U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

NHTSA

DOT HS 812 883

May 2021

Occupant Safety in Vehicles Equipped With Automated Driving Systems, Part 2: Crash Safety Considerations For Out-of-Position Occupant Posture in Vehicles With Automated Driving Systems - Field Data Investigation

DISCLAIMER

This publication is distributed by the U.S. Department of Transportation, National Highway Traffic Safety Administration, in the interest of information exchange. The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration. The United States Government assumes no liability for its contents or use thereof. If trade or manufacturers' names are mentioned, it is only because they are considered essential to the object of the publication and should not be construed as an endorsement. The United States Government does not endorse products or manufacturers.

NOTE: This report is published in the interest of advancing motor vehicle safety research. While the report may provide results from research or tests using specifically identified motor vehicle models, it is not intended to make conclusions about the safety performance or safety compliance of those motor vehicles, and no such conclusions should be drawn.

Suggested APA Format Citation:

Shaw, G., Poplin, J., McMurry, T., Kong, K., Lin, H., & Panzer, M. B. (2021, May). *Occupant safety in vehicles equipped with automated driving systems, Part 2: Crash safety considerations for out-of-position occupant posture in vehicles with automated driving systems - Field data investigation* (Report No. DOT HS 812 883). National Highway Traffic Safety Administration.

This report is one of three deliverables under Contract DTNH2215D00004/0002 awarded to the Center for Applied Biomechanics at the University of Virginia, Charlottesville, Virginia. The three are reports are titled as follows.

Occupant Safety in Vehicles Equipped With Automated Driving Systems, Part 1: Initial Evaluation of Usability, Stability, and Injury Prediction Capabilities

Occupant Safety in Vehicles Equipped With Automated Driving Systems, Part 2: Crash Safety Considerations for Out-of-Position Occupant Posture in Vehicles With Automated Driving Systems - Field Data Investigation

Occupant Safety in Vehicles Equipped With Automated Driving Systems, Part 3: Biofidelity Evaluation of GHBMC M50-OS Against Laboratory Sled Tests

The NHTSA citations and DOT HS report numbers for these three reports are as follows.

Lin, H., Gepner, B., Wu, T., Forman, J., Shaw, G., & Panzer, M. B. (2020, February). Occupant safety in vehicles equipped with automated driving systems, Part 1: Initial evaluation of usability, stability, and injury prediction capabilities (Report No. DOT HS 812 904). National Highway Traffic Safety Administration.

Shaw, G., Poplin, J., McMurry, T., Kong, K., Lin, H., & Panzer, M. B. (2020, February). Occupant safety in vehicles equipped with automated driving systems, Part 2: Crash safety considerations for out-of-position occupant posture in vehicles with automated driving systems - Field data investigation (Report No. DOT HS 812 883). National Highway Traffic Safety Administration.

Poulard, D., Lin, H., & Panzer, M. B. (2020, February). Occupant safety in vehicles equipped with automated driving systems, Part 3: Biofidelity evaluation of GHBMC M50-OS against laboratory sled tests (Report No. DOT HS 812 905). National Highway Traffic Safety Administration.

1. Report No. DOT HS 812 883	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Occupant Safety in Vehicles Equipped With Automated Driving Systems, Part 2: Crash Safety Considerations for Out-of-Position Occupant Posture in Vehicles With Automated Driving Systems - Field Data Investigation		5. Report Date May 2021 6. Performing Organization Code
7. Authors Matthew B. Panzer, Principal Investigator., Greg Shaw, Jerry Poplin, Tim McMurry, Kevin Kong, Hongnan Lin		8. Performing Organization Report No.
9. Performing Organization Name and Address Center for Applied Biomechanics 4040 Lewis and Clark Drive Charlottesville, VA 22911		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTNH2215D00004/0002
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes
James Saunders was the COR for this project.

16. Abstract
One of the main advantages of automated driving systems (ADS) is that they promise to substantially reduce the frequency and severity of crashes. While there is optimism as to their ultimate safety benefit, there will likely be a transition period from human-driven to computer-driven vehicles that may bring new, and potentially increased, risks. Occupants of vehicles equipped with high- or fully automated driving systems will be free to read, converse, and sleep. Vehicle interiors will likely accommodate these activities by offering reclining and possibly rotating seats. These sitting postures and positions are now considered out-of-position (OOP) and are likely detrimental to the performance of occupant safety systems such a restraint belts and air bags. In order to investigate the risk of alternative/out-of-position postures, this study investigated OOP posture frequency and injury risk for the current vehicle fleet via literature review and database analyses.

17. Key Words	18. Distribution Statement Document is available to the public from the National Technical Information Service, www.ntis.gov.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 143	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

Executive Summary

One of the most attractive advantages of automated driving systems (ADS) is that they promise to substantially reduce the frequency and severity of crashes (Litman, 2016; Hayes, 2011; Fagnant & Kockelman, 2013; Levinson, 2015). While there is optimism as to the ultimate safety benefit associated with ADS, there will likely be a transition period from human-driven to computer-driven vehicles that may bring new and potentially increased risks.

Occupants of vehicles equipped with high- or fully automated driving systems will be free to read, converse, and sleep. Vehicle interiors will likely accommodate these activities by offering reclining and possibly rotating seats. These sitting postures and positions are now considered out-of-position (OOP) and are likely detrimental to the performance of occupant safety systems such a restraint belts and air bags.

In order to investigate the risk of alternative/out-of-position postures, this study investigated OOP posture frequency and injury risk for the current vehicle fleet via literature review and database analyses.

Out-of-Position Occupants in the Current Vehicle Fleet

A search carried out with NHTSA's National Automotive Sampling System (NASS) database found that only 0.5 percent of the case subjects surveyed rode OOP, which was consistent with the findings of Disanaike et al., 2008.

In terms of occupant characteristics, a few differences such as age, seating position, and belt use were observed, which showed statistically significant differences between in-position and OOP occupants. That OOP occupants were younger, less likely to be drivers, and less likely to be belted is not unexpected. Drivers must be older than our search minimum of 13 years old and, usually, in-position and less able to assume various postures, given their need to control the vehicle. It is likely that some alternative postures may make belt use uncomfortable or inconvenient.

Although the focus of past studies indicated that "Lying back in a reclined position" would be the most common OOP posture, the NASS analysis results suggest that "Sitting sideways or turned" was coded for almost as many occupants (0.18% turned versus 0.20% lying back). When considering only belted occupants, more ride in the turned posture (0.15% versus 0.12%). It is possible that occupants spend almost as much time turning multiple times, for example, to attend to children in the back seat or a short-term event, than they do reclined sleeping on a long trip, an infrequent event of longer duration.

Further insights as to the reclined sleeping posture were provided by images taken of sleeping volunteers (Lopez-Valdes et al., 2011). All the right front passenger seat volunteer test subjects moved their heads during the test sessions. Most rotated and/or leaned their heads left and right while others nodded forward or extended rearward. Some leaned their heads far enough to the right to place their faces behind the shoulder belts. Our Crash Injury Research (CIREN) case study revealed that most of the sleeping occupants may have been awakened and moved and/or braced prior to the crashes, making it very difficult to know actual pre-crash occupant posture.

Figure 1 summarizes the OOP postures discussed in the literature and that we found identified in the CIREN and NASS databases. The "Feet on the I.P." and the "Legs crossed reading" postures were included as postural variations that may affect occupant kinematics and injury risk.

Injury Risk

Past studies warned that riding in an alternative posture such as substantially reclined increases injury risk for belted occupants due to altered belt fit and the potential to be in the path of deploying air bags. Poor belt interaction can result in neck and cervical spine injuries due to shoulder belt loading as well as abdominal and lower extremity injuries due to submarining (Rehm & Goldman, 2001, Dissanaike et al., 2008, Thorbole, 2015).

Four of the seven CIREN case study subjects reported to be in a reclined posture pre-crash sustained both cervical spine and abdominal injuries. CIREN investigators indicated that altered shoulder and lap belt fit were contributing factors. In other cases, the investigators thought that poor belt fit due to reclined posture may have degraded belt restraint and contributed to subject injuries.

While the CIREN case study reflected past studies that found reclined posture to be associated with increased injury risk, similar information was not found for the turned posture. For no occupant did the CIREN case investigator attribute the occurrence or severity of the injury to the turned posture. While it is possible that this posture, that alters belt fit and occupant orientation relative to air bags, does increase injury risk, we were unable to find supporting evidence either in the literature or in the CIREN database.

While there is sufficient evidence that some alternative postures may increase injury risk in a crash, the increased risk has not been quantified adequately. Our analyses failed to yield significant results regarding increased injury risk associated with OOP because the number of OOP subjects in the database was too low. However, in the matched pair study, a trend was identified suggesting that OOP occupants seemed to be injured at a higher rate although the difference was not statistically significant. Table 1 summarizes the OOP postures that past studies and field data analyses suggest are of concern due to their relative frequency and/or injury risk.

