TYPICAL INJURIES CAUSED BY AIR-BAG IN OUT-OF-POSITION SITUATIONS
- AN EXPERIMENTAL STUDY -

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ABSTRACT

Currently many cars are equipped with an airbag on the driver's or in addition on the passenger's side. Recent reports based on accident investigations in the USA and European Countries, emphasized the safety potential of the airbag. But on the other hand, it was found that in some cases, injuries or even fatalities are reported, when the car occupant is in a so-called out-of-position (OOP), that means parts of the occupant's body are very close to the expanding airbag.

To gain an insight into the injury mechanism, ten experiments were carried out with Post Mortem Test Objects (PMTO). The effect of the inflating full-size airbag was investigated in stationary tests, when the distance to the human head or chest was 0, 50 and 100 mm.

The injury risk was determined by monitoring head and thoracic spine acceleration. The injury patterns were investigated by autopsy -- the injury mechanisms were explained on the basis of high speed film analysis.

The results showed that the registered level of the HIC and the thoracic spine acceleration significantly exceeded the commonly used tolerance levels.

The expanding airbag generated fractures to the rib cage and sternum. Even injuries of internal organs such as the liver were detected. In cases where the expanding airbag contacted the head directly, we observed injuries of the facial region, for example superficial skin injuries, and a nasal bone fracture, as well as severe indirect injuries to the neck region.

BASED ON SURVEYS CARRIED out in the USA, 50 road traffic fatalities -- approx. 60% being children -- have been attributed to the airbag since it's introduction. Several cases recorded incorrect deployment of airbags at extremely low collision speeds. Some of the fatal injuries to children were sustained, where a child's car seat was fitted facing the rear of the vehicle or where the child was not buckled up, as recommended. Fatal injuries were caused by the deployment of airbags, even in the event of a minor accident,

where no fatalities were to be anticipated, when passengers' seat belts are fastened. After close examination, the accident sequence proved that the carholders were in very close proximity to airbag deployment and were obviously injured by the airbag module itself.

The optimal protective function of the airbag for head and thorax areas for the driver and passenger on collision is achieved when passengers are buckled up and seated in a normal position on impact with the completely inflated airbag. In this case the airbag is able to optimize the impact on the head and upper body. In contrast, passengers not seated in a normal position could be injured on different parts of the body, if they are in very close proximity to the airbag during inflation.

We carried out various tests with PMTO's in order to research typical injury mechanisms and risks of injury for all vehicle occupants, in close proximity to airbag deployment.

RESEARCH DEVELOPMENT PROGRAM

A car seat with an adaptable steering wheel was mounted onto a solid metal frame to conform with the seating capacity of a middle size automobile. The steering wheel was fitted with a standard full-size (approx. 65 Litre) airbag-module (year of production 1989).

The study of sequences were achieved by means of 16 mm-high-speed cameras, thereby producing pictures with 1000 exposures per second and additionally an overview of 500 exposures per second.

To research the acceleration affects on PMTO's, acceleration sensors were attached to different parts of the body. A triaxial acceleration sensor was attached to the region of the center of gravity of the head in front of the clivus to monitor the time-history of head acceleration. A further triaxial acceleration sensor was firmly attached to the 6th thoracic vertebra. The results of the evaluations of the curves for head and chest acceleration were diagrammed. The maximum values, the 3-ms-values and the HIC were evaluated.

The autopsy of the PMTO was carried out in the usual way, concentrating on the preparation of the neck structure. The cervical verterbrae and a section of the base of the skull were dissected and frozen. The deepfrozen specimens were initially dissected by means of a band-saw, in the sagital section. In this way, dissections were made between the 3rd and the 4th cervical verterbra, and then vertical dissections of the sagital structure of approx. 35 degrees and 70 degrees were prepared to examine the ligament structures between the dens and the upper head condyle.

EXPERIMENTS

In order to simulate the Out-Of-Position, we inflated the airbag against the head as well as the chest, by means of adjusting the passenger seat and the steering wheel. These fundamental positions are demonstrated in Figure 1 and in Figure 2.

Fig. 1 - Chest-position

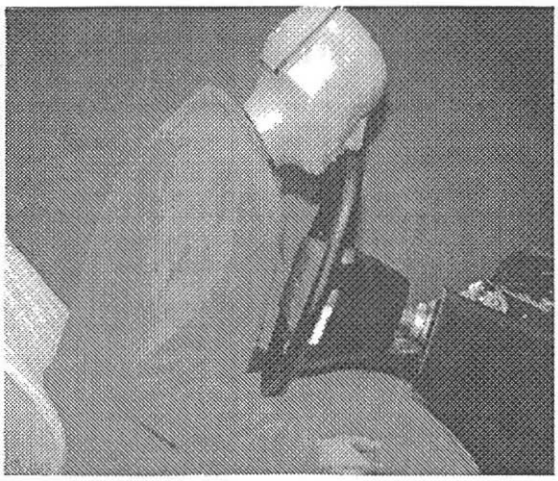
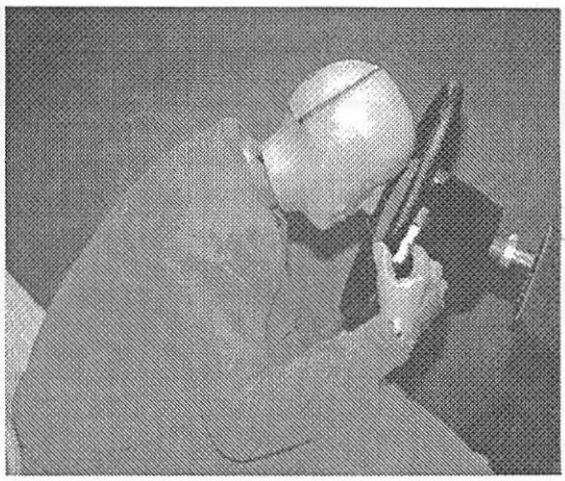


