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Technical parameters influencing the severity of injury of front-seat, belt-protected car passengers on the impact side in car-to-car side collisions with the main impact between the front and rear seats (B-pillars)

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Summary. Authentic car-to-car side collisions ($n = 30$) with the main impact area at the B-pillar were analyzed to find technical parameters corresponding with the injury severities of the front seat, belt-protected car passengers on the impact side. EES (Energy Equivalent Speed) and Δv (delta v, change in velocity) were highly significant predictors of the severity of thoracic and abdominal injuries and total injury severity coded according to the Abbreviated Injury Scale (AIS). At an EES or $\Delta v \geq 40$ km/h all front-seat car passengers on the impact side sustained a total injury severity of Maximum AIS (MAIS) ≥ 4 and died. Although a passenger could survive the crash without injury to one or more body regions up to the highest EES- and Δv-values, at EES or $\Delta v \geq 40$ km/h fatal injuries were sustained in at least one body region. At an EES ≥ 35 km/h or a $\Delta v \geq 15$ km/h no front-seat car passenger on the impact side remained uninjured.

Key words: Side collisions – Front passengers – Injury severity – Reconstruction of accidents

Zusammenfassung. 30 reale Pkw-Pkw-Seitenkollisionen mit Hauptanstoßpunkt B-Holm und stoßnah sitzenden angegurteten Frontinsassen wurden mit forensischer Genauigkeit rekonstruiert und die technischen Parameter mit der Verletzungsschwere, codiert nach AIS (Abbreviated Injury Scale) 1985, in Beziehung gesetzt. EES (Energy Equivalent Speed) und Geschwindkeitsänderung Δv waren hochsignifikante Prädiktoren der Thorax-, Abdominal- und Gesamtverletzungsschwere. Ab einer EES oder $\Delta v \geq 40$ km/h erlitten die stoßnahen Insassen eine Gesamtverletzungsschwere MAIS ≥ 4 und starben. Auch wenn Insassen bis zu höchstens EES- oder Δv-Werten in einer oder mehreren Körperregionen unverletzt bleiben konnten, erlitten sie ab einer EES oder $\Delta v \geq$ 40 km/h tödliche Verletzungen in mindestens einer Körperregion. Ab einer EES ≥ 35 km/h oder einer $\Delta v \geq 25$ km/h blieb kein stoßnaher Insasse mehr unverletzt.

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Schlüsselwörter: Seitenkollisionen – Frontinsassen, Insassenverletzungsschwere – Unfallrekonstruktion

Introduction

Biomechanics and accident research have become an established field of research and expert opinion in forensic medicine. In accident research the analysis of car side collisions has become of great interest. The proportion of side collisions among all car accidents is between 15–40% (Otte et al. 1982; Otte 1990; Rouhana and Forster 1985; Danner et al. 1987; Daimler Benz 1988; Ropohl 1990) [5, 4, 13, 14, 16, 17]. Front seat passengers have a high risk of severe injuries, especially when the impact occurs to front doors or B-pillars (Niederer et al. 1980; Kallieris et al. 1986; Otte 1990) [10, 12, 14]. However, most accidents are analyzed and reconstructed from forensic aspects. Often the forensic expert is asked, what the injuries of the passengers would have looked like, if one or both cars had been driven at a lower speed. For example: Car driver A approaches a crossing with 60 km/h, where only 50 km/h is permitted. With a collision speed of 60 km/h he hits a car crossing from the right side at the left wing. The driver B of the other car is injured. The forensic reconstruction of the accident proves that the other car B would have been hit at the left B-pillar, when A would have driven with the permitted speed of 50 km/h. From this hypothetical accident, one of the forensic questions is, whether the driver B would have been injured too, and which injury severity would be expected. This study of authentic side collisions was made to find technical crucial points of accidents corresponding to certain injury severities.