The NASS Study and Injury Patterns for In-Position and Out-of-Position Occupants study did not find that OOP was related to increased injury risk. Apparently, the younger average age of the OOP occupants was sufficient to reduce their injury risk enough to offset the increased risk reported for the OOP posture and the well documented risk associated with being unbelted (belt use was significantly lower for OOP occupants). This suggests that the increased risk associated with OOP is substantially lower than that due to the 10-year age difference for the older in-position occupants.

Injury Patterns

The findings of our four injury pattern studies are inconsistent from study to study and inconsistent both with our other studies and with prior research publications. For example, the first study found that OOP subjects had fewer injuries than in-position subjects for the head, neck, thorax, upper extremity, and pelvis. This finding was inconsistent with that of the second study that used the matched pair method to ensure similar subject characteristics between the two groups.

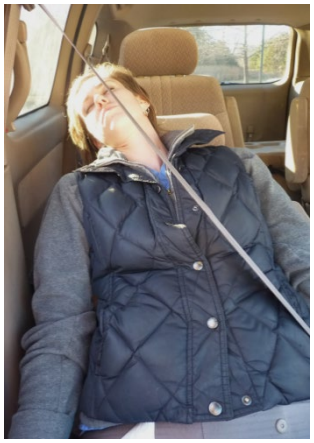
Assuming that many OOP subjects sit reclined and that a reclined posture increases the chances for submarining and the associated injuries to the abdomen due to lap belt loading, to the neck and cervical spine due to shoulder belt loading, and to the lower extremities due to a poorly restrained lower body, we expected all of our studies to find increased abdominal, neck, and lower extremity injuries. The results were mixed with only the second study finding an increase in injuries for all of these body regions. Study three, while finding an increase in OOP lower extremity injuries, did not find an increase in abdominal injuries, most commonly associated with submarining. Study four identified head injuries as much more common for OOP occupants. As head injuries, at least those sustained when the head whips forward over the shoulder belt, may occur for a submarining occupant, the fact that this study did not find an increase in abdominal injuries was puzzling.

While the findings were inconsistent, there was a consistent limitation for the four studies. As was the case for all of our NASS database investigations, the injury pattern studies suffered from a low number of OOP subjects and subject injuries. The low number of OOP subjects and subject injuries limited the statistical power to test for trends or to demonstrate statistical significance in the differences between OOP and in-position occupant injury patterns using the CIREN and NASS databases.

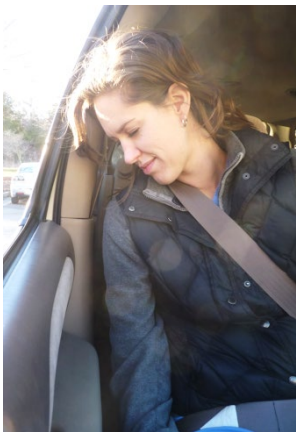
Conclusions

The NASS and CIREN database analyses suggest that occupants in the current vehicle fleet seldom ride OOP. This low number of OOP occupants and injuries limited the statistical power to test for trends or to demonstrate statistical significance in the differences between OOP and in-position occupant injuries and injury patterns. However, the number of OOP riders will likely increase with increasing driving automation control because all occupants will have the freedom now enjoyed by the passengers to relax, recline, or turn to interact with others. Because current restraints have been developed to work most effectively for occupants seated in a midline, upright posture, it is likely that restraint performance will degrade and injury risk will increase as OOP postures become more common. Increased OOP injury risk is supported, if not definitively, both by prior studies and by our CIREN case study and NASS matched pair study.

Partial Recline, Midline



Partial Recline, Leaning Right, Head Behind Shoulder Belt



Partial Recline, Leaning Right, Head in Front of Shoulder Belt

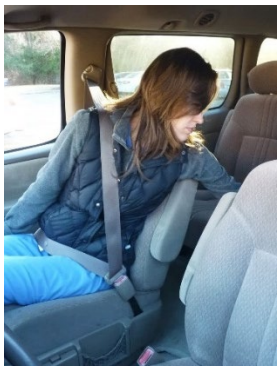
Partial Recline, Leaning Left, Shoulder Belt Path Lateral of Mid Clavicle

Full Recline, Midline, Slouched, Lap Belt Over Abdomen

Full Recline, Midline, Slouched, Lap Belt Over Abdomen

Full Recline, Feet on I.P.

Partial Recline, Legs Crossed Reading



Turning, Reaching to the Back Seat, Shoulder Belt Remained in Place

Figure 1. OOP postures.

Table 1. Investigated OOP Postures Injury Considerations [B]

Reclined [A]	Lateral Leaning [C]		Turned
	Outboard	Inboard	
Submarining injuries including soft tissue abdominal injuries, lower spine fractures. The upper body, initially unrestrained by the shoulder belt, impacts the belt resulting in possible neck soft tissue injuries and cervical and thoracic spine fractures.	Neck near shoulder belt: neck soft tissue injuries. Head, torso, right arm in path of side air bag deployment: head, arm, lateral torso injuries.	Shoulder belt may slip off of right shoulder: anterior torso injuries due to altered belt path, head injuries due to increased head motion.	Shoulder belt may slip off of the shoulder: anterior torso injuries due to altered belt path, head injuries due to increased head motion.

Notes

A – Right front passenger

B – Injury considerations in a frontal crash unless otherwise indicated.

C – Lateral leaning often seen in combination with recline for sleeping occupants

1. Introduction

One of the most attractive advantages of ADS[1] is that they promise to substantially reduce the frequency and severity of crashes (Litman, 2016; Hayes, 2011; Fagnant & Kockelman, 2013; Levinson, 2015). As automated driving technology advances and more vehicles with ADS join the fleet, injury risk will likely fall. One source projects 1,100 lives saved, 200,000 fewer crashes, and a savings from reduced crashes of $18 billion annually, once 10 percent of the fleet feature vehicles with ADS, and that a 90 percent market penetration will result in a 90 percent reduction in crashes and related costs (Fagnant & Kockelman, 2013). Another source states the number of U.S. road fatalities could be reduced from 33,000 annually to hundreds with full driving automation deployment (Levinson, 2015). This echoes Hayes (2011) who indicates that the per occupant mile fatality rate could be reduced by a factor of 100, which would be similar to the rate for air and rail travel. Presently, train passengers ride in a variety of postures and ride unrestrained.

While there is optimism as to the ultimate safety benefit associated with ADS, there will likely be a transition period from human driven to computer driven vehicles that may bring increased risks. Litman (2016) foresees the possibility of vehicle computer system failures and the inability to navigate in certain conditions due to, at least initially, insufficiently advanced ADS control systems. Sivak and Schoettle (2015) believe that ADS may never perform more safely than an experienced, middle-age driver and that safety may degrade during the decades-long transition period during which ADS and driver-controlled cars share the road. The transition period toward a fully ADS fleet is estimated to be at least 30 years with a 10- to 20 percent ADS fleet by 2040 (Litman, 2016).

Therefore, ensuring ADS occupant safety during the transition period will still require investment in occupant protection countermeasures in addition to advances in crash avoidance. Moreover, the public will most likely require enhanced ADS occupant protection in order for ADS to gain acceptance. It is likely that ADS will be held to a higher standard than current vehicles (Fagnant & Kockelman, 2013). ADS will crash and, we predict, these crashes will be more scrutinized than non-ADS crashes, as evidenced by the press coverage of a recent Tesla driver fatality (Singhvi & Russell, 2016). This would mean that even a very limited number of crashes and resulting injuries may slow the adoption of automated driving and thus, slow the potential for reduction in fleet-wide crashes and injuries. If this assumption is correct, reducing injury risk and injury severity should be a priority despite the anticipated decline in ADS crash injuries and the associated difficulty in justifying countermeasure development expenditures using traditional cost-benefits analysis. Note that we acknowledge that this justification for ADS occupant protection differs from the cost-benefit calculation that has been used in the prior allocation of occupant safety resources. For example, the high frequency of injurious frontal crashes has justified the primary focus of National Highway Traffic Safety Administration research for many years in terms of crash dummy development and performance testing.

ADS occupant protection considerations, while similar to those of current vehicles in most respects, will include safety countermeasures that accommodate occupants who are out-of-positon relative to the seat and/or occupant restraint systems due to ADS crash avoidance maneuvers (Battaglia et al., 2013) or who ride in alternative postures. As more ADS drivers become more confident in the potential for reduced injury risk provided by automated driving, they will be more likely to relax, read, interact with other occupants, and sleep - behavior currently enjoyed by passengers (Hayes, 2011).

[1] Automated driving systems refer to SAE International driving automation levels 3, 4, and 5 as defined in SAE J3016.

Because the majority of current occupant restraint systems have been developed for occupants that assume the "standard driving posture" (Dissanaike et al., 2008), there is concern that these systems will be less effective for ADS occupants in alternative postures.

