Suitability of the Available Mechanical Neck Models in Low Velocity Rear-End Impacts

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Abstract

Neck injuries in car accidents are usually classified as AIS 1 but they often cause long term pain and disability. The number of these injuries is on the increase and the costs for the society and the insurance companies are significant. Rear-end impacts give the largest contribution to the number of neck injuries.

Head-restraints offer little protection against neck injuries in rear-end collisions and there is no established method for performance testing. The injury symptoms are well documented but the actual injury, causing the symptoms, has not yet been established. Consequently the relationship between head-neck motion and injury risk is unknown.

A research program to address these problems is ongoing at Chalmers University and one of the main activities is the development of new dummy components for improved rear-end impact testing. Several investigators have noted limitations of the commonest crash test dummy, the Hybrid III. It has a too stiff neck and torso response in rearward sagittal bending.

As a first step, a new RID-neck (Rear Impact Dummy-neck) was designed and validated. This dummy neck has been used to investigate the head-neck motion in various standard car seats during rear-end impacts. TNO have now started producing a more durable and well defined version (TRID-neck). As more test data from volunteer tests have become available, further evaluation of the RID-neck has been undertaken and a need for a decreased resistance to retraction-protraction motion of the head-neck system has been revealed. It has also become evident that realistic stiffness and shape of the whole spine needed to attain .

At the moment a new RID-neck with less resistance to retraction-protraction and a more realistic spinal shape is under development. In parallel, a mathematical model (MADYMO) of the new RID-neck is being developed. A first generation articulated thoracic and lumbar spine for rear-impact testing has been developed and with further refinement it is expected that a complete dummy spine from pelvis to head will result in a dummy with significantly improved biofidelity in the rear-end impact situation.

INTRODUCTION

Neck injuries in rear-end collisions mostly occur at very low impact-velocities, typically less than 20 km/h (Kahane, 1982; Olsson et al., 1990) and are mostly classified as ”minor injury” (AIS 1) on the abbreviated injury scale (AIS) (Foret-Bruno et al., 1991; James et al., 1991; Ono and Kanno, 1993). In spite of this low AIS rating, these injuries lead to permanent disability (disability-degree ≥10%) in some 10% of the cases (Nygren, 1984). This can be compared with other AIS 1 injuries where the risk of permanent disability is 0.1% (Nygren et al., 1985).

According to Ono and Kanno (1993), 50% of all car-to-car accidents in Japan lead to neck-injuries and the number of neck injuries are on the increase. In the Netherlands, the annual number of neck injuries increased by 54% during the period 1983 to 1991 (Kampen, 1993).

Women were found to be up to twice as vulnerable as men in rear-end accidents (Kihlberg, 1969; States et al., 1972; Kahane, 1982; Otremski et al., 1989; Foret-Bruno et al., 1991; vKoch et al., 1995; Spitzer et al., 1995).

Nygren et al. (1985) found that the use of head-restraints decreased the risk of neck injury in a rear-end collision by about 20% on average. Fixed head-restraints gave a 24% reduction and adjustable ones gave a 14% reduction. Similar findings have been presented by O'Neill et al. (1972) and by Huelke and O'Day (1975). However, Nygren et al. (1985) also found that the risk of whiplash injury was not reduced in newer cars. In fact the study disclosed great differences in protective performance between different designs of seats and headrests, which is a clear indication of the need for further research in this area.

States et al. (1969) suggested that the elastic rebound of the seat back could be an aggravating factor for the whiplash extension motion. The rebound of the seat-back can push the torso forward relative to the vehicle at an early stage of the whiplash extension motion when the head begins rotating rearward. This in turn increases the relative linear and angular velocity of the head relative to the upper torso at the same time as it delays contact between the head and the head-restraint. Subsequent studies support this theory (McKenzie and Williams, 1971; Prasad et al., 1975; Romilly et al., 1989; Foret-Bruno et al., 1991; Svensson et al., 1993; Svensson et al., 1996). If the seat-back of the front-seat collapses or yields plastically during a rear-end collision, the elastic seat-back rebound is likely to be reduced. In fact, Foret-Bruno et al. (1991) reported that seat-back collapse decreased the risk of neck injury in rear-end collisions.

The relation between different kinematic and kinetic parameters of the head-neck motion and the risk of sustaining an AIS 1 neck-injury in a rear-end impact are not fully known. SAE (1986) published limits for neck loads at the occipital condyles for volunteers and cadavers (Table 1) based on the work by Mertz and Patrick (1967; 1971).

Table 1: Neck reactions calculated at the occipital condyles for dynamic neck extension tests (SAE, 1993).

