ORIGINAL RESEARCH

Describing a Problem: Rear Seatback Failure and Unsecured Cargo

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Abbreviations:
Δv = velocity
AIS = Abbreviated Injury Scale
CIREN = Crash Injury Research and Engineering Network
ISS = Injury Severity Scale
MVC = motor vehicle crash
NASS-CDS = National Automotive Sampling System-Crashworthiness Data System

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Abstract

Introduction: Currently, there is little in the literature regarding the ability of rear seatbacks to act as a protective barrier from cargo in frontal crashes. However, it has been shown that unrestrained rear passengers pose a danger to front seat occupants. The association of rear seatback failures and intrusions with mortality and serious injury were examined.

Methods: The Seattle CIREN database for restrained, rear-seat passengers in front-end crashes with seatback failure or intrusion was searched. Injury patterns and crash characteristics, including the role of unrestrained cargo were examined. Next, the National Automotive Sampling System- Crashworthiness Data System (NASS-CDS) database was queried for restrained rear-seat passengers in front-end crashes with recorded seat failure or intrusion. Mortality, maximum Abbreviated Injury Scale (AIS) score and mean Injury Severity Scale (ISS) scores were compared with passengers who had no failure or intrusion. Linear regression was used to identify the differences between the groups. Logistic regression was used to estimate the mortality risk associated with seat failure.

Results: There were four CIREN cases that met the criteria. In each case, the occupant suffered significant injury or death. All four of the seat failures were the result of unrestrained cargo striking the seatback. The CDS data revealed a statistically significantly increased mortality (OR = 18.9, 95% CI = 14.0–25.7) associated with seat failure. Both the maximum AIS and mean of the ISS scores were higher in the failure/intrusion group (p <0.0001).

Conclusions: Rear seatback failure/intrusion is associated with increased mortality and injury. Case reports suggest unrestrained cargo plays a significant role in these injuries.

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Introduction

In passenger cars, such as station wagons or sport utility vehicles (SUVs), the cargo area often is contiguous with the passenger compartment. Cargo placed in these areas often is unsecured and, in the event of a collision, may impact the rear passenger seat with high speed. This also is true in vehicles with enclosed trunks. The popularity of fold down rear seats to improve cargo capacity means that the split rear seatback often is the only barrier between the cargo space and the rear passenger.

Currently, in the United States, there is no dynamic testing of the ability that the rear seatbacks must protect occupants during a crash; FMVSS 207, which governs the strength of seat construction, does not require it.[1] This is in contrast to in Europe, where ECE 17 provides for dynamic testing of the passive barrier between the cargo and passenger compartments to ensure passenger safety in the event of a frontal crash.[2] There is little in the literature that suggests that seatback failure (example: seatback folding locks release, the seat back structure

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separates from mounts/anchors), or intrusion from unrestrained cargo results in serious occupant injury or death.

There is evidence that supports that unrestrained rear seat occupants increase the risk of death or serious injury to front-seat passengers.[3–6] It is hypothesized that similarly, unrestrained cargo increases the risk of death or serious injury for rear seat occupants in front-end collisions. The Crash Injury Research and Engineering Network (CIREN) was developed under the [US] National Highway Traffic Safety Administration (NHTSA) to provide detailed crash site analysis and occupant specific injury data to improve the prevention, treatment, and rehabilitation of motor vehicle crash injuries. The Seattle CIREN database was reviewed, and crashes in which there was intrusion or failure of the rear seat back due to unsecured cargo were examined. An analysis was conducted of the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) to determine the national incidence of death and serious injury due to seatback intrusion and failure.

Methods

This study was done in two phases. Phase 1 consisted of a review of the Seattle CIREN database for representative cases in which intrusion of cargo into the rear seatback resulted in death or serious injury of the occupant. This database contains detailed data on motor vehicle crashes including occupant position, measurements of seatback intrusion and failures, and clinical data on injury severity and outcome.

In Phase 2, the NASS-CDS database was utilized to estimate the population-based impact of rear-seat intrusion or failure on outcomes in front-end motor vehicle collisions.

