THE INFLUENCE OF AIRBAGS ON THORACIC ORGAN LESION TYPES

Craig P. Thor, Hampton C. Gabler
Virginia Tech-Wake Forest, Center for Injury Biomechanics.

ABSTRACT

Thoracic organ injuries account for 13% of all serious injuries to belted front seat occupants in frontal crashes. The rate at which thoracic organ injury occurs and the manner in which the injuries occur has not changed significantly with the inclusion of airbags. This study was based on the injury outcomes of over 28,000 belted occupants in frontal crashes from National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) case years 1993-2007. The injury sources of serious thoracic organ injury vary by organ and seating position, but generally not by the inclusion of airbags. However, the airbags were given as the source of 5% of the driver thoracic organ injuries and 16% of the right front passenger thoracic organ injuries. The thoracic organ injury type did not change significantly with airbags, but there was a large reduction in the distribution of heart contusions for occupants with an available airbag. The average delta-V that results in thoracic organ injury is not higher for occupants with an airbag as compared to those without an available airbag. This suggests that the airbag offers little additional protection against thoracic organ injury than provided by seat belts alone.

Keywords: Thoracic Organ Characteristics, Airbags, Frontal Crashes, Seat Belts

INTRODUCTION

The thorax and head have been the body regions that have accounted for the most crash related serious injuries and fatalities in the past [1]. This distribution of serious injuries has changed with the inclusion of occupant safety technologies that are designed to primarily protect these vital body regions. Despite continued advances in these technologies, it is also known that serious injuries, particularly to the chest, still occur. Consequently, it is important to continually advance occupant protection in a manner that continues to improve effectiveness of these safety systems.

Much of the effort to increase thoracic protection has focused on limiting rib fractures due to their predominance in cadaver testing [2, 3]. Blunt thoracic cadaver impact tests have been performed with the specific aim of creating thoracic injury criteria. The ultimate goal of these criteria is to determine the probability of thoracic injury in a frontal crash based on engineering metrics such as acceleration and chest displacement. However it is also known that thoracic organ injuries, separate from rib fractures, occur regularly in frontal crashes as well and have been given limited attention in the literature. Consequently, thoracic organ injury should be investigated separately from rib fracture. Furthermore, not all injury countermeasures produced large benefits and some may have even been harmful to particular body regions. As such, it is prudent to continually analyze the state of occupant protection with the inclusion of new safety technologies.

Objective

The objective of this research is to determine the characteristics of thoracic organ injury independently from rib fracture, and report changes in thoracic injury with the inclusion of airbags.

METHODS

The research presented here is a National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) based study. NASS/CDS is a record of crashes in the United States where at least one of the vehicles involved was towed from the scene. Random selections of roughly 5,000 such cases are investigated each year. Weights are applied to each incident so that each case is given the appropriate representation in the distribution of all crashes in the United States. Case years 1993-2007 will be analyzed in this investigation. The cases were limited to belted front seat occupants involved in a crash where the most harmful event was a frontal collision and the principal direction of force is between the clock positions of 1-o'clock and 11-o'clock (+/- 30°of the longitudinal axis of the vehicle). Rollover events and fully or partially ejected occupants were excluded. Only occupants over the age of 12 were considered. Two primary populations were considered in the analysis: (1) belted front seat occupants without an available frontal airbag and (2) belted front seat occupants with an available frontal airbag. All data compilation and statistical analysis was performed with the SAS statistical software (SAS, Cary, N.C.). The Taylor series linearization method for variance calculation of a stratified and clustered survey design was used to compute 95% confidence intervals. The reported significance findings for differences in distributions and means are based on a two sample t-test, corrected for the survey design.

All injuries were categorized using the Abbreviated Injury Scale (AIS), as defined by the 1990 revision. AIS ranks injury severity by threat to life using a six-level scale where 0 = no injury and 6=fatal injury [4]. Only AIS3+ thoracic injuries (serious and greater injuries) were included in this analysis. The thoracic soft tissues include the lungs, heart, and the great vessels [5]. The liver and spleen are partially protected by the lower rib cage and they are the most commonly injured abdominal organs [6-8]. For the purposes of this research, the liver and spleen were included as thoracic organs along with the lungs and heart and great vessels.

RESULTS

Table 1 gives the number of weighted and unweighted cases with serious thoracic organ injuries used in this analysis. For occupants with an available airbag, there is no reduction in the rate of thoracic organ injuries as compared to those without an available airbag when normalized to all belted front seat occupants in frontal crashes as shown in Figure 1.

Table 1: Distribution of AIS3+ injuries by restraint condition for belted front seat occupants in NASS/CDS case years 1993-2007.

