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查尔摩斯的挥鞭伤研究 EU-ADSEAT 项目的最新进展回顾

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摘　要： 挥鞭伤是一个世界性的问题，这种损伤多发且经常导致长期疼痛或残疾，并带来巨大的经济损失，女性发生挥鞭损伤的风险是男性的 2 倍。这种损伤是由颈部的惯性载荷导致，并且在各个碰撞方向都可能发生。不管碰撞类型如何，损伤的症状都包括颈部的疼痛、虚弱或者异常反应，与颈椎神经相关。查尔摩斯挥鞭伤研究起源于瞬态压力引发对神经根神经节的载荷作用的假设，瞬态压力已经得到检验，神经节神经元的机能失效也得到了验证。在欧盟合作课题 ADSEAT 项目的支持下，利用最新的图像技术，对于女性和男性在损伤阈值方面的差异进行了研究。开发了新型女性后碰撞试验假人。

关键词： 挥鞭伤；颈部损伤；后碰撞试验假人

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Whiplash Injury Research at Chalmers: A Review Including the Latest Developments in the EU-ADSEAT Project

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Abstract: Whiplash injuries, is a worldwide problem. They are frequent and costly since they often lead to long lasting pain and disability. Women are twice as vulnerable as men. These injuries are caused by inertial neck loading and occur in all collision directions. The symptoms are similar regardless of collision type and include pain, weakness or abnormal responses in the neck region, thus associated with nerve paths involving the cervical nerve-roots. The whiplash research focus at Chalmers originates from a hypothesis regarding pressure transients causing load to the nerve root ganglia. The pressure transients have been verified and ganglion nerve cell dysfunction has been found. Our current research utilises recent imaging techniques to understand the difference in injury thresholds between women and men. A new female rear impact dummy model is also developed.

Key words: whiplash injury; neck injury; rear impact dummy

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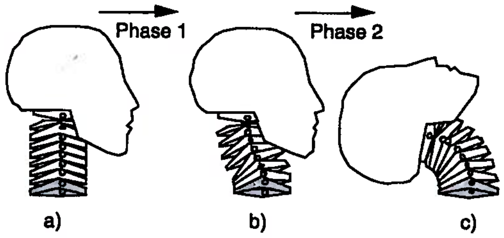
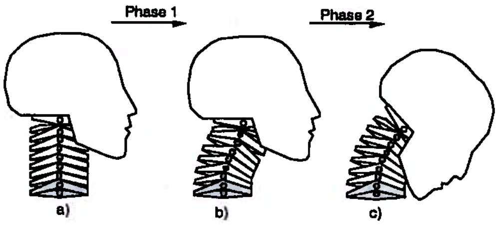
1 Background

During a rear-end car collision the struck vehicle is subjected to a forceful forward acceleration and the car occupant is pushed forward by the seat-back. The head lags behind due to its inertia, forcing the neck into a swift extension motion. In a later phase, the head moves forward relative to the torso and may stop with a somewhat flexed neck posture. This head and neck motion, commonly called 'whiplash motion'. The term 'whiplash' has also been used in the literature for the neck motion in frontal and side collisions. In frontal collisions, the neck usually experiences the same type of inertial loading from the head as it does in rear-end collisions. During the initial phase of these neck-loading situations, the head normally undergoes a horizontal translational displacement relative to the torso. This induces neck protraction motion in frontal collisions and neck retraction motion in rear-end collisions (Figures 1 and 2).



Phase 1: Retraction Motion. Phase 2: Extension Motion

Fig.1 Schematic Drawing of the Head-neck Motion During a Rear-end Collision



Phase 1: Protraction Motion. Phase 2: Flexion Motion

Fig.2 Schematic Drawing of the Head-neck Motion During a Frontal Collision

The neck is exposed to significant mechanical loads when the end of the natural range of protraction or retraction of the neck is reached and neck injuries may well occur at this point (Deng, 1989). This may be one explanation why conventional head-restraints do not provide better neck protection. They may simply come into play too late, after the neck has exceeded the maximum range of retraction motion and gone into extension. More recent anti-whiplash systems are built to reduce the gap to the head restraint and sometimes also to reduce the acceleration loading to the occupant. These systems generally reduce the risk of sustaining whiplash injuries, however less so for women (Jonsson et al. 2011).

The symptoms of injury following neck trauma in rear-end collisions include pain, weakness or abnormal responses in the parts of the body (mainly the neck, shoulders and upper back) that are connected to the central nervous system via the cervical nerve-roots. Vision disorder, dizziness, headaches, unconsciousness, and neurological symptoms in the upper extremities are other symptoms that have been reported (Svensson et al. 2000). The symptoms associated with soft-tissue neck injuries in frontal and side collisions appear to be very similar to those of rear-end collisions (Hildingsson, 1991).

