INJURY PATTERNS AMONG AIR BAG EQUIPPED VEHICLES

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ABSTRACT

The University of Miami's William Lehman Injury Research Center at Jackson Memorial Medical Center conducts interdisciplinary investigations to study seriously injured restrained occupants in frontal automobile collisions. Engineering analysis of these crashes is conducted in conjunction with the National Crash Analysis Center at the George Washington University. The multidisciplinary research team includes expertise in crash investigation, crash reconstruction, computer graphics, biomechanics of injuries, crash data analysis, emergency trauma care, and all of the medical specialties associated with the Ryder Trauma Center at Jackson Memorial Hospital. The Lehman Center is a founding member of the newly created Crash Injury Research and Engineering Network referred to as "CIREN". More than 200 injured occupants and their crashes have been studied in depth.

By careful study of injured crash victims, their vehicles and the crash scene, injury patterns emerge. These patterns form the basis for hypotheses, which can be explored further by analysis of mass crash data, crash tests, and computer modeling. As a consequence, recommendations can be developed for injury control measures.

In the census of cases involving drivers protected by air bags in frontal impacts at the Lehman Center, heart injuries were present in about 9% of the cases, and liver injuries occurred in 19% of the cases. The chest/abdominal region accounted for 44% of the injury weighted harm. The chest comprised 68% and the abdomen 32% of this harm fraction. In examining the harm to the chest, the ribs and heart contributed about 43%. In examining the abdomen, the liver contributed 53% and the spleen 26%.

Liver injuries were most common in cars with right front damage, and with the driver wearing the shoulder belt without the lap belt fastened. Among drivers with lap and shoulder belts, the most common crash mode was the left frontal offset. In crashes with severity around 30 mph, the centerline impact with a rigid narrow object produced liver injury.

In examining heart injuries, all available cases from the Special Crash Investigations file maintained by NHTSA were included. For heart injuries in low to moderate severity crashes, impacts with rigid narrow objects was the most common crash mode. Impacts with soft structures such as the rear and side of other cars were also heart injury producing crash modes.

For both liver and heart injuries, conditions which cause the occupant to be positioned close to the air bag was a recurring theme in low to moderate severity crashes.

Liver and heart injuries are frequently difficult to detect at the crash scene. If not promptly diagnosed and treated, the consequences are often fatal. A major objective of this study is to identify crash conditions beyond crash severity, which can assist in detecting the presence of these occult injuries.

INTRODUCTION

The William Lehman Injury Research Center at the University of Miami has investigated 88 frontal crashes in which the driver air bag deployed and the driver was transported to the Ryder Trauma Center for emergency medical care. Data has been collected from the crash scene, the damaged vehicle, and the injured occupant.

The criteria for admission to the study is as follows: (1) the subject must have been involved in a frontal collision; (2) the subject must have been protected by a safety belt, an air bag, or both; (3) at the crash scene, the subject must have met triage criteria for suspicion of injuries of a severity which justified transporting to the Ryder Trauma Center; and (4) the subject must have agreed to have their records included in the study. The study included 100% of the subjects transported to the Ryder Trauma Center, which met the criteria. Less than 10% of the subjects refused to participate in the study. The decision to transport a patient to the

Ryder Trauma Center is based on the criteria listed in Table 1. If the subject meets one or more of these criteria, transport to the Ryder Trauma Center is mandated.

Table 1.
Adult Trauma Criteria

Systolic BP≤ 90 (Shock
Respiratory rate < 10 per min. or > 29 per min.
Glasgow Coma Scale ≤ 12
Penetrating injury to head, neck, chest, abdomen or groin
Paralysis
2nd or 3rd degree burns ≥ 15% TBSA
Amputation proximal to wrist or ankle
Ejection from motor vehicle
Paramedic Judgment - High Index of Suspicion of Injury

The data collected in the study provides a basis for in-depth analysis of injuries and the crashes in which they occurred. Engineering analysis of these crashes is conducted in conjunction with the National Crash Analysis Center at the George Washington University. The multidisciplinary research team includes expertise in crash investigation, crash reconstruction, computer graphics, biomechanics of injuries, crash data analysis, emergency trauma care, and all of the medical specialties associated with the Ryder Trauma Center at the Jackson Memorial Hospital. By careful study of injured crash victims, their vehicle and the crash scene, injury patterns emerge. These patterns form the basis for hypotheses which can be explored further by analysis of mass crash data, crash tests, and computer modeling. As a consequence, recommendations can be developed for injury control measures. One purpose of this study is to identify injury patterns among severely injured subjects.

