NEARSIDE OCCUPANTS IN LOW DELTA-V SIDE IMPACT CRASHES: ANALYSIS OF INJURY AND VEHICLE DAMAGE PATTERNS

Mark Scarboro
Rodney Rudd
National Highway Traffic Safety Administration
United States
Mark Sochor
University of Michigan Transportation Research Institute
United States
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ABSTRACT

Nearside occupants in side impact crashes often sustain severe injuries resulting in significant economic burden. Continual advancements in safety technology, including reinforced door structures, torso and head curtain air bags, compatibility improvements and other advancements, attempt to provide increased protection to occupants in these side impact crashes. Despite these advancements, serious injuries continue to occur at low delta-V's. In this paper, detailed analysis of field crash data will show which factors have the most influence on occupant outcome in these side impact crashes.

One-hundred and eighty-nine side impact crashes from the Crash Injury Research and Engineering Network (CIREN), National Automotive Sampling System/Crashworthiness Data System (NASS/CDS), and Special Crash Investigation (SCI) databases were selected based on crash criteria including a delta-V below 40 km/h and a principal direction of force (PDOF) between 2 and 4 o'clock or 8 and 10 o'clock. Cases were also restricted to those in which the front-row nearside occupant sustained an AIS 3+ injury to the head, torso, abdomen or lower extremity. Analyzing anatomical injury in conjunction with the vehicle damage patterns allows for the development of injury causation scenarios, which can speak directly to the interaction of the occupant and the components of the vehicle during the crash. These findings may identify trends which could be investigated for potential areas of improvement in future side impact testing and design of countermeasures.

INTRODUCTION

Nearside crashes have higher serious injury and fatality risks as compared to all crash modes [Samaha and Elliot, 2003]. Nearside occupants are at increased risk of significant injury due to their limited ride down space and proximity to the intruding vehicle structures. The limited crush space and intervention time to protect the nearside occupant in a lateral crash makes the development of effective occupant protection features a difficult task. The challenges are even greater with recent shifts in the composition of the U.S. fleet towards a greater proportion of higher-riding trucks and utility vehicles. Dalmotas *et al* [2001] stated that passenger car occupants struck by vehicles with higher ride-heights put nearside occupants at elevated risk for head, chest and abdomen injuries.

Frontal collisions have long been the predominate type of crashes occurring on U.S. roadways. Occupant protection in frontal collisions has been aggressively pursued with mandated air bags, advanced seat belts, crumple zones and other energy absorbing technologies in the struck vehicle as well as in the striking vehicle [Barbat, 2005]. Nearside occupants involved in lateral crashes are currently protected by rigid structures in their door and possibly by some type of side air bag (SAB) designed to protect the occupant (or a body region of the occupant) in a lateral crash. A recent study of SAB effectiveness by the Insurance Institute for Highway Safety (IIHS) found that the presence of a SAB did indeed lower the risk of death to drivers in left-side impacts [McCartt and Kyrychenko, 2006]. Unfortunately, even with modern occupant protection features, serious injuries and fatalities are still occurring in a sizeable number of nearside crashes.

The NASS/CDS weighted data between 1999 and 2005 indicates that 16% of all crash occupants in the United States were in the nearside seating position of side impact crashes for the most significant (Rank 1) impact event. When the same nearside crashes are analyzed by the delta-V for the nearside impact event (Rank 1) using 40 kmph (25mph) as a threshold, the breakdown shows 62% of the crashes occurring with a delta-V less than or equal to 40 kmph and 14% over

40 kmph with the remaining 24% having unknown delta-V's as displayed in Table 1. For the nearside crashes occurring at or below 40 kmph, the incidence of AIS3+ injury is 3.33% (17,212 out of 516,165 occupants).

Table 1.
Nearside Delta-V Distribution
(NASS/CDS 1999-2005)

Delta V	Percent of Nearside Crashes
<= 40 kmph	62
> 40 kmph	14
Unknown	24

Due to the incidence of serious injuries to nearside occupants in side impacts at low speeds, this study was undertaken to better understand modern vehicle crash performance and occupant response. The objective was to identify trends in injury patterns in order to develop target areas for further side impact research.

METHODS

To maximize case count all of the NHTSA crash investigation data systems were queried for side impact cases matching the study's inclusion criteria. Cases were pulled from the NASS/CDS, CIREN and SCI databases.

The following inclusion criteria are utilized;

- AIS $\geq$3 injury to head, chest, abdomen or lower extremity
- Occupant age $\geq$16 years
- Rank 1 event is nearside to the study occupant
- Rank 1 event $\leq$ 40 kmph
- Model year of the study vehicle is $\geq$1998
- No rollover events are recorded for the study vehicle in subsequent crash events
- Row 1 occupants only
- All crash configurations are vehicle to vehicle
- The following Crash Deformation Classification (CDC) [SAE, 1980] values are used –
    - O'clock direction of force is 2-4 or 8-10 (CDC columns 1-2)
    - General area of deformation must equal Right or Left (CDC column 3)
    - Longitudinal damage location must equal P, Y, Z, D, F (CDC column 4)

The NASS and SCI data systems were queried from 1999 to 2004 and the CIREN data system was queried from 1998 to 2005. Since all three of these systems utilize the same investigation and coding standards the same crash and injury fields could be extracted from all systems in the same manner. Once the base variables were collected, all of the cases were reviewed individually to collect detailed injury and vehicle damage data not typically available in hard coded fields. The majority of the additional vehicle details were derived from inspection of the vehicle photos. The case occupant's radiology images/reports and operative reports in CIREN and the mannequin illustrations and annotation fields available in NASS and SCI were utilized to capture injury detail not otherwise coded.

Crash data were augmented by manual review of the case vehicle to classify several different aspects of the vehicle and the crash damage. The lower rocker panel or sill was evaluated on each case vehicle to evaluate any possible underride or override characteristics in the crash. Door deformation was reviewed on each vehicle to evaluate crush patterns. Patterns similar to those used by Tencer *et al* [2005] in their analysis of side impact crashes were utilized. The external crush pattern was also reviewed for engagement of the major structural pillars in the side plane. The vehicle interior photographs were also reviewed to establish the general geometry of the inside panel of each door as well as the existence of a row 1 center floor mounted console. If SAB(s) deployed during the crash event, these air bags were categorized into general protection types based on whether they were intended to protect the head, torso, or both.