Whiplash Associated Disorder (WAD), commonly denoted whiplash injury, is a worldwide problem. These injuries are costly since they are frequent and can lead to long lasting pain and disability. In Europe, the yearly cost for whiplash injuries has been estimated to be 10 billion Euros (Richter et al. 2000). In USA, the annual number of whiplash injuries has been estimated to 800 000. Of these whiplash injuries, 270 000 resulted from rear impacts with an annual cost of $2.7 billion (NHTSA

2004). In Japan, 547 654 traffic related injuries were registered during 1996 and 44% suffered from neck injury (Watanabe et al. 2000). Whiplash injuries account for ~70% of all injuries leading to disability, induced by modern vehicle crashes (Kullgren et al. 2007). Of the injured individuals, 5% ~10% will experience permanent disabilities of varying degree (Nygren 1985; Galasko et al. 1996; the Whiplash Commission 2005). These injuries occur at relatively low speed changes (typically <25 km/h) (Eichberger et al. 1996; Kullgren et al. 2003), and in impacts from all directions. Rear impacts, however, are most common in the accident statistics (Watanabe et al. 2000).

Women have about twice the risk of sustaining whiplash injuries compared to men (Temming & Zobel 1998; Richter et al. 2000; Chapline et al. 2000; Krafft et al. 2003; Jakobsson et al. 2004; Storvik et al. 2009). These differences may possibly be explained by differences in muscle strength, muscle reaction time, vertebral dimensions and angular range of vertebral motion, between men and women.

Men and women generally differ in size and mass distribution which may affect the interaction between the upper body and the seatback/head restraint. The shorter stature of females affects the geometry and the motion of the head relative to the head restraint. A lower mass and/or a lower centre of mass not only decreases the deflection of the seatback padding and springs, but also decreases the deflection of the seat frame. Smaller seatback deflection affects the plastic deformation and energy absorption as well as the dynamic head-to-head restraint distance and the rebound of the torso (Svensson et al. 1993; Croft 2002; Viano 2003).

Females tend to sit in a more upright position, with a 3° smaller seatback angle, than males (Jonsson et al. 2008). Several studies have reported a shorter head-to-head restraint distance for females compared to males (Szabo et al. 1994; Minton et al. 1997; Jonsson et al. 2007; Linder et al. 2008; Schick et al. 2008; Carlsson 2011). A 50th percentile male crash test dummy corresponds to a 90th–95th percentile female in size (Welsh & Lenard 2001). Current seats are likely optimized to the 50th percentile male leaving female occupants with inadequately tested seat designs.

In view of the above, Chalmers became involved in a European research effort named ADSEAT (Adaptive Seat to Reduce Neck Injuries for Female and Male Occupants) project. The overall objective of ADSEAT is to provide guidance on how to evaluate the protective performance of vehicle seat designs aiming to reduce the incidence of whiplash injuries (Linder et al. 2011). The work concentrates on evaluating the protective performance of seats beneficial to female as well as male motor vehicle occupants. For this purpose a finite element crash dummy model of an average female is being developed. This new research tool will be used in parallel with the BioRID II dummy model when evaluating enhanced whiplash injury protection.

New or modified injury criteria will be needed in this new female size dummy model. Davidsson and Kullgren (2011) concluded that the currently best available injury criteria with the BioRID II dummy are the NIC, upper neck shear force, vertical head acceleration and lower neck bending moment. These parameters best predicted the risk of developing permanent impairment given that the occupant had initial symptoms following a rear-end impact.

One shortcoming with the current neck injury criteria is that they were developed without any established link to a physical injury. They were only evaluated in an indirect manner based on the correlation between dummy output in crash tests and the real world safety performance of a limited number of car models. The best basis for the definition of an injury criterion is a know injury site and an established injury mechanism. Siegmund et al. (2009) presented a review of potential whiplash injury mechanisms and injury sites. They found that the early sequence of the whiplash motion to the neck has a high potential for generating injury, and that injury could be induced in different tissue types including muscles, intervertebral discs and facet joints, as well as injuries to the nerve system, in particular the cervical nerve root ganglia.

2 Work in Progress

The ADSEAT project will attempt to address the shortcomings of current injury criteria in several ways. One way will be to find modifiers to the criteria that currently are adapted to the male size BioRID II. This is intended to result in modified criteria that separate the injury tolerance between the female and male portions of the population. Another way will be to carry out biological whiplash experiments. The intension is to use the earlier work and experience at Chalmers as a basis and develop improved or new techniques to identify injury sites.

In the earlier work, anaesthetised pigs were used in whiplash experiments (Svensson et al., 2000). The work was based on a hypothesis regarding transient pressure changes in the spinal canal during whiplash exposure. It has been shown that the volume of the cervical spinal canal increases at flexion and decreases at extension of the neck and all the tissues and fluids inside the spinal canal are virtually incompressible. This means that fluid transportation, to and from the cervical spinal canal, must take place during the flexion–extension motion of the cervical spine to compensate for the volume change. The fluid would most likely be blood in the venous plexus of the epidural space. Due to flow resistance and the acceleration effect on fluid mass, pressure gradients may generate injurious stresses and strains to the exposed tissues, particularly in the intervertebral foramina.

