A Quick Running Model of the Spine for High Rate Axial Loading

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I. INTRODUCTION

Injury to the spinal column is common in events associated with high rate axial loading. At its extreme, in vehicles attacked by explosives, the blast pulse generated may reach the pelvis and lumbar spine within 30 ms, with an upwards peak acceleration of over 100 g at the seat [1]. Insight into the load transfer and kinematics of the spine during high rate loading is key to developing appropriate injury-mitigating strategies.

Human body models (HBMs) developed for the automotive industry and used to predict injury and design mitigation have been validated mostly for frontal or side-impact loading scenarios, but not for vertical and high rate. They are also geometrically complex and computationally intensive. This study aims to develop a fast-running and simple rigid-body (RB) model of the spine that is easy to modify and that can be used to develop a better understanding of the effect of loading conditions, postures, patient specific geometries, including the effect of gender, and injury-mitigating measures on risk of spinal injury.

II. METHODS

The RB model (Fig. 1) is composed of the head and torso (the torso is represented by just the spine). The geometry of the spine was created from CT scans. Each vertebral level represents the axial slice of the torso across the level. The height of each vertebral level is the vertical distance between the superior end plates of adjacent vertebral bodies (VB), measured at their centres. The mass of the torso across the slice is taken as the volume of the slice measured from the CT scan, multiplied by the average density of soft tissue from the literature [2].

Adjacent levels can move freely about the centre of rotation on the bottom VB [3]. This motion is viscoelastic with stiffness (K) and damping (C) properties representing the combined effects of the intervertebral discs (IVD) [4] and soft tissues in the torso.

Simulations using not only this model but also the THUMS v5 and ViVa HBMs, which are used widely in automotive applications, were run to replicate a lab-simulated high rate axial loading scenario on full-body cadaveric specimens [1]. The acceleration signal recorded at the pelvis during the experiment was input to the models as a sacrum acceleration. A sensitivity study of the RB model was carried out to identify the variables with the greatest effect on the resulting acceleration at T1.

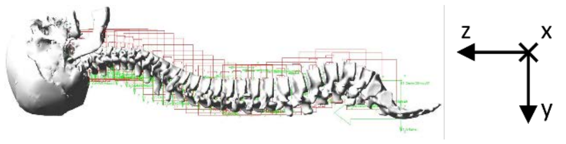

Fig. 1. The rigid-body model is composed of three markers in each vertebral level (green coordinate axes), representing the centre of mass and the top and bottom centres of rotation on the vertebral body. Motion of the vertebral bodies is modelled using viscoelastic elements (red squares). Acceleration is input at the sacrum (large green arrow). The 3D representations of the head and spine are purely for illustrative purposes.

III. INITIAL FINDINGS

The acceleration response of the models at T1 is compared to the experimental data in Fig. 2. In both the y (not shown here) and z axes, where accelerometer data from the experiment were recorded, the RB model presents a reasonably good match to the shape of the plot. The THUMS v5 and ViVa models instead present an underdamped response. All three models predict the duration of the vertical acceleration wave at T1 to last approximately twice as long as the experiment suggests. The ViVa and RB models also predict a lag in the pulse transmission superiorly, approximately 5 ms and 10 ms, respectively. Additionally, all three models predict a large attenuation axially, with the peak acceleration being 10% that of the experimental value. The sensitivity study

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showed that reducing the effective contributing mass of each vertebral level had the largest effect on the resulting acceleration amplitude (Fig. 3).

