TORSO INJURY TRENDS FOR PEDESTRIANS STRUCK BY CARS AND LTVs

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ABSTRACT

As light trucks become more prevalent in the vehicle fleet, it becomes important to consider the implication of vehicle geometry variations on pedestrian injury patters. Historically, studies have shown that the body region priorities should be the head and lower extremity for pedestrians struck by motor vehicles. More recent studies have found that the injury pattern for pedestrians struck by Light Trucks, Vans, and Sport Utility Vehicles (LTVs) is different from that of those struck by passenger cars. Data from the Pedestrian Crash Data Study (PCDS) during the period 1994 to 1998 has shown that the torso should be a significant focus area, preceded only by the head, for pedestrian struck by LTVs. In this study we analyzed the type and severity of AIS 2+ torso injuries recorded in PCDS for adults age 18 to 50. Regardless of impacting vehicle type, the most frequently injured torso structures at the AIS 2+ level are the ribcage, liver, and lung. Considering instead the AIS 4+ level, the most commonly injured torso structures are the aorta, ribcage, and spleen in pedestrians struck by LTVs and the lung, ribcage, and liver in those struck by passenger cars. The results of this study suggest that while the overall torso injury trends may be similar for passenger cars and LTVs, somewhat different injury patterns are occurring at higher severity and may be a result of differences in vehicle geometry and injury mechanisms.

INTRODUCTION

Since the 1970's, pedestrian impact protection has been a significant focus area for automotive safety researchers. Accident data shows that pedestrian impact consistently accounts for more than 10% of the annual fatalities on roadways in the United States (NHTSA, 2004a). In 2003, there were 4,749 pedestrian fatalities and 70,000 injuries in the US (NHTSA, 2004b). 45% of the fatalities and 62% of the injuries are associated with passenger cars, while 39% of the fatalities and 31% of the injuries are associated with LTVs (NHTSA, 2004a).

LTVs have been increasing in popularity in the US since the early 1990's. By 1999, they accounted for nearly 50% of new vehicle sales. This trend has been accompanied by an increasing trend in pedestrian fatalities associated with LTVs (Lefler and Gabler, 2004). Numerous studies have been conducted to understand the pedestrian injury and fatality risk from cars, however only a few investigations have focused on pedestrian interaction with specific vehicle types such as LTVs.

In a 1998 study using the Pedestrian Crash Data Study (PCDS) database, Jarrett and Saul noted that LTVs might pose a more serious threat to pedestrians than cars since LTV impacts dominate the highest levels of injury severity.

A 1999 study by Mizuno and Kajzer looked into the influence of vehicle geometry on pedestrian injury risk using Japanese data (Mizuno and Kajzer, 1999). They found that the risk of fatality for pedestrians is independent of vehicle type for vehicles weighing less than 1400 kg. However, they found that fatality risk is dependent upon the vehicle type for vehicles over 1400 kg,

Lefler and Gabler published a 1998 study looking at pedestrian injury risk from LTVs. This study, revised and updated in 2004 (Lefler and Gabler, 2004), indicates that a pedestrian struck by an LTV has a 2 to 3 times greater likelihood of dying than if struck by a car. The study is based on 543 cases in the PCDS database and includes pedestrians of all ages. The results indicate that the probability of AIS 4 to AIS 6 injury is greater for LTVs and that LTV impacts result in a greater probability of serious head and thorax injury.

Using the PCDS database, Henary et al. (2003) found that LTVs present a significantly greater risk of serious injury and fatality than passenger cars in lower speed impacts. The statistically adjusted odds ratios for serious injury and fatality were 3.34 and 1.87 respectively when comparing LTVs to cars.

Ballesteros et al. (2004) used 1995-1999 data from the Maryland Trauma Registry and found the risk of fatality and high injury severity to be greater for LTVs. He concluded that, compared to cars, SUVs and pickups present a greater risk of serious injury to the brain, thorax, and abdomen, but a lower risk of injury to the region below the knee.

Based on the most frequent pedestrian injuries and consequent HARM, Fildes et al. (2004) set out to determine priorities for vehicle design. The study based on Australian and German data reported that 96% of all fatal pedestrian cases have injuries equivalent to AIS 4 or greater and 59% of the fatalities have some AIS 4+ torso injury.

