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Impacts to the chest of PMHSs – Influence of impact location and load distribution on chest response

Kristian Holmqvist[a,*], Mats Y. Svensson[a], Johan Davidsson[a], Andreas Gutsche[b], Ernst Tomasch[b], Mario Darok[c], Dean Ravnik[d]

[a] *Chalmers University of Technology, Department of Applied Mechanics, Vehicle Safety Division and SAFER Vehicle and Traffic Safety Centre, SE-412 96 Gothenburg, Sweden*
[b] *Vehicle Safety Institute, Graz University of Technology, Inffeldgasse 23/I, 8010 Graz, Austria*
[c] *Institute of Legal Medicine, Medical University Graz, Universitätsplatz 4/II, 8010 Graz, Austria*
[d] *Institute of Anatomy, University of Ljubljana, Kongresni trg 12, 1000 Ljubljana, Slovenia*

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ABSTRACT

The chest response of the human body has been studied for several load conditions, but is not well known in the case of steering wheel rim-to-chest impact in heavy goods vehicle frontal collisions. The aim of this study was to determine the response of the human chest in a set of simulated steering wheel impacts. PMHS tests were carried out and analysed. The steering wheel load pattern was represented by a rigid pendulum with a straight bar-shaped front. A crash test dummy chest calibration pendulum was utilised for comparison. In this study, a set of rigid bar impacts were directed at various heights of the chest, spanning approximately 120 mm around the fourth intercostal space. The impact energy was set below a level estimated to cause rib fracture. The analysed results consist of responses, evaluated with respect to differences in the impacting shape and impact heights on compression and viscous criteria chest injury responses. The results showed that the bar impacts consistently produced lesser scaled chest compressions than the hub; the Middle bar responses were around 90% of the hub responses. A superior bar impact provided lesser chest compression; the average response was 86% of the Middle bar response. For inferior bar impacts, the chest compression response was 116% of the chest compression in the middle. The damping properties of the chest caused the compression to decrease in the high speed bar impacts to 88% of that in low speed impacts. From the analysis it could be concluded that the bar impact shape provides lower chest criteria responses compared to the hub. Further, the bar responses are dependent on the impact location of the chest. Inertial and viscous effects of the upper body affect the responses. The results can be used to assess the responses of human substitutes such as anthropomorphic test devices and finite element human body models, which will benefit the development process of heavy goods vehicle safety systems.

1. Introduction

Chest injuries are a major contributor to occupant fatalities and severe injuries in automotive crashes. Heavy goods vehicle (HGV, truck with a gross vehicle weight rating greater than 3500 kg) drivers are no exception (Sukegawa et al., 2001; Gwehenberger et al., 2002; Zinser and Hafner, 2004). Extensive studies on the biomechanics of the human thorax have been performed since the 1960s and a large amount of response data has been collected. In 1960–1970 the most common load case to generate chest injuries was based on a driver impacting the hub at the centre of the steering wheel (Kroell et al., 1971, 1974; Nahum et al., 1975; Patrick et al., 1967). In 1980–1990, studies on steering wheel impacts to the thoraco-abdominal region where the rim of the steering wheel impacted the upper abdomen were reported (Begeman et al., 1990; Horsch and Viano, 1984; Horsch et al., 1985; Nusholtz et al., 1980; Nusholtz and Kaiker, 1994; Shaw et al., 1999). More recent studies have been conducted, primarily focusing on occupant chest injuries in passenger cars while restrained by safety systems such as seat belt and air bag (Augenstein et al., 1995; Cesari and Bouquet, 1990;

* Corresponding author.
E-mail addresses: kristian.holmqvist@chalmers.se (K. Holmqvist), mats.svensson@chalmers.se (M.Y. Svensson), johan.davidsson@chalmers.se (J. Davidsson), andreas.gutsche@tugraz.at (A. Gutsche), ernst.tomasch@tugraz.at (E. Tomasch), mario.darok@medunigraz.at (M. Darok), dean.ravnik@mf.uni-lj.si (D. Ravnik).

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Kallieris et al., 1998; Kent et al., 2001, 2003, 2004, 2005; Morgan et al., 1994; Shaw et al., 2009).

To be able to apply the acquired response data to a specific anthropometric size, the response may be scaled to account for differences in subject properties as well as test setup parameters (Eppinger et al., 1984; Mertz, 1984; Viano, 1989).

The scaled and original results obtained in past studies have been applied in the development of anthropomorphic test devices (ATDs) and injury risk functions. The same ATDs, as used in the development of passenger car safety systems, are generally used by the HGV manufacturers to improve the safety for HGV drivers.

Differences in driver posture and compartment geometries between passenger cars and HGVs initiated a study by Holmqvist et al. (2013) to determine if the load cases between these two types of vehicles were similar and if it was feasible to evaluate the ATD responses in HGV crash tests properly. The results revealed that there was substantial contact between the chest and the steering wheel rim in HGV frontal collisions even with varying types of seat belt systems and presence of an airbag. It was also found that in HGV crash tests the chest deflection sensor that is commonly mounted in the Hybrid III ATD was not able to accurately resolve the chest response. The sensor was frequently underestimating the response, and the different impact locations on the chest detected in this study, raised questions whether the ATD chest response was valid for impacts at these heights.

