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Lateral impact injuries with side airbag deployments—A descriptive study

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Abstract

The present study was designed to provide descriptive data on side impact injuries in vehicles equipped with side airbags using the United States National Automotive Sampling System (NASS). The database was queried with the constraint that all vehicles must adhere to the Federal Motor Vehicle Safety Standards FMVSS 214, injured occupants be in the front outboard seats with no rollovers or ejections, and side impacts airbags be deployed in lateral crashes. Out of the 7812 crashes in the 1997–2004 weighted NASS files, AIS ≥ 2 level injuries occurred to 5071 occupants. There were 3828 cases of torso-only airbags, 955 cases of torso–head bag combination, and 288 inflatable tubular structure/curtain systems. Side airbags were not attributed to be the cause of head or chest injury to any occupant at this level of severity. The predominance of torso-only airbags followed by torso–head airbag combination reflected vehicle model years and changing technology. Head and chest injuries were coupled for the vast majority of occupants with injuries to more than one body region. Comparing literature data for side impacts without side airbag deployments, the presence of a side airbag decreased AIS = 2 head, chest, and extremity injuries when examining raw data incidence rates. Although this is the first study to adopt strict inclusion–exclusion criteria for side crashes with side airbag deployments, future studies are needed to assess side airbag efficacy using datasets such as matched-pair occupants in side impacts.

Keywords

Lateral impact; Side airbags; Head and chest injuries; Descriptive study

1. Introduction

Airbags are used in modern motor vehicles for enhancing occupant safety during impact. Frontal airbags have been in the vehicle fleet for over a decade, and the United States federal requirements are promulgated through Safety Standards FMVSS 208 (NHTSA, 2005). In contrast, side airbags are more recent than frontal airbags and are intended to primarily protect the occupant during lateral crashes. They are installed as thorax or torso-only airbag, torso–head airbag (combination airbags), or separate torso and head airbags (inflatable tubular structure or curtain). Although federal regulations do not exist in the United States for side airbags, such systems are gaining popularity because of public awareness for safety and their potential injury mitigating characteristics (NHTSA, 1999, 2003). While many studies are conducted to investigate injuries in frontal impacts with frontal airbags, no such systematic evaluations of side impacts with side airbags have been published, to the best knowledge of the authors (Pintar et al., 2000). Only a few studies have begun to appear in the literature with no unified conclusions on side airbag responses. McGwin et al. (2003) used the United States

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National Automotive Sampling System (NASS) database for the years 1997–2000 to determine the association between side airbags and risk of injury in motor vehicle collisions with near-side impact. The authors assumed that all vehicles with side airbags as optional equipment were equipped with the technology and concluded that vehicles with side airbags had a risk of injury similar to occupants of vehicles without side airbags. This assumption is a major limitation of the study, and its validity was not discussed. Using NASS database for the year 2000, another study conducted an analysis of 187 occupants with airbag deployments out of which 62 were in side impacts (Bazarian et al., 2004). Although this study concluded that side airbags may be effective in preventing cranial trauma, less than 1% of occupants were in vehicles equipped with side airbags. These analyses, albeit brief, indicate the need to conduct a more detailed study specific to side airbag deployments. Therefore, the purpose of the present investigation is to focus on a descriptive case series of lateral impact-induced injuries in vehicles with side airbag deployments.

2. Methods

The NASS database was interrogated with the constraint that all vehicles adhere to the Federal Motor Vehicle Safety Standards, FMVSS 214. Case selection criteria was such that the occupant should be involved in a side impact collision with the principal direction of force between 50° and 130° for passengers, and 230° and 310° for drivers, and the primary impact should be in the lateral direction resulting in deployment of a side airbag. All types of airbag systems, i.e. torso alone, side or head curtain or inflatable tubular structure, or a combination of torso and side curtain or head, were included. Other selection criteria included passenger cars, light trucks, and vans. Only outboard front seat occupants, driver and passenger, were included in the study. Rollovers and full ejection events were excluded. The 1990 version of the Abbreviated Injury Scale was used (AIS, 1990) for injury coding. Briefly, the grading system for injury levels is as follows: (0) no injury; (1) minor; (2) moderate; (3) serious; (4) severe; (5) critical; (6) maximum; (7) unknown. Body regions represented the head, face, neck, chest, abdomen, spine, and upper and lower extremities. In addition, the source of injury and confidence in injury assignments was extracted from case-by-case description of injuries in the database. The sourcing of injuries is a separate variable in NASS. The assignment of the injury source and the confidence levels are done by specialists at the Zone center responsible for quality controlling the work of the field investigator that documented the crash. The confidence levels are initially indicated by the field investigator, but these are subject to correction by the specialists at the Zone center. AIS = 1 level data are presented to a limited extent, and since they are less clinically significant, descriptions are limited to occupants sustaining AIS $\geq$ 2 injuries. Weighted data are included in the results and discussion.

