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Difference in Female and Male Whiplash Injury Risk – Indications from Seat Testing and From Fluid Dynamics Modelling of Nerve Injury Mechanisms

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Abstract: Whiplash Associated Disorder (WAD) is still one of the most poorly understood traffic injuries. Cervical dorsal root ganglion lesion is a potential cause of WAD. This short communication covers factors that potentially contribute to the difference in WAD risk between female and male car occupants in rear impacts.

A prototype female rear impact dummy and the male BioRID II dummy were used. In parallel a 3D model of the ganglion and the intervertebral bridging veins was developed in CFD software. The T1 x-acceleration was mostly higher in the female dummy, coinciding with the time of strongest pressure magnitudes.

Car seats interacted differently with the female compared the male dummy. Increased early T1 acceleration of the female indicates a stronger pressure magnitude in the vertebral canal. Increased pressures were also found with more female-like neck joint properties.

The results points to the need to complete the rear impact whiplash protection assessment testing with an average female size rear impact dummy.

Keywords: Whiplash injury, Fluid dynamics, Rear impact, Spinal canal, Spinal ganglion

1 Introduction

Whiplash Associated Disorder (WAD) is still one of the most poorly understood traffic injuries. WAD can occur in all impact directions, but rear - end impacts are the most frequent cause in accident statistics [12]. Furthermore, WAD is a major cause of long term disability, accounting for 70% of all disabilities due to vehicle crashes in Sweden [6]. Although injury mechanisms causing WAD are not fully understood, protective seat designs have shown to be effective in reducing the risk for WAD in rear - end collisions, but more so for males than females [5]. According to Siegmund et al. [11] the literature supports an organic basis for WAD and several anatomical sites of injury have been proposed. Lesions to the dorsal root ganglia in the cervical region is an important potential cause of WAD symptoms. Cairns et al. [1] describes how neuro-inflammatory processes and activation of glia cells in the dorsal root ganglia cause chronic pain sensitization. Örtengren et al. [8] reported spinal ganglion nerve cell membrane dysfunction after whiplash experiments on pigs. They hypothesized that their recorded pressure transients in the CNS could be the cause. Yao et al. [13] developed and evaluated a 1-dimensional Matlab-Simulink fluid dynamics model of the cervical vein plexa. They showed in detail how pressure transients are generated during whiplash motion and were able to replicate experimental results. The EU-ADSEAT project [7] presented a prototype 50th percentile female rear impact dummy [2][10], later refined in [3]. The dummy enables an overall seat response comparison between female and male occupants.

This short communication introduces a few initiatives that investigate factors that potentially contribute to the difference in WAD risk between female and male car occupants in rear impacts.

2 Methods

The updated 50th percentile female prototype dummy [3] was used in a series of sled tests in parallel with the BioRID II dummy (Fig 1).

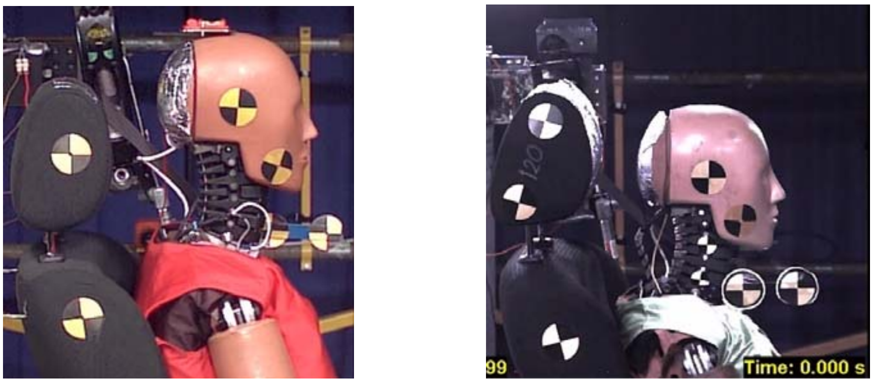

Figure 1: The male size BioRID II (left) and the female size prototype dummy (right) seated in the same car seat type

Nine different types of car front-seats were tested according to the EuroNCAP test protocol to compare differences in seat response between the two dummy sizes.

A new 3D model of the dorsal root ganglion and the bridging veins in the in the intervertebral canal was developed using the open source CFD software OpenFOAM. This model uses output data from the 1-dimensional Matlab-Simulink model [13] to prescribe the pressure time history inside the cervical vertebral canal and to simulate the fluid structure interaction between the fluid systems and the spinal ganglion.

3 Early results

Initial analysis of the sled tests shows that most of the tested seats produced higher initial T1 x-acceleration for the female dummy, in particular during the range 0–75 ms (Fig 2).

