ABDOMINAL INJURY WITH AIRBAG DEPLOYMENT FOR BELTED DRIVERS IN FRONTAL CRASHES

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ABSTRACT

The risk of moderate or serious abdominal injury is higher for belted drivers in frontal crashes with a deployed airbag than for belted drivers not exposed to a deployed airbag. An analysis of roughly 13,000 belted front seat occupants in frontal crashes from National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) case years 1993-2007 with and without airbag deployment were used in this study. There were 2.14 (CI: 1.06-4.33) times greater odds of AIS2+ abdominal injury and 3.48 (CI: 1.27-9.62) times greater odds of AIS3+ abdominal injury when a belted driver was exposed to a deployed airbag as compared to belted drivers not exposed to a deployed airbag. The liver and spleen were not found to have statistically significant higher odds of injury with airbag deployment. It is possible that an increase in abdominal injury potential may be related to a change in occupant kinematics as a result of the occupant engaging the deployed airbag, consequently forcing the occupant to submarine under the lap belt.

Keywords: Abdominal Injury, NASS/CDS, Airbag Deployment, Odds Ratio

INTRODUCTION

The combination of seat belts and airbags is known to be the best combination for preventing occupant fatalities in frontal collisions, yet their combined effectiveness for preventing occupant injury has not been definitively established. Frontal airbags were first proposed in 1969 and became mandatory for both front seat positions in 1998. The original intent of airbag development and the reason for the subsequent introduction of the technology was part of an effort to provide supplemental protection for unbelted occupants [1]. However, belt use in the United States has steadily climbed from 12% in the early 1980s to 82% by 2007 [2]. With a great majority of occupants now wearing their seat belts, a continuing discussion on how to optimize airbag technologies for the increased injury protection of belted occupants as opposed to protection for unbelted occupants has become increasingly necessary.

In 2007 alone, there were roughly 1,500 moderate or worse abdominal injuries for belted drivers exposed to a deployed airbag in a frontal crash. Abdominal injury is often overlooked in relation to other body regions, e.g. the head and chest, in occupant crash protection. However, abdominal injuries can be quite severe in their own respect, particularly liver and spleen injuries which are the greatest in severity and result in the highest mortality rates [3, 4]. Abdominal injuries are often not discovered initially because the symptoms may have a delayed onset. An occult abdominal injury may be present with no other noticeable symptoms, thus the occupant may not be triaged appropriately for the injury [5]. It has been suggested that the airbag can be overloaded by an occupant and result in excessive loading of the abdomen by the airbag itself or the rim of the steering wheel [5]. It is also possible that the occupant may "submarine" under the lap belt as a result of the airbag interaction. This kinematic change has been suggested as the source of greater risk for lower extremity injury seen for belted occupants exposed to an airbag deployment as compared to belted occupants without a deployed airbag [6]. Submarining may cause increased abdominal loading from the lap belt and an increase in abdominal injury potential. McGwin et al (2003) showed no significant increase in the risk of moderate and greater abdominal injury associated with airbag deployment. However, this result was not statistically significant, possibly a reflection of a relatively small sample size. Also, only moderate and greater injuries (AIS2+) were investigated and drivers and right front passengers were combined in the analysis [7]. An improvement to this study would have been to separate the driver and right front passenger to reflect the differences in airbag design and loading conditions seen for these seating locations.

Objective

The purpose of this is study is to investigate the relationship between the deployment of an airbag and the occurrence of abdominal injuries for belted drivers in frontal collisions.

METHODS

The research is based on the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS). NASS/CDS is a collection of crash investigations in the United States where at least one of the vehicles involved was towed from the scene. NASS/CDS contains roughly 5,000 such cases for each year. The survey design for this database includes stratification and clustering. 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 were analyzed in this investigation. A statistical comparison of the odds of abdominal injury for two comparison subpopulations was used. The two subpopulations were defined as (1) belted drivers who were not exposed to an airbag deployment and (2) belted drivers who were exposed to a frontal airbag deployment.