3. Results

NASS data for the years 1997–2004 were used in the study. With the inclusion–exclusion criteria specified earlier, a total of 7812 side crashes had impact-related injuries (all AIS levels). The actual number of sampled cases was 68. Of the 7812 crashes, 7214 were left and 598 were right side impacts. Lap and shoulder belts were used by 7346 occupants, and no belt restraints were used by the remaining 466 occupants. Limiting the analysis to AIS $\geq$ 2 injuries, 4572 crashes occurred to the left side, and 499 crashes occurred to the right side, for a total of 5071 impacts. When data were categorized based on airbag type, there were 3828 cases of torso only airbags, 955 cases of torso–head bag combination, and 288 inflatable tubular structure/curtain systems. Regarding the location, 4724 airbags deployed from the seat, 237 from the door and roof side rail, 59 from the door, 49 from the roof side rail, and nine from the seat back and roof side rail.

Table 1 provides a summary of raw and weighted data based on AIS level and body region. As discussed later, one raw data point had a weighting factor of 2798, and all the remaining data had weighting factors less than 250. AIS 1 level is included for comparison purposes, and as indicated in Section 2, the following weighted results are applicable to $\text{AIS} \geq 2$ trauma. The most commonly involved body region was the chest (4282 occupants), followed by the abdomen (3183 subjects), and head (1492 occupants). No occupants sustained neck injuries. Fig. 1 shows the distribution as a function of body region. Limiting the analysis to include $\text{AIS} \geq 3$ trauma, 1408 side impact cases were identified. The head and chest were identified to be the most frequently affected body regions with 1051 and 1045 occupants. Fig. 2 shows the distribution as a function to body region.

Out of the 5071 occupants with $\text{AIS} \geq 2$ trauma, 727 occupants had injuries to one body region. While head, chest, spine, and lower and upper extremities were involved, no cases were found with only neck, abdomen, or facial injuries. The distribution of these injuries is shown in Fig. 3. Of these 727 subjects, 511 occupants sustained one injury to any body region. In this subgroup of single injury to any body region, head was the most frequently injured body region followed by the upper extremities, spine and lower extremities (Fig. 4). Out of the 278 occupants sustaining a head injury in the group of 511 occupants, all occupants wore lap and shoulder belts. Thorax only bags deployed in 220 crashes and thorax-head airbags deployed in the remaining 58 crashes. The confidence in injury was certain in 25 and probable in 253 cases. A non-contact source was attributed to be the cause of head (brain) injury in 236 occupants, and in the remaining 42 subjects, the right side B-pillar structure was the source.

Out of the 5071 occupants with $\text{AIS} \geq 2$ trauma, 4344 occupants had injuries to more than one body region. In this subset, 1214 occupants had head injuries at the $\text{AIS} \geq 2$ level, and 422 torso airbags, 735 torso-head airbags, and 56 torso and inflatable tubular structure/curtain airbag systems were deployed in side crashes. Out of these 1214 occupants with head injuries, chest injuries occurred to 1195 subjects. A majority of head injuries were at the AIS three and four levels, and the distribution as a function of AIS is shown in Fig. 5. In the same subset of 4344 occupants, 4225 subjects sustained chest injuries at the $\text{AIS} \geq 2$ level, and 3308 torso airbags, 791 torso-head airbags, and 126 torso and inflatable tubular structure/curtain airbag systems were deployed in side crashes. AIS = 2 level injuries were most predominant (Table 1). Injury sources for chest trauma included interior surfaces of the vehicle and pillar, and for head, they included the side roof rail or header. In none of these cases, the side airbag, regardless of bag type, was attributed to injury.

4. Discussion

Studies with side airbag deployments have largely remained anecdotal. Langwieder et al. (1998) reported minor trauma from a single crash in a vehicle with thorax airbag and inflatable tubular structure. Kirk and Morris (2003) while reporting data from 10 cases with different impact directions concluded that “further studies of airbag deployments are essential”. In an analysis of 10 frontal impacts, side impacts, and rollover crashes, Dalmotas et al. (2001) stated “additional field collision data on side airbag systems are needed”. From a study of four side impacts with side airbags, Bauer et al. (2000) stated “a proper statistical sampling could not be achieved at this time” reflecting the limited nature of field data. In contrast to these individual and limited case series, the present study provides descriptive information using weighted samples and forms the largest dataset in the literature focusing only on lateral impacts with deployed side airbags.