The results indicate that the development process of HGV safety systems would benefit greatly if ATDs and finite element human body models (HBMs) were made suitable for evaluating steering wheel rim-to-chest loads. The subsequent step was to correlate HBMs and ATD chest responses to improve the injury risk prediction when the ATD is used in HGV safety evaluations (Holmqvist et al., 2014). One issue pointed out in this study was the lack of chest response data for the specific load case that could be used while evaluating ATDs and HBMs, which would assist in identifying the correctness in distinguishing this type of loading.

Therefore the aim of this study was to evaluate the responses and properties of the human chest when subjected to simulated steering wheel rim impacts, by analysing responses from post mortem human subjects (PMHSs). The testing was carried out to determine how the chest responses change with load distribution and location.

2. Methods

Two subjects were obtained and treated in accordance with the guidelines for PMHS testing and permission was granted by the Slovenian ethical committee, Komisija Republike Slovenije za Medicinsko Etiko, approval no. 47/03/09. Prior to testing, the subjects were returned to room temperature from a frozen state.

The chests of the two PMHSs (Table 1) were exposed to pendulum impacts in a series of five repetitive, low energy impacts. The pendulum front was fitted with either a 152 mm circular disc with an edge radius of 7.5 mm (herein referred to as hub), or with a horizontal bar, 400 mm long and a 30 mm diameter (Fig. 1), used to mimic the loading distribution of a steering wheel rim (herein referred to as bar). The pendulum was equipped with an accelerometer, measuring along the main axis of the pendulum, to estimate the force exerted on the PMHS. Three impacts were carried out at nominal velocities of 2.4 m/s using a bar pendulum mass of 25.8 kg and one impact using the hub pendulum mass of 23.4 kg. One bar impact using low mass and higher speed was conducted at 3.73 m/s and a mass of 9.6 kg (Table 2). The mass and velocity of the pendulum were selected to keep below an estimated energy level believed to initiate rib fractures (Shaw et al., 2006).

Table 1
Subject anthropometry and characteristics.[a]

	PMHS 1	PMHS 2
Age at time of death	80	65
Body mass [kg]	88.0	78.5
Stature [m]	1.71	1.65
Chest depth [m]	0.28	0.23
Chest circum. [m]	1.07	0.99
Chest width [m]	0.36	0.34

[a] Extended anthropometry can be found in Appendix A.

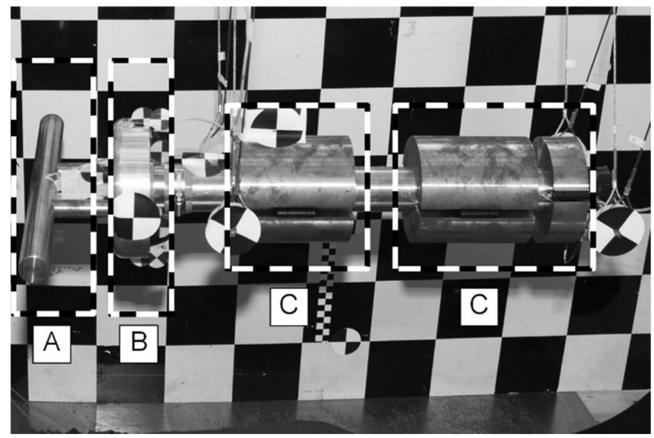

Fig. 1. Pendulum. The pendulum with the hub (B) and the removable bar extension add-on (A). The extra weights (C) were removable for low mass impact.

The impacts using the rigid bar were directed at three locations on the chest, the fourth intercostal space (Middle) and nominally aimed 50 mm above and 50 mm below (Higher and Lower, respectively) (Fig. 2). The hub impact to the Middle location was performed to serve as a reference and connect to previous studies where injury criteria, such as the maximum compression criterion (C_{max}) and the maximum viscous criterion (VC_{max}), have been used.

2.1. PMHS instrumentation and preparation

Subcutaneous X-ray markers (5 mm diameter lead balls) were inserted through a small incision, at the most medial point of

Table 2
Recorded pendulum velocities and impact heights relative to the fourth intercostal space of the anterior chest.

Test abbreviation	Test description	Pendulum mass (kg)	PMHS 1		PMHS 2	
			Velocity (m/s)	Height (mm)	Velocity (m/s)	Height (mm)
HM	Hub Middle Location	23.4	−2.41	3.9	−2.57	23.5
BM	Bar Middle Location	25.8	−2.56	−3.8	−2.59	29.7
BH	Bar Higher Location	25.8	−2.37	14.2	−2.57	67.3
BL	Bar Lower Location	25.8	−2.48	−48.8	−2.65	−41.9
BM*	Bar Middle Location, High Speed	9.6	−3.60	3.1	−3.98	18.4