

**Fast-PC MRI: A Faster, More Precise Method for Non-invasive *in vivo* Dynamic Joint Evaluation**

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**Introduction**

In order to advance the diagnosis and treatment of musculoskeletal disease, non-invasive, *in vivo*, techniques for the measurement of musculoskeletal dynamics are needed. Previously, Cine Phase Contrast (cine-PC) Magnetic Resonance Imaging (MRI) has been used to non-invasively determine *in vivo* patello-tibio-femoral kinematics (Sheehan, *et al.*, 1999), but imaging times were long (~7 min). Although the accuracy was found to be quite good, the precision of the technique was not determined. With the advent of faster MRI techniques a broader range of issues (i.e., patellar maltracking, ACL deficiency, and the effects of load) can now be studied. Prior to applying either technique to clinical trials, subject inter-exam repeatability (SIER) must be quantified.

The goal of this study was to determine the SIER using both the original and the new faster PC techniques in a group of healthy volunteers. In addition, we determined the precision of these techniques in order to determine the overall impact that technique precision has on SIER.

**Methods**

Seven subjects (14 unimpaired knees) participated in this study. Subjects were placed in a supine position within the 1.5 Tesla GE CX magnet and were asked to extend and flex their knee, from ~40° flexion to full extension at 35 cycles/min using a metronome as a guide. Velocity profiles were acquired in a sagittal plane at the centerline of the femur and patella using three sequences A. cine-PC (2 nex, TR=21msec, imaging time =5:33), B. cine-PC (1 nex, TR=21msec, imaging time=2:49), and C. fast-PC (2 nex, TR=9msec, imaging time=2:48). These sequences were presented in random order. The subjects repeated the movement exercise five times, with rests in between. This allowed PC data to be collected using two of the sequences twice and the remaining sequence once.

The SIER was calculated as the absolute difference in orientation angles for patellofemoral and tibiofemoral kinematics between two exams using identical sequences. Regions, graphically prescribed on the femur, tibia, and patella in the first anatomic image, were tracked throughout the motion cycle using Fourier integration (Zhu, *et al.*, 1996). Rigid body mechanics were used to determine the rotation matrix and displacement vector of each bone throughout all time. These matrices were then translated into xyz body-fixed orientation angles (θ1 = flexion, θ2 = tilt, θ3 = twist).

The micro-precision of each sequence was defined as the variance in the orientation angles calculated from 10 independent analyses, averaged over the entire motion cycle. To measure this, data from the first exam using a particular sequence was analyzed by prescribing 10 small independent regions on the femur and tibia in the first anatomic image. Orientation angles were determined as previously described. Based on the theoretical estimate (Pelc, *et al.*, 1994) of variance in phase contrast velocity measures (σv):

\[
\sigma_v = \sqrt{\frac{2}{N_p} \left( \frac{v_{enc}}{\pi \text{SNR}} \right)}
\]

\(N_p\) = Number of pixels

\(\text{SNR}\) = Signal to noise ratio

\(v_{enc}\) = Maximum possible value for velocity
it was evident that the variance was dependent upon the number of pixels in each region. This presented a harsh view since the areas of these regions used in the micro-precision study are much smaller (49 pixels) than regions used in a typical analysis (femur ~ 900 pixels, tibia ~ 920 pixels, patella ~ 145 pixels). Thus, macro-precision was determined by scaling the micro-precision by the area of each region in a typical knee joint study:

\[
\text{MacroPrecision} = \frac{\text{Area (Small)}}{\sqrt{\text{Area (Large)}}} \times \text{Microprecision}
\]

**Results**

The data acquired using fast-PC (2 nex) demonstrated excellent subject repeatability, the lowest absolute difference in orientation angles, of the three techniques used in this study for both tibiofemoral (Figure 1) and patellofemoral (Figure 2) kinematics.

Technique micro-precision for cine-PC (2 nex) and fast-PC (2 nex) was best for the tibia and femur, respectively (Table 1). By scaling these values based on the area of a typical region on the femur and tibia, we estimate the macro-technique precision to be less than 1° for all techniques (Figures 3 & 4). In addition, the patellar macro-precision was predicted in a similar manner. Since 10 small regions would not fit on the patella, due to its small area, we used the femoral micro-technique precision to predict patellar macro-precision (Figure 5).

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<thead>
<tr>
<th></th>
<th>Tibia</th>
<th>Femur</th>
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<tbody>
<tr>
<td></td>
<td>Flexion (θ₁)</td>
<td>Tilt (θ₂)</td>
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<tr>
<td>Cine-PC (2 nex)</td>
<td>2.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Cine-PC (1 nex)</td>
<td>3.9</td>
<td>2.2</td>
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<tr>
<td>Fast-PC (2 nex)</td>
<td>4.9</td>
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Table 1: Technique precision for small regions (49 pixels) in degrees
Discussion

In vivo data acquired non-invasively with fast-PC has been shown to have excellent SIER and thus should prove to be a useful tool in both clinical and biomechanical studies. These data represent true 3D kinematic angles, which are critical for understanding complete joint kinematics. Both 3D biomechanics data as well as the classic 2D clinical angles can be calculated from these data. As a result, variables important to biomechanists as well as clinicians can be determined from a single imaging study. In addition, data analyses using other imaging techniques are based on manually defining clinical measures in every image taken. Using our technique, anatomical landmarks are defined once for each individual exam and analytically tracked throughout the whole motion cycle. Thus, the potential for investigator bias is greatly reduced. As a result, subject specific 3D biomechanical data are available to aid in diagnosis and treatment of musculoskeletal pathology. In addition, clinicians can quantitatively track changes in musculoskeletal kinematics as a result of treatment.

When evaluating data for technique precision, ideally we would like to obtain multiple movement studies (e.g., 5-10 studies) from each subject. As seen by the SIER, it is clear that subjects cannot identically perform the same motion cycle. Thus we used 10 independent regions on the femur and tibia to determine technique precision. By taking the area of the region prescribed for each bone into consideration, the precision for all techniques is approximately $1.0^\circ$ or less. Thus, technique precision is not the limiting factor in this study.

We recommend fast-PC for all future dynamic musculoskeletal studies using MR imaging since it has the best SIER. The difference in technique precision most likely depends upon the susceptibility of the specific phase contrast imaging protocol to the motion artifacts present in the data. Fast-PC collects data at twice the rate (shorter TR) than cine-PC, thus the imaging time can be reduced by half without a loss of temporal resolution yet, the shorter TR makes fast-PC more susceptible to motion artifact. Thus, fast-PC has a slightly poorer technique precision due to its susceptibility to motion artifacts. The reduced imaging time using fast-PC more than compensates for this, resulting in fast-PC having by far the best SIER. Further, this study was performed on healthy volunteers. When expanding this protocol to study specific pathologies, patients may not be able to perform prolonged movement exercises, due to pain and fatigue. In this case, the shorter time of fast-PC becomes a critical factor.

References


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