Materials and methods

The accidents were taken from records of the Heidelberg police from the years 1987–1990 and from the autopsy reports of the In-

Table 1. Spearman-Rank-Correlations. 30 front-seat, belt protected car passengers on the impact side in authentic car-to-car side collisions

	EES	Delta v	Defor-mation	Age	Head-AIS	Neck-AIS	Thorax-AIS	Abdom.-AIS	Spine-AIS	Extrem.-AIS	MAIS
EES	1.000										
Delta v	0.932	1.000									
Deformation	0.911	0.817	1.000								
Age	−0.063	−0.033	0.127	1.000							
Head-AIS	0.465	0.422	0.486	−0.045	1.000						
Neck-AIS	0.606	0.618	0.575	0.221	0.704	1.000					
Thorax-AIS	0.853	0.803	0.837	0.174	0.386	0.599	1.000				
Abdomen-AIS	0.809	0.823	0.741	0.036	0.315	0.525	0.871	1.000			
Spine-AIS	0.318	0.347	0.348	0.022	0.537	0.578	0.265	0.381	1.000		
Extrem.-AIS	0.650	0.652	0.670	0.277	0.459	0.736	0.808	0.766	0.544	1.000	
MAIS	0.816	0.823	0.822	0.046	0.611	0.677	0.882	0.764	0.400	0.709	1.000

stitute of Forensic Medicine in Heidelberg from the years 1983–1990. The accidents could be reconstructed from photographs of the accident situations as well as the damaged cars and from accident sketches. In the case of fatal accidents the cars were examined whereas fatal accidents were only included when a postmortem examination took place. Collision speed, EES and Δv were calculated by standard procedures for the forensic reconstruction of accidents (Slibar 1966; Burg 1973; Burg and Zeidler 1980; Burg and Rau 1981) [1–3, 18]. The EES (Energy Equivalent Speed) is an estimate of impact velocity derived from the energy required to deform the vehicle in simulated collisions with a rigid barrier, Δv is the change in velocity during the collision phase. From 272 selected occupants sustaining authentic car-to-car side collisions, 30 front-seat car passengers on the impact side where the car was struck at the main impact area of the B-pillar were selected for further investigations. A pillar is a vehicle roof support structure and the B-pillar is between the front and rear seats.

The injuries were coded according to the Abbreviated injury Scale (States et al. 1980) [20] 1985 revision. The AIS-scale differentiates between injury grades from 0 (uninjured) to 6 (immediately fatal) in the body regions skin, head, neck, thorax, abdomen, spine and extremities. The maximum-AIS (MAIS) is the highest value of the regional AIS. The crucial point of potentially fatal injuries which however are normally survived is between (M)AIS 3 and 4. As this was a retrospective study, anthropometric parameters like height and weight could only be found in the autopsy cases. The ages were known in all cases in this part of the study.

The data in this study was analyzed and statistically calculated on an Apple Macintosh Computer with the data analyses program Datadesk III Professional™ (distributions, boxplots, Spearman Correlations), Odesta Corporation, Northbrook Illinois (USA), and JMP™ (contingency table analysis by means of analysis of log-likelihood). SAS Institue Inc., Cary, NC (USA).

The box in a boxplot extends from the 25% point to the 75% point. The horizontal bar is at the median. The T-bars extend from the top and bottom of the box to depict the extent of the main body of the data. Extreme values are plotted individually, usually with a circle. Very extreme values are plotted with a star.

Results

The Spearman-Correlation (Table 1) shows the connection between EES, Δv, maximum deformation, age and injury severity. Relatively high correlations were found between EES and Δv as well as deformation and of the severity of injury. The highest correlation values were found between the technical parameters and Thorax-AIS, Abdomen-AIS and MAIS. The age of the occupants showed no high correlation with the severity of injury. The highest relation between the regional injury severities was found between Thorax-AIS and Abdomen-AIS.