Phase 1

An in-depth review of local cases with rear seatback failure or intrusion using the CIREN. The Harborview Injury Prevention and Research Center is one of eight centers contributing to this resource. The database (1996–present) consists of detailed case reviews of serious motor vehicle collisions, establishing patterns of injury and correlating clinical findings with crash scene kinetics. Each case contains approximately 650 crash elements and 250 medical elements for each occupant. The crash investigator records details of the crash scene (e.g., skid marks, scaled drawing of impact locations) that are used to reconstruct the mechanics of the collision. The vehicles are inspected to assess the damage severity, interior component intrusion, restraint use, and occupant contact marks. Prehospital data are obtained from emergency medical services (EMS) records. Patient observation teams at the trauma center record details of the patient's hospital course, radiological findings, operations, and outcome. The crash investigator, bioengineers, physicians including a trauma surgeon and radiologist, and a research nurse review each case and establish the mechanism of injury based on the clinical and crash investigation findings.

The database was queried for front-end collisions with restrained, rear-seat occupants and seatback failure or intrusion to identify the injury pattern and severity of the seatback failure. Injury patterns were examined and correlated to the seatback intrusion or failure.

Phase 2

The NASS-CDS project operated by the NHTSA is a probability sample of all police-reported tow-away motor vehicle crashes (MVCs) that resulted in injury, death, or property damage each year in the US. A crash investigation is performed that is similar to that performed in CIREN. All injuries are documented and scored using the Abbreviated Injury Severity (AIS)–90 coding. Data on approximately 5,000 MVCs are collected annually. These data can be weighted to provide a national estimate.

The NASS-CDS database for front-end collisions from 1993–2006 were searched. Analysis included restrained, rear-seat occupants, in which there was a seatback intrusion or failure. The mortality, maximum Abbreviated Injury Scale (AIS) score, and Injury Severity Scale (ISS) score were compared between occupants who experienced seat intrusion or failure and those who did not. Linear regression was used to test for statistically significant differences between the two groups. Logistic regression was used to estimate the increased risk of death associated with seatback failure.

Results

Phase 1: CIREN

Four cases were identified within the Seattle CIREN database where a frontal collision resulted in rear seatback intrusion from unsecured cargo (Table 1). In each case, serious injury to the occupant occurred, which was attributed to the seatback intrusion and any subsequent failure.

Case 1—A four-year-old boy was a restrained (lap belt only, no booster seat), middle, rear-seat passenger in a 1997 sedan that was involved in a frontal collision with a tree, at a Δv (velocity) of 28 mph. The trunk of the vehicle contained groceries that impacted the back of the rear seat. The back of the seat intruded forward onto the child and rescuers found him pinned under the seatback, covered in groceries. The boy was taken to a trauma center where his injuries were identified as a cervical spinal cord contusion with C1-C2 dislocation, a thoracic spinal cord contusion T10, T11, and a left femur shaft fracture.

During the case review, the mechanisms of the boy's injuries were identified. His cervical injury was attributed to striking the front seatback with his head as he buckled forward over the lap belt. The fact that the seatback was pushed forward by the groceries may have contributed to this extension. For the femur fracture, it was determined that the force of the seatback intrusion and cargo into the lower back of the child created a bending moment of the femur with the lap belt.

Case 2—A six-year-old boy was riding the second rear seat position in a 2000 sports utility vehicle involved in a frontal crash with a tree stump (Figure 1). The Δv was 32 mph. While the boy was restrained with a lap belt, the shoulder portion of the restraint was behind his back at the time of

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Case	Vehicle Type	Δv (mph)	Age/Gender	Injuries	Death
1	Sedan	28	4M	Cervical Dislocation Cord Contusion Femer Fx	N
2	SUV	32	6M	TBI Cervical Fracture Cord Contusion Abd. Aortic Laceration	Y
3	Sedan	35	31F	Lumbar Cord Laceration Retroperitoneal Hematoma Rib Fractures	Y
4	Sedan	35	21F	TBI Cervical Cord Contusion Lung Contusion Lumbar Fx. Cord Contusion	N

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Table 1—Case occupants (Δv = velocity, Adb = abdomen; Fx = fractures, TBI = traumatic brain injury)



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Figure 1—Photographs depicting front-end damage and failure of the seatback as well as intrusion in the lumbar area.

the collision. Behind the rear seat there was a large quantity of cargo that was thrown forward as a result of the impact. This cargo pushed the seatback forward onto the child. The intruding seatback loaded the shoulder belt portion of the child's restraint causing the lap belt to tighten over his abdomen. The boy was airlifted to a trauma center where his injuries were a C3 fracture/dislocation with cord laceration, thoracic spine contusion with dislocation, an abdominal aorta laceration, a jejunum perforation, intracranial hemorrhage, and a skull fracture. He died of his injuries at the hospital.

