Comparisons of Three Hip Joint Center Estimation Methods in Estimating Knee Mechanical Axis using Motion Capture
Hunter J. Bennett, Guangping Shen, Songning Zhang
Biomechanics/Sports Medicine Lab, The University of Tennessee, Knoxville, TN, USA
e-mail: hbennet4@vols.utk.edu

INTRODUCTION

The knee mechanical axis has been utilized in assessment of frontal plane knee alignment in knee osteoarthritic and total knee replacement populations, and associated with frontal plane knee joint loading, osteoarthritic disease severity, and progression. The mechanical axis is the angle between lines drawn from the center of femoral head to the center of the tibial spines and down to the center of the talus, measured using radiographs [1]. As an alternative measure, the mechanical axis can be approximated utilizing hip joint centers and centers of the femoral epicondyles and malleoli with a three-dimensional motion capture system [2]. Although epicondylar and malleolar centers can be found more easily and accurately, determining hip joint centers is more challenging.

The three commonly used hip joint center methods are the Bell (BELL) [3], functional (FUN) [4] methods, and a method using 25% distance between the greater trochanters (TROCH) [5]. As these methods have been previously shown to differ slightly in hip joint center locations [5], it is important to determine if these differences affect knee mechanical axes estimated from motion capture data. Therefore, the purpose of this study was to validate estimations of the knee mechanical axis using the three hip joint center methods with the mechanical axis measured on a long standing lower limb radiograph.

METHODS

Seven healthy subjects (aged: 26±3 yrs, mass: 78.9±19.2 kg, height: 1.77±0.1 m) were included in this study. Each subject had a full limb anteroposterior radiograph, while standing barefoot with tibial tuberosities facing forward [1,2]. Knee mechanical axes of each limb were determined with the previously defined standardized measures using the radiograph [1, 2]. The center of the femoral head was measured through fitting a circle to the head. A nine-camera motion capture system (240Hz, Vicon) was used in determining joint centers during static and dynamic trials. Anatomical markers were placed bilaterally on the anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), iliac crest and greater trochanter, femoral epicondyles, and malleoli. Tracking markers on rigid shells were placed on the posterior pelvis, thighs, and shanks. One static trial was captured with the subject in the same standing position used during x-ray data collection. Two functional hip trials were performed (one for each limb) using an arc motion, which included flexion/extension, ab/adduction, and circumduction of the hip [6]. All data were processed and analyzed using Visual3D (5.0, C-Motion, Inc.). The marker data were filtered using a low pass fourth-order Butterworth filter at a cutoff frequency of 8 Hz. Each anatomical marker was corrected for the diameter of the marker and its base.

Both BELL and TROCH methods were computed using the static trial. The BELL hip joint centers were determined using the CODA pelvis (determined by ASIS and PSIS) in Visual3D. The TROCH hip joint centers were determined using 25% distance between the trochanters. The FUN hip joint centers were determined based on the methods of Schwartz and Rozumalski [4] using the functional trials. All three hip joint centers were applied to the static trial and subsequently used to determine the respective knee mechanical axes.

The differences between mechanical axes measured with x-rays and the three hip joint center methods using motion capture were used for comparisons per limb. A 2×3 (limb×method) ANOVA was used to detect variations between hip joint center methods and x-ray scores.
RESULTS AND DISCUSSION

The difference scores for each hip joint center method are provided in Table 1. There was no significant limb by method interaction (p=0.54) or main effects for limb (p=0.75) or method (p=0.54). All three methods overestimated the x-ray mechanical axis by less than 2.3° on average. On an individual subject basis, mechanical axes varied as high as 4.6° and as low as 1.0° between hip joint center methods (Table 2).

Overall, the differences between x-ray and motion capture knee mechanical axes, on average, were quite small. These results assist in solidifying motion capture as a non-invasive alternative to x-ray assessments of the knee mechanical axis. The lack of significant differences between each method and the x-ray mechanical axes provides further evidence for the validity of each method in determining hip joint centers. As these methods are commonly utilized in biomechanics research, and variations in epicondylar and malleolar centers are likely to be much smaller, validation of these methods is important when considering knee frontal plane alignment using motion capture systems.

While we found no significant differences between methods for the knee mechanical axis, significant variations of the hip joint center locations have been found in the frontal plane [5]. It is possible that the hip joint center locations could still be different between methods, but they did not seem to contribute significantly to the variations of the motion capture knee mechanical axis.

A larger sample size is needed to strengthen the results. Further research is warranted to determine the validity of these methods in all three anatomical planes as well as assess their accuracy in diseased populations. Additionally, further research should focus on how each method affects lower limb biomechanics during dynamic movements.

CONCLUSIONS

Knee mechanical axes measured using motion capture were shown to differ from x-ray based mechanical axes by less than 2.3°. Comparisons of the three common hip joint center methods were shown to produce similar frontal plane knee alignment measures as the gold standard x-rays. Therefore, all three hip joint center methods seem to be valid choices when used in motion capture assessments of the frontal plane knee alignment.

REFERENCES


Table 1. Averaged Mechanical Axis Differences between Three Hip Joint Center Methods: mean ± STD.

<table>
<thead>
<tr>
<th></th>
<th>LEFT LEG Mechanical Axis</th>
<th>RIGHT LEG Mechanical Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TROCH</td>
<td>BELL</td>
</tr>
<tr>
<td>Difference (°)</td>
<td>1.84±1.79</td>
<td>1.79±2.15</td>
</tr>
</tbody>
</table>

Table 2. Largest and Smallest Individual Mechanical Axis Differences between Three Hip Joint Center Methods.

<table>
<thead>
<tr>
<th>Subject</th>
<th>LEFT LEG Mechanical Axis</th>
<th>RIGHT LEG Mechanical Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TROCH</td>
<td>BELL</td>
</tr>
<tr>
<td>3</td>
<td>3.24</td>
<td>2.15</td>
</tr>
<tr>
<td>4</td>
<td>1.01</td>
<td>1.79</td>
</tr>
</tbody>
</table>