1.1 Field Data Investigation Objectives, Methods, and Report Organization

The objective of this field data investigation is to better define alternative occupant postures and to estimate their effect on risk of injury or severity of injury should a crash occur. We began with a review of published works regarding alternative postures for occupants in moving vehicles. This informed the study of relevant CIREN cases and analyses of the NASS CDS field crash database cases to evaluate OOP posture frequency and injury risk.

2. Literature Review

Concern that OOP postures may increase injury risk has motivated a limited number of studies over the last 30 years that have focused on the dangers of riding reclined.

In 1988 the National Transportation Safety Board (NTSB) conducted a study of seat belt use in 167 crashes during 1984 to 1986, finding that belt protection can be compromised by a reclined seatback. In one case, they found evidence that the reclined occupant "submarined" under the lap belt, causing injurious neck loading by the shoulder belt (Figure 2). The authors concluded that, although some car user manuals warned against riding reclined, this message was contradicted by advertisements showing reclined occupants. The NTSB issued Safety Recommendation H-88-009 suggesting that "NHTSA should determine to what degree a seatback can be reclined and still allow the occupant to be properly and safely restrained by a lap/shoulder belt" (NTSB 1988). NHTSA did not agree with NTSB's recommendations for testing to determine a safe recline angle and in June of 1990 "because the NHTSA is unwilling to devote resources to this safety problem, the board has classified H-88-9 as "Closed –Unacceptable Action."www.ntsb.gov/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=H-88-009

We found three papers involving case studies that reported neck and cervical spine injuries sustained by sleeping, fully reclined front passengers who loaded the shoulder belt in frontal crashes. All were young females. In one case, the 17-year-old occupant sustained a soft tissue injury to her cervical spine (Rehm & Goldman, 2001). In the other case, the 25-year-old occupant sustained fracture of the pedicles of the axis and the posterior arch of the atlas (Jeffery & Cook 1991). In the third case, the 25-year-old sustained extensive cervical spine fractures and other injuries attributed to hyperflexion of her neck over the shoulder belt. The neck interaction with the shoulder belt was thought to have also resulted in a subdural hematoma, a sub arachnoid hemorrhage, and a cerebral contusion. In this case, the upright driver was uninjured in a 64 kilometers per hour (km/h) change in velocity (delta V) frontal crash (Thorbole, 2015).

In addition to injuries caused by being in a poor position relative to the belt restraints, occupants who ride reclined could be in a hazardous position relative to deploying air bags. Lopez-Valdes et al. (2011) found that several volunteers who participated in a sleeping right front passenger study slept with their head and upper torso resting against the B-pillar and possibly in the path of deploying side air bags (Figure 3). Appendix A, Sleeping Postures, provides additional images of volunteers sleeping in the right front passenger seat.

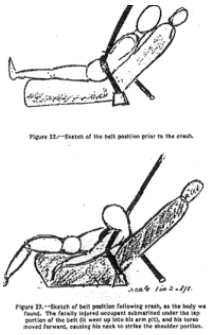


Figure 2. Original source: NTSB Report NTSB/SS-88/02, Performance of Lap/Shoulder Belts in 167 Motor Vehicle Crashes (Vol 1).

Figure 3. Lateral sleeping posture. Source Lopez-Valdes et al. (2011).

Dissanaike et al., 2008 conducted what they described as "the first published analysis of the effect of seatback position on MVC outcome" using a combination of 1995-2000 CIREN and NASS CDS field data for front seat belted and unbelted occupants. They found that fully reclined occupants were more likely to be right front passengers than drivers (although nearly 50% were drivers) and that they likely reclined the seatback to sleep on longer trips. Fully reclined occupant overall injury severity and mortality was greater than for those partially reclined. However, they found that only a very small proportion of occupants travel in the fully reclined position, based on 90,412 cases they reviewed (upright 17.6%, partially reclined 50%, fully reclined 0.3%, 24% seatback angle not recorded, 8% seatback not adjustable). For some belted, fully reclined occupants, flexion and compression injuries over pretensioned lap and shoulder belts resulted in severe thoracic abdominal and spine injuries with a high associated mortality. Increased lower extremity injuries also were noted. Study limitations included reliance on the accuracy of two databases, the accuracy of the recorded seatback position, and the fact that seatback angles are not quantified. The authors cautioned that seatback position may have been changed post-crash. Moreover, the authors assumed that post-crash seatback angle reflected pre-crash occupant posture. Appendix B, Seatback Recline Study, describes a method to quantify the seatback angle and how accurately seatback angle correlates with occupant torso angle.

Thorbole, 2015 reported that greater seatback recline angles reduced belt protection in frontal crashes including a greater probability of submarining under the lap belt resulting in abdominal injuries and altered kinematics that can result in injurious neck loading by the locked shoulder belt.

Countermeasures

As discussed in the NTSB recommendation (1988), the simplest, although ineffective, countermeasure employed to avoid the higher injury risk associated with a reclined position is to discourage riding in this position in the vehicle's owner's manual. The NTSB favored limiting seatback recline to a position that has been proven not to degrade restraint performance. An alternative method, using information from ADS technology sensor systems, is to place the seat and its occupant into a less reclined position pre-crash. The Mercedes pre-safe system, in addition to pretensioning the belts, can incline the backrest to a more upright position, increase the incline of the seat cushion, and can move a far-forward front passenger seat rearward (Figure 4). Benefits claimed include avoidance or reduction of undesirable occupant pre-crash movement, better occupant restraint, improved position, greater distance from deploying air bags and/or intruding structures, and a reduced risk of submarining (Schöneburg et al., 2003). A more recent Mercedes submarining countermeasure developed for the reclining rear seat of its most recent S Class model involves the "Cushionbag" – a seat cushion mounted air bag that deploys as a barrier to pelvic forward motion. Figure 5 illustrates an example of a seat cushion air bag. (www.mbusa.com/mercedes/vehicles/build/standard_features/modal/class-S/model-S600V/allStandardFeatures-true#item-3-22. www.caranddriver.com/features/dissected-2014-mercedes-benz-s-class-feature).

Reduction of backrest recline. Increase seat cushion inclination. Move seat rearward.

Figure 4. Mercedes Pre-Safe

Figure 5. Seat cushion air bag. Source IIHS

An alternative to moving the reclined occupant's torso closer to the B-pillar mounted shoulder belt D-ring is to install the D-ring to the seatback so that shoulder belt fit is independent of seatback angle (Figure 6). This should improve belt fit regardless of seating position (Rashidy et al., 2001) and should reduce the risk of interaction between the shoulder belt and the neck in frontal crashes (Thorbole et al., 2015).

Figure 6. Seat with integrated shoulder belt. Source Rashidy, 2001.

In summary, riding in an OOP posture, such as substantially reclined, increases injury risk for belted occupants due to altered belt fit and the potential to be in the path of deploying air bags. Poor belt interaction can result in neck and cervical spine injuries due to shoulder belt loading as well as abdominal and lower extremity injuries due to submarining. Countermeasures for a frontal crash include limiting seatback recline, active pre-crash seat adjustments such as reducing seatback recline, angling the seat to limit forward pelvic motion, moving the entire seat rearward, and mounting the shoulder belt D-ring to the seatback. While there is sufficient evidence that alternative postures may increase injury risk in a crash, the increased risk has not been quantified adequately.

3. CIREN Case Study

The CIREN database includes an Injury Analysis text field that captures the review group's estimate of how the injuries occurred and how various elements of the crash, occupant, and vehicle environment may have contributed. For this reason, we selected cases that would, via this depth of detail, provide information to inform our investigation of OOP and its association with increased injury risk.

Appendix C, CIREN Case Study: Laying-Back Posture Cases, provides additional information on occupant posture and seat position. Appendix D, CIREN Case Study: Case Summaries, provides crash scene diagrams, vehicle damage photos, occupant injuries, and crash parameters.

Method

We conducted two searches of the CIREN database. For the first search the occupant posture was coded as "lying back." In the second search the occupant posture was coded as sitting "turned." The "lying back" search was limited to belted right front passengers 13 or older involved in a frontal crash. The "turned" search was limited only by occupant age, 13 or older.

3.1 Search 1: Lying Back

We examined seven CIREN cases in which occupant posture was coded as "lying back" (Table 2). The frontal impact longitudinal delta Vs ranged from 13 to 61 km/h. There were five females; three were 29 to 31 years old and two were 65 and 66 years old. The other two case subjects were middle aged men 49 and 59 years old.

