**Intrasubject Variability of In Vivo Patellofemoral Kinematics for a Three-Dimensional Model-Based Technique**

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**INTRODUCTION:**
Patellofemoral pain syndrome (PFPS) affects many millions of Americans that make running a regular component of their fitness regimen, placing them at risk for patellofemoral osteoarthritis. Abnormal mechanics and patellar maltracking have been implicated as contributing to PFPS symptoms, but treatment modalities designed to correct these abnormal mechanics have shown limited success, particularly with regards to long-term outcomes. Analysis of PFPS has been limited by the difficulty of accurately analyzing in vivo patellofemoral mechanics during moderate- to high-velocity movements of clinically-relevant activities such as squatting and running.

We have shown previously that high-speed biplane radiography and model-based tracking using computed tomography (CT)-based bone models allows for precise assessment of tibiofemoral and patellofemoral kinematics during clinically relevant joint loading. 1 We are currently conducting a pilot study using this technique to evaluate patellofemoral tracking in patients with PFPS and matched healthy control subjects. As a first step, the purpose of this initial study was to determine the intrasubject variability for patellofemoral joint kinematics in healthy control subjects during the active flexion phase of a single-leg squat. These data are essential for establishing the sensitivity of this technique for detecting tracking abnormalities associated with PFPS.

**METHODS:**
Study population: Four female recreational runners without lower extremity injury, disease, surgery, or knee pain were recruited as control subjects as part of a larger, IRB-approved study to assess in vivo patellofemoral tracking, joint contact kinematics, and cartilage contact patterns. Average age was 24.8 ± 1.7 years. Average body mass index was 22.6 ± 0.9 kg/m².

Data acquisition and processing: Subjects underwent three trials of a single-leg squat. Motion was captured using biplane radiography at 50 frames per second. High-resolution CT scans were obtained of the tested knee, which were reconstructed to produce subject-specific 3D bone models. Three-dimensional positions of the femur, patella, and tibia were determined using a model-based tracking method that maximizes the correlation between biplane x-ray images and digitally reconstructed radiographs generated from the bone models.

**RESULTS:**
Measurement variability was relatively independent of tibiofemoral flexion angle or subject (Figure 3). For translations, within-subject variability in the lateral-medial direction was nearly twice that in the proximal-distal and anterior-posterior directions, but maximum standard deviation for all translations remained below 1 mm (Table 1). For rotations, patellar spin and tilt showed higher variability than patellar flexion-extension. Average standard deviations for all rotations were less than 2 degrees.

**DISCUSSION:**
Trial-to-trial variability is due primarily to two factors: measurement imprecision and actual differences in task performance by the subject. A prior validation of this combined method of dynamic biplane radiography with model-based tracking for the in vitro patellofemoral joint showed precision in the order of 0.1 mm for translation and 0.4 degrees for rotation. 1 Variability in this study is approximately 3 to 5 times greater. Since this study employed nearly identical imaging protocols and tracking methods, this increase is most likely due to small alterations from trial to trial in task performance by the subjects. However, differences between in vivo and in vitro analyses (movement speeds, presence of the other limb, less predictable movement patterns) may also have contributed to the increased variability.

The results of this study provide essential data needed for planning future studies to determine differences in kinematics of those with and without PFPS. These studies are currently underway, and it is anticipated that determination of distinctive kinematic features between affected and unaffected patients may guide the development of improved treatment modalities for PFPS.

**REFERENCES:**

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**Figure 1:** The origin and axes are shown for the tibia, femur, and patella.

**Figure 2:** The six patellofemoral kinematic measures are defined.

**Table 1:** Average standard deviations and ranges of standard deviation for each translation (mm) and each rotation (deg) are shown.

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<thead>
<tr>
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<th>Standard Deviation (mm or deg)</th>
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<tbody>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>Lateral-Medial</td>
<td>0.485</td>
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<tr>
<td>Proximal-Distal</td>
<td>0.246</td>
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<tr>
<td>Anterior-Posterior</td>
<td>0.271</td>
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<tr>
<td>Flexion-Extension</td>
<td>0.796</td>
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<tr>
<td>Spin</td>
<td>1.783</td>
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<tr>
<td>Tilt</td>
<td>1.699</td>
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