In Vivo Kinematic Analysis of the Hip during Activities of Daily Living.

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Disclosures:

Introduction: 3D-to-2D model registration technique has been used for evaluating 3D kinematics from 3D surface models of the prostheses or bones and radiographic image sequences [1, 2]. However, to our best knowledge, no studies have employed 3D-to-2D model registration technique to analyze in vivo healthy hip kinematics under dynamic weight-bearing conditions. Accurate kinematic analysis of healthy hips could be useful as the normative data when comparing to pathological hips. The purpose of this study is to observe healthy hip kinematics during activities of daily living using 3D-to-2D model registration technique and to evaluate the accuracy of this technique.

Methods: Subjects: Six healthy male subjects, averaging 33 years (31-36), 173 cm (170-177), and 67 kg (56-80), gave informed consent to participate in this Institutional Review Board approved study, and they were informed of the risk of radiation exposure required.

Measurement: Continuous anteroposterior radiographic images of walking, chair-rising, squatting, and twisting were recorded using a flat panel X-ray detector (Ultimax-I, Toshiba, Tochigi, Japan) (Fig. 1). This produced 3.5 frames/sec with an image area of 420 mm (H) × 420 mm (V), and 0.274 mm × 0.274 mm/pixel resolution. 3D bone models of the pelvis and the femur were created from computed tomography (CT) images to produce the density-based digitally reconstructed radiograph (DRR). Each hip joint was CT scanned (Aquilion, Toshiba, Tochigi, Japan) with a 512 × 512 image matrix, a 0.35 × 0.35 pixel dim, and a 1-mm thickness spanning from superior edge of the pelvis to below the knee joint line. The CT models were projected onto the actual radiographic images as the DRRs. An automated matching algorithm maximizing correlations between the DRRs and the actual radiographic images was applied to determine the 6 degrees of freedom of the pelvis and the femur (Fig. 3). The relative positions and orientations of the femur with respect to the pelvis were also determined. Pelvic angles in the sagittal and axial planes were defined as pelvic tilt angles and rotation angles. The positive or negative pelvic tilt and rotation were defined as posterior or anterior tilt, angles ipsilateral or contralateral rotation angles respectively. Femoral and hip angles in the sagittal and axial planes were defined as femoral/hip flexion-extension angles and rotation angles respectively (Fig. 2). The positive or negative femoral/hip flexion-extension and rotation were defined as flexion or extension and internal or external rotation respectively.

Accuracy evaluation experiment: The pelvis and the femur of a pig were fixed to a jig which can translate and rotate in increments of 0.1 mm 0.1 degree, respectively. Radiographic images of the fixed pelvis and femur were acquired at six different translations along both in-plane and out-of-plane directions and six different rotations around the axis of any non-overlapping each axis of the world coordinate system. Each radiographic image was analyzed five times using 3D-to-2D model registration technique and the root mean square (RMS) errors were calculated.

Results: Kinematics of each activity (Table 1)
The mean maximum hip flexion angles were 29.6±2.7° (mean ± SD) for walking, 81.3±13.6° for chair-rising and 102.4±13.1° for squatting. Because the pelvic tilt angles changed in the different timing from the femoral flexion angles during chair-rising and squatting, the hip flexion angles peaked in the midstream of the motion. The hip maximum internal/external rotation angles were 29.1±13.1°/30.7±17.2° for twisting and were not larger than that of the pelvic rotation angles because the femur was somewhat compensated by the pelvic rotation. Both pelvic, femoral and hip rotation angles peaked at almost the same time.

Accuracy evaluation experiment
The RMS errors of the pelvis/the femur were 0.21 mm/0.15 mm in the in-plane direction, 0.14 mm/0.23 in the out-of-plane direction, and 0.25°/0.23° in the rotation, respectively.

Discussion: We analyzed dynamic kinematics of normal hip joints using 3D-to-2D model registration techniques with high accuracy. This method could evaluate the coordinate motion between the pelvis and the femur separately and at the same time during various activities of daily living with, and revealed that the pelvic position changed in the different timing from the femoral position.

Significance: This method achieved both high accuracy and less-invasiveness for measurement of the hip kinematics during functional activities. The results of this study are expected to be useful as the normative data when comparing to pathological hips.
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<table>
<thead>
<tr>
<th>Activity</th>
<th>Max pelvic tilt</th>
<th>Min pelvic tilt</th>
<th>Max femoral flexion</th>
<th>Min Femoral flexion</th>
<th>Max hip flexion</th>
<th>Min hip flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
<td>-2.7±5.4°</td>
<td>-6.0±5.0°</td>
<td>25.7±3.5</td>
<td>-4.2±2.8°</td>
<td>29.6±2.7°</td>
<td>1.3±7.4°</td>
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<tr>
<td>Chair-rising</td>
<td>12.4±7.3°</td>
<td>-11.7±9.4°</td>
<td>83.5±8.0°</td>
<td>-4.2±6.6°</td>
<td>81.3±13.6°</td>
<td>-2.9±11.9°</td>
</tr>
<tr>
<td>Squatting</td>
<td>10.7±8.1°</td>
<td>-10.8±8.1°</td>
<td>108.5±13.1°</td>
<td>-4.1±4.9°</td>
<td>102.4±12.3°</td>
<td>-0.4±4.7°</td>
</tr>
<tr>
<td>Max pelvic rotation</td>
<td>Min pelvic rotation</td>
<td>Max femoral rotation</td>
<td>Min femoral rotation</td>
<td>Max hip rotation</td>
<td>Min hip rotation</td>
<td></td>
</tr>
<tr>
<td>Twisting</td>
<td>47.2±6.2°</td>
<td>-51.7±8.1°</td>
<td>24.6±10.6°</td>
<td>-17.9±7.5°</td>
<td>29.1±13.1°</td>
<td>-30.7±17.2°</td>
</tr>
</tbody>
</table>

Fig. 1. Photography of each motion.
Subjects walked on a level treadmill, a), got up from sitting on chair, b), got up from maximam hip flexion to standing position, c), rotated the trunk contralaterally first from the neutral standing position to maximum rotation and returned to the standing position, and then rotated ipsilaterally in a similar way,
Fig. 2. 3D-to-2D model registration technique
The hip motions, a) were captured as continuous X-ray images using a flat panel X-ray detector, b). CT slices scanned by each subject, c) were reconstructed to the density-based digitally reconstructed radiograph (DRR) and projected onto the actual radiographic images, d). Using 3D-to-2D model registration technique, the actual radiographic images were applied to determine the 6 degrees of freedom of the pelvis and the femur,
Fig. 3. The coordinate system of the right hip joint.

The coordinate system of the pelvis was based on the APP, a), b). The coordinate system of the femur was based on the center of the femoral head and the trans-epicondylar axis, c). The positive or negative pelvic tilt and rotation were defined as posterior or anterior tilt and ipsilateral or contralateral rotation respectively a), b). The positive or negative femoral/hip a flexion-extension and rotation were defined as flexion or extension and internal or external rotation respectively, d), e).

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