CRASH ATTRIBUTES THAT INFLUENCE AORTIC INJURIES IN NEAR-SIDE CRASHES

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ABSTRACT

NASS, CIREN and WLIRC cases are examined to determine the factors that influence aortic tear. In addition to a qualitative evaluation of cases, regression analysis is performed to determine which factors are predictive of aortic tear. Occupant factors such as age, restraint status and seat location are considered along with crash characteristics such as intrusion, delta-v, crush, damage location, and striking vehicle class.

Age, delta-v and intrusion have been confirmed predictors of aortic tear. In addition, damage to the struck vehicle, beginning forward of the A-pillar, is a statistically significant predictor. Occupants in non-catastrophic crashes with damage patterns that include the front 2/3 of the vehicle are more than twice as likely to sustain aortic tear as occupants in vehicles that do not exhibit that damage pattern. This is significant as it can be used as an on-scene indicator of a possible aortic injury, allowing for better triage.

INTRODUCTION

Previous research on near-side impacts has shown chest/abdomen to be the most frequently MAIS 3+ injured body region in NASS-CDS, with arterial injuries as the largest source of AIS 6 injuries in this crash configuration. [1] Another study identifying crash characteristics indicative of aortic tear has shown near-side impacts as a statistically significant factor. [3]

The William Lehman Injury Research Center (WLIRC) performs in-depth studies on car crashes involving seriously injured occupants. The Lehman Center has studied 168 cases of near-side crashes. In these crashes, 41 sustained aortic injury resulting in 35 fatalities. Of these cases, 21 were transported to the trauma center and 15 survived for more than an hour. Six of these cases were treated successfully with no long-term impairment. Proper identification and treatment of the injury may have prevented the high level of mortality of these occupants.

Near-side impacts account for sixty percent of aortic tear cases in the WLIRC database. While the average delta-v for aortic tear cases in frontal impacts is 54.7 km/h (34 mph), the average delta-v for nearside impacts is much lower at 46.7 km/h (29 mph). WLIRC data shows aortic tear occurring more frequently in near-side impacts and at lower crash severities, making it a particular area of interest for further study. Additionally, aortic tears were not observed in the cadaver tests that were used to develop the side impact dummy injury criteria. Consequently, the present test and dummy criteria may not predict these injuries.

Occupants who survive initially but have latent aortic injuries have a high fatality risk when the injury is undetected. However, if detected and treated promptly, the outcome is generally excellent with no long-term impairment. Latent aortic injuries are often difficult to detect at the scene or in the emergency room. Twenty-three percent of latent aortic injury cases in near-side vehicle-to-vehicle crashes in the WLIRC database did not meet traditional physiologic trauma criteria at the scene, although most were transported to the trauma center under the paramedic judgment of high suspicion of injury. Fifty percent of these occupants subsequently died from the injury. A method for using crash parameters to predict the potential presence of latent aortic injuries is vitally needed to alert first-care providers and emergency room physicians of the critical injury that is not apparent from the standard physiological measurements of blood pressure, temperature, respiration rate, etc.

Six percent of near-side vehicle-to-vehicle cases in the WLIRC data did not meet trauma criteria and were initially transported to other hospitals, requiring transfer to the trauma center. By looking at crash characteristics and understanding their influences on incidence of aortic tear, occupants suspect of the injury may be transported to a level-1 trauma center and screened for aortic tear, possibly reducing the level of mortality associated with these injuries.

METHODS AND DATA SOURCES

This study uses three main sources of data: National Automotive Sampling System (NASS-CDS), Crash Injury Research & Engineering Network (CIREN), and William Lehman Injury Research Center (WLIRC). NASS-CDS is a nationally representative sample of crashes in the United States in which at least one of the vehicles involved in the crash required towing from the scene. The Crash Injury Research and Engineering Network (CIREN) is a network of ten level-1 trauma centers located throughout the United States that conduct detailed investigations of occupants seriously injured from car crashes. While NASS-CDS gives representative information of all tow-away crashes in the United States, CIREN provides a more detailed examination of a subset of crashes with severe or fatal injuries in a particular area surrounding each trauma center. The National Highway Traffic Safety Administration maintains these databases and provides access to the public. WLIRC is one of the ten CIREN centers. They maintain a separate database of their cases in parallel to the NHTSA CIREN database. This WLIRC database was used in addition to the CIREN and NASS-CDS databases.

Each NASS case is assigned a weighting factor that permits the data to be extrapolated to predict national averages. In this paper, only unweighted data is used so that it can be compared with the unweighted data from the William Lehman Injury Research Center and other CIREN Centers. No attempt is made to extrapolate this unweighted data to the national population.