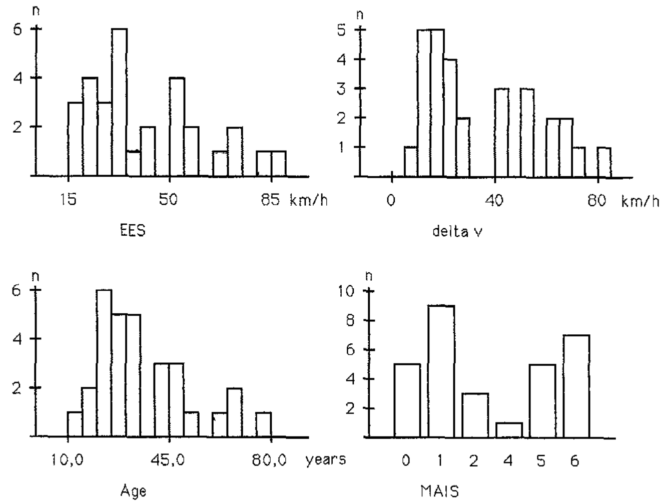

Fig. 1. Distributions of EES, delta v, age and MAIS 30 front-seat, belt protected car passengers on the impact side in authentic car-to-car side collisions

Figure 1 shows the distributions of EES, Δv, age and MAIS. The bar chart of MAIS presents an almost biomodal distribution of the total injury severity. Many cases were investigated with MAIS 0–1 and 5–6, and only a few cases with MAIS 2–4. This distribution could be an effect of the case selection while sampling the data, but as recommended above, we tried to get a uniform distribution of injury severities. In fact, the lack of MAIS 2–4 could be a sample effect, especially when comparing the distributions of EES and Δv. By combining the values > 50 or 60 km/h, we have an almost bimodal distribution, too. In fact, the cases with an EES or $\Delta v < 40$ km/h reflect the accidents from the police reports, and the cases with an EES or $\Delta v \geq 40$ km/h reflect the accidents from our autopsy reports. But it could be, that there is a very small transition from serious to fatal injuries for front-seat car passengers on the impact side in car-to-car side collisions. The age of the occupants ranged from 10 to 77 years with an average of 35 years.

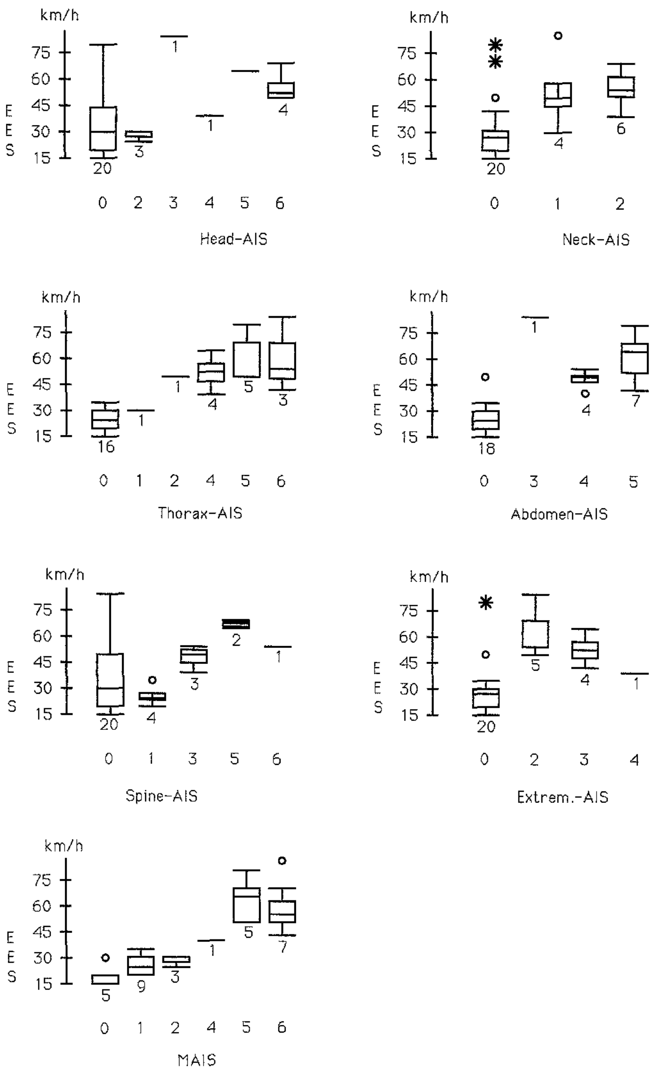

Fig. 2. EES and (M)AIS 30 front-seat, belt protected car passengers on the impact side in authentic car-to-car side collisions