Fig. 2 - Head-position



In these test series, two trials were carried out in each case with inflation of the airbag against the ribcage at distances of 100 mm, 50 mm and 0 mm as well as on the region of the head with a distance of 0 mm between the mid forehead and the airbag. The PMTO were between 20 and 75 years old, two of them females. The body length and weight are compiled in Table 1.

Table 1 - Testobjects

Run No.	against	distance [mm]	age [y.]	sex	length [cm]	weight [kg]
B100a	chest	100	20	male	178	72
B100b	chest	100	74	male	177	70
B50a	chest	50	45	female	168	65
B50b	chest	50	74	male	170	68
B0a	chest	0	50	male	175	87
B0b	chest	0	35	male	190	91
K0a	head	0	74	male	174	87
K0b	head	0	75	female	160	73

RESULTS

The data for the 3ms-G's and the HIC of the resulting head acceleration as well as the 3ms-G's of the resulting chest acceleration are compiled in Table 2. In one case, the data acquisition system failed, so that the results for B100b are not available.

Table 2 - Measurement results

Run No.	3ms-Head-G's	HIC36	t1 [ms]	dt [ms]	3ms-Chest-G's
B100a	35	112	6.9	32.9	33
B100b	-	-	-	-	-
B50a	47	229	5.5	28.5	83
B50b	83	480	6.0	24.1	27
B0a	61	187	3.6	15.2	60
B0b	90	514	10.5	7.7	80
K0a	100	1308	3.5	1.7	28
K0b	252	4896	2.0	3.7	44

The injuries which were identified after the autopsy and after inspection of the cervical verterbrae, are compiled in Table 3.

DISCUSSION

Based on the time history of the measures, the maximum of each head and breast acceleration was already reached in a few milli-seconds after the deployment of the airbag. The evaluations of the high speed films showed that these were obtained during the initial phase of airbag inflation and, therefore, immediately after the module cover released the airbag.

During the trials with deployment of the airbag against the torso section, flexing movements in the neck section, due to the mass of inertia of the static head, were observed. Finally, upper body and head were increasingly accelerated through the expanding airbag in the direction of the backrest. The full expansion of the airbag was reached, on the average, approx. 30 milli-seconds later. Depending on the seat position, the accelerated body made an impact 70 to 125 milli-seconds after deployment, against the car seat back-rest and head-rest. The speed of impact was measured at 21 to 35 km/h according

Table 3 - Detected injuries

B100a :	• skin lesion and laceration of the skin in front of the chest.
B100b :	• no detected injuries.
B50a :	• skin lesion below the chin and laceration of the skin in front of the chest. • fracture of the sternum at the chondrosternal junction of the 4th rib. • fracture of the 3rd rib on the right, 9 cm beside the median line.
B50b :	• skin lesion above the front of the chest. • fracture of the sternum at the chondrosternal junction of the 2nd rib. • tear of the anterior and posterior ligament of the cervical spine between vertebra 5-6. • tear of the Lig. apicis dentis at the appendix of the dens.
B0a :	• skin lesion above the front of the chest and on the front of both upper arm regions. • tear of the anterior ligament of the cervical spine between vertebra 5-6.
B0b :	• skin lesion above both clavicula regions and on the chin. • fracture of the Sternum at the chondrosternal junction of the 4th rib. • fracture of the 3rd rib on the right, 11 cm beside the median line.
K0a :	• skin lesion and laceration of the skin in front of the forehead. • bruises of both eyeballs with lacerations above both roof of the orbits and of the upper eyelids. • open fracture of the nasal bone. • part tear of the anterior ligament of the cervical spine between vertebra 3-4. • hemorrhage above the spinal meninx in the cervical vertebrae region. • bruising of the soft tissues in-between the processus spinosus in the region of the cervical vertebra 5-6 of the cervical spine.
K0b :	• skin lesion above both eyeballs sockets as well as above the bridge of the nose and the front of the neck. • tear of the anterior ligament of the cervical spine between vertebra 6-7. • tear of disk between cervical vertebrae 4 until thoracic vertebrae 1 (degenerative pathological changes). • bruising of the soft tissues in-between the processus spinosus in the region of the cervical vertebra 2-3 until 5-6. • fracture of both upper bones of the larynx.

to the film analysis. The body was thrown towards the back and was lifted slightly upwards, depending on the direction of inflation of the airbag and the seat position of the PMTO. After collision of the torso with the car seat, the head was rotated far backwards over the head-rest, causing extreme retroflection.