Table 2. CIREN Cases With Occupant Position Coded as "Lying Back" (Search 1)

CIREN ID	Model Year	Model Name	Direction of force (deg)	Total delta v (km/h)	ISS	MAIS	Age (yr)	Sex
286014504	2004	TL	350	28	22	3	66	F
317118807	2012	IMPALA/CAPRICE	10	13	11	3	49	M
359458609	2009	MAZDA3	10	38	19	3	29	F
385166433	2010	CX-7	~15	Not estimated	34	4	29	F
407063518	1999	SL	0	61	19	3	59	M
551110814	2003	CAVALIER	0	44	19	3	31	F
852122288	2006	SCION TC (< 2012)	0	48	75	6	65	F

The CIREN investigators reported that five of the seven case occupants were sleeping prior to the crashes. For six of the seven, the seatbacks were in a fully reclined position with one case (407063518) coded as slightly reclined but described in the text as mid to fully reclined. In five of the seven cases, there was pre-impact vehicle motion due to off the roadway terrain and/or pre-crash braking that may have altered the occupants' posture, awakened them, and/or resulted in pre-impact bracing. Four seats were adjusted to the rearmost track position; two to the mid position and one to a mid-to-forward position.

Six of the seven subjects sustained a total of 9 spinal fractures: 4 cervical spine, 3 thoracic spine, 2 lumbar spine. Five subjects sustained abdominal injuries, four sustained chest injuries, two sustained head injuries, and one sustained a lower extremity injury.

Five investigators suggested that the reclined posture degraded pre-crash restraint belt fit so that, in some instances, the shoulder belt was not in contact with the shoulder or upper chest and that the lap belt was over the abdomen. For the occupant in case 852122288, the lap belt position was described as "lap belt across abdomen." Given her 136 kg (300 lbs.) weight, a similar belt fit would have been recorded had she not been reclined.

Three investigators hypothesized that the upper torso moved forward unrestrained until it contacted or struck the shoulder belt that was pulled tight by a retractor pretensioner in six of the seven cases. This sudden loading of the shoulder belt by the upper torso was thought to be responsible for cervical spine injuries caused by inertial loading of the head. In two cases (407063518, 852122288), non-contact head injury was attributed to the resulting head motion. Lower thoracic spine and upper lumbar spine fractures and abdominal injuries, commonly associated with submarining, were attributed to flexing around the lap belt. Four of the seven subjects sustained both C-spine and abdominal injuries.

Only one subject (case 551110814) sustained an AIS3+ lower extremity injury (femur fracture) and the investigator thought it possible that the reclined posture/lower extremity orientation may have explained the spiral fracture pattern.

Observations

Case 407063518 suggests that it is possible that the occupant assumed a lying back posture despite the seatback not being fully reclined. This means that "occupant posture" and "seatback recline" are not interchangeable terms as assumed by Dissanaike et al. (2008). See Appendix B for further information.

The finding that most of the sleeping occupants may have been awakened and moved and/or braced prior to the crash makes it very difficult to reconstruct pre-crash occupant posture.

Four of the seven subjects sustained both C-spine and abdominal injuries, which are commonly reported for submarining occupants and suggestive that altered shoulder and lap belt fit were contributing factors. Occupants who sit in a reclined posture are more likely to submarine due to a posteriorly rotated pelvis that is less able to capture and to load the lap belt (Figure 1) (Thorbole, 2015).

Other injuries may have been due to degraded belt fit. In case 385166433, the head injury was due to head contact with the roof or windshield header, both rare contact points for a normal posture occupant in a frontal crash. It is possible that the poor belt fit allowed greater upper body and head motion.

In one case (407063518), the reviewer suggested that the fully reclined occupant was back too far to load the air bag and his upper body was restrained only by the shoulder belt and did not benefit from the designed belt and air bag torso load sharing.

In some cases, the injury distribution appeared to be similar to that typically seen for a frontal crash in which the occupant is in a normal posture. For example, in case 317118807, the major injury was an L1 burst fracture, which is not uncommon for belted occupants in frontal crashes with a vertical acceleration component (as was possibly true in this case due to impact with a ditch). However, given that the 13 km/h delta V is relatively low, it is possible that the altered pelvic posture associated with recline was a contributing factor.

Limitations

The above observations and conclusions, while useful in that they may point toward additional investigation, are based on a small number of examined cases. The assertions regarding injury causation included in the Injury Analyses are, in most cases, opinions of one or more of the CIREN review team who did not

have definitive supporting evidence, such as laboratory data. For example, the idea that the initial gap between the shoulder belt and the shoulder increases the injury risk due to an "impact" with the pretensioned belt, while plausible and expressed in prior studies (NTSB 1988), has not, to our knowledge, been verified by physical testing.

3.2 Search 2: Turned

We examined 17 CIREN cases in which occupant posture was coded as "turned" (Table 3 and Table 4). The last seven columns of Table 3 summarize the occupant posture as described in the case text fields as well as our comments provided in Table 4.

The total delta Vs ranged from 8 to 82 km/h. Thirteen crashes were frontal impacts with principal directions of force (PDOF) 0 ± 40 degrees. There were 13 females, 8 younger than 30 years old. Seven of the 17 were belted although one rear seat occupant rode with her shoulder belt behind her back (831060464). There were 3 drivers, 7 right front passengers, and 7 rear seat passengers.

The case text fields provided some additional information as to occupant posture. Three occupants were described as riding slightly turned and two were reported to have changed posture just prior to the crash. Case 831060464 provides the most comprehensive description of pre-crash posture:

> *The 15-year-old female right-rear passenger (case occupant) was seated abnormally with her back against the right-rear door and her legs stretched out on the seat cushion. She was using the 3-point seat belt inappropriately by wearing it loosely and placing the shoulder belt behind her.*

Four rear seat passengers turned to talk to another rear seat occupant, attend to a child in the rear seat, or, to play cards with their rear seat partner.

Two occupants, a driver and a right front passenger, turned to either speak to rear seat passengers or to attend to a child in the rear seat.

In addition to searching the case text fields for information on posture, we also extracted opinions of the CIREN investigators regarding the relationship of the turned posture to the reported injuries. For 7 of the 17 case occupants, there was no mention that posture was a factor for the injuries. For 4 of the 17 case occupants, the investigators used the location of the injuries to support their estimate that the occupant was turned pre-crash. For no occupant did the investigator attribute the occurrence or severity of the injury to the turned posture.

Table 3. CIREN Cases With Occupant Position Coded as "Turned" (Search 2)

									Summary of Occupant Posture Description (Table 4)						
CIREN ID	**PDOF (deg)**		**Total Delta V (km/h)**	**Belt Used**	**MAIS**	**Seating Position[A]**	**M/F**	**Age (yr)**	**Turned slightly**	**Talking to rear seat pass.**	**Playing cards in rear seat**	**Attending child in rear seat**	**Turn did not contribute to injury**	**Turn did contribute to injury**	**Changed posture pre-crash**
32736	0		82	N	6	13	F	24	1					1	
100074572	20		27	N	3	13	F	25		1					1
286032675	40		20	Y	3	13	F	17					1		
318844405	40		31	N	3	22	M	57				1	1		
431556136	260		-	Y	5	11	F	63				1			
438035386	340		28	N	5	13	F	30					1		
470040209	320		23	Y	3	13	F	29					1		
490111300	10		30	N	3	11	F	26					1		
551079604	10		35	Y	3	21	M	27						1	
588593985	0		61	N	5	13	F	34	1						
590132936	0		30	Y	3	21	F	47	1	1					
608037704	0		33	N	4	13	F	23						1	
608094111	50		19	N	3	11	M	57					1		
831060464	290		-	Y	3	23	F	15							
842024468	350		-	N	3	21	F	72			1				
842024507	350		-	N	4	23	F	74			1			1	1
852178475	310		8	Y	5	21	M	17					1		

Notes:

A - Seating positon key:

11	Driver
13	Right front passenger
21	Rear seat left
22	Rear seat middle
23	Rear seat right

Table 4. Turned Cases: Reported Occupant Posture and Comments

CIREN ID	Case Text and *Comment*
32736	It is believed that the passenger's torso and legs were somewhat turned to the left to face the driver at the time of the crash. This position is consistent with the passenger's injuries as well as the position in which she was found.
100074572	The unbelted right front seat passenger was conversing with a back seat passenger and stated her body was turned towards the left, but just prior to the crash she turned her face toward the front.
286032675	*Case subject had osteogenesis imperfecta, no mention that turned posture was a factor in her spine fractures*.
318844405	This occupant had reportedly just removed his belt and slid from the second row right seat to the second row middle seat to attend to the child in the second row left seat. *Injury Analysis (IA) has no mention of being turned as a factor in injuries*.
431556136	The restrained 63-year-old female driver of Vehicle 1 (V1) was presumed to be postured abnormally with the seat adjusted to a mid-track position. The police and witnesses reported that the driver of Vehicle 1 was turned inboard and faced away from traffic while tending to the rear-seated child passenger.
438035386	*No mention of being turned was a factor for fatal injuries sustained in a near-side severe impact by large truck.*
470040209	*Case subject was pregnant. Lower extremity injuries not attributed to turned posture.*
490111300	*Case did not include an IA*. The case study participant is the 44-year-old driver of V1. There were two other occupants in V1, an 18 month old female in the rear left position and a 4-year-old male in the rear right seat position. The case study participant was restrained by the deployed frontal air bag only. The rear left seat passenger was restrained in a forward facing child restraint seat and the rear right seat passenger had unbuckled the available lap and shoulder belt just prior to the crash. *None of the injuries attributed to the belt*.
551079604	*Rear seat passenger with lap belt above the pelvis combined with rotated torso to injure left side of abdomen: turned posture implicated in abdominal injury.*
588593985	Occupant sitting, in a suspected non-optimal postured position (slightly turned or leaning towards the left).
590132936	Occupant sitting upright with hands in her lap. She was relaxed, slightly turned to the right and holding conversation with the right rear passenger. *No mention of turned posture as contributing to her injuries.*
608037704	Based on the nature of the sacral fractures, it appears the case occupant was seated with her back to the door at the time of impact. *Unbelted and passenger air bag did not deploy.*
608094111	*Coded as sitting sideways but no mention of it in the Injury Analysis. Far side unbelted driver*.
831060464	The 15-year-old female right-rear passenger (case occupant) was seated abnormally with her back against the right-rear door and her legs stretched out on the seat cushion. She was using the 3-point seat belt inappropriately by wearing it loosely and placing the shoulder belt behind her.
842024468	The unrestrained 72-year-old female rear left passenger of the 2003 Toyota Camry was seated in an abnormal posture, turned to the right facing inward. The rear left passenger was reportedly playing cards with the rear right passenger.
842024507	The unrestrained 72-year-old female rear left passenger of the 2003 Toyota Camry was seated in an abnormal posture, turned to the right facing inward. The rear left passenger was reportedly playing cards with the rear right passenger. The passenger may have been

CIREN ID	Case Text and *Comment*
	leaning slightly forward and bracing against the front right seatback, in anticipation of the impending guardrail impact. *She did sustain right rib fractures that were attributed to right front seatback - orientation of torso to Involved Physical Component (IPC).*
852178475	*Occupant sitting behind the driver and one of three rear seat passengers, coded as sitting sideways or turned but unlikely that he was turned substantially given the narrow back seat. Severe head and torso injuries due to near side impact and were not associated with altered sitting posture.*

Observations

Although most vehicles have only a single occupant (the driver) (DOT, 2001), only 3 of 17 of the study sample were drivers. This is consistent with the driver's need to control the vehicle rather than turning to interact with other occupants.

Less than half of the turned occupants were belted. This belt use rate is much lower than the 88.5 percent reported for all U.S. passenger car occupants by NHTSA (Pickrell and Li, 2016). It is possible, as apparently it was for the 15-year-old case 831060464 occupant, that the belt is inconvenient or uncomfortable in a turned posture.

Aside from the description of this occupant's posture, there were few details that specified the turned posture although three were described as "slightly turned." The fact that two occupants were reported to have changed posture immediately prior to the crash further complicates our attempt to define pre-crash posture.

Given that safety systems have been designed for occupants seated forward facing, the finding that no CIREN investigator attributed an injury or the severity of an injury to the turned posture is interesting. We propose three potential reasons for this:(1) the investigators did not believe the turned posture increased injury risk; (2) as stated above, the actual pre-crash posture is poorly defined; and (3) there are no laboratory studies that have explored the injury potential of a turned posture. For one or more of these reasons, the investigators may have elected to simply report the altered posture and refrained from citing it as a contributing factor for subject injury.

Conclusions and Recommendations

The CIREN case review indicated that a "laying back" posture can adversely affect the restraint performance either by altering belt paths (i.e., pelvis to abdomen), changing the pre-crash torso position relative to the shoulder belt, or placing the torso too far rearward to benefit from air bag restraint. The results can include an increased injury risk from belt loading or greater occupant motion due to compromised belt restraint.

Given that this review echoed the prior investigator's opinion regarding the increased risk of a reclined posture and the resulting pre-impact gap between the shoulder and the shoulder belt, it may be interesting to explore this hypothesis in the course of our OOP study using finite element human body models.

This hypothesis should be considered as a possible scenario to be investigated.

For the lying back posture, this strategy yielded six belted case subjects. For the turned posture, we identified only two belted right front passenger subjects (Table 3) and, for this posture, we expanded the analysis to include all turned occupants.

Reviewer comments indicating that turned subjects adjusted their posture pre-crash, combined with the wide variety of reclined or sleeping postures indicate that the database occupant posture information may or may not have accurately reported immediate pre-crash occupant posture.

4. NASS Study

Occupants of vehicles with fully automated driving automation will all be passengers who will be free to read, converse, and sleep. These sitting postures and positions are now considered out of position (OOP) and likely detrimental to the performance of occupant safety systems such a restraint belts and air bags. This study uses retrospective field data to characterize OOP occupants and to estimate the crash injury risk associated with being OOP.

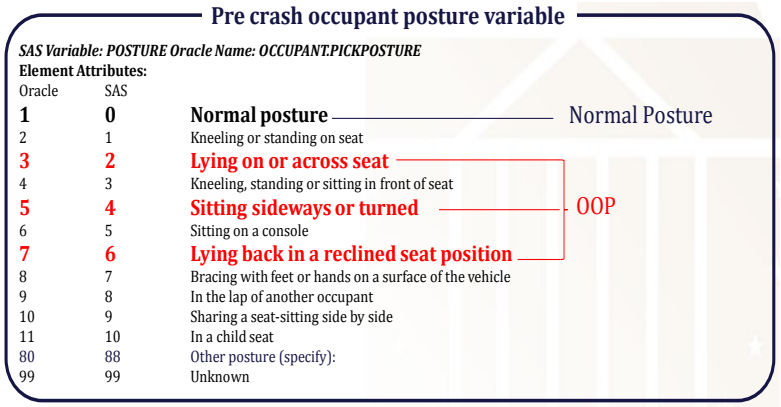
Method

We conducted a matched analysis using NASS-CDS cases years 2000-2014 (Table 5).

Table 5. NASS Search Criteria

Search Criteria	**NASS CDS**
Age	≥13yr
Case year enrolled	2000-2015
Seating Position	All
Crash type	All planar (no rollo-ver)
Restraint use	Belted, un-belted
Occupant posture*	All
Total # of cases	~49,000

Table 6. Definition of OOP



OOP Definition

For the purposes of this study, OOP is defined as SAS pre-crash occupant posture variables 2, 4, and 6. In-position is defined as SAS variable 0 (Table 6). The other non-normal codes relate to children (SAS = 1, 3, 8, 9, and 10) or, in the case of 7, "Bracing….." may be protective.

Analysis

The primary objective of this study was to compare occupant and crash characteristics for OOP and in-position occupants and to estimate the severity of injury sustained in a crash. Results are expressed as a percentage of the weighted frequency or the mean value and 95 percent confidence intervals.

Results

Table 7 categorizes occupants by the NASS pre-crash posture codes. Normal posture was coded for 97 percent of the occupants. Figure 7 presents these results combining the three categories of OOP occupants selected for this study. The percentage of occupants coded as lying across the seat, sitting sideways or turned, or lying back in a reclined position ranged from 0.12 to 0.2 percent but, because of relatively large standard deviations, the frequency differences between normal and OOP posture were not significant.

Table 7. Frequency of Occupant Pre-Crash Posture

SAS Variable	POSTURE All Occupants	Fre-quency	WgtFreq	StdDev	Row-Percent	RowStd Err	RowLow-erCL	RowUp-perCL
0	Normal posture	47446	23510341	2832439	97.2939	0.3077	96.6381	97.9497
1	Kneeling or standing on seat	10	1642	1467	0.0068	0.0063	0.0000	0.0201
2	Lying on or across seat	49	28247	16119	0.1169	0.0650	0.0000	0.2554
3	Kneeling, standing or sitting in front of seat	0	.	.	.	.	.	.
4	Sitting sideways or turned	141	43783	12906	0.1812	0.0545	0.0651	0.2973

SAS Variable	POSTURE All Occupants	Frequency	WgtFreq	StdDev	RowPercent	RowStd Err	RowLowerCL	RowUpperCL
5	Sitting on a console	3	243.80200	208.21564	0.0010	0.0008	0.0000	0.0027
6	Lying back in a reclined seat position	115	48666	13059	0.2014	0.0452	0.1050	0.2978
7	Bracing with feet or hands on a surface of the vehicle	217	75750	20140	0.3135	0.0759	0.1517	0.4753
8	In the lap of another occupant	1001	455586	96115	1.8854	0.2429	1.3676	2.4032