The standard injury data were bolstered by a detailed review of the chest and pelvic injuries. The thoracic injury detail consisted of the actual number of fractured ribs, as well as the actual location of the rib fractures in the anterior-posterior direction along the curvature of the rib and in the inferior-superior direction by the anatomical rib number(s) fractured. Evidence and location of actual contact to the exterior chest wall was sought in all cases, but documented evidence was difficult to find in a majority of the cases. Evidence of thoracostomy procedures (chest tube) was also sought to determine whether pneumothorax (PTX) or hemothorax (HTX) injuries to the thorax were significant enough to warrant invasive intervention. Many times small amounts of blood and/or air in the thoracic cavity will be recorded, which can result in an increase in the severity of the injury coding. However, the presence of a chest tube is a better indicator for aggressive evacuation of intra-thoracic air and/or blood which may be life threatening. Attempts to capture chest tube procedures on occupants sustaining a PTX and/or HTX proved quite difficult in the NASS and SCI data. Pelvic fractures were reviewed to extract fracture pattern detail as well as the actual location and number of fractures. Although the pelvis is usually referred to as a single bone, it is actually three separate bony structures connected by very strong ligaments. The symmetric hemi-pelves comprise two of the three bony structures and better known by their substructures, which are the pubic, ischium and iliac bone(s). The hemi-pelves establish the right and left aspects of the pelvic ring. The third component completing the pelvic ring, or girdle, is the sacrum, which constitutes the posterior part of the pelvic ring. Each of these bony structures was reviewed in each case for fractures and/or dislocations.

Several different approaches were taken in reviewing the data with regards to the occupant's injuries and their interaction with the vehicle and other crash parameters. Along with the detailed review of the study group, a general comparison was undertaken on the study group and the weighted NASS/CDS data for nearside crashes with delta-V's of 40 kmph or below. The weighted data reviewed included all nearside occupants from NASS/CDS 1999-2005 with a 3+ maximum abbreviated injury score (MAIS).

RESULTS

A total of 189 occupants meeting the inclusion criteria were extracted from NASS, CIREN and SCI. The general demographics of the study group are displayed in Table 2. Fifty-six percent of the occupants were female and the mean age was 47 years (range 16-93). The case occupants in the study group averaged 170 cm (67 in.) in height with an average weight of 76 kg (168 lbs). Gender differences indicated (as expected) taller and heavier males compared to females, with the male population being older by seven years on average.

Table 2.
Demographic Data

n	189	
	Mean	**Range**
Age	47 years	16-93 years
Height	170 cm 67 in	150-193 cm 59-76 in
Mass	76 kg 168 lb	39-133 kg 86-293 lb
Gender	**Female**	**Male**
n	105	84
% of group	56%	44%
Mean Age	44 years	51 years
Mean Height	165 cm 65 in	178 cm 70 in
Mean Mass	69 kg 153 lb	85 kg 187 lb

General crash and injury parameters are detailed in Table 3. The study occupant was the driver in 76% of the 189 cases captured for review. The delta-V's for the study group ranged from 5 kmph (3 mph) to 40 kmph (25 mph) with a mean of 29 kmph (18 mph). One-hundred and forty-five occupants (77%) were belted in 3-point manual belts. Thirty-one of the occupants (16%) had some form of deployed SAB at their seating position. In an additional four cases, SAB were available, but did not deploy. Impact angles were generally described as oblique or lateral. Left or driver's side impacts with a principal direction of force (PDOF) between 260 and 280 degrees and right or passenger's side impacts with a PDOF between 80 and 100 degrees are classified as lateral. All other cases are classified as an oblique impact. During the manual case review, intrusions were evaluated for each study vehicle. Intrusions at the study occupant's position were reviewed to determine the maximum value applicable to each case occupant. The vehicle component with the highest intrusion value for each of the study occupant positions was captured, and this value would override larger intrusion values that occurred at non-study seating positions. The mean maximum occupant intrusion measure for the study group was 25 cm (10 in.). Although the CIREN enrolls only occupants transported to a level 1 trauma center, the occupant intrusion measures and delta-V's were lower on average for the CIREN cases compared to the NASS/CDS and SCI cases. Intrusion averaged 23.6cm (9.3 in) in the CIREN cases and 26cm (10.2 in) for NASS/CDS and SCI. Delta-V's followed the same trend with the CIREN average at 27.8 kmph (17.3 mph) and the NASS/CDS and SCI average at 29.5 kmph (18.3 mph).

Table 3.
Crash and Injury Data

Occupant Seating Position	
Driver (Left Front)	143 (76%)
Restraint Status	
Belted	145 (77%)
Side air bag deployed	31 (16%)
Impact	
Mean Delta-V	29 kmph (18 mph)
Impact angle	
Oblique[1]	121 (64%)
Lateral[2]	68 (36%)
Crash Configuration	
Car[3]-Car	76 (40%)
Car[3]-LTV	86 (45%)
LTV[3]-Car	7 (4%)
LTV[3]-LTV	20 (11%)
Mean maximum intrusion at occupant position	25 cm
1 – oblique crashes with PDOF between 30º -80º or 280º -330º 2 – lateral crashes with PDOF between 80º-100º or 260º -280º 3 – indicates study vehicle	

Injury Summary

All injury data were extracted on the study occupants and initially evaluated on the general categories of Maximum Abbreviated Injury Scale (MAIS), Injury Severity Score (ISS), and the individual AIS codes. The MAIS mean for the group was 3.7 and the mean ISS was 23, indicating significant injury in multiple body regions (Table 4).

Table 4.
Injury Severity

Mean ISS	23
Mean MAIS	3.7

The percent of AIS3+ injury by individual body regions indicated that the chest and lower extremity are the two most severely injured body regions in the study group. Sixty-three percent of the study group sustained an AIS3+ injury to the chest. The lower extremity body region ranked second with 42% sustaining AIS3+ injury. Interestingly, the head ranked third in our group with a 26% injury rate at an AIS3+ level. Figure 1 demonstrates the findings for all body regions in the current study. The abdomen was the only remaining body region with an injury rate in the double digits with a 17% occurrence.

Ribs and Pelvis

Utilizing the AIS and volume of coded injuries, the chest and lower extremities are the two most severely injured body regions in the study group. The distribution of injured organs within each of these body regions indicated a significant concentration of rib and pelvic fractures (Figures 2 and 3) within each of the general body regions.