A first group of animals was used to measure pressure in the CNS during the exposure. A second group was used for histopathological examination. A schematic view of the test set-up for the experimental neck extension–flexion trauma is shown in Figure 3.

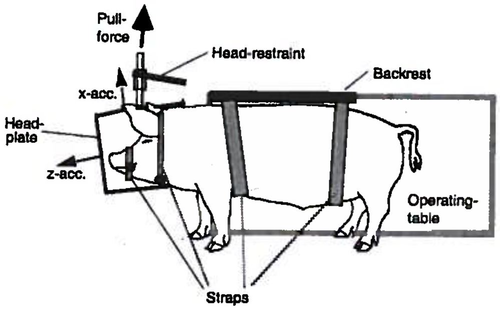


Fig.3 The Test Set-up Seen from Above

In Figure 3, the anaesthetised animal is lying side down on the operating-table, strapped to the backrest. The head is strapped to the bolts in the horizontally movable head-plate. During the experiment a pre-tensed rubber-strap pulls the head-plate (in posterior, lateral or anterior direction) by the pull-rod. The pull force is active until the pull-rod is disconnected, and thereafter the head moves in the sagittal plane due to its inertia.

The head was pulled either in the posterior, anterior or lateral direction. In some extension-motion test runs a head-restraint was introduced. Gaps of 100~130 mm were used between head and head-restraint. A gap of 100 mm prevented the neck from reaching full retraction, and a gap of 130 mm allowed the neck to pass the point of full retraction but prevented it from reaching the maximum physiological extension angle. The animals used for the pressure measurement experiments had catheter pressure transducers introduced into the subarachnoid space in the cervical spine. Pressure measurements were taken under various loading conditions. The pull force was varied from 150 N to 900 N.

The animals in the group that underwent histopathological examination were given an intra-venous injection of Evans Blue (EB) dye (which normally conjugates to albumin in the blood) before the test. After the experiment the brain and the spinal cord to about the T4 level were dissected. The spinal ganglia and proximal parts of corresponding nerves were isolated (Örtengren et al., 1996). Cryostate microtome sections were prepared and examined in a fluorescence microscope. EB will normally pass into the inter-cellular space of the spinal ganglia, but not into the nerve cells. Thus EB inside the nerve cells indicates dysfunction of the nerve cell membranes and the satellite cells. Macroscopic inspection during the autopsies of the animals exposed to trauma revealed no bleeding or fractures of vertebral structures, or ruptures of ligaments. However, fluorescence microscopic examination of the satellite cells and nerve cells in the spinal ganglia of the exposed animals disclosed red fluorescent material, indicating EBA leakage and thus cell membrane dysfunction. These findings were most obvious at the C6–C8 levels. There was no sign of such sham-exposed animals in the same study.

In the ADSEAT project, a new, more refined pull-rig has been built but still using the simple and well controlled rubber band principle. Figure 4 shows an example of a pressure recording in a reaward whiplash exposure in a pilot experiment including a 30 kg piglet. A pressure drop of almost 120 mmHg was recorded in the middle of the cervical spine. A 800 N pull force resulted in a maximum head extension angle of 55° at 70 ms. The plan is to adapt new investigation techniques to the pig spinal ganlia. Microscopy analysis will be carried out using for instance inflammatory markers. We plan to use immunohistochemistry-staining of ganglions with the transcription factors CFOS and ATF3.

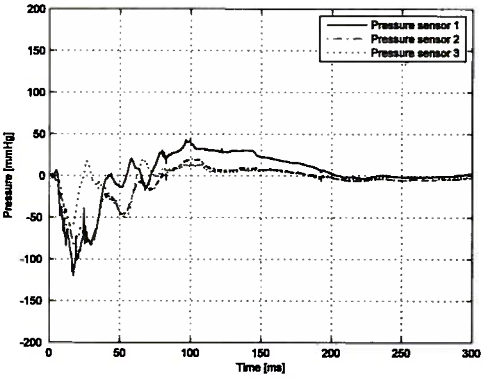


Fig.4 Pressure Readings in the Spinal Canal of Pressure Sensors 1) C1, 2) C4, 3) C7, with Vertebral Levels. Rearward Whiplash Exposure at a Pull Force of 800N

The ambition of the ADSEAT work is to find more reliable injury indications, primarily to the cervical spinal ganglia. If these can be established the next step will be to establish a link between the mechanical response of the head neck complex (for example the head acceleration values) and the severity of ganglion injury and spinal canal pressure amplitude. ADSEAT also investigates differences in mechanical responses between women and men (Carlsson et al., 2011) and a new female size rear impact dummy model will be developed (Linder et al., 2011). These different activities will be merged into a final demonstrator activity that will give indications on the need, and the potential improvement in protection, of new whiplash protection systems that adapt to the biomechanical properties of both women and men.

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