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 [3]. In this study, two injury thresholds were investigated: AIS2+ abdominal injuries (moderate and greater injury) and AIS3+ abdominal injuries (serious and greater injuries). Liver and spleen AIS3+ injuries were analyzed separately. The analysis was limited to belted drivers 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. Seat belt and airbag interactions for children are different than for adults, and it is the interactions with adults that are of interest to this study. The study was restricted to those cases of crash severity for which an airbag could be expected to deploy. Only crashes with an estimated vehicle total change in velocity (delta-V) of at least 15 kph were included. Since few airbags deploy below this threshold and injury rates are also low below this threshold, including low delta-V cases in the analysis would unfairly bias the result against airbags. Limiting the dataset to only cases above the general airbag deployment threshold creates comparison populations in which the occupants were exposed to a similar cumulative distribution of crash severity. Assuming that the airbag offers protective effects, it is at these speeds that the increase in protection should be noted. Segui-Gomez (2000) showed that there is an increased risk of occupant injury in lower severity crashes with airbag deployment as compared to those without airbag deployment [8]. However, none of the abdominal injury cases occurred in crashes below a delta-V of 15kph. As a result, we are able to eliminate any crash severity bias that may exist in either subpopulation while preserving all cases that resulted in abdominal injury.

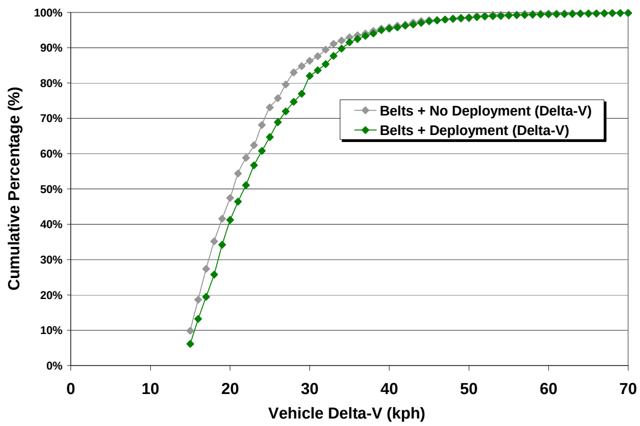

Figure 1. Cumulative distribution of vehicle delta-V for belted drivers with and without airbags (NASS/CDS 1993-2007 - Weighted).

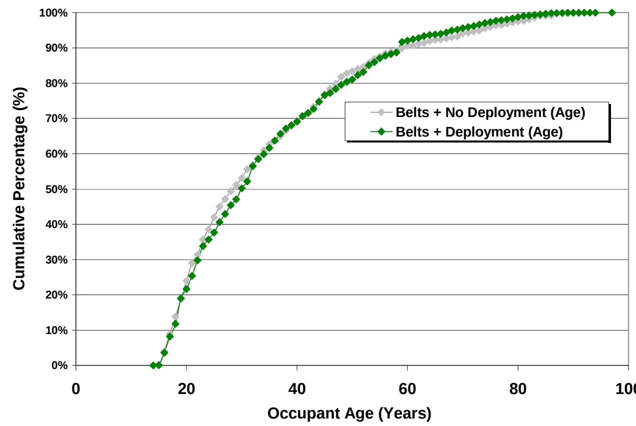

Figure 2. Cumulative distribution of vehicle occupant age for belted drivers with and without airbags (NASS/CDS 1993-2007 - Weighted).

The distribution of vehicle delta-V and occupant age are presented for both subpopulations in Figure 1 and Figure 2, respectively. Statistical t-tests for means, adjusted for the survey design, revealed that there were no significant difference in the average age ($p > 0.05$) or vehicle delta-V ($p > 0.05$) for the two comparison subpopulations. A statistical t-test for proportions, adjusted for the survey design, revealed that the airbag deployment subpopulation contained a larger percentage of cars and a smaller percentage of trucks in than the non-deployment subpopulation. There was no difference in the distribution of minivans. The final distribution of cases used in the analysis is given in Table 1.

Table 1. The initial unweighted population, the number of case exclusions, and the final population of weighted and unweighted cases for belted drivers not exposed to airbag deployment and those exposed to airbag deployment (NASS/CDS 1993-2007).