Study Group vs. Weighted NASS/CDS

The NASS weighted data extract was compared to our study group by occupant age, fatality and MAIS. The age distribution from the weighted data is shown in Figure 4 along with that from the current study group. The NASS distribution was similar to that of the study group, with the exception of the 16-25 and the 36-45 groups.

The fatality rates for the weighted data were considerably lower than the study group. The weighted data indicates a 5.9% (16% unweighted) fatality rate for the nearside crashes below 40 kmph when a nearside occupant sustains an AIS3+ injury, whereas the study group had a 13% fatality rate. It is generally understood that weighted data from the NASS/CDS sampling underestimates actual fatality risk for a given group.

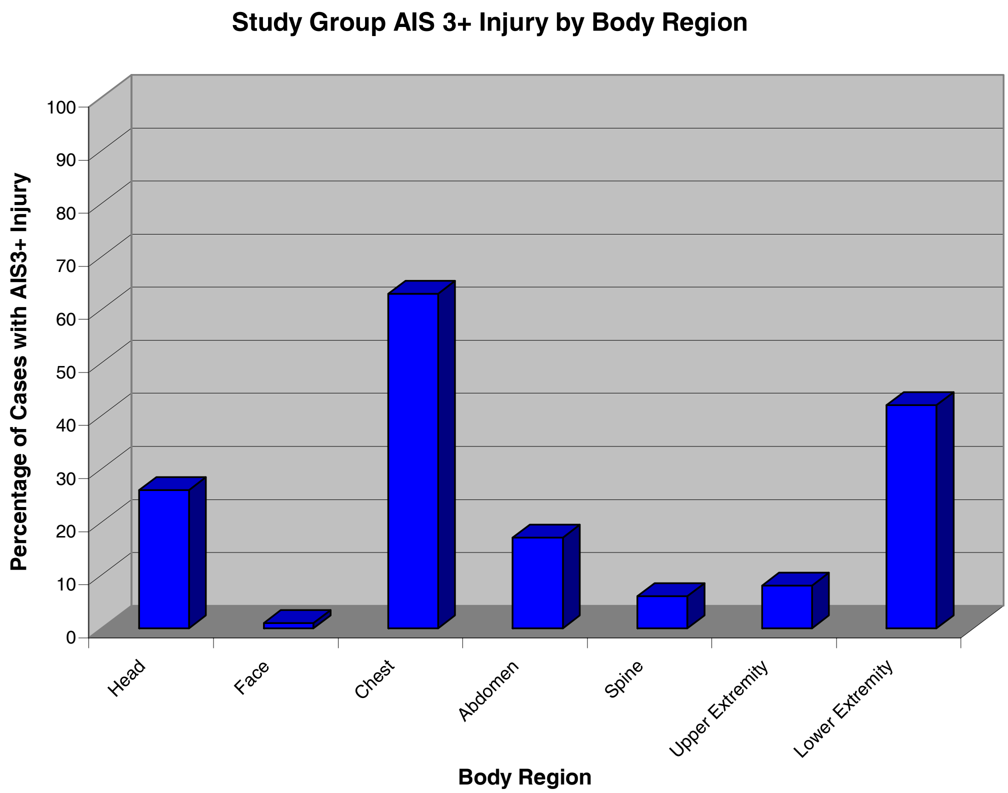

Figure 1. Percentage of cases with AIS 3+ injuries by body region.

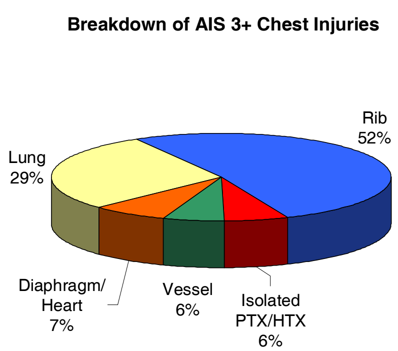

Figure 2. Breakdown of serious chest injuries by organ.

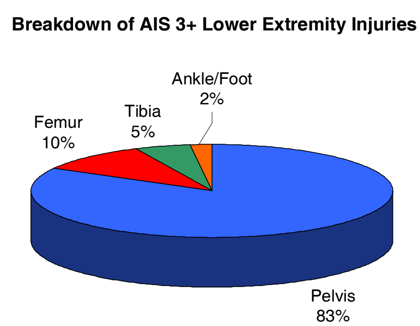

Figure 3. Breakdown of serious lower extremity injuries by organ

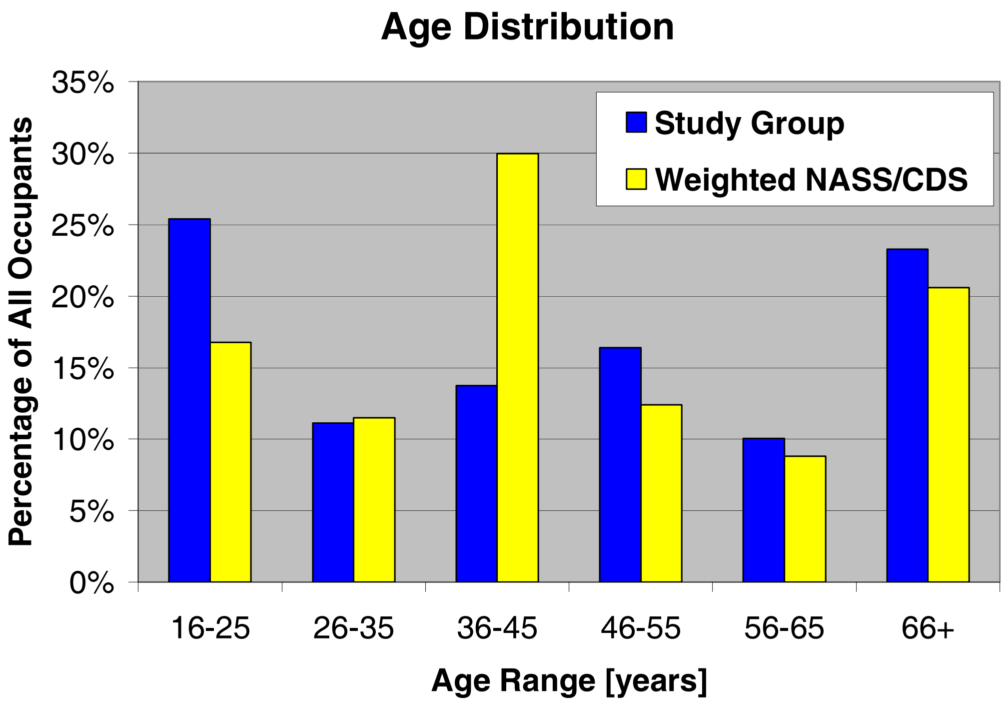

Figure 4. Age distribution of study group vs. weighted NASS/CDS.