INJURY PATTERNS FROM NASS/CDS DATA

The NASS/CDS is intended to provide a representative sample of crashes in the United States in which one of the vehicles was damaged sufficiently to be towed away from the crash scene. *Figure 1* shows the distribution of frontal crashes, injuries and fatalities based on NASS/CDS data, years 1988-1996.

Analysis of NASS data by NHTSA suggests several areas in which air bag performance may be lower than expected. NHTSA's *Third Report to Congress: Effectiveness of Occupant Protection Systems and Their Use,* provides data on air bag effectiveness in injury reduction for different populations and body regions. Table 2 shows the likelihood of reducing moderate (AIS 2+) injuries for selected populations. The bold print indicates statistically significant differences from the risk of unrestrained occupants. Those figures not in bold print are not statistically significant. All of the effectiveness numbers are relative to the unrestrained population. The inherent effectiveness of the belt system in included as part of the AB+Belt numbers. Consequently, the AB+Belt effectiveness is expected to be higher than the 3pt Belt effectiveness.

Air-bags-plus-belts are shown to be very effective in reducing moderate injuries to belted males. However, the benefits to restrained females and older drivers is less evident.

Tables 3 shows data for injury effectiveness in reducing serious (AIS 3+) injuries, by body region.

Table 2.
The Likelihood Of Reducing Moderate Injuries For Selected Populations

System Used	Male Drivers	Female Drivers	Drivers 50+	Drivers <65"	Drivers <135lbs
AB + Belt	**64%**	**59%**	**57%**	**48%**	**55%**
AB Only	12%	25%	9%	31%	-36%
3pt Belt	**38%**	**59%**	**54%**	**55%**	**42%**

Table 3.
Effectiveness of Occupant Protection Systems In Reducing the Likelihood of Serious Injury By Body Region

System Used	Head	Chest	Upper Extrem	Lower Extrem.
AB + Belt	**75%**	**66%**	-40%	**78%**
AB Only	16%	18%	14%	-5%
3pt Belt	**38%**	**54%**	28%	**79%**

The data from Table 3 shows the excellent head injury protection provided by the air-bag-plus-belt. Serious chest injuries are also reduced, but to a lesser extent. The NASS/CDS data for the air bag only restraint is not statistically significant. However, reductions in serious head and chest injuries are indicated. With regard to lower extremities, the air bag plus belt has about the same effectiveness as the 3pt belt. Similarly, the air bag only has no statistical effect in reducing lower extremity injuries.

Further analysis of NASS has been conducted to better understand air bag performance. This analysis examined the risk of AIS 3+ injury per 100 exposed drivers in frontal crashes. The injury risks for each body region are shown in Figure 2. The population not protected by air bags includes drivers in air bag vehicles who were in crashes below the threshold for air bag deployment. The presence of these non-deployment cases reduces the average crash severity for the belt only and the unrestrained populations relative to the air bag populations.

Other studies have indicated that the unrestrained population is involved in crashes that are more severe than the restrained population [Malliaris, 96]. This observation holds for the unrestrained population protected by air bags. Because of the differences in crash severity, the data in Table 2 can not be used to assess the effectiveness of belts or air bags. However, it is useful in examining the shifts in the injury distribution which can be expected in tow-away crashes when air bag deployment occurs.

Figure 2 shows a large reduction in head injuries for air bag protected drivers. Reductions in trunk injuries are less pronounced. The increased risk of lower limb injuries with air bag deployment is postulated to be indicative of the higher average crash severity for the air bag cases.

To further examine performance of air bags in NASS\CDS, a more detailed examination of injuries was undertaken. The concept of average injury weighted harm per occupant was used for this analysis. Injury weighted harm is based on all injuries in the NASS 1988-95 file, each weighted according to its average cost. Table 4 shows the AIS injury weighting factors used in the analysis. These weighting factors are the average monetary cost incurred by injured persons at each AIS level and normalized for the cost of a fatality.