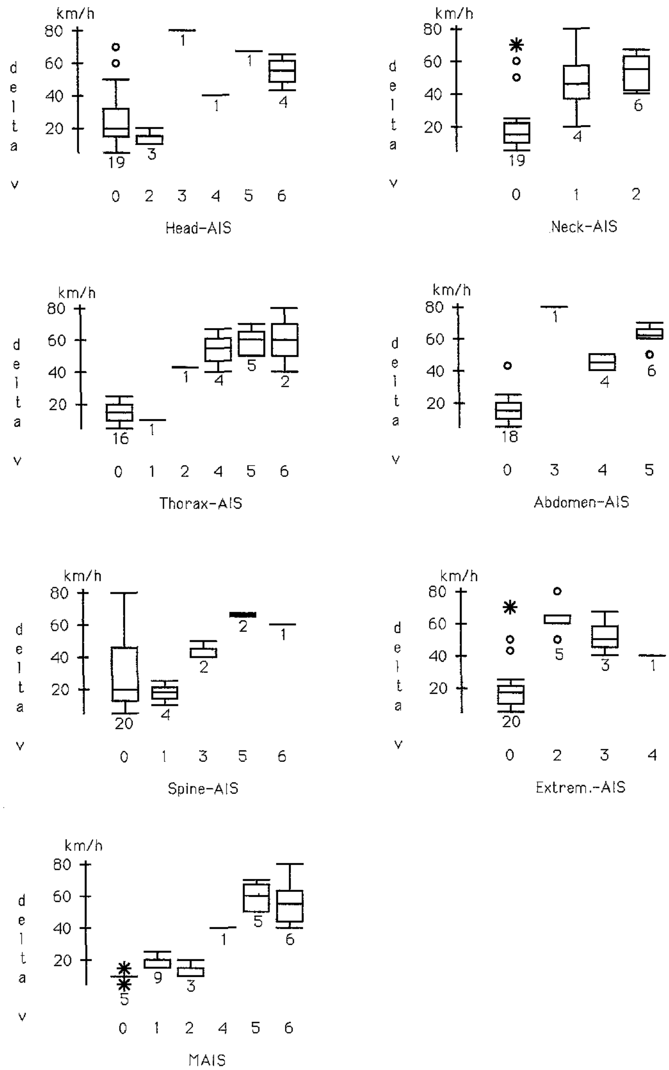

Fig. 3. Delta v and (M)AIS 29 front-seat, belt protected car passengers on the impact side in authentic car-to-car side collisions

Figures 2 and 3 show the boxplots for EES and Δv versus injury severities. Neck-AIS, Thorax-AIS and MAIS show a distinct increase of injury severity with increasing EES- and Δv-values. At EES- and Δv-values ≥ 40 km/h all front-seat car passengers on the impact side sustained MAIS ≥ 4. All 13 passengers with MAIS ≥ 4 died. Causes of death were shock lungs (2 cases), hemorrhagic shock (2 cases), polytrauma (5 cases) and air embolism, pericardial tamponade, head-trauma, trunk-trauma (1 case each). Six victims were killed immediately, 2 died within one hour of the accident, the others survived up to 28 days. The occupants were not necessarily injured in all body regions. While sustaining fatal injuries to a certain body region, the head, neck or spine could remain totally uninjured up to the highest EES- and Δv-values. Above an EES of 30 km/h or a Δv of 15 km/h all persons were injured in at least one body region. As this was a retrospective study and some hematomas and spine strains may have appeared after filling out the accident records, the crucial points for MAIS > 0 might be at an EES less than 30 km/h and at a Δv less than 15 km/h.