SAS Variable	POSTURE Belted	Frequency	WgtFreq	StdDev	RowPercent	RowStd Err	RowLowerCL	RowUpperCL
0	Normal posture	40155	20606475	2391764	97.7050	0.2821	97.1038	98.3062
1	Kneeling or standing on seat	5	1598	1466	0.0076	0.0071	0.0000	0.0227
2	Lying on or across seat	9	12990	11238	0.0616	0.0517	0.0000	0.1717
3	Kneeling, standing or sitting in front of seat	0	.	.	.	.	.	.
4	Sitting sideways or turned	91	31031	8246	0.1471	0.0424	0.0569	0.2374
5	Sitting on a console	0	.	.	.	.	.	.
6	Lying back in a reclined seat position	63	24565	8150	0.1165	0.0307	0.0510	0.1819
7	Bracing with feet or hands on a surface of the vehicle	175	67926	17149	0.3221	0.0761	0.1598	0.4844
8	In the lap of another occupant	624	345911	74341	1.6401	0.2292	1.1517	2.1286

SAS Variable	POSTURE Belted Front Seat	Frequency	WgtFreq	StdDev	RowPercent	RowStd Err	RowLowerCL	RowUpperCL
0	Normal posture	7933	3695019	511465	96.2843	0.9285	94.3053	98.2633
1	Kneeling or standing on seat	2	1033	1033	0.0269	0.0274	0.0000	0.0854

SAS Variable	POSTURE Belted Front Seat	Fre-quency	WgtFreq	StdDev	Row-Percent	RowStd Err	RowLow-erCL	RowUp-perCL
2	Lying on or across seat	3	54.67800	38.32213	0.0014	0.0010	0.0000	0.0035
3	Kneeling, standing or sitting in front of seat	0	.	.	.	.	.	.
4	Sitting sideways or turned	48	14653	5114	0.3818	0.1308	0.1031	0.6606
5	Sitting on a console	0	.	.	.	.	.	.
6	Lying back in a re-clined seat position	48	13209	2347	0.3442	0.0816	0.1703	0.5181
7	Bracing with feet or hands on a surface of the vehicle	70	26687	8339	0.6954	0.1854	0.3002	1.0906
8	In the lap of another occupant	163	86958	47223	2.2659	0.9819	0.1732	4.3587

Notes: Codes in **BOLD** defined in this study as OOP.

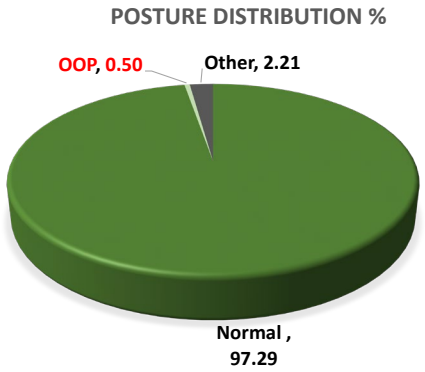
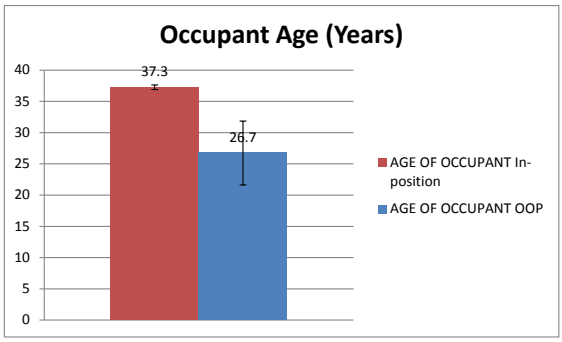


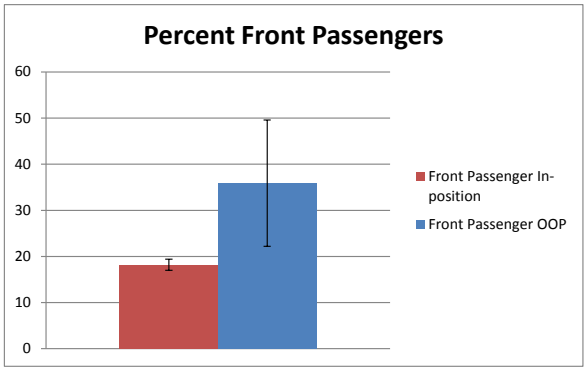
Figure 7. Posture distribution.

OOP occupants were more likely to be younger (Figure 8), right front or rear passengers (Figure 9) and unbelted (Figure 11). Crash characteristics such as delta V and PDOF were similar for both groups. The only difference identified was travel speed as indicated by the posted speed limit. OOP occupant vehicles were more likely to travel at higher highway speeds of at least 89 km/h (55 mph) although this difference was not significant (p-value = 0.0796) (Figure 11). Injury severity, in terms of average MAIS and average ISS, was not significantly different for OOP occupants (Figure 12).



Note: 95 percent confidence interval also provided for all plots.

Figure 8. Occupant age.



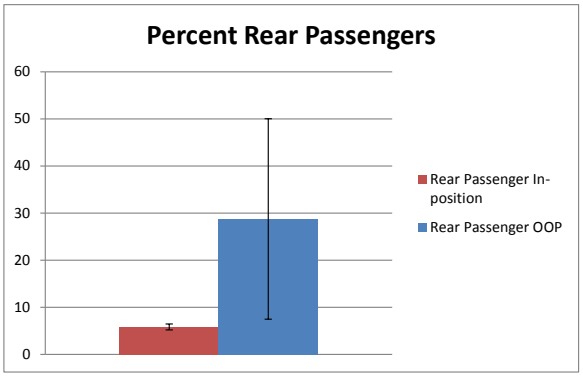


Figure 9. Seating position.

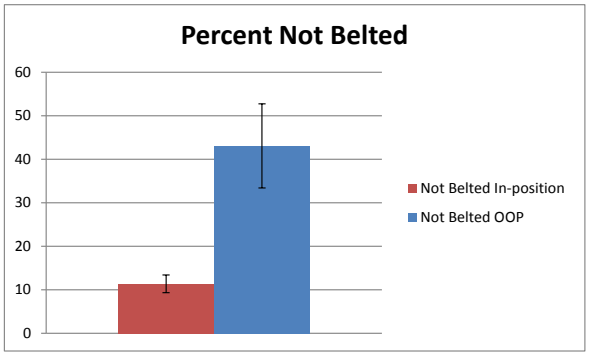


Figure 10. Percent unbelted.

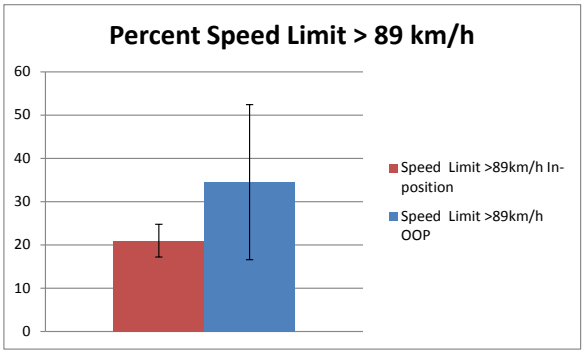
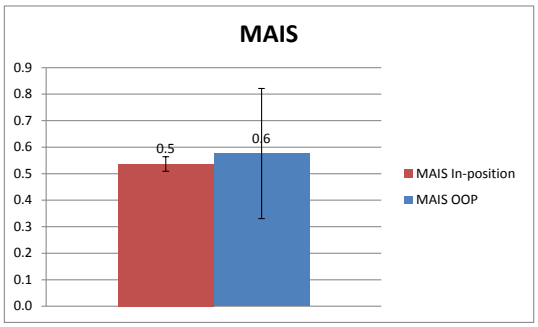


Figure 11. Percent of cases for which the posted speed limit was at least 89 km/h.



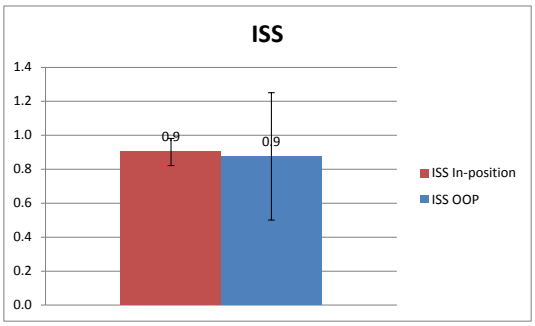


Figure 12. Relative injury severity, all occupants.

Discussion

As we define them, OOP occupants comprise only 0.5 percent of the total sample. For belted occupants, only 0.33 percent were coded as OOP (Table 7).

Before conducting this field data search, we assumed that the "Lying back in a reclined position" code would dominate the non-normal categories. The literature review reinforced this impression as all of the papers and reports discussed reclining/sleeping occupants. However, the results of this study do not support this. Instead, the results suggest that "Sitting sideways or turned" was coded for almost as many occupants (0.18% versus 0.20% Table 7 Posture All Occupants). In fact, when considering only belted occupants, more ride turned (0.15% versus 0.12% Table 7 Posture Belted) as do belted front seat occupants (0.38% versus 0.34% Table 7 Belted Front Seat). It is possible that occupants spend almost as much time turning multiple times, for example, to attend to children in the back seat, a short-term event, than they do reclined sleeping on a long trip, an infrequent event of longer duration.