According to the kinematics, three critical situations for the body could be observed. During the inflation phase of the airbags, two injury mechanisms are to be expected, taking into account the monitored acceleration. The first of these occurs through the direct force in the contact area between the expanding parts of the airbag system itself and the human body. The second occurs through indirect injury mechanisms as a consequence of bending, tensile and shearing forces between parts of the body accelerated a) directly, by the airbag and parts of the body and b) indirectly, outside the area of the expanding airbag. Furthermore, after the expansion phase, injuries can be expected during impact of the body in the region of the backrest unit.

With the trials at a distance of 100 mm against the front rib cage, the resulting acceleration of the chest was lower than 60 g. Accordingly, only one case of skin laceration and skin lesion above the front of the chest without inner injuries, was observed. With this constellation, only impact localization with bone support, due to tangential force to the skin, laceration was observed; the parts of the body exposed to vertical pressure components, however, showed no obvious direct or indirect injuries. With these experiments, none of the parts of the opening airbag cover module came into direct contact with the body, so that the sustained skin injuries can only be explained as a result of direct contact of the expanding airbag. Our research was carried out with unclothed upper torsos for the purpose of analysis by kinematics, in respect to possible injury mechanisms. Therefore, the observed skin lacerations and lesions inflicted on the unclothed torso would not be expected in case of fully clothed persons.

In experiments with distances of 50 mm between the airbag unit and the body, we observed lesions above the front of the body due to similar injury mechanisms. The results of the film evaluation were that, at this distance at the beginning of the airbag deployment, parts of the opening airbag module made contact with the front ribcage.

In both 50 mm tests rib cage fractures resulted. In both cases fractures of the sternum at the chondrosternal junction of the 2nd or the 4th rib occurred; these were bending fractures resulting from direct impact force against the front rib cage. In one experiment, we observed a further isolated rib fracture pushed inwards through the same injury mechanism.

The evident injuries of the neck/head region can be indicated best as a result of indirect forces due to retroflection, causing bending and shearing

forces to the spinal structure, resulting in tearing of the anterior and posterior ligaments of the cervical spine.

Comparable injury patterns could be observed with tests where the torso was placed directly on the airbag module (distance 0 mm). Here it was also evident that -- obviously also by retroflection -- in one case, a tear of the anterior ligament of the cervical spine was detected.

In the first experiment open fracture of the nasal bone, as well as skin lesion and laceration of the skin in front of the forehead, were caused by the immediate deployment of the airbag against the head. After analysis of the high-speed films, this could be explained by the direct contact with the airbag module cover. For the second experiment, we removed the cover in order to isolate the injuries which were caused by the cover itself.

In this experiment we observed only laceration to the skin in areas with a support of the facial bone structure (roof of the orbits, bridge of the nose), without fractures to the facial bone itself.

In both cases, injuries in the neck/head region were sustained, which can be attributed to the retroflection mechanism, resulting from the direct impact force during the airbag deployment phase.

Through the injury mechanisms, described above, all injuries observed on the neck/head region and the surrounding tissue structure can be explained. The first experiment resulted, apart from the ligament and disk injuries, in a hemorrhage above the spinal meninx in the cervical vertebrae region. In the second experiment, additionally, partial instability of the cervical vertebrae with uncertain bruising of the spinal cord was detected. Also, the evident fracture of both upper bones of the larynx can be explained through the extreme retroflection of the head, whereby the back of the larynx makes direct contact with the cervical spine.

Both evaluated HIC-values of tests with the airbag deployment against the head were considerably above 1000; that already signifies a life-threatening potential. The risk of injury to the brain, respectively the blood vessels inside of the skull, is less objective by autopsy, but these injuries can be sustained by living human beings. This is especially evident for ruptures to the blood vessels in the skull as a consequence of rotation acceleration of the head around the atlanto-occipital-joint, observed by film analysis.

CONCLUSION

Based on market analyses, approx. 500.000 annual global airbag deployments are estimated for the year 2000, as a result of a gradual increase

in the quota of vehicles being equipped with airbags. Apart from accidents with absolutely proven life-saving functions of the airbag for belted occupants, there will also be cases where injuries or fatalities occur when occupants are subjected to Out-Of-Position constellations. The inflated airbag undoubtedly protects the head and torso of the passenger in the event of a head-on collision. However, the expanding airbag material poses a potential danger, not to be underestimated, especially at the initial expanding phase, if parts of the body are in very close proximity to the airbag module. It is therefore our aim to reduce the proven risks of injuries, caused by airbag systems. On the one hand, extreme OOP-situations, e.g. distances of less than 100 mm to direct contact with the module surface, can be prevented by means of constructive measures in the inner parts of the vehicle. On the other hand, further optimization of the systems should be aimed at, e.g. through the improvement of airbag material of the module cover, the deployment technique, as well as a sophisticated airbag system adaptive to occupant parameters.

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