To get larger groups for statistical analysis we combined the injury severities of the group (M)AIS 0, (M)AIS 1–3 and (M)AIS 4–6. EES and Δv were split into the groups 0–19 km/h, 20–39 km/h and ≥ 40 km/h. In this way, we analyzed in detail Head-AIS. Thorax-AIS, Abdomen-AIS and MAIS (Tables 2–5). With the exception of Head-AIS (Table 2) and EES/Abdomen-AIS (Table 4) we found in these models a good prediciton for the injury severities (Rsquare 0.70–0.81). The *P*-values for Δv and Head-AIS were < 0.05, otherwise < 0.001. In each AIS, category, especially in Thorax-AIS and MAIS, we saw a distinct increase of the injury severity with increasing EES and Δv. Furthermore we found no (M)AIS ≥ 4 below an EES or Δv of 40 km/h and minor injuries only exceptionally occurred above an EES or Δv of 40 km/h.

Other technical variables such as car mass, collision speed or collision angle had, alone or in combination, no significant influence on the severity of injury of the occupants. As mentioned above, anthropometrical variables such as height and weight could not be taken into consideration, the only available antropometrical vari-

Table 2. Influence of EES and delta v on Head-AIS. Analysis of Loglikelihood. 30 front-seat, belt protected car passsengers on the impact side in authentic car-to-car side collisions

Head-AIS	0–19 km/h	20–39 km/h	> 39 km/h	Total
EES (Rsquare 0.26, $P < 0.001$)				
0	3	11	6	20
1–3	0	3	1	4
4–6	0	0	6	6
Sum	3	14	13	30
Delta v (Rsquare 0.25, $P < 0.05$)				
0	9	5	5	19
1–3	2	1	1	4
4–6	0	0	6	6
Sum	11	6	12	29

Table 3. Influence of EES and delta v on Thorax-AIS. Analysis of Loglikelihood. 30 front-seat, belt protected car passsengers on the impact side in authentic car-to-car side collisions

Thorax-AIS	0–19 km/h	20–39 km/h	> 39 km/h	Total
EES (Rsquare 0.73, $P < 0.001$)				
0	3	13	0	16
1–3	0	1	1	2
4–6	0	0	12	12
Sum	3	14	13	30
Delta v (Rsquare 0.73, $P < 0.001$)				
0	10	6	0	16
1–3	1	0	1	2
4–6	0	0	11	11
Sum	11	6	12	29

Table 4. Influence of EES and delta v on Abdomen-AIS. Analysis of Loglikelihood. 30 front-seat, belt protected car passsengers on the impact side in authentic car-to-car side collisions

Abdomen-AIS	0–19 km/h	20–39 km/h	> 39 km/h	Total
EES (Rsquare 0.17, $P < 0.001$)				
0	3	14	1	18
1–3	0	0	1	1
4–6	0	0	11	11
Sum	3	14	13	30
Delta v (Rsquare 0.70, $P < 0.001$)				
0	11	6	1	18
1–3	0	0	1	1
4–6	0	0	10	10
Sum	11	6	12	29

Table 5. Influence of EES and delta v on MAIS. Analysis of Loglikelihood. 30 front-seat, belt protected car passsengers on the impact side in authentic car-to-car side collisions

MAIS	0–19 km/h	20–39 km/h	> 39 km/h	Total
EES (Rsquare 0.81, $P < 0.001$)				
0	3	2	0	5
1–3	0	12	0	12
4–6	0	0	13	13
Sum	3	14	13	30
Delta v (Rsquare 0.75, $P < 0.001$)				
0	5	0	0	5
1–3	6	6	0	12
4–6	0	0	12	12
Sum	11	6	12	29

able age, had no influence on severity of injury, perhaps as an effect of distribution.

Discussion

Authentic car-to-car side collisions were analyzed to find the technical crucial points for certain injury severities of front-seat car passengers on the impact side. EES and Δv gave the best prediction of the severity of injury of the occupants. Other technical variables such as collision speed, collision angle and car mass alone had no significant influence on the severity of injury. Testing these variables by a multivariate analysis in a factorial design with EES or Δv reduced the injury prediction of EES and Δv.

