Methodology and Validation for Predicting Pelvis H-point Kinematics from Femur Kinematics Calculated by Motion-capture Marker Clusters

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I. INTRODUCTION

Pelvis kinematics are critical in predicting occupant response [1], which is one of the biggest challenges for assessing ATD biofidelity [2], and crucial in evaluating the risk of submarining [1][3], an injury mechanism that may become more prominent with the introduction of highly autonomous vehicles and reclined seating postures [4-8]. Although frontal impact sled tests have been performed with post-mortem human subjects (PMHS) in both upright and recline postures [4][6-7][9-11], these tests used simplified seats, most of which did not contain a seat-back. Use of a seatback obstructs the visibility of motion-tracking markers fixed to the pelvis posteriorly [7][9] and will limit the ability of motion-tracking systems to measure pelvis kinematics. Tracking pelvis kinematics in sled tests with a seatback requires a surrogate measurement. Although a previous study described an approach to use femur kinematics to predict pelvis kinematics [4], the predicted pelvis kinematics were not validated. The goal of this research was to develop and evaluate the accuracy of a methodology for predicting pelvis kinematics using motion-captured femur kinematics and coordinate transformations.

II. METHODS

A frontal impact, 35 g, 50 km/h, sled test was conducted on a mid-size female adult PMHS using a reverse acceleration sled system (1.4 MN ServoSled®, Seattle Safety, Auburn, WA, USA). The test replicated prior studies of reclined PMHS subjected to frontal impacts [6-7][9]. A 1000 Hz optoelectronic motion-capture system (Vicon MX™, VICON, Centennial, CO, USA) was used to track clusters of four retroreflective spherical markers rigidly fixed to the left posterior superior iliac spine (PSIS) and left femoral shaft (Fig. 1).

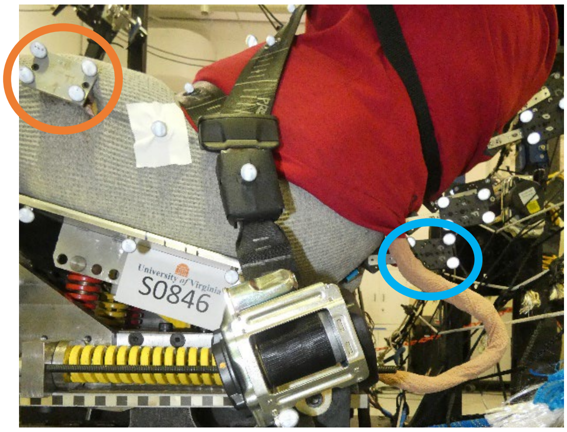

Fig. 1. Sagittal view of left femur and pelvis marker clusters. The pelvis marker cluster is partially obstructed by the PMHS umbilical.

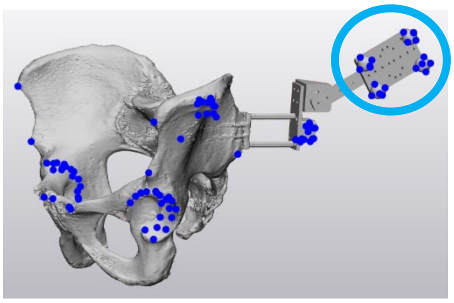

Fig. 2. Pelvis cluster fixation hardware. Blue dots reflect digitized points.

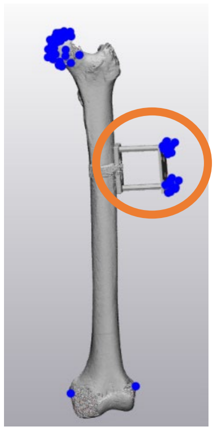

Fig. 3. Femur cluster fixation hardware.