Using the PCDS database Longhitano et al. (2005) studied differences in adult pedestrian injury patterns and injury sources based on vehicle type. The study looked at the number of injuries per body region sustained by pedestrians struck by passenger cars compared to those struck by light truck vehicles such as SUVs, vans, and pickup trucks (Figure 1). One significant finding was that serious injuries to the torso are much more frequent for pedestrians struck by LTVs than for those struck by cars. For LTVs, torso injuries are preceded by head injuries, but occur in greater numbers than lower extremity injuries.

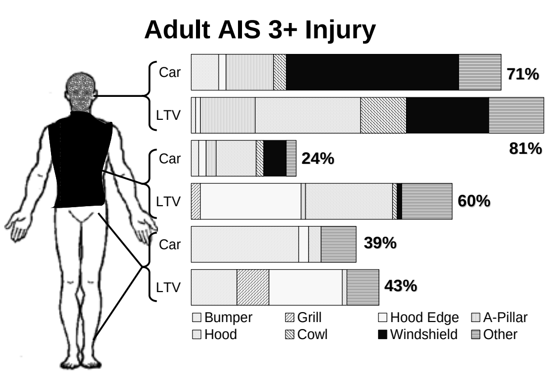

Figure 1 – Distribution of AIS 3+ Injuries by Body Region, Vehicle Type, and Injury Source.

Based on these previous studies it is evident that torso injury is an important area of consideration for mitigating pedestrian injuries and fatalities. This study was designed to focus on the specific type and severity of torso injuries recorded for adult pedestrians in the PCDS database. The purpose is to identify the organs and structures which sustain injury so that future countermeasures can be developed to mitigate their frequency.

METHODOLOGY

Data Source

The PCDS database was used as the primary source of data for this study. PCDS contains data for 552 pedestrian impacts and includes approximately 4,500 pedestrian injuries. The data was collected for late model vehicles from 6 US cities in the years 1994 to 1998 (Chidester and Isenberg, 2001). The database contains information on crashes of all severities for pedestrians struck by passenger vehicles including passenger cars, SUVs, vans, and light trucks.

Inclusion and Exclusion

For the purpose of this study, we limited the data to adult pedestrians aged 19 to 50 years. Children of age 18 and under were excluded due to numerous confounding factors such as size and biomechanical characteristics associated with growth and development. Adults over 50 were also excluded to avoid age related issues such as degradation in bone mineral density. In addition, cases which included multiple vehicles and/or multiple pedestrians were excluded.

The remaining data was divided into two categories: Car cases, which contains cases in which the impacting vehicle was a passenger car; and LTV cases, which includes cases in which the impacting vehicle was an SUV, van, or light truck. Within each of these subsets, the torso injury data was then filtered at the AIS 2+, AIS 3+, and AIS4+ levels. Torso injuries were defined as those injuries with an AIS code associated with the thorax, thoracic spine, abdomen, or lumbar spine.

The AIS 1 level injury has been excluded from this study as they are largely skin or other non-specific injuries that would not improve the analysis and may even mask other existing relations.

To focus on vehicle related factors, ground contact injuries were also excluded. This was accomplished by filtering all injuries that the PCDS crash investigators attributed to ground or other non-vehicle contact.

Torso Injury Type & Severity

For each division of AIS injury level the recorded torso injuries were divided into groups by the organ or structure injured. These groups were determined by the organ classification of the AIS code for each recorded injury. These classifications included aorta, lung, thoracic cavity, ribcage, liver, spleen, kidney, and other. Items were classified as other because either the specific portion of the torso was unclear or because the total number of injuries was relatively low. This data was then taken and each injury classification was shown as a fraction of the cumulative injury at that level for each vehicle type.

Relative HARM Assessment

A HARM approximation was used in order to differentiate the relative importance of torso injuries as a function of frequency and severity. This is accomplished by assigning a societal cost factor to each AIS injury level (Malliaris, 1982).