To calculate injury weighted harm, each injury in the population is multiplied by its weighting factor and by its NASS expansion factor and the quantities are summed. Risk per hundred exposed occupants is determined by dividing the injury-weighted harm by the NASS weighted number of crash exposed occupants with similar restraint systems. No correction for crash severity has been included in this data. The values of injury weighted harm per occupant provide the relative magnitude of the risks for specific types of injuries. The risks of injury for individual body regions contain considerable uncertainties, but are useful in examining large differences in risk.

Table 4.
Injury Weighting Factors
For Harm Calculations

AIS Injury	AIS #	Weighting Factor
Minor	1	0.004
Moderate	2	0.034
Serious	3	0.114
Severe	4	0.218
Critical	5	0.839
Fatal	6	1.000

Table 5 shows the injury-weighted harm per crash exposed occupant for critical organs in the chest/abdomen. The critical chest/abdominal organs are the heart and liver. Injuries to these organs are time critical. If not treated immediately, serious consequences or death can result.

Table 5 indicates that the belted and belted plus air bag populations have the lowest harm risks for these critical thorax body regions. The air bag only data is not statistically significant. For the unrestrained population, the present day air bag does not appear to mitigate injuries to these critical regions of the body. The heart and liver injuries are among the most difficult to detect. By mitigating the more obvious head injuries, the residual air bag injuries become more difficult to detect.

Table 5.
The Injury Weighted Harm/
Occupant for Heart, and Liver

System Used	Harm Risk
AB + Belt	0.017
AB Only	0.227
3pt Belt	0.025
Unrestrained	0.096

LEHMAN CENTER DATA

The distribution of Lehman Center cases by restraint use, fatalities, and average delta-V is shown in *Table 6.*

Table 6 Lehman Center – Driver Cases 1991-97

	#	Avg dV	Fatal	Avg dV	%Fatal
AB+LS	39	22.4	9	26.6	23.1
AB+Sh.	5	26.4	2	36.0	40.0
AB Only	44	25.6	12	22.8	27.3
All	88	24.8	23	28.5	26.1

Figure 3 provides a comparison of the injury severity of subjects in the Lehman Center as compared with NASS population expanded to represent the national distribution. The Lehman Center population provides a sample of the serious and fatally injured crash victims in the Miami region. It is an extremely enriched sample of AIS 3+ injuries. As such, it provides a basis for examining injury patterns in detail and developing insights which can be further examined using other population based data systems and resources.

Figure 4 shows the distribution of AIS 3+ injuries for the 88 air bag cases in the Lehman Center compared to NASS/CDS 1988-1996. A comparison of the frequency of fatal injuries in the NASS projected population and the Lehman population is shown in *Figure 5.* It is evident that the distributions of AIS 3+ injuries are generally similar, but The Lehman Center has more injuries in the lower crash severity ranges. The Lehman Center data also has more fatalities in the lower crash severity ranges and in the 40 to 45 mph speed ranges.

The distribution of harm by body region is shown in *Figure 6.* The trunk is the largest source of harm and will be examined in more detail. Within the trunk harm fraction, 32% of the harm is to the abdomen, and 68% to the chest.

Figure 7 shows the distribution of harm

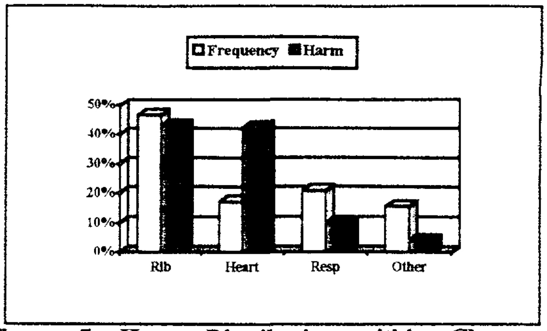

Figure 7. Harm Distribution within Chest Region

within the chest region. Heart and ribs are the largest chest sources of chest harm. *Figure 8* shows the distribution of harm within the abdominal region. Liver and spleen are the largest harm fractions.