	Belt + No Deployment		Belt + Deployment	
	Total Cases	**Abdominal Injury**	**Total Cases**	**Abdominal Injury**
Belted Drivers	30,794	262	48,590	226
Only Frontal Impacts	11,270	69	11,959	113
No Rollover/Ejection	11,238	66	11,938	112
Age $\geq$ 12	5,966	39	8,159	64
No Missing Model Variables	5,219	33	7,770	59
Total Unweighted	**5,219**	**33**	**7,770**	**59**
Total Weighted	**2,685,290**	**1,178**	**2,905,767**	**4,521**

Odds ratios were computed to describe the effect of airbag deployment on the risk of abdominal injury. Odds ratios are a statistical method for comparing the probability of injury based on the given reference condition. For this analysis, the reference condition was the odds of abdominal injury for belted drivers who were not exposed to a deployed airbag. An odds ratio greater than one would indicate that the risk of injury for belted occupants exposed to a deployed airbag was higher than the injury risk to belted occupants not exposed to a deployed airbag. This relationship is expressed in Equation 1. Here, the variable, p , is the probability of abdominal injury based on the given airbag deployment condition for a belted driver.

$$OddsRatio = \frac{\left[p_{Deployment} \Big/ \left(1 - p_{Deployment}\right) \right]}{\left[p_{No\_Deployment} \Big/ \left(1 - p_{No\_Deployment}\right) \right]} \qquad \textbf{Equation 1}$$

The SAS statistical software was used to compute the point estimates for the odds ratios and the 95th percent confidence intervals (SAS, Cary, N.C.). Occupant age and delta-V were included as continuous variables. Vehicle type (defined as light truck, car, or mini-van) and the presence or absence of a deployed airbag were included as categorical variables in the logistic regression model. A least squares fit was applied to the model and as such, the computed odds ratio based on airbag deployment for a belted driver is normalized by the contributions of the other model predictors. Missing case information for any of the logistic regression model variables were excluded from the analysis. The jackknife variance calculation method for stratified and clustered survey designs was used in the calculation of the confidence intervals. The statistical significance of each result was also in agreement with a chi-square analysis when corrected for the weighted data based on the stratification and clustering.

RESULTS

Figure 3 compares the distribution of serious injuries by body region for belted drivers exposed and not exposed to airbag deployment. There was no statistically significant difference in the fraction of serious injuries incurred to the abdomen when an airbag deployed as compared to the fraction of injuries from occupants not exposed to a deployed airbag. However, this distribution should not be interpreted as a measure of relative risk of injury to any body region.

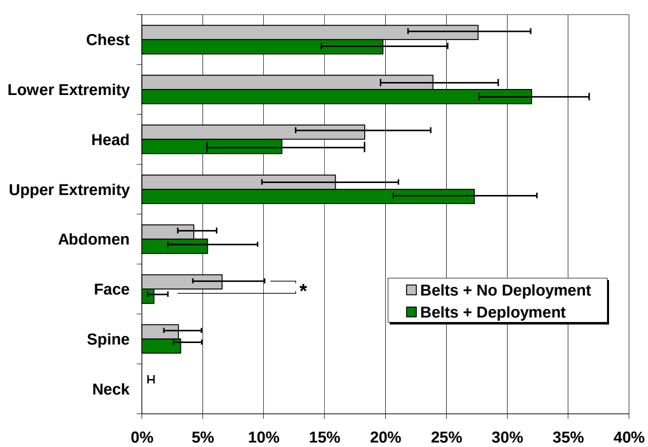

Figure 3. Distribution of AIS3+ injured body regions for belted drivers with and without airbag deployment (NASS/CDS 1993-2007 - Weighted).

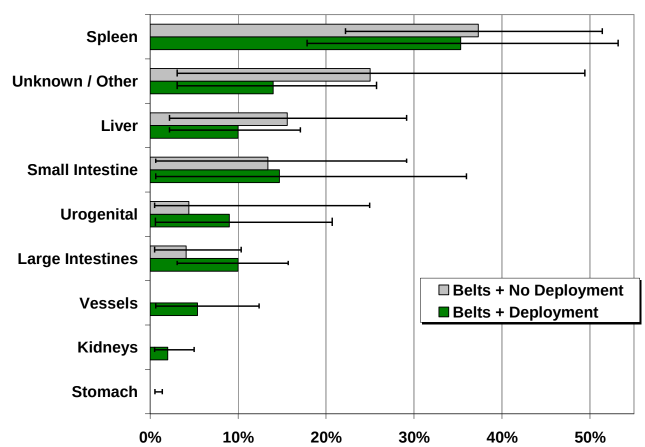

Figure 4. Distribution of AIS3+ abdominal injuries for belted drivers with and without airbag deployment (NASS/CDS 1993-2007 - Weighted).