Detailed data were collected by WLIRC from 1991-2000 for near-side vehicle-to-vehicle crashes. Qualitative analysis of these cases was performed to assess the scope and trends of aortic tear in near-side crash environment. Following this qualitative analysis, the data from WLIRC, NASS-CDS and CIREN were merged to examine a larger set of near-side crashes for statistical analysis. The data were narrowed to include only front-seat occupants involved in vehicle-to-vehicle crashes. Data from NASS 1997-2000 were treated as unweighted so each case is considered individually, with no representation of the population. The resulting data set includes 679 near-side vehicle-to-vehicle crashes. Fifty-eight of these sustained aortic tear. Variables for each crash pertaining to the occupant, restraint use, and crash information were compiled to understand the contribution of the variables in the incidence of aortic tear. Table 1 shows the variables used in the analysis. Occupant information including age, height, weight and gender were considered along with seat belt use and frontal air bag deployment. Crash characteristics such as delta-v, crush, intrusion and damage location were examined. Damage location, denoted DL, is a binary variable that indicates the presence of damage that includes the front 2/3 of the vehicle. This damage pattern is denoted in the SAE Collision Deformation Classification as Y, for damage to the front 2/3, and D, for damage distributed along the length of the vehicle, Figure 1.[5] This damage pattern has been noted as common in cases of aortic tear.[2] Finally, a binary variable indicating the striking vehicle as an SUV/Lt.Truck/Van or Large Truck/Bus was also included.

Table 1.

Variables examined in regression analysis

Variable	Type	Description
Age	Continuous	Occupant age in years
Ht	Continuous	Occupant height in meters
Wt	Continuous	Occupant weight in kilograms
Sex	Binary	Occupant gender
Belt	Binary	Proper use of 3-point belt
AB	Binary	Frontal air bag deployment
Delta-v	Continuous	Delta-v in km/h
DL	Binary	Damage located in Y or D
Crush	Continuous	Maximum crush in cm
Intrusion	Continuous	Maximum intrusion into occupant compartment in cm
SUV	Binary	Striking vehicle is an SUV/Lt.Truck/Van or Large Truck/Bus

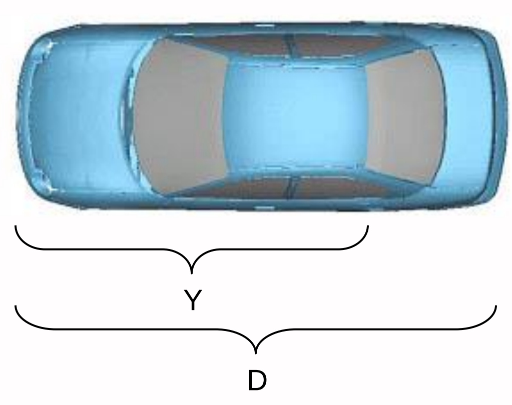

Figure 1. Definition of damage location, DL, includes Y and D damage patterns.

Some crashes are so severe in nature that an occupant may have sustained aortic tear but will also have sustained other life threatening injuries. In such cases, it is likely that the occupant would sustain other injuries that would result in physiological signs and increase the likelihood of appropriate triage to the trauma center. It may be unreasonable to expect that proper triage of an aortic tear will improve the survivability of the crash. For this reason, the data in this analysis were divided into two groups: one group contains crashes of all severities, the second contains a subset of crashes with a delta-v of 48.3 km/h (30 mph) and below. By examining these as two separate groups, it is possible to see the important factors in all aortic tear cases, but more importantly, highlight the parameters that first responders and emergency care providers should look for in lower severity crashes.

Univariate logistic regression was performed on both sets of data to understand the significance of individual variables on the incidence of aortic tear. Multivariate analysis was also performed to understand the combined effects of variables. All regression analysis was carried out in SAS/STAT version 8.01. Significance level for entry into the models was set at $p<0.05$.

RESULTS

Summary of WLIRC Crashes

From 1991-2001, the William Lehman Injury Research Center collected and studied 160 cases of near-side crashes. In these crashes, 41 sustained aortic tear resulting in 35 fatalities. Twenty-one of these cases were transported to the trauma center and 15 survived for more than an hour. Six of these cases were treated successfully with no long-term impairment. Eight of these occupants did not meet traditional trauma triage criteria and were either taken to the trauma center under high suspicion of injury or transferred from another hospital.

Ninety-seven percent of the WLIRC cases had concurrent AIS 3+ injuries. Each occupant averaged 3.9 AIS 3+ injuries in addition to the aortic tear. Ninety-seven percent sustained thoracic injuries, 56% had head injuries and 47% had abdominal injuries. Rib fracture was the most common concurrent thoracic injury (77%), followed by lung contusion (59%) and heart injuries (27%). Abdominal injuries were primarily liver (32%) and spleen (18%) lacerations. Pelvic fractures were present in 27% of cases.