Crash Compatibility

The effects of the geometry mismatch between passenger cars and light trucks were examined by looking at the prevalence of serious injuries for different crash configurations. Figure 5 shows the percentage of cases with AIS 3+ head, chest, abdomen and lower extremity injuries for passenger cars (PC) and light trucks (LTV), depending on their striking vehicle. The average ISS was also shown on the graph. The differences in ISS were small overall, although the LTV occupants struck by passenger cars did have the highest average ISS of 23.7. Serious chest injuries were more common among passenger car occupants than LTV occupants, with those struck by LTVs having AIS 3+ chest injuries 71% of the time. The manual case reviews indicated over 25% of the case vehicles exhibited minimal to no rocker panel engagement. In the car struck by LTV group, the rate of minimal to no engagement was 26%.

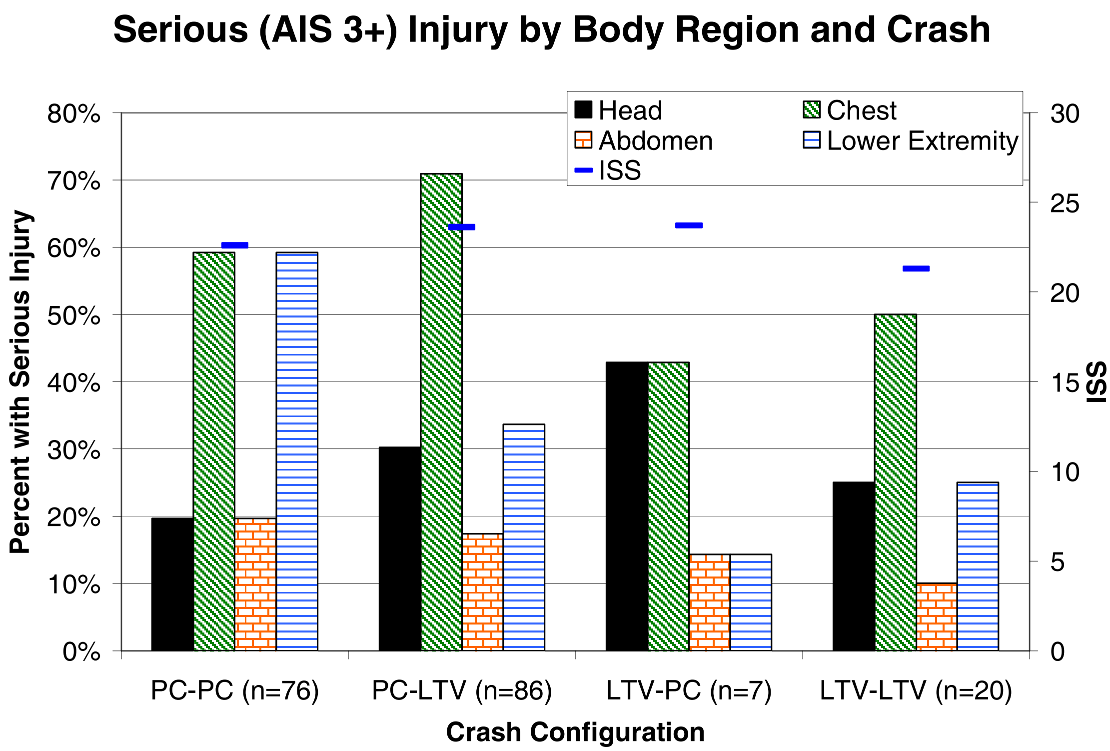

Figure 5. Percentage of occupants sustaining serious (AIS 3+) injuries by crash configuration and body region for current study group. The first vehicle type is the struck vehicle and the second is the striking vehicle. Some less-severely-injured body regions have been omitted for clarity.

Side Air Bags

A small subset of the study group (16%) had a SAB deploy to aid in mitigating the forces of the crash. Comparison of these thirty-one occupants to the remaining study group (without SAB deployment) indicates serious injury can still occur (see Table 5) in body regions with SAB protection.

The head injury group indicated 39% occurrence of AIS3+ injury when a SAB was deployed compared to only 23% when no SAB was present. The chest injury group indicated a slight advantage with SAB protection, with 55% AIS3+ injury compared to 65% when there was no SAB available.

Since the SAB type was captured during the manual case reviews, the injury analysis was revised to take into consideration the exact type of protection provided by each type of SAB in our study group. For example, if the SAB was intended to protect the head based on the position of the bag (head/thorax combo bag, head tube, or side curtain), it was considered to have a head SAB in the secondary analysis. Those cases with only a thorax bag were not considered to offer any head protection. The findings did not show a big improvement for the head injury group with head SAB. Thirty-one percent of the cases with head SAB sustained an AIS3+ injury to the head. An analysis of the chest injury severity for cases with and without thorax SAB protection shows that 52% of the cases with chest protection sustained AIS3+ injury to the chest. These findings are detailed in Table 5.

Table 5.
Crash and Injury Data for Cases With and Without Side Air Bag (SAB) Deployment

	With SAB (n=31)	**Without SAB (n=158)**
Mean Age	52	46
Mean MAIS	3.8	3.6
Mean ISS	22	25
Mean Delta-V	29 kmph (18 mph)	29 kmph (18 mph)
% of occupants with serious (AIS 3+) injury		
Head	39%	23%
Face	3%	1%
Neck	0%	0%
Chest	55%	65%
Abdomen	19%	17%
Spine	13%	4%
Upper Extremity	0%	9%
Lower Extremity	48%	41%
Head SAB[1]	*n=16*	*n=173*
Head	31%	25%
Thorax SAB[2]	*n=29*	*n=160*
Chest	52%	65%

1 – Cases with SAB intended for head protection (combination head/thorax, head tube or head curtain)
2 – Cases with SAB intended for thorax protection (thorax, combination head/thorax)

In an attempt to gain clarity into these perplexing results, the cases were further divided by the impact angle classifications previously described. When each of the two groups are sub-divided by impact angle of the striking vehicle (oblique vs. lateral), a more distinct pattern appears as shown in Table 6. The lateral impacts with SAB deployments appear to be more protective of the head and chest when compared to the oblique impacts. These new groups were again divided by the exact type of protection design available. The group with SAB designed to protect the head (N=10) indicated a 40% occurrence of AIS3+ head injury in oblique crashes while those in lateral crashes (N=6) sustained AIS3+ head injury at a rate of 17%. The chest injury group had less dramatic differences between impact angles with 58% of the oblique group sustaining AIS3+ chest injury compared to 40% in the lateral group. However, the difference may not be as impressive as the basic fact that 58% of the oblique and 40% of the lateral cases sustained an AIS3+ chest injury when an advanced countermeasure was present in a crash of moderate severity.

