A Comparison of the Compressive Behaviour of Lumbar Intervertebral Discs in Five Human Body Finite Element Models

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I. INTRODUCTION

Human body models (HBMs) are used to gain a better understanding of injury biomechanics in order to design mitigation strategies for the automotive industry, but also for other applications that involve high rate loading of the human body. It is expected that their use will increase in future consumer protection tests [1]. To ensure their response is biofidelic, such that they can be used reliably to develop mitigation strategies, a thorough validation is required. As the structural support of the upper body is provided by the lumbar spine, it is an important component of HBMs, particularly when predicting injuries in new seating positions, such as those currently being investigated in autonomous vehicles. Due to its complexity, it is appropriate to employ a 'bottom up' approach for validation of the spine in HBMs. This involves first validating smaller components, such as the intervertebral disc, then gradually increasing complexity until, finally, the full-scale HBM is validated.

The aim of this study is to compare the response of the intervertebral discs in five widely used HBMs against an experimental corridor in axial compression.

II. METHODS

In order to investigate modelling differences that could have an influence on the validation, five different HBMs were examined. The five HBMs used were the Total Human Models for Safety (THUMS) 3, 4 and 5, the Global Human Body Model (GHBM), and the Virtual Vehicle-Safety Assessment (ViVa) (Fig. 1). These were selected because they are state-of-the-art models that are currently being used in industrial and academic settings. The responses of these models was compared against the experiments described in [2].

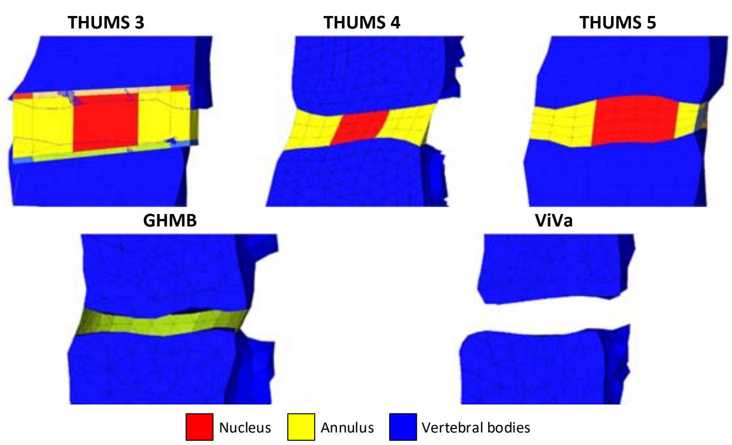

Fig. 1. Representations of the five human body models used in this study.

The material properties used in these models are summarised in Table I. The boundary conditions (BCs) for each model were assigned to match the experimental setup (Fig. 2). The upper boundary (hood) displacement was assigned an average displacement measured by the vertical LVDTs in the 12 experiments, while the lower boundary (bottom mounting pot) was fixed rigidly. The cortical bone of the vertebrae was fixed rigidly to the mounting pots and the vertical force was measured at the upper pot. Simulations were run for each spinal level (L1-L2, L2-L3, and L3-L4) in each lumbar spine model, and an average curve per model was calculated.

TABLE I

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DESCRIPTION OF MATERIAL PROPERTIES USED FOR THE FIVE HBMS.
ANNULUS FIBER ANGLES ARE RELATIVE TO THE TRANSVERSE PLANE

Model	Nucleus	Annulus Matrix	Annulus Fibers
THUMS 3	Linear Elastic Solids	Linear Elastic Solids	Seatbelt Beams, Three Layers, ±45°
THUMS 4	Isotropic Elastic Plastic Solids	Fu Chang Foam Solids	Seatbelt Beams, Two Layers, ±45°
THUMS 5	Ogden Rubber Solids	Viscoelastic Solids	Discrete Cables, Three Layers, ±25°
GHMB	6DOF Beam Force-Displacement, Moment-Angle Curves		
ViVa	6DOF Beam Force-Displacement, Moment-Angle Curves		

III. INITIAL FINDINGS

The force-displacement curves of the simulations and experiments are presented in Fig. 3. Experimental data up to 1.2 mm of compressive displacement were consistently recorded for all samples. At this displacement, THUMS 4, THUMS 5 and the GHMB predicted forces that are 93%, 16% and 38% higher than the experimentally measured forces, respectively. Conversely, THUMS 3 and ViVa predicted forces that were 32% and 67% lower, respectively.