The results given in Table 2 show that the odds of injury for belted drivers exposed to a deployed airbag are greater than the odds for belted drivers without an airbag deployment. There are 2.14 (CI: 1.06-4.33) times greater odds of AIS2+ abdominal injury and 3.48 (CI: 1.27-9.62) times greater odds of AIS3+ abdominal injury. The confidence intervals and the Wald Chi-square likelihood estimate p-values are given. Figure 4 shows that the spleen and liver are two of the most commonly injured abdominal organs. Although the large and small intestines account for a large percentage of abdominal injuries as well, the liver and spleen injuries are investigated independently of other abdominal organs because of their increased severity and potential to result in a fatality. Table 3 shows that the deployment of an airbag is not a significant predictor of AIS3+ liver or spleen injury when corrected for age, delta-V, and vehicle type. Despite a lack of statistical significance, both point estimates suggest an increase in the risk of injury to both of these organs with the deployment of an airbag, particularly the spleen.

Table 2. Significance data for the odds ratio of AIS2+ and AIS3+ abdominal injury for a belted driver with the deployment of a frontal airbag as compared to those not exposed to a deployed airbag. The logistic model is corrected for age, delta-V and vehicle type. (NASS/CDS 1993-2007 - Weighted).

	Odds Ratio	Lower CI	Upper CI	p-value
AIS2+	**2.14**	1.06	4.33	0.0338
AIS3+	**3.48**	1.27	9.62	0.0156

Table 3. Significance data for the odds ratio of AIS3+ liver and spleen injury for a belted driver with the deployment of a frontal airbag as compared to those not exposed to a deployed airbag. The logistic model is corrected for age, delta-V and vehicle type. (NASS/CDS 1993-2007 - Weighted).

	Odds Ratio	Lower CI	Upper CI	p-value
Liver	**2.36**	0.673	8.26	0.180
Spleen	**3.85**	0.964	15.38	0.056

DISCUSSION

Figure 3 shows that there is no significant difference in the fraction of serious abdominal injuries with respect to all injured body regions with or without the deployment of frontal airbags. Table 2 expresses that the risk of abdominal injury for belted drivers exposed to an airbag deployment is higher than for drivers without an airbag deployment for both AIS2+ and AIS3+ injury levels. The liver and spleen account for the highest percentage of abdominal injuries [4]. Exposure to an airbag deployment did not change the risk of injury for either of these organs. However, the estimated odds ratio for each does suggest a higher risk of injury for each of these organs with airbag deployment.

Estrada et al (2004) suggested that an increased risk of lower extremity injury associated with airbag deployment could be the result an occupant submarining under the lap belt. Submarining results in increased pelvic excursion and a greater chance of the lower extremities contacting the knee bolster. Assuming this mechanism to be true, the pressure exerted on the abdomen by the lap belt may also increase as a result of submarining. Serious injuries to the solid organs of the abdomen are known to be the result of compression, resulting in pressurization of the organ that places the outer layers in tension, which produces deep lacerations [4, 9-11]. The liver and spleen would be particularly susceptible to an increased abdominal pressurization from the lap belt due to a submarining mechanism as both organs are located in anteriorly in the abdomen. This would possibly result in direct engagement from the lap belt. In fact, upon further analysis, it was found that almost half of all injuries to each of these organs were attributed to the belts when an airbag was available. Submarining of the occupant due to a change in occupant kinematics with airbag interaction is a possible explanation for the increase in the odds of abdominal injury with airbag deployment.

It was found that there were no abdominal injuries below 15kph. This leads to two conclusions. First, applying a delta-V cutoff at 15kph does not change the finding of this analysis and preserves all cases where an abdominal injury occurs. Secondly, because there were no abdominal injuries below a delta-V of 15kph in either subpopulation, it is possible that a higher delta-V is required to produce abdominal injury.

CONCLUSIONS

Airbag deployment presents a significantly greater risk of abdominal injury for belted drivers in frontal crashes as compared to belted drivers not exposed to airbag deployment. This research used odds ratios to show that there was a greater risk of both AIS2+ and AS3+ abdominal injury when a belted driver was exposed to a deployed airbag. The most frequently injured abdominal organs, the liver and spleen, were not found to have significantly higher odds of injury for belted drivers with airbag deployment as compared to those without airbag deployment. However, the point estimates do suggest this trend. One possible explanation for the greater abdominal injury risk associated with airbag deployment maybe related to a change in occupant kinematics resulting in the occupant submarining under the lap belt after the chest and head engage the deployed airbag.

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