed methods of normalizing kinematic measurements obtained in vivo: (1) static stance, and (2) seated knee extension. We hypothesized that normalization to knee extension would produce less variability and thus more accurate description of the change in knee kinematics that occurs with physical activity.

METHODS: Eleven healthy subjects (6M, 5F; age 26.9±6.4yrs) completed 5 drop landings from a height of 40cm inside a biplane fluoroscopy system. Subjects then performed a seated, knee extension task as well as a standing (bilateral support) static trial. Fluoroscopy images were captured at 100 Hz for one soft landing, the knee extension task and the standing trial. Bone geometries reconstructed from CT scans were matched onto the calibrated fluoroscopy images after their contours were detected semi-automatically (Medis Specials, Leiden, Netherlands).

Normalization to the static pose was achieved by subtracting a single kinematic value collected during static standing. Normalization to knee extension was achieved by subtracting the translation and rotation of the tibia during knee extension from data collected during the landing task at the same knee flexion angle. For example, ATT during the knee extension task was subtracted from ATT at the corresponding knee flexion angle achieved during the landing task.

RESULTS: The two normalization methods produced significantly different results for ATT (p = .002), external rotation (p < .001), and valgus rotation (p = .005) at all angles of knee flexion (Figures 1). When normalized to knee extension data, the variability in ATT was reduced by approximately 50% (Table 1). The variability of valgus and external rotation was similar between normalization schemes. The amplitude of each variable was smaller for normalization to knee extension (Table 1). The largest differences in amplitude were noted for external rotation, where mean differences reached approximately 15°.

DISCUSSION: External rotation normalized to static standing data was substantially smaller (~15 degrees) than data normalized to the knee extension task. This is because individuals normally internally rotate during passive flexion of the knee. When static standing was used to normalize to the dynamic task of landing, the value of external rotation was subtracted from absolute rotational data, yielding a large internal rotation. When normalizing to knee extension, external rotation angle was not biased by the value of external rotation observed at full knee extension.

Normalizing to knee extension angle reduces the variability associated with anterior tibial translation. During passive knee extension, the femur rolls forward on the tibia, producing posterior tibial translation. By normalizing data to kinematics measured at each flexion angle of a low load task, this bias is removed. As a result, this normalization scheme provides kinematics associated specifically with the forces applied to the lower limb during the task.

Due to the presence of muscles, in vivo normalization to a knee extension task does not provide no-load kinematic motions as do in vitro studies. However this task is a repeatable, technically simple, low-load task. ACL strain during knee extension has been shown to be quite low (2.8% strain [6]) and are less than that for walking.

Table 1: Average value of ATT, external rotation, and valgus rotation of the tibia during the landing task.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Static Stance</th>
<th>Knee Extension</th>
</tr>
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<tbody>
<tr>
<td>ATT</td>
<td>6.74 (2.38)</td>
<td>3.91 (1.09)</td>
</tr>
<tr>
<td>External Rotation</td>
<td>-18.42 (3.79)</td>
<td>-4.81 (5.07)</td>
</tr>
<tr>
<td>Valgus</td>
<td>-2.77 (1.46)</td>
<td>-6.02 (1.73)</td>
</tr>
</tbody>
</table>

CONCLUSION: Applying normalization to precision kinematic measurements further reduces variability and allows for meaningful comparisons of the changes in knee kinematics induced by activity and external load.

REFERENCES:

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