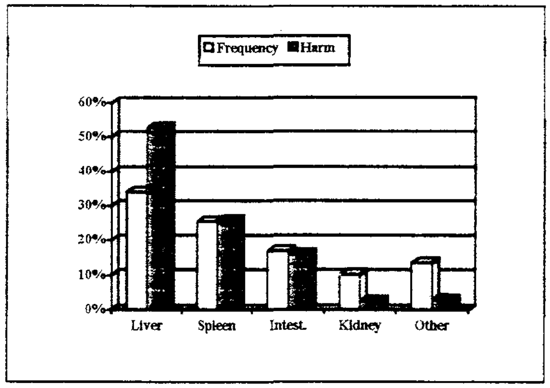

Figure 8. Harm Distribution within Abdominal Region

PATTERNS OF LIVER INJURIES

The Lehman Center data contains 17 drivers with air bag deployment in frontal crashes

Figure 7. Distribution of Harm and Liver Injury

and liver injuries. Seven of these cases were fatalities. Nine drivers were restrained by lap and shoulder belts plus air bag, five were restrained by shoulder belt plus air bag, and three had only the air bag. Characteristics of the crashes with liver injuries are summarized in Tables 7, 8 and 9. The delta-V (dV) listed in these tables is crash severity in mph. The principal direction of force (PDOF) is the clock direction.

Table 7.
Liver Injury Cases - Lap + Shoulder Belt Restrained Drivers

Case #.	dV	Age	Sex	Fatal	PDOF	Type	Remarks
96-013	19	54	F	No	11	Left Offset	12"L.I.P. Int. (Truck)
94-010	20	19	M	Yes	11	Left Offset	27" Header Intr. (PU)
97-021	21	32	F	No	11	Left Offset	High G Crash (Truck)
92-023	22	50	M	No	12	Left Offset	CCW Spin Post crash
95-016	29	39	M	No	12	Ctr Narrow	High G Crash (Close in)
97-014	30	20	M	No	12	Ctr Narrow	High G Crash
95-001	33	37	M	No	11	Left Offset	12" L.I.P. Intrusion
96-001	38	66	F	Yes	12	Left Offset	22" L.I.P. Intrusion
96-002	38	72	F	Yes	12	Left Offset	Severe Crash

The cases of lap & shoulder belt protected drivers with liver injuries fall into three crash severity categories. There are four cases with crash severity below 23 mph, two cases with crash severity around 30 mph, and three cases with delta-V above 32 mph.

The two 38-mph cases both involved severe intrusion of the driver side instrument panel and deformation of the steering column. Fatalities from multiple injuries resulted in both cases. Older occupants were involved in both of these cases. A third case, at 33 mph exhibited the same crash pattern and compartment intrusion as the two 38-mph crashes, but the younger occupant survived at this lower crash severity.

Both of the subjects in 29 and 30 crashes survived. Both were in frontal impacts with narrow objects - a condition which produces a severe acceleration late in the crash pulse. The air bag deployment may be delayed in such a crash. This type of crash also produces high loading by the safety belt.

Case 96-013 was an override by a heavy truck. The delta-V was 19 mph, but 12 inches of A-pillar intrusion resulted. In addition to a liver laceration, the driver suffered head and lower extremity injuries.

Case 94-010, was an override of a small car by a pickup truck. The windshield header was displaced 27 inches into the occupant compartment. The belted driver died from multiple head and chest injuries caused by the intruding pick-up truck. This case illustrates how delta-V may not adequately predict the severity of the crash environment experienced by the occupant in certain types of real world crashes. This case also produced a heart injury that is included in the section to follow.

Case 97-021 was a 21-mph left offset collision of a minivan with a heavy truck. Approximately 5 inches of dashboard intrusion resulted. An AIS 4 liver injury resulted.

One case, 92-023, involved an impact with the rear of a stationary car. The left rear of the stationary car was on a jack for a tire change. A delayed air bag deployment may have resulted from a soft crash pulse followed by a CCW spin.

Table 8.
Liver Injury Cases - Unrestrained Drivers

Case #.	dV	Age	Sex	Fatal	PDOF	Type	Remarks
92-006	20	34	M	No	12	Right Offset	Mild Crash Pulse
93-026	23	67	M	Yes	1	Full Frontal	Close-in
96-017	45	40	F	Yes	12	Left Offset	Severe Crash

Table 8 shows the crashes of unrestrained drivers with air bag deployment. Of the three unrestrained cases, one was extremely severe, and the other two drivers were believed to be close to the air bag at the time of deployment.