Table 6.
Crash and Injury Data for Cases With and Without Side Air Bag (SAB) Deployment by Crash Configuration

	With SAB (n=31)		**Without SAB (n=158)**	
Impact Angle[1]	O (n=20)	L (n=11)	O (n=101)	L (n=57)
Mean MAIS	3.9	3.7	3.6	3.6
Mean ISS	25.5	24.4	22.9	21.9
% of occupants with serious (AIS 3+) injury				
Head	45%	27%	26%	19%
Face	5%	0%	1%	0%
Neck	0%	0%	0%	0%
Chest	60%	45%	65%	6%3
Abd.	15%	27%	15%	21%
Spine	15%	9%	5%	4%
Up. Ext.	0%	0	12%	5%
Low. Ext.	40%	64%	36%	51%
Head SAB[2]	*n=10*	*n=6*	*n=111*	*n=62*
Head	40%	17%	28%	21%
Thorax SAB[3]	*n=19*	*n=10*	*n=102*	*n=58*
Chest	58%	40%	66%	64%

1 – O: oblique crashes 30º -80º or 280º -330º, L: lateral crashes 80º-100º or 260º -280º
2 – Cases with SAB intended for head protection (combination head/thorax, head tube or head curtain)
3 – Cases with SAB intended for thorax protection (thorax, combination head/thorax)

Since the chest (ribs) and lower extremity (pelvis) comprised the highest percentage of AIS3+ injured body regions, the data were analyzed for severity by fracture count. When the fracture details for the ribs are broken down by number of fractured ribs, impact angle and the presence of a chest protection SAB, oblique crashes produced an overall higher degree of severity (Table 6). Although the n values were low, there were no rib fracture counts above five for any occupant with a SAB in a lateral crash. Conversely, for the occupants with a SAB designed to protect the chest and an oblique impact angle, 21% (4/19) sustained 6 to 12 rib fractures per occupant. Even in the cases where no SAB was available only 9% of the lateral crashes sustained 6 or more rib fractures per occupant and 20% of the oblique crashes sustained 6 or more rib fractures per occupant. Of the four groups indicated in Table 7, it should also be noted that the highest percentage of occupants with no rib fractures (60%) was the lateral impact group with a deployed SAB. The lateral impact group without an available thorax SAB indicated only 34% of the occupants did not sustain any rib fractures.

Table 7.
Rib Fracture Count for Cases With and Without Thorax Side Air Bag (SAB) Deployment by Crash Configuration

	With Thorax SAB[2] (n=29)		**Without Thorax SAB (n=160)**	
Impact Angle[1]	O (n=19)	L (n=10)	O (n=102)	L (n=58)
Rib fx count	*% of occupants with rib fracture*			
0	42%	60%	44%	34%
1-2	16%	20%	11%	29%
3-5	16%	20%	16%	17%
6-12	21%	0%	15%	7%
13+	0%	0%	5%	2%
Multiple Unknown	5%	0%	10%	10%

1 – O: oblique crashes 30º -80º or 280º -330º, L: lateral crashes 80º-100º or 260º -280º
2 – Cases with SAB intended for thorax protection (thorax, combination head/thorax)

The pelvic fracture detail indicates more fractures in the lateral impact group with a deployed SAB than any other group (Table 8). Only 30% of the lateral impact cases with a thorax SAB did not sustain a pelvic fracture. In contrast, the oblique impact group without a SAB indicated the best pelvic results with 57% sustaining no pelvic fracture.

Intrusion Level with Side Air Bag

Injury severity was evaluated relative to the maximum occupant intrusion level and whether or not a SAB deployed (Figure 6). Although there is a general trend of higher ISS for higher levels of intrusion, low severity scores were present in some of the more severely intruded cases and some cases with little or no intrusion produced relatively high injury severity scores. Cases with SAB deployment did not produce a trend that was noticeably different except at intrusion levels below about 15 cm.

Table 8.
Pelvis Fracture Count for Cases With and Without Thorax Side Air Bag (SAB) Deployment by Crash Configuration

	With Thorax SAB[2] (n=29)		**Without Thorax SAB (n=160)**	
Impact Angle[1]	O (n=19)	L (n=10)	O (n=102)	L (n=58)
Pelvic fx count	*% of occupants with pelvis fracture*			
0	47%	30%	57%	41%
1-2	16%	40%	23%	34%
3+	37%	30%	21%	24%

1 – O: oblique crashes 30º -80º or 280º -330º, L: lateral crashes 80º-100º or 260º -280º
2 – Cases with SAB intended for thorax protection (thorax, combination head/thorax)

Age Factor

The study group matched up well by age with the national data with the exception of the two age groups previously mentioned. The data analysis included the age of the study group in relation to injury severity. Figure 7 is a distribution of body region injury severity by age. Although an increasing level of severity is expected as age increases, several spikes in the plot were interesting. The highest percentage of serious head injuries was in the 16-25 year old group. The highest percentage of lower extremity injuries fell into the 56-65 year old group. Quite surprisingly, the highest percentage of chest injuries was in the 36-45 year old group at a rate of 85%. The same analysis was run on the weighted CDS data of nearside AIS 3+ occupants. The findings are detailed in Figure 8. The study group clearly demonstrates a greater level of severity than the weighted CDS data in almost every body region in every age group. The CDS data indicates the expected general rise in severity, with the majority of body regions, with age. There is a clear spike at age 36-45 for lower extremity injury. There is also a substantial spike at age 66+ for chest injury.