Restraint Type		Occupants w/ AIS 3+ Injuries (Weighted)	Occupants w/ AIS 3+ Injuries (Unweighted)	AIS 3+ Injuries (Weighted)	AIS 3+ Injuries (Unweighted)
Belts + No Airbag	**Thoracic Organ Injury**	**16,700**	**241**	**21,186**	**366**
	Any Injury	*69,939*	*862*	*135,147*	*2,180*
Belts + Airbag	**Thoracic Organ Injury**	**26,993**	**385**	**32,289**	**541**
	Any Injury	*141,995*	*1,687*	*245,623*	*3,809*

On average, Table 1 shows that 1,800 belted front seat occupants with airbags suffer a total 2,150 serious or greater thoracic organ injuries in frontal crashes every year in the United States. This accounts for roughly 13% of all serious injuries in frontal crashes for belted occupants with available airbags.

Figure 2 shows that there is a significant increase in the fraction of lung injuries with respect to all AIS3+ thoracic organ injuries when airbags are available. There also appears to be a reduction in the fraction of spleen and heart and great vessel injuries with the inclusion of airbags, however these results are not statistically significant.

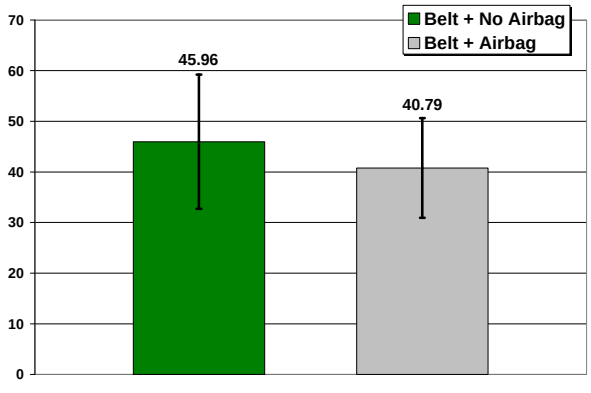

Figure 1: Number of occupants with thoracic organ injury / 10,000 exposed occupants (weighted).

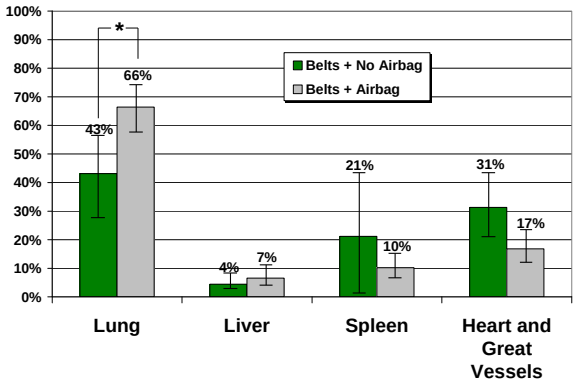

Figure 2: AIS3+ Thoracic organ injuries in frontal impacts (weighted). *- Significantly Different.

The distribution of contact sources attributed to thoracic organ injury can vary by seating position and are given in Table 2. Overall, the airbags account for 5% of driver thoracic organ injuries and 16% of right front passenger (RFP) thoracic organ injuries. Further analysis found that the lungs are injured significantly less frequently by the steering column (No airbag: 74% vs. Airbag: 31%) and more often by the belts (No airbag: 14% vs. Airbag: 65%) for the driver when an airbag is present. The airbag was given as the source for a higher percentage of RFP lung injuries (22%) than for any other thoracic organ in either seating position. Significantly more liver injuries were attributed to the vehicle interior for the RFP as compared to the driver without airbags (2% driver vs. 57% passenger) and with airbags (2% driver vs. 48% passenger). The spleen was injured by interior components more for the driver than for the right front passenger with airbags (35% driver vs. 10% passenger), although the result was not significant. Alternatively, the belt restraints accounted for significantly more RFP (79%) spleen injuries than for the diver (46%) with an airbag.

Table 2: Distribution of AIS3+ thoracic organ injuries by injury source for belted drivers (D) and right front passengers (RFP) (weighted) [ST – Steering Wheel; BR – Belt Restraint; VI – Vehicle Interior; OV – Other Vehicle; AB – Airbag; UN – Unknown].