The crash in Case 96-017 was severe and loss of occupant compartment integrity resulted

The vehicle in case 92-006 impacted a residence wall and the left front of the car entered through a sliding glass door. The air bag deployment was probably delayed by the mild crash pulse. Consequently, it is likely that the unrestrained driver was close to the deploying air bag. The liver injury was not discovered at the scene and no medical treatment was provided until the subject passed out at a police station.

The driver in case 93-026 was observed to be close to the steering wheel before the impact. This driver also sustained a fatal heart injury.

Table 9.
Liver Injury Cases - Shoulder Belt Only Drivers

Case #.	dV	Age	Sex	Fatal	PDOF	Type	Liver Injury
97-049	12	32	M	No	1	*RF	R. Lobe
94-005	16	39	F	No	12	RF	R. Lobe
93-020	32	53	F	No	1	RF	R. Lobe
97-023	34	70	M	Yes	12	Full Frontal	R. Lobe
96-045	38	23	F	Yes	1	RF	R. Lobe

*RF= Right Front

Table 9 lists five drivers with shoulder belt only, and air bag deployment. These cases form a distinct pattern of liver injury. In all cases, the injury occurred to the right rear lobe of the liver. This injury pattern was similar to that reported earlier (Augenstein, 1995). The injury is attributed to loading by the shoulder belt. In lower severity crashes the damage was to the right front of the car. As the crash severity increases to 25 mph other damage patterns are observed.

HEART INJURY CASES

The Lehman Center data contains eight cases with heart injury. Seven of the cases were fatalities. Four of the occupants were restrained by lap and shoulder belts and four were unrestrained.

Characteristics of the cases in which the drivers were restrained by lap and shoulder belts are shown in Table 8.

Table 10.
Heart Injury Cases - Restrained Drivers

Case #	dV	Age	Sex	Fatal	PDOF	Type	Remarks
97-013	17	78	M	Yes	2	R. Corner	Right Sideslap (SUV)
94-010	20	19	M	Yes	11	L Offset	27" Header Intrusion (PU)
92-017	37	63	M	No	11	Offset	Occult Injury
96-001	38	66	F	Yes	12	Offset	22" Dash Int.

Two of the fatalities in the restrained cases involved massive intrusion of the occupant compartment or complex multiple impacts. The air bag did not contribute to increasing or reducing the chest injuries in these cases. Case 97-13 was an impact between the right front of a small car and the front of a sport utility vehicle. Counter-clockwise rotation followed by a side slap resulted. The side loading by the belt may have induced the liver injury.

The survivor, Case 92-017 was in a very severe crash. He had no head injuries. His only apparent chest injuries were fractures of the right anterior ribs 2, 3, & 4. There was no initial vital signs to indicate that a heart injury had occurred. His heart injury was not recognized until deterioration in his condition occurred. This case illustrates one of the characteristics of air bag protected occupants. In the absence of major head injuries and rib fractures, the presence of internal injuries may be difficult to detect at the scene.

Characteristics of the cases in which the drivers were unrestrained are shown in Table 11.

Table 11.
Heart Injury Cases - Unrestrained Drivers

Case #.	dV	Age	Sex	Fatal	PDOF	Type	Remarks
93-026	23	67	M	Yes	1	Full Frontal	Close-in
97-036	26	63	M	Yes	12	Complex	Missed Air Bag
94-007	37	20	M	Yes	1	Multiple Crash	Missed Air Bag
97-043	46	29	M	Yes	11	Full Frontal	High G Pulse (Van)

Two of these cases, 97-036, and 94-007 involved crash forces which caused the unrestrained occupant to miss the air bag and impact the interior surfaces on the vehicle. Case 97-043 was a severe crash which caused loss of integrity of the occupant compartment.

Case 93-026 was a 23-mph frontal crash in which the occupant was close to the steering wheel. The air bag probably contributed to the heart injury.

A study of heart injuries in the NHTSA Special Crash Investigations file was undertaken to supplement the Lehman data.