The PCDS data was divided by injury severity level at AIS 2, 3, 4, and 5+ for each injury classification and vehicle type. AIS 5 and 6 injuries were combined because AIS 5 would normally be weighted higher than AIS 6 due to the cost of medical treatment associated with the AIS 5 injuries. (AIS 6 injuries are by definition not treatable, therefore associated medical costs are greatly reduced when compared to AIS 5 injuries.)

Each injury was assigned a HARM weighting factor based solely on the AIS level. These factors are 2.7, 7.1, 38.8, and 186.6 for AIS 2, 3, 4, and 5+ injuries respectively. For each injury classification region, the cumulative cost factor was calculated and normalized by dividing by the cumulative cost for the vehicle type classification. These calculations were performed for the cars, LTVs, and the overall vehicle sample.

RESULTS

After filtering the data by age and vehicle type there were 169car cases and 85 LTV cases remaining for further analysis. In the passenger car cases there were 67 AIS 2 or greater (AIS 2+) torso injuries recorded and there were 77 AIS 2+ torso injuries in the LTV cases. The number of torso injuries at AIS 3+ is reduced to 40 and 46 for cars and LTVs respectively. At AIS 4+ there are 18 and 21 torso injuries recorded for car and LTVs respectively.

Table 1. Adult Torso Injuries in PCDS.

	Cars	LTVs	Total
AIS 2+	67	77	144
AIS 3+	40	46	86
AIS 4+	18	21	39

AIS 2+ Torso Injuries

There were 144 torso injuries of moderate or greater severity (AIS 2+) included in the sample of the PCDS database studied. Figure 2 shows the breakdown of these injuries by organ or structure as indicated by the AIS injury coding. This data indicates that of the major organs and structures the ribcage sustains injury at the greatest frequency, followed by the liver and lung.

The breakdown for passenger cars (figure 3) shows a similar trend to the overall breakdown, with the ribcage being the most frequently injured followed by the lung and liver. For LTVs, the breakdown (figure 4) is also similar though the frequency of spleen injury is greater than observed for passenger cars.

AIS 3+ Torso Injuries

When the PCDS sample was filtered for torso injuries of AIS 3 severity or greater, 86 injuries remained. Figure 5 indicates that in terms of serious injury the ribcage and lung are injured with the greatest frequency.

In the case of passenger cars, the distribution of AIS 3+ injuries again follows a similar trend to the data for all vehicles (figure 6). One notable difference is that there is an increased fraction of representing injury to the thoracic cavity.

Ribcage and lung continue to be of greatest importance at the AIS 3+ level for LTVs. (figure 7). The spleen also continues to be an appreciable fraction for LTVs, and the fraction associated with the aorta is of increasing importance.

AIS 4+ Torso Injuries

At AIS 4+, all but the most severe injuries are filtered out. In figure 8, we can see that the aorta encompasses a much greater fraction than at the AIS 3+ or AIS 2+ levels. The lung and ribcage, however, retain the greatest number of injuries.

The injury breakdown for passenger cars shown in figure 9 indicates that the lung and ribcage continue to be the predominant torso injuries even at the greatest severity levels for this classification.

For light trucks, the aorta and spleen occur at a frequency level in excess of the lung for severe torso injuries (figure 10). The spleen accounts for approximately 14 percent of the AIS 4+ injuries and the ribcage and aorta each account for approximately 23%.

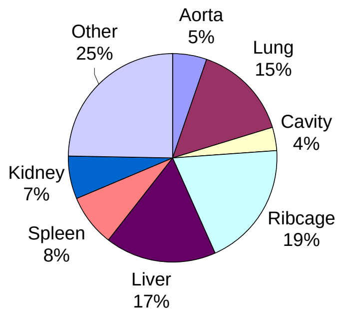

Figure 2. AIS 2+ Torso Injury Distribution For All Vehicles.

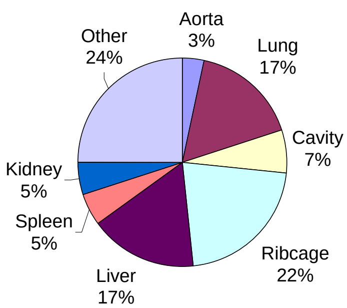

Figure 3. AIS 2+ Torso Injury Distribution For Passenger Cars.