Side airbags began to enter the vehicle fleet as an optional feature in 1990s, reflecting the emerging nature of the technology. No cases with side airbags were found in the present study prior to the year 1997. Different types of airbag systems have been introduced including torso-

only, torso-head (combination bag), torso-curtain or, inflatable tubular structure/curtain. These bags deploy from the door, seat, and side rail components of the vehicle. Only 59 side airbags deployed from the door. The door-mounted torso only airbag is being installed less frequently because of its response to out-of-position occupants. Laboratory investigations have shown their deleterious effect specifically in the out-of-position scenario demonstrating increased craniocervical loads and chest deflections (Pintar et al., 1999). The side airbag out-of-position injury technical working group remarked: “there have not been enough deployments to assess the out-of-position injury risk of side airbags from accident data”, and viewed that “new systems should be designed according to these recommendations for further limiting out-of-position occupant injury risk largely because new technology is emerging that is expected to meet the guidelines while still providing side impact protection (Lund, 2000)”. Dinas and Fildes (2002) reported that “a significant number of occupants were seated out-of-position while traveling on the road and that a number of these were seated in a manner that may possibly result in injury from the deployment of a side airbag”. A need thus exists to evaluate positioning issues in side impacts.

In the present study, out of 5071 crashes with AIS ≥ 2 injuries, a majority were torso-only side airbags without supplementary systems such as curtain. The primary function of these airbags is to offer torso protection. Torso-head systems, i.e. combination airbags, followed torso-only airbags with 955 cases. Because the function of the combination system is to protect the torso and head, they have additional volume. Occupant kinematics may be different between the two systems. The objectives of the two different airbags in separate torso-curtain systems are to protect the torso and head with independent kinematic controls. Therefore, these different side airbag systems offer unique features in their form and function for occupant protection. The general trend in the United States market is a shift toward separate torso and head airbag systems instead of combination airbags. For the model year 2004, torso side airbags outnumbered the combination system by three to one.

Examining injuries, occupants with trauma to more than one body region at the AIS ≥ 2 level, chest injuries occurred along with head injury in >90% of the subjects. This finding suggests a coupling phenomenon between the two body components. Chest injuries did not occur in isolation at AIS ≥ 3 levels. A similar conclusion was advanced in another study wherein an association was found between cranial and cervical column trauma (Yoganandan et al., 1990). In this previous study, cervical injuries were attributed to external load transfer from head impact within the interior component of the vehicle. In the present context, lateral impact loading was delivered to the torso secondary to interaction with the interior of the vehicle. This finding was based on injury source identification in the database. Although side airbags might have served to distribute the load to the chest, one possibility is that occupant positioning may have been less than optimal to fully realize injury mitigating characteristics of side airbags. It is well known in impact biomechanics literature that positioning affects load transfer, injury mechanism, and tolerance (Yoganandan et al., 2002; Maiman et al., 2002). The effects of subject positioning on head and torso injuries with side airbags have not been investigated and the current motor vehicle safety standards (FMVSS 214) do not directly address the issue. While NASS is not ideal for this determination, other databases such as Crash Injury Research Engineering Network may be used. The latter database contains detailed kinematics and medical information to better evaluate airbag responses (Yoganandan et al., 2005). As discussed, this topic needs further consideration for an improved assessment of side airbag efficacy.

It is possible to compare the findings with data obtained from cases without side airbag deployments. Hassan et al. (1999) reported that 90% of AIS ≥ 2 severity side crashes in 1988–1996 NASS files occurred at a delta-V of less than 39 km/h. Analysis using the present data indicated a similar delta-V (37 km/h) to be associated at the same severity. Although this

finding does not appear encouraging, several limitations should be recognized. For example, different types of airbags intended to protect different regions of the occupant were included in the analysis; torso-only bag for chest and curtain-only bag for head. Vehicles were not FMVSS 214 compliant in the previous study, and injuries included body regions not intended for protection from the deploying side airbag. NASS data during the earlier years represented lower proportions of belted occupants while in the present 1997–2004 study, majority of crashes involved belted occupants. Although the role of such restraint systems in side crashes has been reported in earlier literature, their effects on modern vehicles (some have pretensioning belts) with or without side airbag deployment have not been studied (Mills and Hobbs, 1984). Most importantly, this is not a matched-pair comparison of the two groups. These issues underscore the need to further investigate side impacts with side airbag deployments from epidemiological and laboratory biomechanical perspectives for a better assessment of their efficacy.