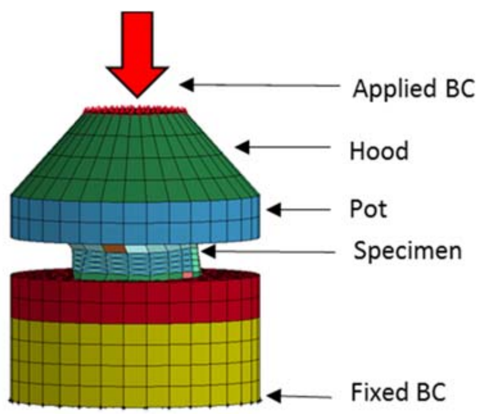

Fig. 2. Schematic of the simulation setup. A displacement was applied to the top of the hood, and the vertical force applied to the specimen was measured at the upper pot.

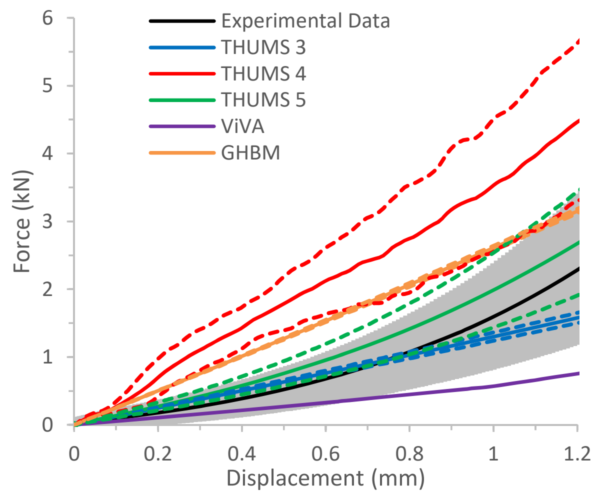

Fig. 3. A comparison of the force-displacement response of the experimental and numerical results. The shaded region represents ±1 SD for the experimental data, and the dotted lines represent ±1 SD for the HBMs.

IV. DISCUSSION AND OUTLOOK

This is the first study to compare the responses of five HBMs in axial compression against experimental corridors. Only THUMS 3 and THUMS 5 had average values that were within the experimental corridor throughout the compression, but the linear response of THUMS 3 (probably due to having solely linear elastic material properties) may be considered unrealistic in comparison to the shape of the experimental response corridor. Similarly, the shape of the THUMS 4 response did not follow that of the experimental response, likely due to the annulus matrix being constructed with a highly compressible foam. Therefore, of all the HBMs, THUMS 5 had the closest match to the experimental data.

THUMS 4 and 5 appear to be the only models with a large spread over the spinal levels; this is probably due to geometrical factors, as the material properties are consistent. THUMS 3 also shows a slight variation across levels, but as the disc geometry stays relatively constant, and with consistent material definitions across spinal levels, the response is relatively consistent. GHBM and ViVa show almost no variation across levels, most likely because the geometries at each spinal level are similar, and their material properties are the same.

Future work includes investigating other modes of loading, incorporating posterior elements into the validation strategy, and considering strains and strain rates which cause injury. The response of multiple spinal segments, and their interactions with other tissues, will also be the focus of future studies.

V. References

[1] van Ratingen, M., IRCOBI, 2016.
[2] Newell, *et al*., IRCOBI, 2017.