Fewer occupants were described using the third OOP code, "Lying on or across the seat" (0.12%) versus Turned (0.18%); Laying back (0.20%) (Table 7 Posture All Occupants). As suggested by a couple of cases that UVA reviewed for CIREN in the last 5 years, we suspected that the occupants would be lying across the back seat unbelted. Indeed, only 0.001% were belted front seat occupants. However, approximately half of the lying occupants were belted (0.0616 / 0.1169 = 0.53 [Table 7]) suggesting that some believed that belt restraint, even when compromised by posture, is better than riding unrestrained despite likely discomfort or hindrance.

In terms of occupant characteristics, there were a few differences such as age, seating position, and belt use that were strongly statistically significant for in-position and OOP occupants. That OOP occupants were younger, less likely to be drivers, and less likely to be belted (Figures 8, 9, 10) is not unexpected. Drivers must be older than our 13-year-old search minimum and, usually, in-position and less able to assume various postures given their need to control the vehicle. Except for the "Lying on or across the seat" occupant (as discussed above), the average OOP occupant was less likely to be belted. It is likely that some alternative postures make belt use uncomfortable or inconvenient.

Despite several papers and reports identified in the literature review that provide evidence that OOP, more specifically a reclined posture, is more injurious than a normal posture, our study failed to support this finding. A statistical difference was not achievable because of an insufficient number of NASS OOP cases. It is possible that injury severity differences were diluted by the many case subjects uninjured or with only minor injuries (95 subjects MAIS=0, 143 subjects MAIS = 1). This explains the average MAIS and ISS values less than 1 (Figure 6). It also is possible that the increased risk associated with OOP was masked by the relative youth of the OOP occupants who were, on average, 10 years younger than the in-position occupants. Age has been found to be related to injury risk (Carter et al., 2014, Stigson et al., 2012).

Limitations

OOP occupants are extremely rare in NASS, which limits the statistical power. Small numbers of OOP occupants mean large confidence intervals and difficulty in identifying statically significant differences relative to in-position occupants. Large confidence intervals mean that most of the percentage differences could reasonably be explained by random variation rather than by systematic differences in outcomes by posture.

Conclusions and Next Steps

This study found that:

1. Very few occupants who were involved in a crash were OOP. The rarity of OOP occupants in NASS resulted in difficulties identifying statistically significant differences relative to in-position occupants.
2. "Sitting sideways or turned" was coded for almost as many occupants as was "lying back."
3. OOP occupants were younger, less likely to be drivers, and less likely to be belted.
4. Injury levels were similar for OOP and in-position occupants, an unexpected finding given prior studies that found OOP – laying back – to be more injurious.

The limitations of this study motivated a subsequent study using a matched pair method to mitigate the problems associated with a small sample size.

5. NASS Matched Pair Study

We assume that the occupant in conventional driver position of ADS-equipped cars may sit much like right front passengers who are free to sit reclined or turned to interact with others in the vehicle. In order to estimate if this new-found freedom of sitting position will increase the chance or severity of a crash injury, we conducted a retrospective study of injury for OOP occupants relative to those in-position. Specifically, our research design involved a search of the NASS CDS database to compare injury for OOP right front passengers with drivers who sat in a normal posture.

Method

We conducted a matched analysis using NASS-CDS cases years 2000 to 2015 (Table 8).

Matching Criteria

OOP right front passengers were matched with in-position drivers. We matched up to 5 drivers to each passenger, if good quality matches were available. Occupants were exactly matched on parameters in Table 9. For certain parameters for which exact matches were not required, such as age, Mahalanobis metric matching with a caliper of 0.25 standard deviations was used (Table 10) (Rubin et al., 1980).

Analysis

Odds ratios were estimated using the conditional logit model to account for matching, and then further adjusted for the continuous match variables, age, height, weight, and dvtotal.

Table 8. NASS Search Criteria
NASS-CDS Years 2000–20015 Vehicle age < 10 years Rollovers excluded All vehicle types < 4,536 kg Occupant age > 12 years old

Table 9. Occupant Match Parameters
Sex Belt status (yes/no/missing) Missingness for height/weight/dvtotal PDOF category (front/rear/near side/far side) Vehicle body type (car/suv/van/truck) General area of damage (reflected across the longitudinal axis for right front passengers)

Table 10. Occupant Match Parameters (Exact matches not required)
Occupant age, height, and weight DVTotal PDOF (reflected for right front passenger) Model year Ratwgt

Results

Table 11 lists the occupant comparisons including occupant and crash characteristics. There were 155 OOP right front passengers matched with 749 in-position drivers on the parameters listed in the first column. Figure 13 presents the odds ratios by injury level for all matched OOP occupants and for those with a specific OOP posture: Turned or Lying Back. The differences between OOP and in-position occupants were not significant at the p=0.1 level as illustrated by the large odd ratio confidence intervals that spanned 1 (no difference). See Appendix E for the analysis statistical output.

Table 11. Occupant Comparisons

	All:In Pos	All:Out of Pos	Matched:In Pos	Matched:Out of Pos
n	34384	158	749	155
Age	36 (25,51)[A]	25 (20,34)	28 (21,39)	25 (20,33)
Sex F	16867 (49.1%)	79 (50.0%)	365 (48.7%)	76 (49.0%)
Belted: Yes	29842 (86.8%)	99 (62.7%)	491 (65.6%)	99 (63.9%)
Belted: No	4177 (12.1%)	57 (36.1%)	252 (33.6%)	54 (34.8%)
Belted: Missing	365 (1.1%)	2 (1.3%)	6 (0.8%)	2 (1.3%)
Height	170 (163,178)	173 (165,178)	170 (165,178)	173 (165,178)
Height NA	343 (1.0%)	1 (0.6%)	5 (0.7%)	1 (0.6%)
Weight	77 (64,91)	70 (59,83)	73 (61,83)	70 (59,82)
Weight NA	419 (1.2%)	3 (1.9%)	6 (0.8%)	2 (1.3%)
Driver's seat	34384 (100.0%)	0 (0.0%)	749 (100.0%)	0 (0.0%)
Model year	2002 (1999,2006)	2002 (1999,2005)	2001 (1999,2005)	2002 (1999,2005)
DV total	20 (15,29)	23 (15,32)	23 (17,32)	23 (15,32)
DV total NA	12899 (37.5%)	57 (36.1%)	267 (35.6%)	55 (35.5%)
PDOF CAT: Front	19265 (56.0%)	102 (64.6%)	503 (67.2%)	101 (65.2%)

	All:In Pos	All:Out of Pos	Matched:In Pos	Matched:Out of Pos
PDOF CAT: Back	2787 (8.1%)	19 (12.0%)	77 (10.3%)	18 (11.6%)
PDOF CAT: Near	3276 (9.5%)	11 (7.0%)	42 (5.6%)	10 (6.5%)
PDOF CAT: Far	2718 (7.9%)	9 (5.7%)	45 (6.0%)	9 (5.8%)
PDOF: NA	6338 (18.4%)	17 (10.8%)	82 (10.9%)	17 (11.0%)
GAD: Front	18829 (54.8%)	93 (58.9%)	456 (60.9%)	92 (59.4%)
GAD: Back	2550 (7.4%)	17 (10.8%)	74 (9.9%)	17 (11.0%)
GAD: Near	4507 (13.1%)	18 (11.4%)	78 (10.4%)	17 (11.0%)
GAD: Far	3645 (10.6%)	17 (10.8%)	76 (10.1%)	16 (10.3%)
GAD: U	32 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
GAD: 9	4821 (14.0%)	13 (8.2%)	65 (8.7%)	13 (8.4%)
Body type: Car	22440 (65.3%)	112 (70.9%)	544 (72.6%)	112 (72.3%)
Body type: SUV	5917 (17.2%)	23 (14.6%)	95 (12.7%)	21 (13.5%)
Body type: Van	2418 (7.0%)	9 (5.7%)	45 (6.0%)	9 (5.8%)
Body type: Truck	3609 (10.5%)	14 (8.9%)	65 (8.7%)	13 (8.4%)
ratwgt	173 (50,487)	78 (23,231)	145 (40,370)	78 (23,238)

Notes:
A – Median (1st quartile, 3rd quartile)