Subject	Bending moment (Nm)	Shear force (N)	Axial Force (N)	AIS rating	Comments
Volunteer	30.5	231	249	0	No injury
Cadaver	47	-	-	0	No damage
Cadaver	57	-	-	3	Ligamentous damage

The risk of neck injury to rear seat occupants was only about 50% of the risk of neck injury for front seat occupants in rear-end collisions (Kihlberg, 1969; States et al., 1972; Carlsson et al., 1985; Lövsund et al., 1988; Otremski et al., 1989).

The injury symptoms following neck trauma in rear-end collisions include pain, weakness or abnormal response in the neck, shoulders and upper back as well as vision disorders, dizziness, headaches, unconsciousness, and neurological symptoms in the upper (States et al., 1972; Nygren et al., 1985; Hildingsson, 1991; Watkinson et al., 1991; Spitzer et al., 1995). Spangfort (1985) used Figure 1 to describe the stages of the symptoms. Findings similar to those of Spangfort (1985) were reported by Deans et al. (1987).

According to Svensson (1993), a synthesis of findings by Mertz and Patrick (1967; 1971) and by McConnell et al. (1993) indicate that AIS 1 neck injuries during a rear-end impact are prevented if the displacement between head and torso are eliminated. The injury can on the other hand occur without hyperextension of the complete cervical spine.

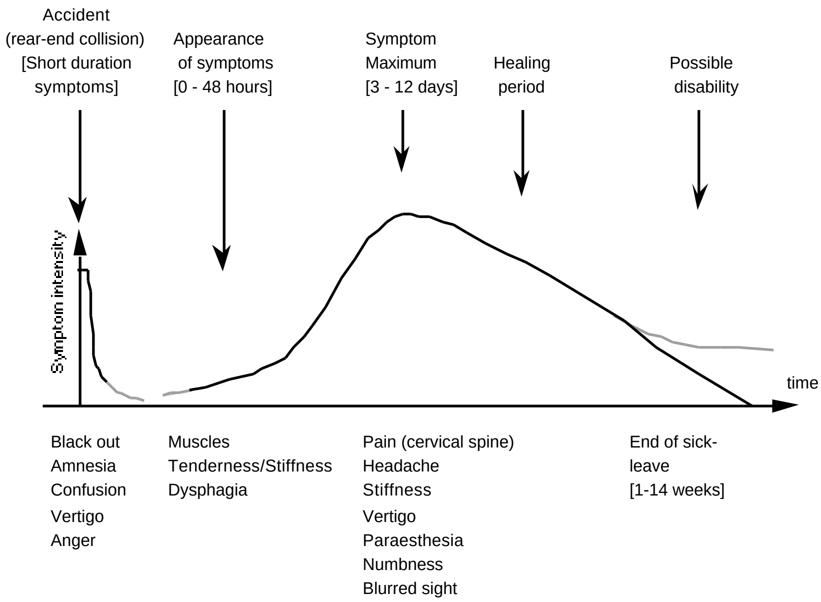

Figure 1: The stages of the neck injury symptoms sustained in a rear-end collision (adapted from Spangfort, 1985).

CURRENT NECK DESIGNS

Until recently there has been no adequate tool for testing the performance of car seats and head-restraints in rear-impacts. The currently best available dummy is the Hybrid III. The neck and spinal structure of this dummy is stiff and unlikely to interact with the seat-back in the same compliant way as would the human spine.

Seemann et al. (1986) found the Hybrid III neck far too stiff to respond in a human-like manner in the sagittal plane. Deng (1989) reported that results from a mathematical model of the Hybrid III neck indicated that the neck has a torque response similar to that of the human neck but has a higher shear response. Foret-Bruno et al. (1991) compared the Hybrid III dummy with a cadaver in simulated rear-end impact using a headrest closely fitted to the head, to minimise the relative movement between head and torso. The cadaver showed no sign of injury. In spite of this, very large shear forces at occipital level were registered in the Hybrid III test. The authors concluded that the human head can be moved relative to the torso with no stresses in the neck, but this is not the case for the dummy. In volunteer tests, McConnell et al. (1993) found that during the acceleration phase of a rear-impact, when the occupants body was pressed against the seat-back, the spinal curvature straightened. This in turn caused an upward motion of the head and thus an elevated head contact point on the head-restraint. In a comparative study using volunteers and a Hybrid III-dummy, Scott et al. (1993) found that the dummy was less prone to ramp up along the seat-back than were the volunteers.

Svensson and Lövsund (1992) developed and validated a Rear Impact Dummy-neck (RID-neck) that can be used on the Hybrid III dummy (Fig. 2). The new neck was meant to be used in rear-end collision testing at low impact-velocities. It consisted of seven cervical and two thoracic vertebrae. It was designed to resemble the human anatomy to enable a trajectory, and angular range of motion similar to that of the human in the sagittal plane. The RID-neck was validated using data from a test series with volunteers published by Tarriere and Sapin (1969) after a French study by Tisserand and Wisner (1966). These validation data only included the angular displacement of the head relative to the torso but did not allow for validation of the initial rearward translational motion of the head (head lag). A later validation study by Geigl et al. (1995) indicated that the head lag is too small with the RID-neck. This problem could probably be solved if the RID-neck design was supplemented with anterior and posterior muscle elements (Svensson and Lövsund, 1992) and this type of design was also proposed for the next generation frontal impact dummy (Eppinger et al., 1994).