	Lung				Liver				Spleen				Heart & Great Vessel			
	No Airbag		Airbag		No Airbag		Airbag		No Airbag		Airbag		No Airbag		Airbag	
	D	RFP	D	RFP	D	RFP	D	RFP	D	RFP	D	RFP	D	RFP	D	RFP
ST	74%	-	31%	-	63%	-	52%	-	15%	-	16%	-	74%	-	67%	-
BR	14%	65%	65%	39%	35%	37%	43%	52%	80%	74%	46%	79%	22%	73%	11%	19%
VI	9%	31%	13%	39%	2%	57%	2%	48%	4%	26%	35%	10%	1%	23%	9%	66%
OV	2%	2%	-	-	-	-	1%	-	-	-	-	-	1%	-	1%	-
AB	-	-	6%	22%	-	-	1%	-	-	-	-	7%	-	-	9%	10%
UN	1%	1%	1%	-	-	7%	1%	-	1%	-	3%	4%	1%	3%	3%	5%

Similar to injury source, the introduction of airbags has not largely changed the distribution of lesion types for thoracic organ injuries as shown in Table 3. The lungs injuries are almost always contusions. Liver and spleen injuries are almost always lacerations. 69% and 73% of heart and great vessel lacerations were vessel injuries for occupants without and with airbags available, respectively. 100% of the contusions were to the heart. The distribution of heart contusions dropped from 28% to 4% with the inclusion of airbags.

Table 3: Distribution of AIS3+ thoracic organ injury lesion types by restraint condition for belted front seat occupants (weighted).

	Contusion		Laceration		Unknown		Rupture		Avulsion	
	No Airbag	Airbag	No Airbag	Airbag	No Airbag	Airbag	No Airbag	Airbag	No Airbag	Airbag
Lung	86%	95%	11%	1%	3%	4%	0%	0%	0%	0%
Liver	4%	4%	96%	96%	0%	0%	0%	0%	0%	0%
Spleen	2%	2%	96%	96%	0	0%	2%	2%	0%	0%
Heart and Great Vessels	28%	4%	67%	88%	3%	3%	2%	2%	0%	3%

Table 4. Average age of those with an AIS3+ thoracic organ injury compared to those without.

	Organ Injury	All Occupants	Significance
All Thoracic Organs	**47.8**	**36.7**	**Significant**
Lung	**47.3**	**36.7**	**Significant**
Liver	39.4	36.7	Insignificant
Spleen	32.2	36.7	Insignificant
Heart and Great Vessels	**49.7**	**36.7**	**Significant**

Table 5. Average delta-v of vehicles in which an occupant sustained a serious thoracic organ injury with the presence of an airbag compared to those without an airbag present.

	No Airbag (kph)	Airbag (kph)	Significance
All Thoracic Organs	49.9	48.2	Insignificant
Lung	48.4	42.8	Insignificant
Liver	57.8	58.9	Insignificant
Spleen	45.0	41.6	Insignificant
Heart and Great Vessels	52.1	67.0	Insignificant

Occupants who suffer thoracic organ injuries were generally older than all belted front seat occupants in frontal crashes. From the perspective of the individual organs, the average ages of injured occupants were shown to be significantly higher for the lungs and heart and great vessels as shown in Table 4. The average age of occupants with serious spleen injuries was lower than the average occupant in a tow-away crash, although this was not significant. An analysis of the types of crashes that result in thoracic organ injury found that the average delta-V, a measure of crash severity, for crashes where the occupant suffered a thoracic organ injury with an available airbag was not shown to be significantly different than occupants in vehicles without available airbags as shown in Table 5.

DISCUSSION

Thoracic organ injuries have been shown to make up a large portion of all serious injures for belted front seat occupants in frontal crashes. The primary focus of occupant thoracic injury protection has historically been centered on the ribs. However, this research has shown that the thoracic organs themselves can be an important part of evaluating thoracic protection in crashes. Furthermore, the inclusion of airbags, a technology designed to provide additional protection to the chest beyond the use of seat belts, has not been shown by this research to significantly reduce the rate of thoracic organ injury. In particular, the lungs have been shown to be significantly affected by the inclusion of airbags. This may be related to a possible increase in a distributed load across the chest from an interaction with the airbag.

The contacts given as the source of thoracic injuries did not largely change with the inclusion of airbags. However, it was shown that the majority of vehicle interior contact sources given for liver injury were to the right front passenger as opposed to the driver. Interestingly, of the interior component injury sources for the liver, 89% were on the right side of the occupant. This relates to the location of the organ within the body. Similarly, 93% of spleen injuries from interior components were on the left side of the occupant, again reflecting the location of the organ within the body. On the other hand, the belts accounted for more right front passenger splenic injuries than driver splenic injuries. The seat belts crosses over the lower left ribs, which protect the spleen, and thus would make the spleen more susceptible to injury from extra belt loading in the event of a crash.