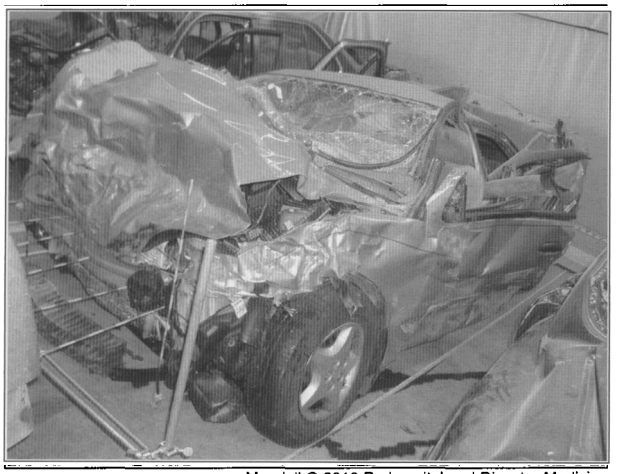
Analysis of the crash revealed the mechanism of the child's abdominal and thoracic injuries. They were attributed to the increased loading of the restraint system by the deformation of the seatback. The seatback pushed on the child and the shoulder belt causing significantly more loading and tension on the system than the occupant loading alone would have caused. The child's head and c-spine injuries also were attributed to some contact with the front seat back as he buckled forward. There was no direct injury to the child from the cargo itself.

Case 3—In this case, a 2002 sedan was involved in a frontal collision with side of another sedan at a Δv of 35 mph (Figure 2a and 2b). The case occupant is a 31-year-old woman who was in the left second seat. She was restrained with a manual lap and shoulder harness. The trunk of the vehicle contained two 80-pound bags of concrete mix. The force of the collision caused these bags to punch through the seat back structure that had separated. This also resulted in 40 cm/16" of seatback intrusion in the middle seat position and 30 cm/12" of intrusion into this case occupant's seated position. With the entire seatback punched out of place and intruding with the cargo, her seatbelt became a fulcrum over which her body bent. Her injuries included right 1–2 rib fractures, left 8–11 rib fractures, retroperitoneal hematoma, transection of the vertebral column at L1-L2, tearing of the paraspinus muscles, and abdominal skin avulsion. Her injuries were fatal.

Crash analysis revealed that the most probable cause of the occupant's injury was flexion over her fixed seatbelt as unsecured cargo intruded into the seatback from behind her.

Case 4—This case occupant is a 12-year-old girl who was located in the right second seat in the same 2002 model sedan described in Case 3 (Figure 2a and 2b). She was restrained with lap and shoulder harness in place. Ten centimeters of intrusion into the right seatback was identified during crash reconstruction. The girl's injuries were extensive including closed head injury, facial fractures, cervical spinal cord contusion, bilateral lung contusions, L4 burst fracture with cord contusion, massive small bowel lacera-

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Figure 2a—An exterior view of the case vehicle demonstrating front-end damage.



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Figure 2b—Top down view of the rear seat showing significant intrusion.

	Seatback Failure or Intrusion	
	Yes	No
Mean Age	17.5 (95% CI = 13.8–21.2)	15.3 (95% CI = 13.9–16.7)
Gender		
Male	715	7,438
Female	597	7,000
Body Type		
SUV	140 (0.32%)	2,468 (15.4%)
Sedan	1,134 (2.83%)	11,557 (78.5%)
Wagon/Other car	49 (0.01%)	631 (2.92%)
Mean Δv kph	29.0 (95% CI = 26.4–31.7)	19.1 (95% CI = 18.2–21.2)

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Table 2—Demographic characteristics of subjects and vehicles in the NASS-CDS data (Δv = velocity; SUV = Sport Utility Vehicle)

tion, massive mesenteric laceration, massive colon laceration, retroperitoneal hematoma, liver contusion, and abdominal skin avulsion. Ultimately, she survived these injuries. Review of this crash indicated that her lumbar spine and abdominal injuries were likely due to loading on the lap belt of her restraint system as the cargo impacted her seatback causing it to intrude forward into her back. The occupant was flexed over the lap belt resulting in severe abdominal injury. Her bilateral lung contusions were attributed to contact with the intruded seatback. The cause of her head and spine injury could not be definitively determined.