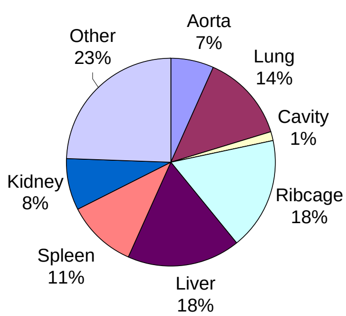

Figure 4. AIS 2+ Torso Injury Distribution For LTVs.

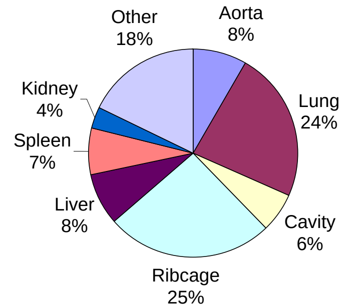

Figure 5. AIS 3+ Torso Injury Distribution For All Vehicles.

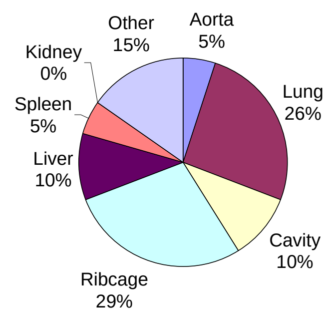

Figure 6. AIS 3+ Torso Injury Distribution For Passenger Cars.

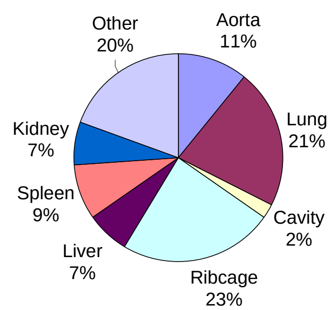

Figure 7. AIS 3+ Torso Injury Distribution For LTVs.

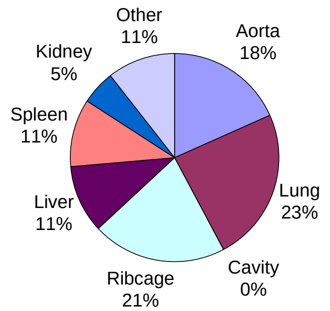

Figure 8. AIS 4+ Torso Injury Distribution For All Vehicles.

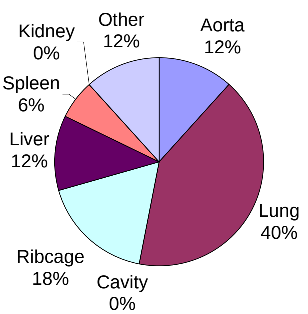

Figure 9. AIS 4+ Torso Injury Distribution For Passenger Cars.

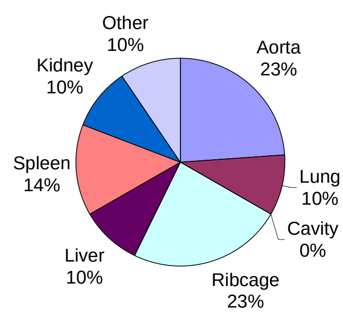

Figure 10. AIS 4+ Torso Injury Distribution For LTVs.

Cumulative HARM

Since it can the difficult to ascertain the relative importance of each injured organ or structure across a range of injury severities, a simplified relative HARM analysis was performed. For the cases studies, the percentage of total HARM within the torso was calculated for each major organ and structure for LTVs, cars, and the overall sample (Figure 11).

The data in Figure 11 indicates that the lung and aorta are the torso components at the greatest risk for HARM in pedestrian impacts. The lung predominates in cases with passenger cars due to a number of incidences where AIS 5+ lung injury is reported. For LTVs, the aorta is the most significant component, which is again due largely to the severity being recorded as AIS 5+.

A breakdown of injured torso region by injury severity and vehicle classification can be found in Appendix A.