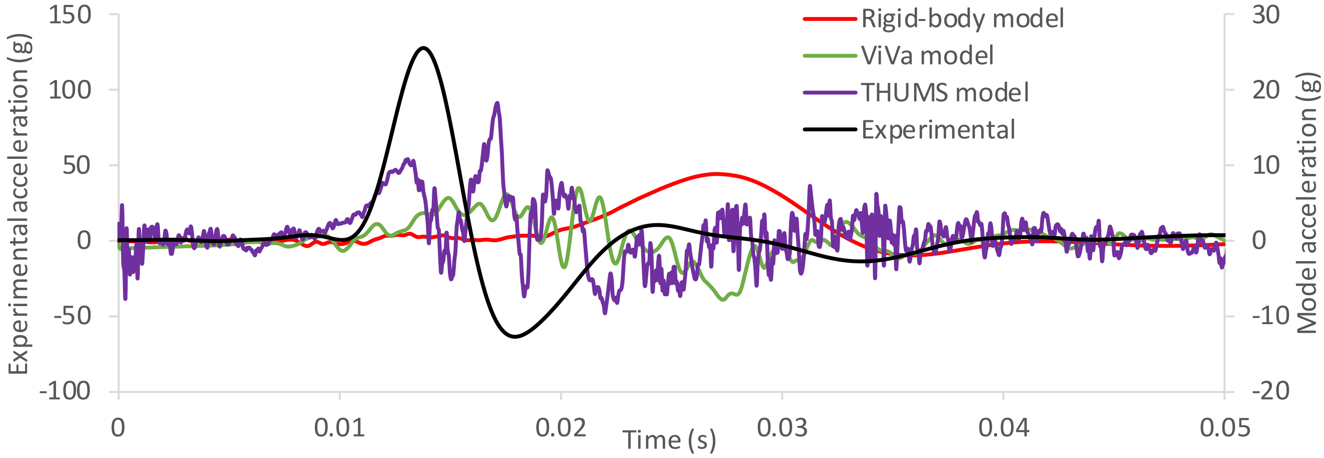

Fig. 2. Vertical acceleration at T1 from experiment and models. All models (right y-axis) predict an acceleration response whose amplitude is an order of magnitude lower than that recorded in the experiment (left y-axis).

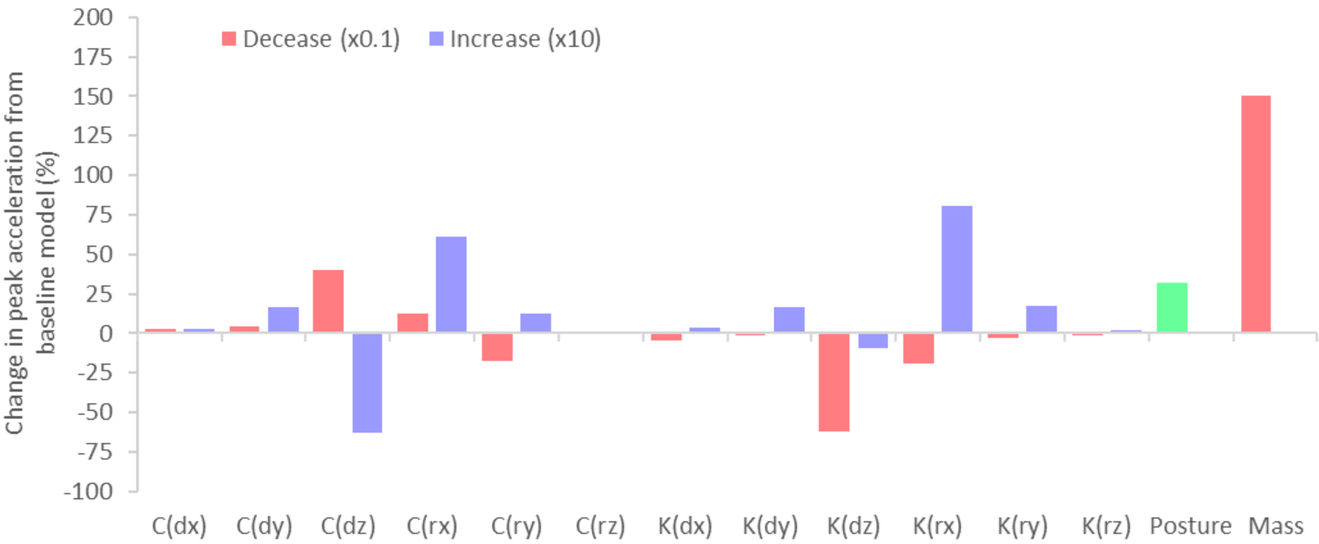

Fig. 3. Sensitivity study of the variables in the rigid-body model. Stiffness (K) and damping (C) in all 6 degrees-of-freedom (dx, dy, dz, rx, ry, rz) and the mass of the body are individually varied by a factor of 0.1 and 10. Posture sensitivity was performed by manually straightening the spinal curvature.

IV. DISCUSSION

A fast-running and simple RB model was developed for high rate axial loading and compared to relevant experimental data and the THUMS v5 and ViVa HBMs. None of the models was able to capture the experimental response, but the sensitivity study on the RB model showed that the recruited mass had the largest effect on the mechanical response of the spine. Implementing a smaller mass would represent a reduced recruitment of tissue, which is likely due to the short timescale of the pulse. The THUMS v5 and ViVa models implement the tissue and the spine in detail. However, as automotive frontal models, they are not validated for this vector or intensity of loading. Next steps will use multiple existing high rate axial load experiments with more VBs instrumented and the RB model to determine the effective mass recruitment before running multiple RB simulations to ascertain the effect of posture, anatomy and mitigation technology on probability of injury.

V. REFERENCES

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