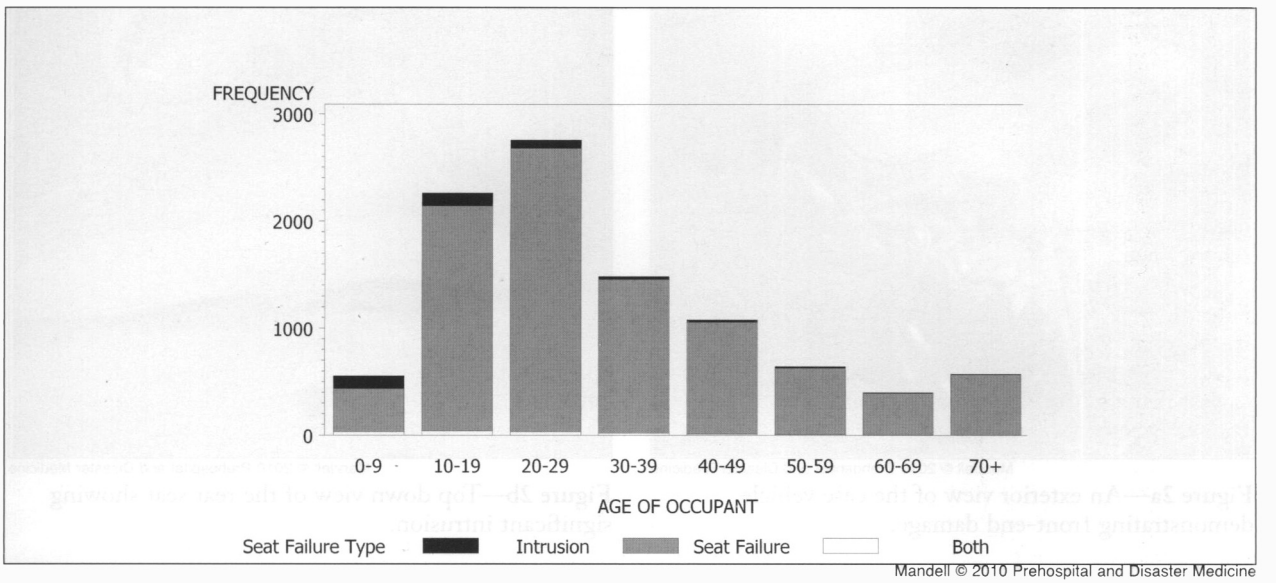
Phase 2: NASS-CDS

Information for a total of 16,017 restrained, second seat passengers involved in frontal collisions between 1993 and 2006 was in the database (Table 2). The Δv was higher for occupants who experienced some seatback failure than for those that did not. This could be because the force of the crash itself results in the failure. However, if this were true, the Δv should be much higher than 29 kph, which is below the speed commonly used in crash testing. It also may be that this difference is because the higher crash forces propel cargo at a higher velocity resulting in loading of the seatback. Seat failure or intrusion was identified in 1,326 (8.3%) of the cases in the database. The weighted national estimate for the number of seat failures and intrusions was 217,712 for the period of study.

It is notable that the majority of passengers who experience seat failure or intrusion were in the youngest age groups (Figure 3). Of the observed cases of intrusion or failure, 32.8% were in the 0–9 year-old age group, 30.5% in the 10–19 year-olds, and 19.7% in 20–29 year-olds. This pattern indicates that it is primarily younger occupants that are experiencing seatback malfunction or intrusion. This is likely because younger individuals and children are more likely to be rear-seat passengers.