AIR BAG CASES WITH HEART INJURY - NHTSA SPECIAL INVESTIGATIONS

The NHTSA Special Crash Investigations file contains records of 1258 drivers who were in vehicles with air bag deployment. The criteria for inclusion in this file is varied. Consequently, it is not possible to extrapolate results determine frequency of occurrence. However, the file is useful for examining injury patterns, which can be compared with nationally representative files.

Table 12.
Summary of Heart Injury Cases from Special Studies

Case No	Yr	Make	Model	DV	AIS	objstruck	AGE	Contact	FATAL	Belt?
CA8933	89	Mercedes-Benz	300/500	-1	4	TREE	44	IP	Y	Y
CA9109	91	Ford	Taurus	7.7	5	83 BUICK RIVIERA	79	AB ???	Y	Y
NC9307	91	Cheverolet	Corsica	8	5	TREE	78	AB	Y	N
CA9303	91	Mercury	Capri	9	5	89 CHRYSLER	22	AB	N	N
DS9422	94	Cheverolet	Corsica	11	6	90 ECLIPSE SIDE	73	AB	Y	Y
IN9506	90	Lincoln	Continental	12	5	VAN	38	AB	Y	N
CA9112	90	Dodge	Shadow	14.4	3	UTILITY POLE	36	SEAT	Y	Y
CA9309	90	Ford	Taurus	16	5	CAR	71	AB	Y	N
DS8912	85	Ford	Tempo	17.6	4	CAR REAR	53	AB	Y	N
CA9110	91	Pontiac	Firebird	18.9	4	TREE	46	AB??	Y	Y
CA9502	94	Ford	F-150	19	4	CAR REAR	56	AB	Y	N
IN9407	92	Oldsmobile	Delta 88	22	5	TREE	68	AB/SW	Y	Y
DC9012	90	Ford	Taurus	25.3	3	VEHICLE TWO	21	SW	N	Y
IN9201	91	Cheverolet	Impala	32.4	5	CAR	48	SW	Y	N
DC9108	90	Dodge	Charger	33.5	5	VEHICLE 2 ESCORT	49	SW	Y	N
CA8951	89	Dodge		60.2	4	SUPPORT PILLAR	24	UNK	N	N
SW8922	87	Mercedes-Benz	200/300	HI	5	UTILITY POLE	42	L SIDE	Y	N

The file contains 56 cases with fatal injuries. Fifteen of these (27%) had severe heart injuries. Among the fatals with severe heart injury, 67% were at crash speeds of less than 20 mph. Six were at crash severities of less than 15 mph. In addition to the fatal injuries, there were 3 drivers with AIS 3+ heart injuries who survived. One of these was at a crash speed below 10 mph.

A summary of the drivers with heart injury documented in the NHTSA Special Study is shown in Table 11.

The data from Table 11 indicates 12 cases of heart injury at crash speeds below 22 mph. Five of these were impacts with poles. Two were impacts with the rear of another car. These types of crashes produce relatively low acceleration crash pulses, which may delay the deployment of air bags. It is possible that the occupant may have been close to the deploying air bag in these cases.

In the data from Special Studies of Air Bag Crashes, heart injuries represent about 1% of the injuries but 26% of the fatalities. The majority of these fatalities occurred at crash speeds below 22 mph. Crashes involving poles and car front to car rear are over represented in these low speed crashes. Older persons are also over represented. Combinations of these factors may be useful in suspecting the presence of rare, but serious heart injuries.

DISCUSSION OF LIVER INJURY CASES

Of the nine cases of lap and shoulder belt restrained occupants, 6 were at crash severities less than 31 mph. Five of these were impacts with trucks or trees - events which produce high g crash pulses and/or steering column and instrument panel intrusion. Two patterns appear to emerge from these data - left offset crashes with trucks and pickups (below 25 mph), and frontal crashes with rigid narrow objects (at around 30 mph).

Of the two cases of unrestrained occupants at crash severities less than 24 mph, close proximity to the air bag at deployment appears to be a common pattern. In one case, a late deployment was probable. In the other case, the driver was positioned close to the wheel prior to the crash.