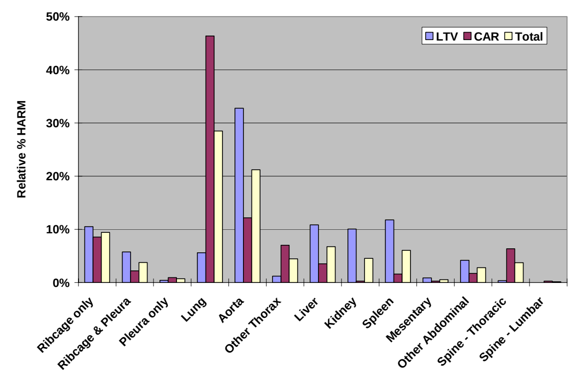

Figure 11. Relative Percentage of Torso HARM.

DISCUSSION

When looking at the distribution of AIS2+ torso injuries, it at first appears that the types on injuries sustained when struck by an LTV are similar to those for a passenger car. The ribcage is the dominant area of injury, followed by injuries to the lung, liver, spleen, and thoracic cavity.

This distribution changes noticeably when looking at higher severity injuries, AIS 4+. At the severe injury level, lung and ribcage injury dominate the passenger car dataset; while lung, ribcage, aorta, and spleen are all important for LTVs.

HARM analysis shows a further divergence between cars and LTVs. For cars, 45 percent of the cumulative HARM is associated with lung injury.

This is due to a number of instances of AIS 5 lung injury in the passenger car dataset. In the LTV dataset, the lung is not as significant. For LTVs, it is the aorta which indicates the greatest cumulative HARM accounting for over 30 percent. This is due to a large number of AIS 5 and 6 aorta injuries in the LTV sample. Liver, kidney, and spleen injuries are also evident in the LTV HARM analysis, but not for the passenger cars. The ribcage is also of importance in both datasets, where it sustains approximately 10 percent of the cumulative HARM.

This shift of injury distribution is indicative of the change in loading characteristics between passenger cars and LTVs. High leading edge profiles of LTVs produce an inherently different interaction with the pedestrian. When struck by a car, a pedestrian will normally wrap the front of the vehicle with the thigh interacting at the hood edge before being thrown forward. For LTVs, the hood edge strikes between the pelvis and thorax of the pedestrian. This results in a more direct penetrating loading for the torso.

CONCLUSIONS

Torso injury is an important area of consideration for the mitigation of pedestrian injuries and fatalities. At lower AIS levels, the distribution of torso injuries is substantially similar between vehicle types with the ribcage being the dominant area of injury followed by the lung and liver. At higher AIS levels, the injury pattern shifts. For cars at the AIS 4+ level, injury to the lung and ribcage is still dominant. For LTVs at this higher level the aorta and spleen also account for large percentages of the injuries.

When these injury distributions are looked at in terms of HARM, the focus shifts. For cars, the lung is the dominant area accounting for 45% of the HARM. For LTVs it is the aorta that dominates with over 30% of the HARM. The ribcage, liver, kidney, and spleen are also significant components of HARM in the case of LTVs.

Based on these findings, further work is necessary to better understand mechanisms for the injuries occurring so that tools can be developed to evaluate the risk of these injuries during vehicle development.

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APPENDIX A

Table A1.
Passenger Car Injury by Organ and Severity.

Car	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**AIS 6**
Ribcage only	3	4	1	1	
Ribcage & Pleura		4	1		
Pleura only		4			
Lung			3	7	
Aorta				1	1
Other Thorax		4			1
Liver	6	2	2		
Kidney	3				
Spleen	1	1	1		
Mesentary	3				
Other Abdominal	5		1		
Spine - Thoracic	3			1	
Spine - Lumbar	3				

Table A2.
LTV Car Injury by Organ and Severity.

LTV	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**AIS 6**
Ribcage only	2	3	1	1	
Ribcage & Pleura		3	3		
Pleura only	1	1			
Lung		8	2		
Aorta			1	3	1
Other Thorax		4			
Liver	10	1	1	1	
Kidney	3	1	1	1	
Spleen	4	1	2	1	
Mesentary	5	1			
Other Abdominal	3	2	2		
Spine - Thoracic	3				
Spine - Lumbar					