Regarding injuries to specific body regions, a comparison of data from the present study with findings from the Hassan et al. study indicated the following (Table 2). Using weighted data as a basis, at the AIS 2 level, head injuries in the presence of a deploying side airbag appeared to be reduced compared to side impacts without side airbags from the United States and United Kingdom databases. This trend was also true for upper extremity trauma. Chest and abdominal injuries showed a dramatic increase with the presence of a side airbag. However, a single raw data point with a weighting factor of 2800 contributed to the increase; all other cases had weighting factors less than 250. When raw data were used as a basis for comparison, as shown in Table 2, both head and chest injuries demonstrated a decreasing tendency in side airbag deployed lateral impacts, a positive trend towards occupant safety and vehicle crashworthiness. When AIS =3–6 level trauma were considered, raw data showed increases in head and chest injuries with the present side airbag ensemble, suggestive of increased survival with serious injuries. However, as discussed earlier, this interpretation must be supported with additional analysis.

As indicated earlier, the dataset available for this study was small and weighted occupants are based on this low sample size. Confidence decreases when weighted estimates from such selected samples are extracted from a probability-sampled database; NASS is no exception. Consequently, conclusions from this study should be viewed with this important sample size recognition. Confidence in the results can be increased by adding samples from other datasets such as the Cooperative Crash Injury Study from the United Kingdom. Because of sample size limitations, it is difficult to conclude that side airbags reduce injuries, and therefore, to quantify and address their efficacy, additional data are needed which may be obtained by coalescing with sources such as CCIS and/or including specific cases from Crash Injury Research Engineering and Network studies. These are avenues for future research.

5. Conclusions

Using NASS database for the years 1997–2004, this study identified injuries in 7812 side impact crashes with side airbag deployments. The majority of side airbags were torso-only followed by torso–head combination systems. Head and chest injuries were coupled for the vast majority of occupants with injuries to more than one body region. In no case was the side airbag attributed to be the source of AIS ≥ 2 injuries. Chest injuries did not occur in isolation at AIS ≥ 3 levels. Although this is the first study to adopt strict inclusion–exclusion criteria for side crashes with side airbag deployments, future studies are needed to assess side airbag efficacy using datasets such as matched-pair occupants in side impacts.

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Fig. 1. Bar chart showing the number of occupants sustaining $\text{AIS} \geq 2$ injuries as a function of body region.

Fig. 2. Bar chart showing the number of occupants sustaining $\text{AIS} \geq 3$ injuries as a function of body region.

Fig. 3.

Bar chart showing the number of occupants sustaining only injuries to one body region at the AIS ≥ 2 level.

Fig. 4. Bar chart showing the number of occupants sustaining only one injury to any body region at the AIS ≥ 2 level.

Fig. 5.

Bar chart showing the number of occupants with head injury as a function of AIS level. Data obtained from the group of occupants with AIS two plus injuries to more than one body region and focusing only on AIS ≥ 2 head trauma.

Number of occupants sustaining injuries as a function of body region

AIS level	Head		Face		Neck		Chest		Abdomen		Spine		Up extremities		Low extremities	
	Weighted	Raw data	Weighted	Raw data	Weighted	Raw data	Weighted	Raw data	Weighted	Raw data	Weighted	Raw data	Weighted	Raw data	Weighted	Raw data
AIS 1	174	3	1040	18	223	5	179	3	246	6	354	5	467	13	3321	10
AIS 2	441	10					3237	6	3042	6	522	5	388	8	652	10
AIS 3	401	6	47				378	6	141	4			163	1	336	11
AIS 4	315	4					288	6			132	2				
AIS 5	42	1					61	3			9	1				
AIS 6	84	1														
AIS 7	209	1					318	3								

Table 2

Comparison of data (% injuries) from the present study with literature

Description	Head	Chest	Abdomen	Up extremities	Low extremities
AIS = 2 raw data	24.4	14.6	14.6	19.5	24.4
AIS = 2 weighted data	8.7	63.8	60.0	7.7	12.9
Hassan et al. US data	37	18	9	29	23
Hassan et al. UK data	30.6	16.1	11.8	28.3	31.1
AIS = 3-6 raw data	29.3	36.6	9.8	2.4	26.8
AIS = 3-6 weighted data	16.6	14.3	2.8	3.2	6.6
Hassan et al. US data	9	13	3	3	6
Hassan et al. UK data	15.3	22.8	9.3	3.3	24.2