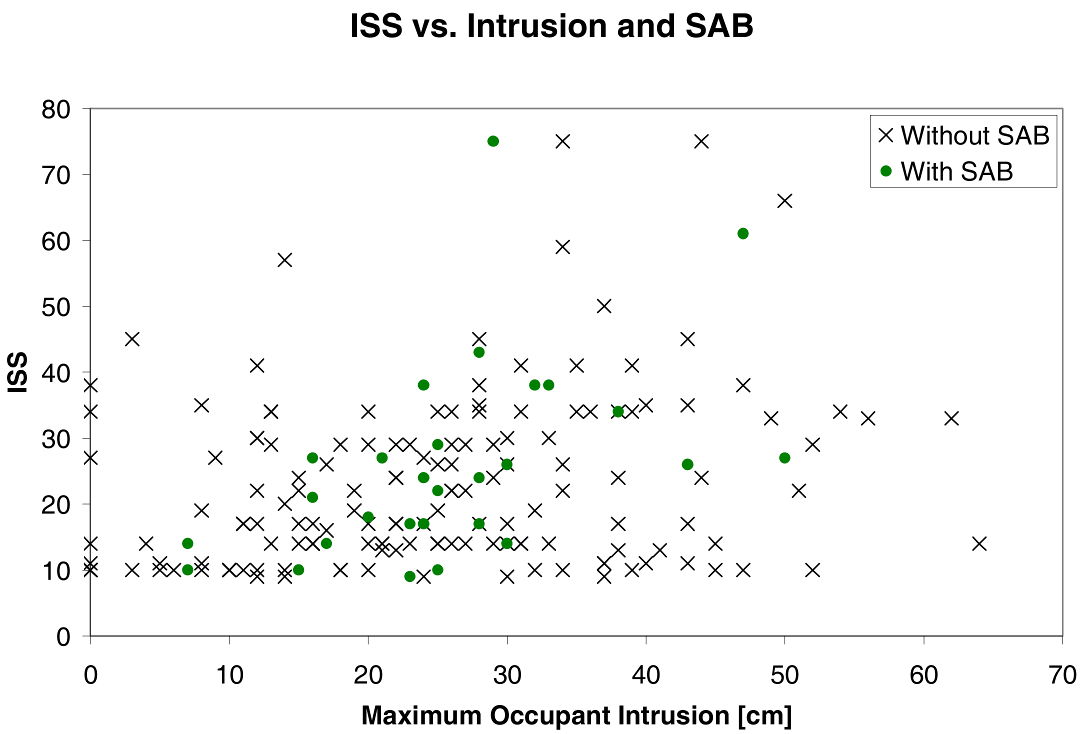

Figure 6. Injury Severity Score for occupants with and without side air bags by maximum intrusion at occupant seating position.

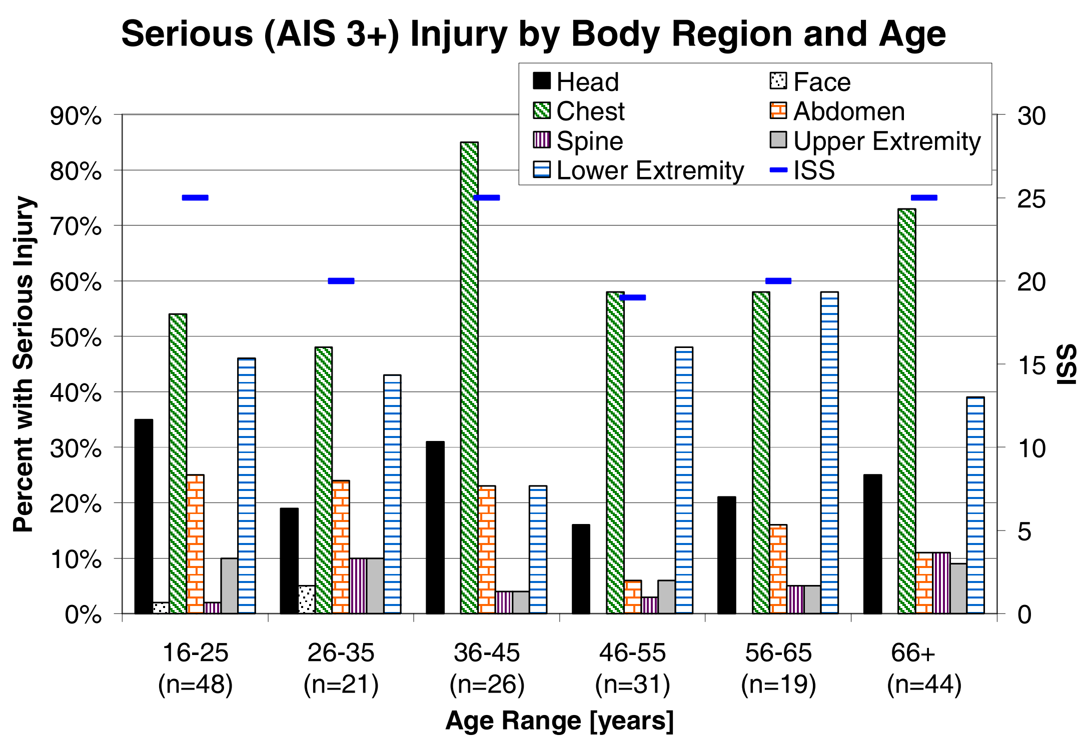

Figure 7. Percentage of occupants sustaining serious (AIS 3+) injuries by age group and body region for current study group. No occupants sustained AIS 3+ neck injuries.