Over the 13-year study period, there was a weighted CDS figures estimate of 9,500 deaths in the US among rear passengers who experience seat failure or intrusion for a mortality rate of 4.38%. For those passengers without intrusion, the rate of mortality was 0.24% (Table 3). The odds of death among occupants who experienced seatback intrusion or failure were 18.9 times those who did not. The maximum AIS score for occupants with intrusion or failure

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Figure 3—Seat failure by occupant age group

	Seatback Failure or Intrusion		
	Yes	No	
Mortality			
Yes	202 (4.38%)	289 (0.24%)	OR = 18.9 (95% CI = 14.0–25.7)
No	1,121 (95.6%)	14,367 (99.8%)	
Mean Maximum AIS score	1.17 (95% CI = 1.02–1.32)	0.35 (95% CI = 0.30–0.39)	p <0.0001
Mean ISS score	3.99 (95% CI = 3.1–4.9)	0.66 (95% CI = 0.59–0.73)	p <0.0001

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Table 3—Mortality, maximum AIS, and ISS (AIS = Abbreviated Injury Scale; ISS = Injury Severity Scale)

also was higher, 1.17 (95% CI = 1.02–1.32) compared with 0.345 (95% CI = 0.30–0.39) for those without it. For the ISS, the mean values of the scores were 3.99 (95% CI = 3.12–4.85) and 0.658 (95% CI = 0.58–0.73) for those with intrusion or failure and those without, respectively. For both the mean of the maximum AIS score and the mean values of the ISS score, the differences were statistically significant at p <0.0001. For children <15 year of age, 3.24% of those with seat failure or intrusion died compared with 0.1% of those without it. This translates to an estimated 230 deaths per year for children <15 years of age with seatback intrusion or failure during the period of study.

Discussion

In recent years much attention has been paid to the dangers faced by passengers in the front seats of motor vehicles. This is true particularly regarding children. By comparison, less is known about dangers unique to passengers in rear seat positions. In this case series, four cases are presented in which cargo moved forward due to a frontal impact and overwhelmed the barrier between the cargo and the passenger, in each case, the rear seat. Compression between the seatback and the immobile seatbelt was a characteristic feature of these cases. The result is a trapping or pinning of the body between the intruding seatback and seatbelt causing compressive forces to the abdomen, chest, and spine. A similar injury pattern was described in a case report by Byard *et al* where two children in a rear seat were crushed by computer equipment that projected forward and intruded into the seatback. The rear seatback failed to protect passengers from cargo placed behind them.[7]

The dangers posed to front seat passengers by unrestrained rear seat occupants are well-established.[3–5] Forces generated by the rear occupant acting as a projectile into the back of the front seat increase the risk of death for restrained front seat occupants. There is less information on the forces generated by cargo as a projectile into restrained rear seat passengers. One reason for this is that there is little data on the type of cargo or how frequently it is carried. While NASS-CDS data records seat failures and intrusion, details regarding involved cargo are not routinely collected. As a result, a limitation of this NASS analysis is that data cannot directly attribute the seatback failure cases to an impact from cargo. It is possible that the seatback may have failed due to crash forces alone.

By placing cargo behind the rear seatback during crash testing, European crash tests have demonstrated that in frontal crashes, there can be significant intrusion into the

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rear passenger seat. This intrusion leads to loading of the seatbelt and can result in injury to children.[8] The ECE 17 regulations currently require dynamic crash testing with 36 kg (79.2 lbs) of unsecured cargo in the cargo area. Some investigators have suggested that this volume of cargo is inadequate, and crash tests performed with larger amounts of cargo (four standard suitcases) have shown significant damage to rear seatbacks and the restrained crash test dummies in them.[2]

The CIREN and NASS-CDS data document the amount of cargo weight, but unfortunately, the stored location in the vehicle is not identified. While the authors cannot quantify how much cargo poses a threat to rear occupants, it is clear that a substantial number of seatback intrusions and failures occur on US roadways. Further, at least in some cases, there is an association between the shifting cargo, seat intrusion, and severe morbidity and mortality. It also is important to note that the majority of these injuries occur in children. It seems likely that at least in some cases, a more rigorous barrier between cargo and occupants may prevent injury or death. Improved methods of securing cargo also may be effective. Further research in this area is warranted, perhaps beginning with more comprehensive data collection of cargo type, weight, and stored location in current data collection systems. Recently, the NASS and CIREN systems have begun to document seatback deformation by cargo. These new data may help further define the association between cargo and seat failures or intrusion and should help delineate preventive measures in the future.

Conclusions

The results suggest that there is an association between rear seatback failure or intrusion and increased mortality in front impact crashes. Injury severity also is associated with seat failure or intrusion. Review of detailed CIREN case studies suggests that unrestrained cargo in the rear of the vehicle contributes to this increased morbidity and mortality. Improved data collection pertaining to cargo within the vehicle will help delineate this problem further and identify potential mechanisms for injury prevention.

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