Development of a 50th Percentile Female Human Body Model

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I. INTRODUCTION

For restraint development, the design standard is the 50th percentile male, with a stature of 175 cm and a weight of 77 kg [1]. However, for Whiplash Associated Disorders (WAD), injury statistics show that the average female is at 1.5–3 times higher risk than males of sustaining injury [2]. WAD occur in all impact directions, but rear-end impacts are the most frequent cause. Hence, seat design is central for good occupant protection. Previous work has shown differences in the response of male- and female-sized dummies in evaluation of different seat concepts [3]. For the average male occupant, several numerical Human Body Models (HBMs) have been developed and are used for impact biomechanics research; for the average female, much more limited modelling efforts have been made [4]. Therefore, the aim of this study is to create a 50th percentile female HBM. The model will be released under the Open Source license GPL v3, and at the present stage the work is focused on rear-end impacts and seat assessment by developing a detailed cervical spine model and a kinematic whole-body model (WBM).

II. METHODS

In a previous study [5], a 50th percentile female ligamentous cervical spine model was developed from surface data and validated for physiological loading. Here, this model is integrated into a WBM developed from image data acquired using a multi-modality approach [6-8].

Whole-body Model Development

A 50th percentile female subject of 161.6 cm stature and 60.8 kg weight was selected (close to the reported 161.8 cm and 62.3 kg for a 50th percentile female [1]), and a total of 138 scan series, with approximately 20,000 images, were captured in an automotive seated posture. Stereolithography (STL) surfaces were created from the image data and based on this surface data, a finite element (FE) mesh was created (Fig. 1). Soft tissues are modelled with deformable elements, and the skeleton was modelled with rigid bodies, connected by compliant kinematical joints, to provide a biofidelic kinematic response during impact.

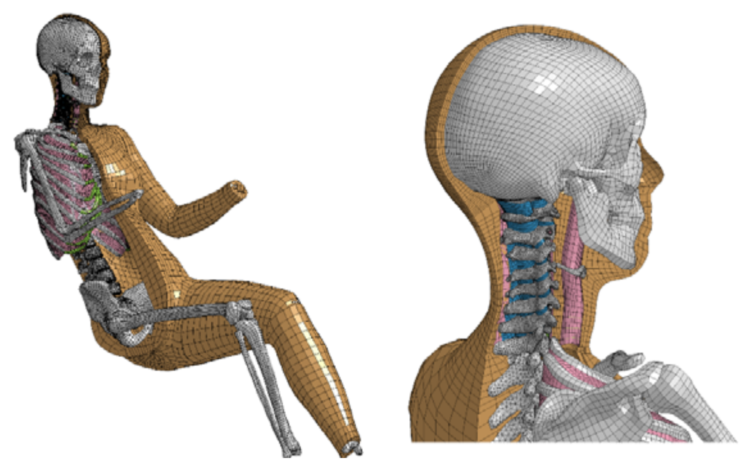

Fig. 1. Overview of the WBM (*right*) and the integrated cervical spine model in the WBM (*left*).

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Integration of the Cervical Spine Model

The ligamentous cervical spine model [5] fit the geometry of the WBM relatively well, and the mesh was translated into position without any scaling. The atlanto-cranial ligaments were connected to the skull by a continuous connection of the meshes, while the cranial occipital joint cartilage was connected to the skull with a tied contact. The spinous processes of C6, C7 and T1 were shortened 10 mm by cutting the most posterior portions, as they protruded outside the skin of the WBM geometry. The interspinous ligament (ISL) at C6C7 and C7T1 level was remodelled to half its previous anterior-posterior width, to match the shorter spinous processes. To provide the same cross-sectional area of the ligaments, the thickness was increased to 1.0 mm (from 0.5 mm), and the material properties of the new ligament geometry were fit as described in [5]. Lastly, to evaluate the influence of this change, simulations of the flexion-extension response of C6C7 and C7T1 segments were made with the explicit FE code LS-DYNA MPP R7.1.1 (LSTC, Livermore, CA).

III. INITIAL FINDINGS

The flexion-extension range of motion (ROM) for the C6C7 and C7T1 segments increased after the modification of the ISL ligaments (Fig. 2). The C7T1 ROM now closely matches the average reported for female post-mortem human subjects (PMHS) [9], while the C6C7 ROM better matches the C5C6 ROM for PMHS [9].

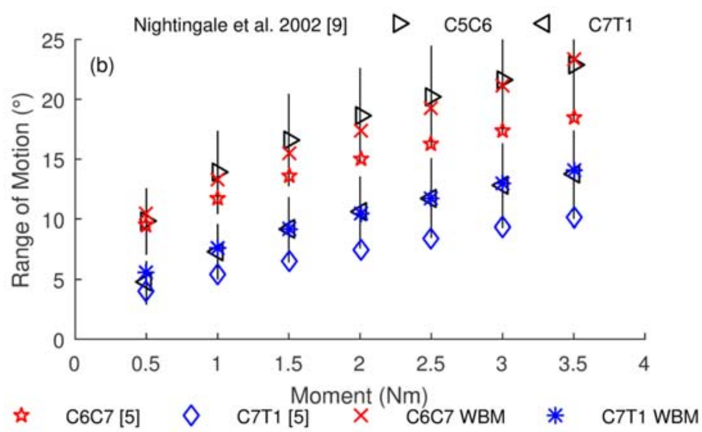

Fig. 2. Flexion-extension ROM after modifications for incorporation into the WBM (*red cross and blue asterisk*) compared with [5] (*red star and blue diamond*) and PMHS data [7].

IV. DISCUSSION

A 50th percentile female HBM is being developed, with an initial focus on the cervical spine and assessment of occupant protection in rear-end impacts. The kinematics of the WBM will be validated with published PMHS data, and the cervical spine model, along with soft tissues and muscles, will be further validated in dynamic loading with PMHS and volunteer data. Here, the cervical spine model [5] was modified by shortening the processes of the C6, C7 and T1 and this provided a larger flexion-extension ROM (Fig. 2). The likely cause of this was the reduced lever arm for the ISL ligament, and hence subjects with longer spinous processes can be expected to have a less compliant flexion response, given that the cross-sectional area and strength of the ISL is similar. The VIVA OpenHBM 50th Percentile Female Occupant Model described in this paper will be available for downloading and use under an Open Source license at: http://www.chalmers.se/en/projects/Pages/OpenHBM.aspx.

Acknowledgement

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V. REFERENCES

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