The collision speed of the strinking car was not an appropriate predictor of the injuries of the passengers in the impacted car, because the speed of the struck car was not taken into consideration. The influence of the collision angle on injury severity could not be demonstrated, although the angle of impact energy has been found to be an essential influential parameter Otte (1990) [14], as a result of the fact that in 22 out of 30 cases the collision angles were 90 or 270 degrees. The influence of car mass and car size on the injury severity of the passengers has been established by Glaeser (1982); Evans (1985); Evans and Wasielewski (1987); Robertson and Baker (1976); Otte et al. (1990) [6–9, 13–15], but in our study we could not prove the influence of the mass of the unloaded cars or the total mass of the cars. This might be due to the small number of cases in our study. Moreover, the unloaded mass of the cars did not differ very much. Because this was a retrospective study, the total car mass at the time of the accident could only be estimated. In many cases we did not have the weights of the surviving passengers, and in none of the cases could the contents of the petrol tank or the load of the cars be measured.

Age showed no significant influence, although an influence of age on injury severity has been previously established experimentally. Kallieris et al. (1986); Mattern et al. (1979); Schmidt (1979) [10, 11, 19] found a high correlation between the age of PMHS (postmortem human subjects) and thoracic injury, mostly represented by the number of rib fractures.

In our study fatal crashes occurred at an EES or $\Delta v \geq 40$ km/h and an MAIS ≥ 4. Thus, the AIS-scale differentiated clearly between surviving and non-surviving occupants. Below an EES or Δv of 40 km/h no regional AIS < 4 occurred. These results correspond with the results of Otte (1990) who also found a dramatic increase of MAIS 5–6 with the front-seat car passengers on the impact side between a Δv range from 40 to 50 km/h in car-to-car side collisions. However, in our study it must be taken into consideration, that only very few cases of AIS 3 or 4 were found. Thus, with more cases at the transition from regularly survived to potentially fatal injuries, the crucial point to fatal injuries might not have become as abrupt as shown in this study. Although we tried to find an approximately equal number of cases for all AIS-grades, we again returned to a bimodal distribution with many cases (M)AIS 0–2 as well as many cases (M)AIS 5–6. Not considering the sample effect, the frequent bimodal distribution of injury severity in car-to-car side collisions might reflect the extremely narrow gap between life and death for front-seat car passengers on the impact side.

The box-plots (Figs. 2 and 3) demonstrate, that a fatally injured person might have severe injuries in only one or more body regions. Especially the head, neck and spine were sometimes totally uninjured up to the highest EES- and Δv-values. In side collisions the main contact area for head injuries of front-seat passengers on impact side is the B-pillar. Small variations in the seat position in relation to the B-pillar or in the collision angle, the influence of 2 or 4-door cars or the individual body posture at the time of the impact can determine the difference between fatal and no head injuries. Neck injuries were quite seldom, because Neck-AIS comprise only injuries of the organs, soft tissues, nerves, vessels, etc., without spinal injuries. High degrees of Neck-AIS were only found in our larger accident sample in side collisions with trucks, trees or buildings at high impact speeds. The thoracic and lumbar areas of the spine are well protected in side collisions, and injuries mostly refer to the cervical spine in the form of direct impact trauma or indirect deceleration trauma.

In a retrospective study it is difficult to register trivial injuries. As taken from the police records, many persons were recorded as being uninjured at the scene of accident. In this study at an EES $\geq$ 30 km/h or a $\Delta v \geq$ 15 km/h no occupant remained uninjured. It can be assumed with a high probability that some of the persons experienced pain or noticed hematomas later. So the crucial points for MAIS > 0 might be below an EES of 30 km/h or a Δv of 15 km/h. Otte (1990) [14] found totally uninjured passengers up to a Δv of 50 km/h. This might result from the fact that Otte considered impacts to the whole passenger compartment, while we only selected main impact areas at the B-pillar. On the whole, our retrospective study showed a good correlation to the larger prospective study of Otte (1990) [14].

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