Pre-test CT scans and hardware CAD assemblies were combined in CAD software (3-matic, Materialise NV, Leuven, Belgium) to recreate anatomical, hardware, and marker fixation orientations, which were used for retroactive digitisation of anatomical landmarks and marker clusters (Fig. 2 and Fig. 3) [6][12]. Points digitised around each marker were used to develop a local marker coordinate system (CS) and transformation matrix relative to the CAD CS ($T_{Marker/CAD}$). Anatomical landmarks were used to define each local bone CS and transformation matrix relative to the CAD CS ($T_{Bone/CAD}$) [12]. For each frame, motion-capture data were used to define the marker CS transformation matrix relative to the VICON CS ($T_{Marker/VICON}$) [6][12]. A global CS was defined

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on the sled buck in accordance with the SAE J211 specifications and used to develop the transformation matrix of the global CS relative to the VICON CS ($T_{Global/VICON}$) [6]. Multiple transformation matrices were developed and applied to ultimately develop transformation matrices between each bone CS and the global CS (Equations 1–3). The bone CS origins relative to the global CS, defined by the sphere fit centres of the left acetabulum and left femoral head for the pelvis and femur, respectively, were used to track and predict pelvis kinematics.

$$T_{Marker/CAD}^{-1} * T_{Bone/CAD} = T_{Bone/Marker} \quad (1)$$
$$T_{Marker/VICON} * T_{Bone/Marker} = T_{Bone/Vicon} \quad (2)$$
$$T_{Global/VICON}^{-1} * T_{Bone/VICON} = T_{Bone/Global} \quad (3)$$

III. INITIAL FINDINGS

Initially, the centre of the femoral head was approximately 2 mm rearward (-X), 15 mm rightward (+Y), and 2 mm upward (-Z) relative to the centre of the left acetabulum. Kinematic trajectories of the femoral head and the acetabulum varied by, at most, 13 mm and 24 mm along the X and Z axes, respectively (Fig. 4). Peak measured and predicted pelvis forward and downward excursion occurred at approximately the same time, whereas peak upward excursion occurred approximately 17 ms earlier for the femoral head than for the acetabulum (Fig. 5 and Fig. 6).

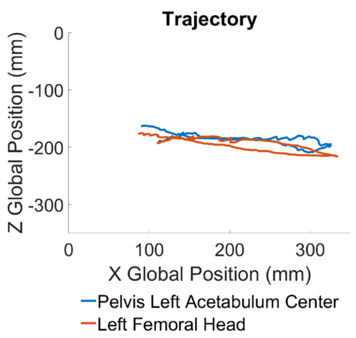

Fig. 4. Global X and Z trajectories.

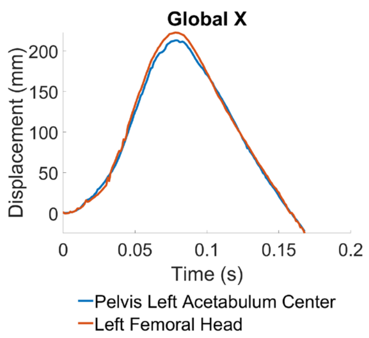

Fig. 5. X-displacement time history.

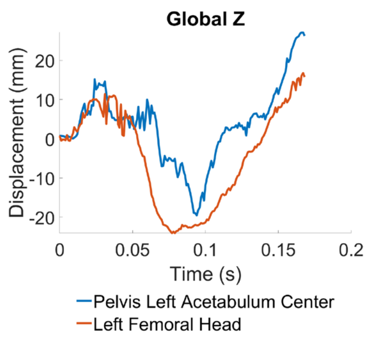

Fig. 6. Z-displacement time history.

IV. DISCUSSION

Kinematics of the pelvis were shown to be predicted reasonably well by transforming motion-captured femur kinematics, which provides for an approach to capture pelvis kinematics in PMHS tests that utilise seatbacks. Differences between the femoral head and acetabulum kinematics measured here may have been due to femoral head motion within the acetabulum resulting from the relatively high forces and accelerations created by the sled test. Further, since rotations of the pelvis and femur contribute to measured translations of the centre of the acetabulum and femoral head, non-identical rotations of the pelvis and femur will introduce error between measured pelvis translations and pelvis translations predicted by the femur. Differences between the femoral head and acetabulum trajectories appear to be due to a combination of error introduced by non-identical rotations of the bones, relative motion of the bones with respect to one another due to high forces, and deformation of the pelvis and femur themselves. The current methodology was evaluated for one impact condition and severity, and thus further investigation should be done in tests of varying occupant postures and severities where both the pelvis and femur can be tracked to ensure differences in predicted kinematic behaviour remain low.

V. REFERENCES

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