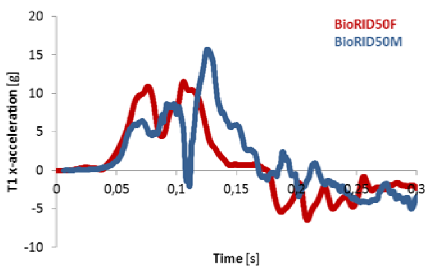

Figure 2: Example of T1 x-acceleration of the two dummy sizes in the same seat (Fig. 1). The female size dummy, BioRID 50F, shows a higher acceleration magnitude during the initial 0–75 ms phase. This is the time window when the neck undergoes the characteristic whiplash s-shape motion and where pressure transients peak in the spinal canal.

During this time range the characteristic s-shape of the cervical spine is developed and the pressure magnitudes in the spinal canal reach a first minimum according to the fluid dynamics model of Yao et al. [13] (Fig 3).

4 Discussion

The work in the present short communication indicates that, in rear impacts, car seats interact differently with an average female occupant compared to an average male. Females typically experience higher torso acceleration, likely due to their lesser body mass and lower torso center of gravity.

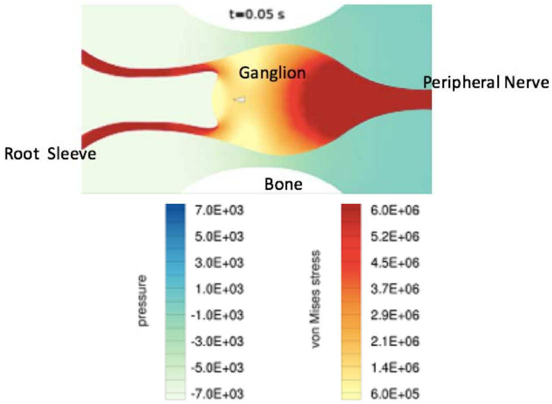

Figure 3: Results of the 3D OpenFoam model showing fluid pressure and solid material stress at 0.05 s. The figure shows a vertical slice of the intervertebral canal with the spinal ganglion in the middle and the bony boundary above and below. The interior spinal canal space on the left and the nerve root sleeve extends to the left from the periphery of the ganglion. The peripheral nerve extends from the ganglion to external soft tissue volume to the right. At 0.05 s the fluid pressure has a transient drops inside the spinal canal and the spinal ganglion structure is exposed to deformation and stress. This is hypothesised to be the explanation of earlier findings of signs of spinal ganglion nerve cell membrane dysfunction by Örtengren et al. [8].

The increased early T1 acceleration of the female prototype dummy indicates a more rapid s-shape bending of the neck. Yao et al. [13] demonstrate how the magnitude of the early pressure drop in the vertebral canal increases with increased speed of the s-shape motion (Fig 4). Yao et al. [13] also showed indications of increased pressures with increasing neck joint angular range of motion, thus indicating higher pressures in females (Fig 4).

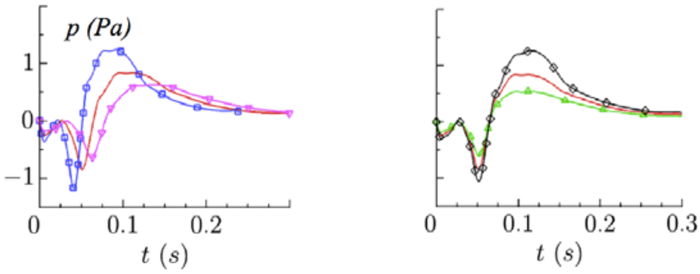

Figure 4: Pressure at the spinal levels C1-T1 from the Matlab-Simulink model of internal venous plexus of cervical spinal canal by Yao et al [13]. Pressure magnitudes increase, with increasing speed of the neck motion (left), and with increasing intervertebral range of motion (right). These two situations represent the trend you may expect when comparing female and male car occupants.

The results of the present work points to the need to test the rear impact whiplash protection also with an average female size dummy to ensure equal protection levels. The sled test results point out that females typically experience more severe torso acceleration and, using input from the fluid dynamics model of Yao [13], the 3D CFD model indicates higher nerve root ganglion injury probability in females. The findings presented by Cairns et al.[1], regarding the role of dorsal root ganglion neuro-inflammation in chronic pain, indicate that pressure induced ganglion cell dysfunction following whiplash trauma is a likely cause of long term WAD.

The present work also stresses the need for a new biofidelic 50th percentile female rear impact dummy. The present prototype cannot reproduce various female properties e.g. higher angular range in the vertebral joints. In parallel with a physical female size dummy there is potential for additional parameter with potentially improved injury assessment, by the use of human body models like the ones by Kitagawa et al [4] and Östh et al [9].

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