COMPARISON OF THREE PLUG-IN-GAIT PROTOCOL VARIATIONS IN GAIT ANALYSIS

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INTRODUCTION

Gait analysis is recognized as an important diagnostic tool for the management of patients with gait pathologies. The Vicon® motion capture system is one of the most sophisticated systems used for gait analysis and the Plug-in-Gait (PiG) [1] skeletal model is widely used. As compared to other models, PiG results are reliable in the sagittal plane but show increasing variability in the frontal and transverse planes [2]. The PiG model relies heavily on the capability of the clinician to identify anatomical landmarks and hence is prone to errors. To overcome this drawback, Vicon® has incorporated a functional calibration method (PiG-FJC) to estimate the hip joint center position and knee rotation axes by moving the associated segments through their functional range of motion. This study evaluates the inter-protocol variability of hip and knee angles using three variations of the Plug-In Gait protocol during gait. The first protocol (PiG) is the conventional PiG model based on the original ‘Newington model’ [1, 3]. The second method, PiG-FJC, uses optimum common shape technique (OCST) [4] to create virtual rigid bodies. The method then uses symmetrical center of rotation estimation (SCoRE) [5] to estimate the hip joint center and symmetrical axis of rotation analysis (SARA) [6] to estimate the knee joint axes. SCoRE and SARA are then combined into the conventional PiG model. The third protocol (PiG-MED) uses medial knee and ankle markers to estimate the thigh rotation offset, shank rotation offset and tibial torsion to be adapted into the conventional PiG model.

METHODS

After providing informed consent approved by the institution’s human subjects review board, one female (22 years, 1.68 m, 63.7 kg) and two male subjects (23 and 33 years, 1.75 m and 1.83 m, 80.6 kg and 94 kg) participated in this study. A comprehensive marker set was designed by combining individual markers and clusters as required by the three protocols to allow simultaneous data capture. The subjects were marked in accordance to the PiG for the lower body with additional markers on the knee (medial epicondyles) and ankle (medial malleolus) which are necessary for the PiG-MED protocol. For the

Figure 1: Marker locations and skeletal model.

PiG-FJC, four-marker clusters were attached to the anterior-lateral aspect of the thigh and shank. 3-D marker trajectories were acquired at 100 Hz by an 8 camera motion capture system (VICON MX-T40S, Oxford Metrics, UK) and the data was processed independently according to each protocol.

The PiG and PiG-MED protocols require the same static calibration to be performed where the subjects stands in a static up-right posture. The medial markers were removed after static capture. The PiG-FJC uses functional calibration to estimate the hip joint center and knee joint axis. To estimate the hip joint center using SCoRE the subjects performed a star arc pattern consisting of flexion-extension, abduction-adduction and internal-external rotation while standing on the contralateral limb. For the SARA procedure the subjects performed a knee flexion movement pattern while standing on the
contralateral limb. Relevant anthropometric measures were taken as required by the PiG protocol. The subjects were asked to walk barefoot at their natural speed, and five walking trials were recorded. After data acquisition, 3D marker trajectories were reconstructed and the right and left stride phases identified for all five trials.

Figure 2: Five trial averages and standard deviations for joint angles with the lowest correlation coefficients. PiG (red), PiG-MED (blue) and Pig-FJC (green).

RESULTS AND DISCUSSION

The intra-subject kinematic variability observed was good over the five trials and within a maximum standard deviation of 6.43° for PiG, 6.39° for PiG-MED and 6.64° for PiG-FJC. Good waveform correlation was also observed for hip and knee flexion/extensions for all three protocols.

Table 1: Walk cycle correlation coefficients.

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<thead>
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<th>Protocols</th>
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<tr>
<td></td>
<td>PiG vs.</td>
<td>PiG vs.</td>
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<tr>
<td>Hip flexion/extension</td>
<td>1.000</td>
<td>0.999</td>
</tr>
<tr>
<td>Hip abduction/adduction</td>
<td>1.000</td>
<td>0.997</td>
</tr>
<tr>
<td>Hip internal/external</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Knee flexion/extension</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Knee abduction/adduction</td>
<td>0.998</td>
<td>0.997</td>
</tr>
<tr>
<td>Knee internal/external</td>
<td>0.999</td>
<td>0.986</td>
</tr>
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The PiG and PiG-MED show similar results for all kinematics. Out-of-sagittal plane rotations, especially hip internal/external rotation and knee abduction/adduction revealed poor waveform correlation for PiG-FJC when compared to PiG and PiG-MED as indicated in red (Table 1). The largest variability was observed at the knee abduction/adduction where opposite trends were observed (Fig. 2). The PiG-FJC hip joint centers were found to be consistently posterior and lateral relative to the PiG hip joint center (Fig. 3). In all three cases the flexion/extension axes for PiG-FJC were externally rotated (Table 2).

Figure 3: Hip joint center locations with respect to the pelvic coordinate system.

Figure 4: Flexion/extension joint axes for PiG in the transverse plane; (red), PiG-MED (blue) and PiG-FJC (green).

Table 2: Angle on transverse plane between PiG-FJC and line connecting medial-lateral knee marker.

<table>
<thead>
<tr>
<th>Subject</th>
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<tbody>
<tr>
<td>Subject 1</td>
<td>13.1°</td>
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<tr>
<td>Subject 2</td>
<td>14.64°</td>
<td>12.36°</td>
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<tr>
<td>Subject 3</td>
<td>8.54°</td>
<td>12.11°</td>
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REFERENCES