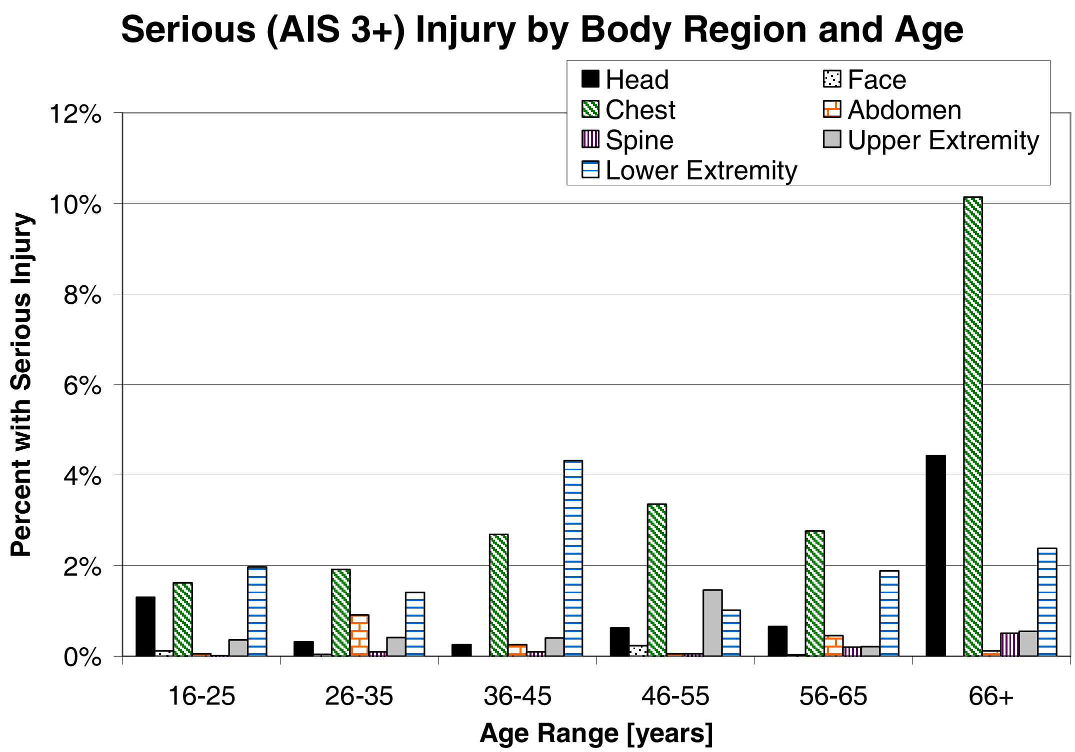

Figure 8. Percentage of occupants sustaining serious (AIS 3+) injuries by age group and body region for weighted NASS/CDS data.

Fatalities

The cause of death was determined for each of the 25 cases in which the occupant did not survive. The fatal cases were reviewed, and the injury region most likely responsible for the fatality was selected based on injury severity coding and rank as well as biomechanical and clinical factors. The ages of the fatally-injured occupants are plotted in Figure 9 and grouped by the body region where the fatal injury occurred. Most of the older occupants died of thoracic injuries, while most of the younger occupants died of head trauma.

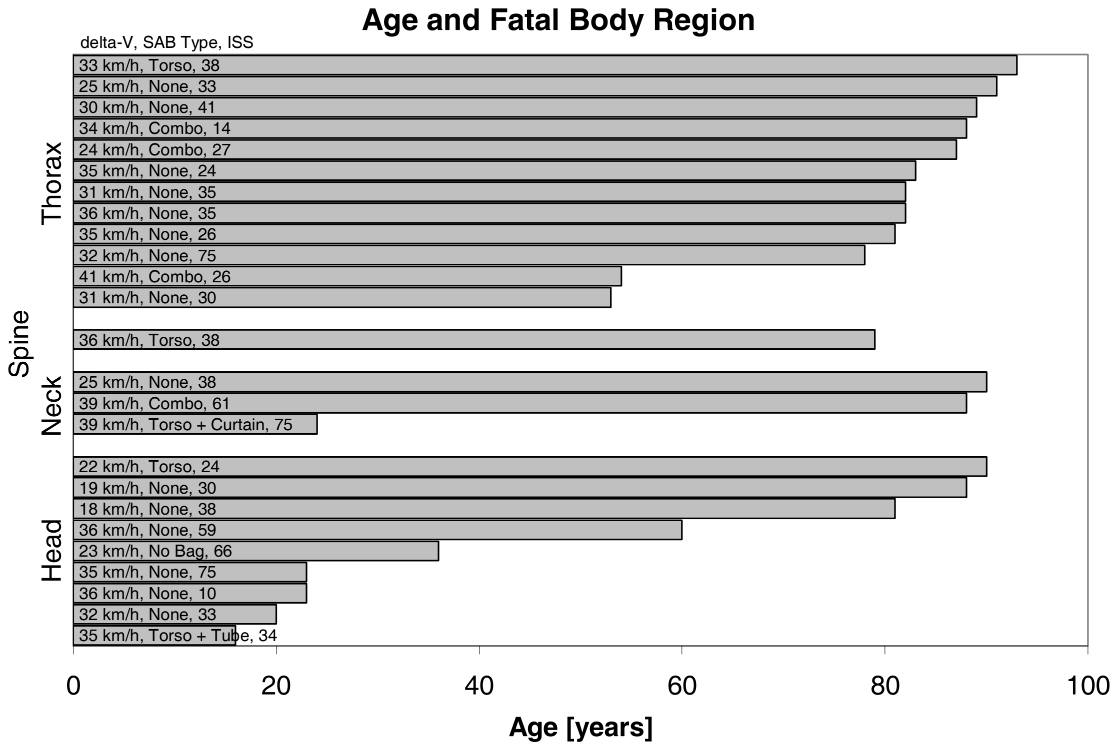

Figure 9. Body region linked to cause of death by age. Crash delta-V, SAB type, and ISS are shown in each bar.

DISCUSSION

The issue of side impact crashes continues to be a complicated problem with a multitude of factors contributing to occupant injury risk. The final study group was comprised of crashes with both pure lateral and oblique impact angles. The delta-V's, as calculated by the WinSmash algorithm place the study group at or below the delta-V's observed in sixty-two percent of nearside crashes in the United States.

Based on prior knowledge, it was expected that the analysis of the study group would yield certain facts about occupant injury and vehicle compatibility. These expected results included elderly drivers sustaining more severe thoracic injuries, an overall increase in injury severity with increased intrusion levels, greater injury for passenger car occupants struck by LTVs, distinct structural deformation differences among passenger cars struck by LTVs, less severe injuries in LTV occupants and an overall protective effect from SAB deployment. In general, these preconceived thoughts were supported by the results, but a number of unexpected results were also discovered throughout the analysis.