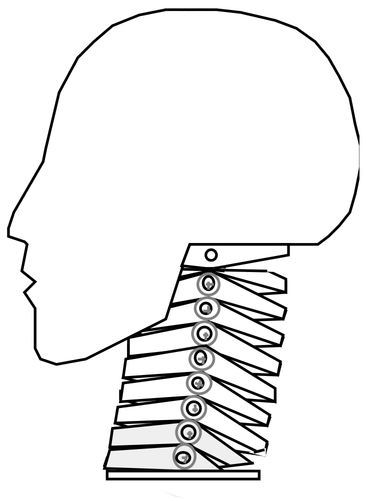

Figure 2: The RID-neck with a Hybrid III head.

Thunnissen et al. (1996) developed a new rear impact dummy neck, the TRID-neck (TNO Rear Impact Dummy-neck) based on the RID-neck design. The TRID was subjected to a more extensive validation work involving new validation data from tests with volunteers and human cadavers, but validation was still restricted to the angular displacement between head and torso. The number of pin joints was reduced from nine (RID) to seven (TRID) and efforts were made to attain adequate repeatability and reproducibility which had turned out to be weak points in the RID-neck design. The dynamic response of the two neck types appears to be very similar. The TRID-neck is likely become a valuable tool for assessing the performance of car seats and head-restraints.

FUTURE DUMMIES

To get a more detailed assessment of the occupant body motion and interaction with the car seat and head-restraint it will not be enough to replace the neck of the Hybrid III-dummy. In order to get a realistic interaction with the seat-back, the dummy torso must have a bending stiffness similar to that of the human torso. The dummy spine must further have a realistic spinal shape in order to allow for correct conditions (timing and contact height) in the contact with the head-restraint. A currently ongoing project at Chalmers University is aiming at developing a new Rear Impact Dummy according to the concept in Figure 3. A Hybrid III- dummy is equipped with an articulated spine with a realistic spinal shape.

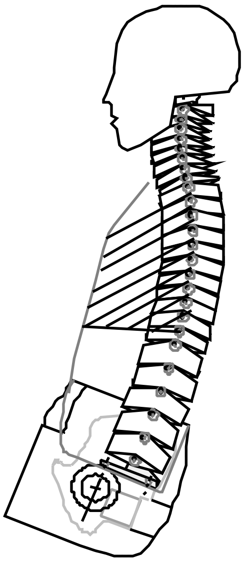

Figure 3: A rear Impact Dummy concept with an articulated spine
and with a realistic spinal shape.

The current rear impact dummy-neck designs (RID-neck and TRID-neck) have not been validated regarding head lag. Several studies indicate that head lag has significant influence on the head-neck kinematics in the rear-end collision situation (Severy et al. 1955; Clemens and Burow, 1972; Huelke et al, 1979; Geigl et al., 1995; McConnell et al., 1995). Figure 4 shows a schematic view of the neck in Figure 3 supplemented with anterior and posterior muscle substitutes in the form of straps between the head and the torso. With this type of muscle elements it will be possible to increase the head lag to more realistic levels.

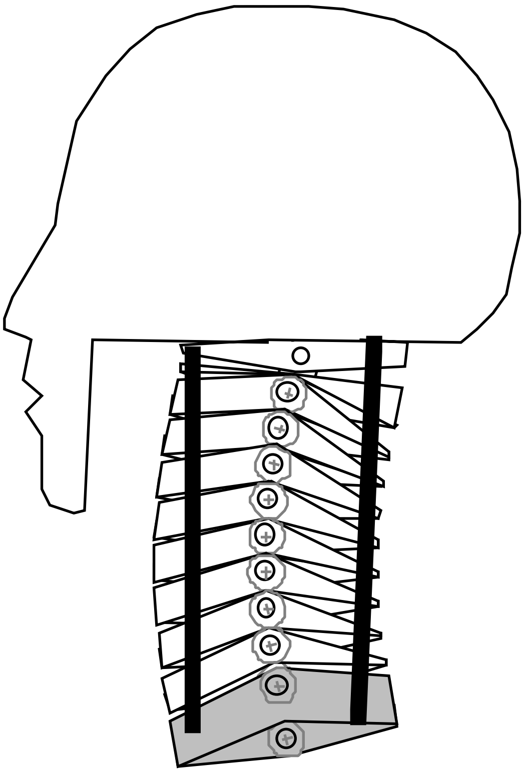

Figure 4: Dummy head and neck concept with anterior and posterior muscle substitutes.

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