Eighty percent of the near-side crashes were vehicle-to-vehicle impacts, with the remaining twenty involving fixed objects. The overall rate of aortic tear in vehicle-to-vehicle crashes was 0.27, slightly greater than for fixed objects, at 0.22. The average delta-v for aortic tear cases in vehicle-to-vehicle near-side crashes was 44.4 km/h (27.6 mph) and ranged from 22.5 to 72.4 km/h (14 to 45 mph). Fixed object aortic tear crashes had an average delta-v of 59.2 km/h (36.8 mph) and a range from 38.6 to 80.5 km/h (24 to 50 mph). In the WLIRC near-side data, vehicle-to-vehicle crashes are more common, have a higher incidence of aortic tear and aortic tear cases have a lower average delta-v than fixed object crashes.

For vehicle-to-vehicle near-side crashes, the average age of the occupants with aortic tear was 49 years-old. The youngest was 15 and the oldest 89. Forty-four percent of occupants were properly restrained using the available 3-point belt. Frontal air bags deployed in 24 percent of cases. One-hundred percent of cases had more than six inches of intrusion into the occupant compartment. Sixty-eight percent of the vehicles exhibited Y or D damage patterns.

All Crashes

Following the initial summary of the detailed cases at WLIRC, data were combined from NASS, CIREN and WLIRC for statistical analysis. All crashes were analyzed initially, followed by an analysis of the subset of lower severity, non-catastrophic crashes. For each data set, univariate analysis examined the effect of individual parameters and multivariate analysis examined the effect of variable combinations and interactions on the incidence of aortic tear. The univariate and multivariate analysis was performed on all crashes followed by the subset of lower severity crashes.

Univariate analysis showed age as the only occupant factor significant in prediction of aortic tear for crashes of all severities. Crash factors of delta-v, intrusion, crush, and SUV were all significant. Factors including height, weight, gender, 3-point belt use and frontal air bag deployment were not statistically significant. Table 2 shows the odds ratios for each of the individual predictors.

Table 2.

Significant individual predictors of aortic tear in all crashes

Variable	Odds Ratio	P value
Age	1.023	<0.01
Delta-v	1.067	<0.01
Crush	1.009	<0.01
Intrusion	1.073	<0.01
SUV	1.864	0.02

For the multivariate analysis, a stepwise selection procedure was used to find an optimized set of parameters that were most predictive of aortic tear. Multivariate analysis takes the effects of interactions of the variables into consideration. While some variables may be significant when looked at individually, they may not be significant when combined with other variables. Table 3 shows the significant variables for prediction of aortic tear in near-side vehicle-to-vehicle crashes for all crash severities. The most important factors for prediction of aortic tear are the occupant's age, the delta-v of the crash and intrusion into the occupant compartment.

Table 3.

Combination of predictors most indicative of aortic tear in all crashes

Variable	Odds Ratio	P value
Age	1.032	<0.01
Delta-v	1.038	<0.01
Intrusion	1.064	<0.01

Non-Catastrophic Crashes

Non-catastrophic crashes were considered as crashes with a delta-v of 48.3 kph (30 mph) or below. These crashes were analyzed in separate regression models to understand which parameters are important for crashes that may appear less severe and may not result in a trauma alert. For these crashes, the univariate analysis found occupant age, delta-v, crush, and intrusion were all still factors predictive of aortic tear, as seen in crashes of all severities. However, in the non-catastrophic crashes, damage located in the front 2/3 of the vehicle was also predictive of aortic tear. Occupants in crashes with this damage pattern were more than two times more likely to have a resulting aortic tear, Table 4. Three-point belt use approached statistical significance with an odds ratio of 0.539 and a p-value of 0.052.

Table 4.

Significant individual predictors of aortic tear in crashes with delta-v of 48.3 km/h (30 mph) or below

Variable	Odds Ratio	P value
Age	1.03	<0.01
Delta-v	1.105	<0.01
DL	2.261	0.03
Crush	1.009	0.01
Intrusion	1.081	<0.01

The multivariate analysis showed the combination of age, delta-v, intrusion, and damage to the front 2/3 of the vehicle to be most predictive of aortic tear. When the variables of age, delta-v, and intrusion are controlled, occupants in crashes with damage to the front 2/3 of the vehicle were 2.35 times more likely to sustain aortic tear. This model has a 90% accuracy rate with sensitivity of 44% and specificity of 93%.

Table 5.

Combination of predictors indicative of aortic tear in crashes with delta-v of 48.3 km/h (30 mph) or below

Variable	Odds Ratio	P value
Age	1.036	<0.01
Delta-v	1.079	0.05
DL	2.352	0.04
Intrusion	1.069	<0.01

For all crashes examined, 100% of the aortic tear cases sustained intrusion into the occupant compartment. More than 70% had Y or D damage patterns. Frontal air bags deployed in 24 percent of the cases and 47 percent of aortic tear occupants were properly restrained in a 3-point belt. Almost half were females.