Because of changes in bone properties and skeletal structure, the chest tolerance of older persons decreases making them more susceptible to higher severity thoracic injuries [Kent *et al*, 2003]. The age-based incidence of serious chest injuries shown in Figure 7 does indicate an increase in prevalence with increasing age, but the 36-45 year old group stands out as having the greatest percentage of AIS 3+ chest injuries. While the data do support the expectation of increased severity with increased age, the spike shown for the 36-45 year old group was not well understood. Overall, AIS 3+ chest injuries occurred frequently. Serious chest injuries were seen in 63% of the cases, which is similar to findings in other side impact studies [Samaha and Elliot, 2003]. Attempts to break down the detail of the chest injuries proved difficult beyond the organ level. Although the count and general location of the rib fractures were available for most cases, it was evident from the occupant's outcome and minimal hospital stay that the chest injury may not have been quite as life-threatening as the AIS code would suggest. Rib fractures are coded in conjunction with or without the presence of PTX and/or HTX. When a PTX and/or HTX is present, the AIS severity is increased one level. Many of the PTX and HTX are quite small and warrant no intervention with the exception of a follow-up radiological scan to determine if it has become worse. When a PTX and/or HTX are of sufficient size and severity, the medical intervention typically involves insertion of a chest tube to allow for decompression of the thoracic cavity. The lack of this data in the SCI and NASS cases hampered the ability to discern if the chest injuries scaled by AIS were truly as life-threatening as coded. The newest version of AIS [AAAM, 2005] has adopted a new method of separating the PTX/HTX diagnosis from the rib fractures which allows a greater level of sensitivity to the chest injury severity. Future use of the new AIS 2005 in crash investigation data systems would benefit this issue along with other injury research.

The head is typically the second most-seriously injured body region in nearside impacts [Samaha and Elliot, 2003]. The results of this study showed the lower extremity to be the second most-seriously injured region, with 42% of the cases resulting in an AIS 3+ lower extremity injury. More in-depth analysis showed that pelvic fractures were responsible for the high prevalence of lower extremity injuries in the study group.

Larger intrusion levels did tend to produce more serious injury, as evidenced by the upward trend in the ISS data in Figure 6. Although the crashes in this study group were considered of minimal to moderate severity based on delta-V, large amounts of intrusion and crush were seen in most of the vehicles. One finding of note is that the average maximum occupant intrusion of 10 inches is two inches less than the current American College of Surgeons Field Triage guidelines recommendation for immediate transport to a Level-1 trauma center [American College of Surgeons, 1999].

The study group consisted of a large number of passenger cars struck by LTVs, which was useful in attempting to evaluate compatibility issues. Injury results shown in Figure 5 indicate this group had the highest prevalence of serious chest injuries followed by the passenger cars struck by other passenger cars. This finding supports the original belief that passenger car occupants were more susceptible to thoracic injury, but the results for head injuries were not consistent. The group of LTV occupants struck by passenger cars showed the highest percentage of serious head injuries, although this group had a small n value which may have amplified the percentage. The manual case review involved extensive analysis of photographic evidence for the case vehicles in an attempt to determine whether compatibility played a role in the injury causation. These photograph-based estimations were required due to a lack of hard coded measurements determining override/underride in the side plane from the current field investigation techniques. Although all crashes are coded with a CDC that describes the damage in a particular plane, this has limitations for researching override/underride scenarios. It would be advantageous to develop new measurement techniques or hard-coded fields to identify override/underride in side impacts.

Side impact air bags were only available in 16% of the case vehicles, but the comparison of cases with SAB deployment to those without produced some interesting results. Overall, considering all crash types together and all SAB types together, there did not appear to be a large benefit from SAB deployment for the cases under study. However, it should be noted that the small number of SAB cases made the percentages of serious injury much more sensitive than in the larger non-SAB group. The mean MAIS was slightly higher in the group with SAB deployment, and the head and lower extremities sustained a greater percentage of serious injuries in the SAB-protected group. The fact that head injuries were more prevalent in the group with SAB is counterintuitive. One possible explanation might be multi-trauma injury patterns where one body region may benefit from SAB availability, yet others are not protected. Yoganandan *et al* [2007] observed that chest injuries do not occur in isolation and are associated with a head injury in >90% of subjects with AIS ≥ 2 injuries in more than one body region. Once the SAB group is farther sub-divided by defined head and/or chest protection, head injury declines from sixteen percent to six percent. Decreased prevalence of serious thoracic and abdominal injuries was observed in those cases with SAB deployment. After breaking the cases down by crash direction (lateral vs. oblique) and SAB type, the benefits and limitations of the SAB became more evident. The lateral impacts with SAB resulted in better head and chest injury outcome compared to the oblique impacts, possibly indicating the occupant is missing the bag or not getting full benefit because of the longitudinal motion when the impacting vehicle is approaching at angles greater than +/- 10 degrees from pure lateral. The portion of the study group with head-protective SAB had approximately two-thirds seat-mounted torso-head combo SAB that may not give the same amount of protection coverage as a curtain type SAB. Increased SAB size or improved position of the occupant by manual restraints may increase the effectiveness of SAB. With increasing amounts of vehicles entering the fleet with SAB installed, future research on this issue will benefit through increased exposure and the resulting improved data capture.

The study population was assembled from every crash investigation data system available at NHTSA (NASS, CIREN and SCI). The breakdown of the study group compared to the weighted NASS/CDS data indicates a substantial bias towards serious injury for the study group. This discrepancy does not have a simple explanation. Attempts to compare the raw NASS/CDS data indicated a discrepancy in injury severity as well, just not as large. The most logical explanation for such a discrepancy is the study group is extremely biased toward serious multi-trauma, whereas the weighted data may be more representative of single system serious injury. Although the distribution of injury was quite different between the study group and the weighted data, chest and lower extremity injury ranked 1 and 2 respectively in both groups.

CONCLUSION

The side impact crash is a particularly harmful crash mode with many complicated factors creating a risky environment for the nearside occupant. Even at relatively low delta-V's, serious injuries and fatalities continue to occur in modern cars with side impact countermeasures. The chest, pelvis and head are the primary body regions sustaining such life-threatening injuries, and the chest, in particular, accounts for many of the injuries across a broad age-range. The current countermeasure of choice for this crash mode is a side impact air bag, which currently exists in several different forms. The limited SAB cases included in this study indicated improved protection improvements were evident in the lateral crashes. The findings suggest the need to further investigate the role the SAB plays in side impacts with longitudinal acceleration components that potentially force the occupant away from the SAB coverage area.

A small case study such as this one permits in-depth case review to determine SAB characteristics and compatibility factors, which are not hard-coded fields in the current data systems. The manual review undertaken in this study allowed for a more complete evaluation of the exact type of countermeasures available to each occupant and how the crash and vehicle dynamics contributed to the occupant's injury severity.

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