The type of lesion seen for each organ was not significantly different with or without airbags present. Thoracic organ injuries are mainly the result of blunt chest trauma. Often, the injury occurs due to compression of the organ resulting from the deceleration of the occupant [5, 9]. As a result, it could be assumed that airbags do not significantly change the loading scenarios seen by the organs, thus the types of injuries seen are the same with and without airbags. However, there was a large reduction in heart contusions with the inclusion of airbags. Heart injuries are often more severe with regard to their threat to life than other thoracic organ injuries. Thus any reduction in heart injuries can also greatly reduce the risk of fatality. It is possible that the explanation for a reduction in heart contusions is related to the distributed load seen with airbag interaction. With belts only, the compression would be more localized over the sternum, below which lies the heart. By distributing the load, it may reduce the compression of the heart, lessening the chance for injury.

Occupants who sustained thoracic organ injury were generally older than the average front seat occupant in the United States. In particular, the lungs and heart and great vessel injuries occurred in significantly older occupants. This may be related to increased chest compression for older occupants, resulting in the subsequent compression of the underlying organs. Interestingly, occupants with spleen injury are on average younger than the average front seat occupant, although this result was not significant. The spleen increases in size through puberty and decreases in size later in life. Hence, younger occupants would have larger spleens than older occupants, possibly making them susceptible to injury. An analysis of the crash circumstances that lead to thoracic organ injury did not show any difference in the average delta-V for thoracic organ injuries in occupants with and without airbags. It would be assumed that if the airbags offered protective effects against thoracic organ injury, a higher severity crash would be required, and thus a larger delta-V to produce injury with airbags.

CONCLUSIONS

Thoracic organ injuries account for a significant portion of all serious injuries for belted occupants in frontal crashes with airbags. The introduction of airbags is shown to have little effect on the types of thoracic organ injuries or the sources of these injuries. It is possible that, regardless of the existence of protective measures, the organs are particularly susceptible to certain injury sources and that the injuries only present themselves as certain lesion types. However, it was shown that the crash severity required to result in thoracic organ injury is not different for belted front seat occupants with and without airbags. This, coupled with the lack of a significant reduction in the rate of thoracic injuries with airbags suggests that this technology has had little to no affect on the occurrences of thoracic organ injuries, with the exception of increased protection against cardiac contusion.

ACKNOWLEDGMENTS

This work received support from the Toyota Motor Corporation. However, the views presented in this thesis are not necessarily a reflection of the views held by Toyota or its affiliates.

REFERENCES

[1] Nahum, A. M. and Melvin, A. M., *Accidental Injury: Biomechanics and Prevention*, 2nd ed. New York: Springer-Verlag, 2002.

[2] Eppinger, R., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., Kuppa, S. M., Nguyen, T., Takhounts, E., Tannous, R., Zhang, A., and Saul, R., "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems - II," Washington, D.C. 1999.

[3] Kroell, C. K., Schneider, D. C., and Nahum, A. M., "Impact Tolerance and Response of the Human Thorax II," in *Proceedings of the 18th Stapp Car Crash Conference*, Warrendale, PA, 1974, p. 383.741187

[4] AAAM, " Association for the Advancement of Automotive Medicine. The Abbreviated Injury Scale, 1990 Revision, Update 98 (1998)," 1998.

[5] Cavanaugh, J. C., "The Biomechanics of Thoracic Trauma," in *Accidental Injury: Biomechanics and Prevention*, 2nd ed, A. M. Nahum and J. W. Melvin, Eds. New York, NY: Springer-Verlag, 1993, pp. 362-390.

[6] Lau, V. K. and Viano, D. C., "Influence of impact velocity on the severity of nonpenetrating hepatic injury," *The Journal of Trauma: Injury, Infection, and Critical Care*, vol. 21, pp. 115-23, Feb 1981.

[7] Walt, A. J., Thomas, J. G., and Williams, R. D., "Blunt Abdominal Injury: A Review of 307 Cases," in *Impact Injury and Crash Protection*, E. S. Gurdjian, W. A. Lange, and L. M. Thomas, Eds. Springfield, IL: Charles Thomas, 1970, pp. 101-124.

[8] Morgan, R., Eppinger, R., Haffner, M., Yoganandan, N., Pintar, F., Sances, A., Crandall, J., Pilkey, W., Klopp, G., Kallieris, D., Miltner, E., Mattern, R., Kuppa, S. M., and Sharpless, C., "Thoracic Trauma Assessment Formulations for Restrained Drivers in Simulated Frontal Impacts," in *Society of Automotive Engineers*, 1994.942206

[9] Rouhana, S., "Biomechanics of Abdominal Trauma," in *Accidental Injury: Biomechanics and Prevention*, 2nd ed, A. M. Nahum and J. W. Melvin, Eds. New York, NY: Springer-Verlag, 1993, pp. 391-428.