Case Study

The following case from the William Lehman Injury Research Center highlights the need for understanding the crash factors that influence aortic tear.

Figure 2. Case vehicle for a 22.5 km/h (14 mph) crash resulting in aortic tear.

The case vehicle was a 1990 Lexus ES-250 equipped with 3-point restraints for both frontal seating positions. The vehicle was equipped with a driver air bag, which deployed in the crash. The 62 year-old male driver was wearing the available 3-point lap and shoulder restraint.

The case vehicle was traveling in a southerly direction, the wrong way on a one-way street. At the end of the street, the driver entered an intersection and attempted to make a left turn to drive in an easterly direction. The case vehicle drove directly across the path of a 1983 Oldsmobile Cutlass, the principal other vehicle (POV), and was struck on the left side by the front of the POV. The driver of the POV saw the case vehicle coming from his right and attempted to avoid a collision by steering to the left. The point of impact began forward of the left front wheel and continued along the front door of the case vehicle. The case vehicle subsequently rotated clockwise and impacted the POV in a side-slap configuration. The case vehicle continued to rotate through a complete revolution and came to final rest facing in a southerly direction. The total delta-v of the crash was 22.5 km/h (14 mph) with a principal direction of force of 10 o'clock, which is consistent with the severity of left-side damage.

Upon impact, the driver moved to the left with respect to the decelerating vehicle and in a path consistent with the 10 o'clock impact. The left front door intruded laterally 21 cm and the driver contacted and loaded the intruding door surface with his left pelvis and left torso. The driver sustained a pelvic fracture and several thoracic injuries, including multiple bilateral rib fractures and a ventricular laceration. The driver also sustained a laceration to the ascending aorta.

Following the impact, the occupant was alert and talking on-scene and did not meet traditional trauma criteria based on physiological criteria. He was triaged to a trauma center based on high suspicion of injury. He arrived at the trauma center 37 minutes post-crash. However, the aortic injury was not properly diagnosed and the occupant died at the trauma center more than an hour after arriving.

The paramedics correctly recognized that the occupant was at risk for occult injury based on the information they found on-scene. The paramedics triaged the occupant to the trauma center based on high suspicion of injury, despite not meeting physiological trauma criteria on-scene. However, the aorta was not screened for injury during the initial evaluation at the trauma center. This crash was a near-side impact with damage to the front 2/3 of the vehicle. There was intrusion into the occupant compartment and the occupant was over 60 years-old. An indication that this injury was likely based on mechanism may have focused attention to the thorax during the initial evaluation at the trauma center, possibly resulting in a better outcome for the occupant.

DISCUSSION

Age, delta-v and intrusion have been highlighted in the past as predictors of aortic tear.[3,4] However, this is the first analysis showing statistical significance of damage beginning forward of the A-pillar. Occupants in vehicles in near-side crashes with delta-v less than 48.3 km/h (30 mph) and with damage patterns that include the front 2/3 of the vehicle are more than twice as likely to sustain aortic tear as occupants in vehicles with delta-v less than 48.3 km/h that do not exhibit that damage pattern. This is significant as it can be used as an on-scene indicator of a possible aortic injury, allowing for better triage.

An examination of the data set of side-impact crashes with delta-v less than 48.3 km/h discloses that about 60% have the front 2/3 damage pattern and about 57% of the MAIS 3+ injuries occur in these crashes. However, 73% of the MAIS 3+ aortic injuries occur in these crashes.

Most side-impact testing of vehicles involves crashes that produce damage to the center 1/3 of the struck car. Crashes that involve damage to the front 2/3 suggest several phenomena that may not be present in crashes with damage to the center 1/3. First, the speed of the struck car may be higher than anticipated by the test that produces only central damage. Second, the initial impact may involve hard structure, well in front of the center of gravity and result in higher rotation rates than anticipated. Third, the phasing and direction of lateral acceleration and intrusion may be different from the test conditions. These differences require additional research to determine which might contribute to aortic injury.

CONCLUSIONS

Age, delta-v and intrusion have been confirmed predictors of aortic tear. In addition, damage to the struck vehicle beginning forward of the A-pillar and continuing into the occupant compartment is a statistically significant predictor. Occupants in vehicles with damage patterns that include the front 2/3 of the vehicle are more than twice as likely to sustain aortic tear as occupants in vehicles that do not exhibit that damage pattern. This is significant as it can be used as an on-scene indicator of a possible aortic injury, allowing for better triage.

First-responders should recognize the need for triage to a trauma center with a screen for aortic injury if the vehicle exhibits the following: damage to the front 2/3, intrusion into the occupant compartment, and an occupant positioned where the side intrusion occurs. The presence of an older occupant in the vicinity of the intrusion further increases the risk of aortic injury.

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