Of the five cases of shoulder belt restrained occupants, the crash and injury patterns were similar - right front vehicle damage, and right side liver damage. This pattern of crash and injury has been observed earlier, and has been attributed to shoulder belt loading.

Of 17 cases involving liver injury, the air bag may have contributed to the injury in two cases involving unrestrained occupants in crashes below 23 mph. The shoulder belt only may have contributed to two liver injuries at crash severities below 17 mph and three above 30 mph.

Most of the liver injuries (59%) occurred at crash severities of 30 mph or less. However, in several cases the delta-V was not a suitable measure of the violence of the crash.

DISCUSSION OF HEART INJURY CASES

There are eight heart injury cases in the Lehman Center data. Seven of them were fatal. It is expected that heart injury occur primarily in very severe crashes. Six of the eight crashes were very severe - either with crash severity greater than 37 mph, or with extensive intrusion or complex non-frontal motion. In two of the severe cases, the unrestrained occupant missed the air bag and impacted hard interior structures.

The air bag probably caused the injury in one of the eight cases. In this case, the older driver was close to the bag at deployment, and was fatally injured.

In the special studies data, 80% of the heart injuries occurred at crash severities less than 22 mph. Of 12 cases, 5 were impacts with poles or trees, and 2 were with the rear of another car. Late deployment of the air bag is most likely in low severity crashes with narrow objects, relatively soft objects, or objects moving in the same direction.

CONCLUSIONS

Vehicles equipped with air bags provide large reductions in head injuries. They also provide injury reduction for chest and abdominal injuries, but to a lesser extent.

For unrestrained drivers, the residual severe chest/abdominal injuries are more likely to be to the heart and liver than if the driver is belted. The presence of a deployed air bag appears to reduce critical head injuries for the unrestrained driver. However, critical injuries to the heart and liver may not be reduced significantly. The presence of these injuries are frequently difficult to detect at the scene.

In the census of cases involving drivers protected by air bags in frontal impacts at the Lehman Center, 44% of the injury weighted harm was from chest/abdominal injuries. The chest comprised 68% and the abdomen 32% of this harm fraction. In examining the harm to the chest, the ribs and heart each made up about 43% of the harm. In examining the abdomen, the liver contributed 53% and the spleen 26%.

Heart injuries occurred in 9% of the cases, and liver injuries occurred in 19% of the cases. These two injury modes, along with rib fractures, were the most harmful chest/abdominal injuries.

The most distinct injury pattern observed was injury to the right lobe of the liver induced in drivers wearing their shoulder belt only - without the lap belt fastened. In all of the shoulder belt only cases with air bags, the predominate damage was to the right front of the car. Liver injuries in these types of crashes have been shown to be induced by shoulder belt loading [Augenstein 1995]. The air bag did not prevent these belt induced injuries.

For belted drivers protected by air bags, frontal centerline impacts with rigid narrow objects at crash speeds close to 30 mph produced liver injuries. These types of crashes produce higher than normal acceleration forces at the 30 mph severity level. As a result, higher belt loading and possible delayed air bag deployment may result.

The left-offset frontal crash with heavier vehicles was the most frequent crash type in crashes less severe than 21 mph. Extensive intrusion of the steering wheel and left instrument panel occurred in these cases. The normal delta-V may not be an adequate indicator of crash severity in these crash modes. Additional indicators of the crash severity are needed to predict these higher risk cases.

For unbelted drivers, pre-crash conditions that produced close proximity with the deploying air bag were the common thread in the low severity crashes with liver injuries. Identification of conditions which position the driver close to the air bag.

Seventy-five percent of heart injuries in the Lehman Center data were in severe crashes. However, the air bag was implicated for one unrestrained driver who was close to the air bag in a moderate severity crash. In order to gain a larger sample of heart injuries, cases from the NHTSA Special Crash Investigations file were included. The low severity events that produced heart injuries were impacts with fixed narrow objects, and with the rear of other vehicles. Both of these types of crashes can result in delayed air bag deployments. Older drivers were over represented among the cases with heart injuries. Driver age and position relative to the air bag appear to be critical factors, independent of delta-V.

The combination of data from the William Lehman Injury Research Center with data from NASS/CDS and SCI files provides valuable insights into injury patterns among air bag protected occupants and crash characteristics that produce the injuries.

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