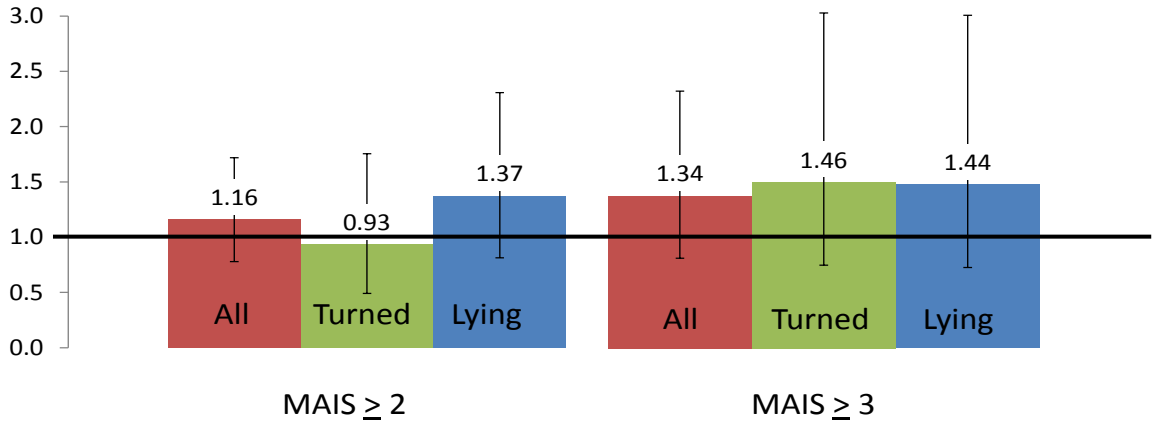


Figure 13. Odds ratios for OOP right front passengers relative to in-position drivers for MAIS ≥2 and MAIS ≥3 with 2.5 percent and 97.5 percent confidence intervals.

Discussion

While most of the occupant and crash characteristics were similar for in-position drivers and OOP right front passengers, the results indicated some differences. The OOP occupants were approximately 10 years younger and less likely to be belted, results similar to those of our NASS Study (Table 11). While the age difference is consistent with reports that right front passengers who have been involved in a crash have been reported to be younger than drivers (Braver et al., 2008) and is consistent with the age limitations for

drivers, the discrepancy for belt use may be new information. GES data indicates similar (~90%) belt use for both drivers and right front passengers who had been involved in a crash Braver et al. (2008). It is possible that OOP occupants are more likely to find the belt cumbersome, uncomfortable, or ineffective for an altered sitting posture.

The odds ratios for either MAIS $\geq$2 or $\geq$3 injury levels approached significance indicating that the results can neither confirm nor deny that being OOP is associated with a higher level of injury severity. While the analysis failed to yield significant results, it did reveal potentially useful information. All but one of the odds ratios were greater than one suggesting that OOP may be more injurious. This trend is more evident for the MAIS >3 analysis. This finding is consistent with both prior work (Dissanaike et al., 2008, Thorbole, 2015) and precepts of occupant restraint design. It is generally accepted that good belt fit is necessary for optimum restraint performance and an OOP occupant, less likely to have good belt fit, would be more likely to be injured or injured more severely.

Limitations

The inability to find significance in the analyses of NASS data was due to an insufficient number of cases with OOP occupants. Furthermore, there are very few NASS OOP occupants with MAIS 2+ injuries.

Conclusions

This study found:

1) OOP occupants were approximately 10 years younger and less likely to be belted.
2) The analysis failed to yield significant results regarding increased injury risk associated with OOP. However, the odds ratios were generally greater suggesting that OOP may be more injurious, a trend more evident for the MAIS >3 analysis.
3) The insufficient number of NASS cases with OOP occupants and even fewer OOP occupants with MAIS 2+ injuries limited our ability to identify statistically significant differences between OOP and in-position occupants.

6. Injury Patterns

In addition to exploring OOP effects on injury risk, the following four studies used CIREN and NASS case information to investigate injury pattern differences as a function of sitting posture.

6.1 Injury Patterns for In-Position and Out-of-Position Occupants

This analysis used the search criteria described in the NASS Study (Table 5 and 6). The AIS 2+ coded injuries were grouped by body region as per the AIS codes (Table 12).

Table 12. Injury Grouping by Body Region

Body Region	AIS Code Initial Digit
Head	1
Face	2
Neck	3
Thorax	4
Abdomen	5
Spine	6
Cervical Spine	
Thoracic Spine	
Lumbar Spine	
Upper Extremity	7
Lower Extremity	8
Pelvis	
Thigh	
Knee	
Leg	
Foot	
Unspecified	-

Results

Due to few OOP subjects, 11 of 16 injury category comparisons produced differences that were not statistically significant (Appendix F). Of the 5 that did produce significant differences, head, neck, thorax, upper extremity, pelvis, the weighted injury frequency was lower for OOP subjects.

Discussion

We found no neck injuries for OOP occupants. If the injury mechanism proposed in Figure 2 is a common one for fully reclined occupants – the neck impacts the pretensioned shoulder belt – then there should have been at least a few AIS 2+ neck injury cases for OOP occupants. Moreover, we found no increase in the frequency of cervical spine injuries for OOP occupants.

Although the results suggest that being OOP is protective, we believe that the differences between the in-position and OOP occupants might explain this unexpected finding. As indicated in the NASS Study above, the OOP occupants were much younger and less likely to be belted (Figure 8, 9, 10). Given that younger occupants are less likely to be injured and their injuries are less severe (Carter et al., 2014; Stigson et al., 2012), this advantage may have outweighed the (reported) increased risk of OOP – and that of being unbelted.

Limitations

As for the overall NASS Study, OOP occupants are extremely rare in NASS, which limits the statistical power. Small numbers of OOP occupants mean large confidence intervals and difficulty in identifying statically significant differences relative to in-position occupants. Large confidence intervals mean that most of the percentage differences could reasonably be explained by random variation rather than by systematic differences in outcomes by posture. Because differences in occupant characteristics limited this analysis we conducted an alternative investigation that minimized the effects of occupant differences by using a matched pair strategy.

6.2 Injury Patterns for In-Position and Out-of-Position Occupants: Matched Pair Analysis

This analysis used information defined by the search criteria and matching strategy described in the NASS Matched Pair Study (Tables 8, 9, 10). Occupants with AIS 2+ coded injuries were grouped by body region in which the injury occurred (Table 12.)

Results

Table 13 presents the results of the analysis for both belted and unbelted occupants (All) and for only belted occupants.

Figure 14 charts the results for the belted occupants. The percentage of occupants with lower extremity injuries was greatest for both belted in-position (7.1%) and belted OOP occupants (11.1%). The percentage of occupants with thorax, head, and upper extremity injuries ranged from 3.0 to 6.1 percent.

Figure 15 presents the ratio of OOP occupant and in-position occupant percentages. For 10/16 body regions, the ratio of the percentage of OOP occupants to in-position occupants was greater than 1 indicating relatively more OOP injury. The largest ratios were for the foot (3), abdomen (2.5), and the thorax (1.9).

Figure 16 shows these ratios only for cases involving four or more OOP occupants. For all four of these body regions the ratio of the percentage of OOP occupants to in-position occupants was greater than 1.

Table 13. Comparison of AIS 2+ Injuries by Body Region

Body Region	All In-Position	All OOP	Belted In-Position	Belted OOP
	Occupant Count (%)	Occupant Count (%)	Occupant Count (%)	Occupant Count (%)
Number of Occupants	749	155	491	99
Head	37 (4.9%)	7 (4.5%)	18 (3.7%)	4 (4.0%)
Face	15 (2.0%)	3 (1.9%)	8 (1.6%)	1 (1.0%)
Neck	1 (0.1%)	0 (0.0%)	1 (0.2%)	0 (0.0%)
Thorax	33 (4.4%)	9 (5.8%)	16 (3.3%)	6 (6.1%)
Abdomen	13 (1.7%)	5 (3.2%)	6 (1.2%)	3 (3.0%)
Spine	21 (2.8%)	7 (4.5%)	9 (1.8%)	2 (2.0%)
Cervical Spine	14 (1.9%)	3 (1.9%)	6 (1.2%)	2 (2.0%)
Thoracic Spine	3 (0.4%)	3 (1.9%)	0 (0.0%)	1 (1.0%)
Lumbar Spine	6 (0.8%)	2 (1.3%)	3 (0.6%)	0 (0.0%)
Upper Extremity	40 (5.3%)	7 (4.5%)	19 (3.9%)	3 (3.0%)

Body Region	All In-Position	All OOP	Belted In-Position	Belted OOP
	Occupant Count (%)	Occupant Count (%)	Occupant Count (%)	Occupant Count (%)
Lower Extremity	74 (9.9%)	20 (12.9%)	35 (7.1%)	11 (11.1%)
Pelvis	15 (2.0%)	1 (0.6%)	9 (1.8%)	1 (1.0%)
Thigh	21 (2.8%)	9 (5.8%)	12 (2.4%)	4 (4.0%)
Knee	17 (2.3%)	3 (1.9%)	7 (1.4%)	2 (2.0%)
Leg	23 (3.1%)	3 (1.9%)	8 (1.6%)	2 (2.0%)
Foot	18 (2.4%)	5 (3.2%)	5 (1.0%)	3 (3.0%)
Unspecified	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

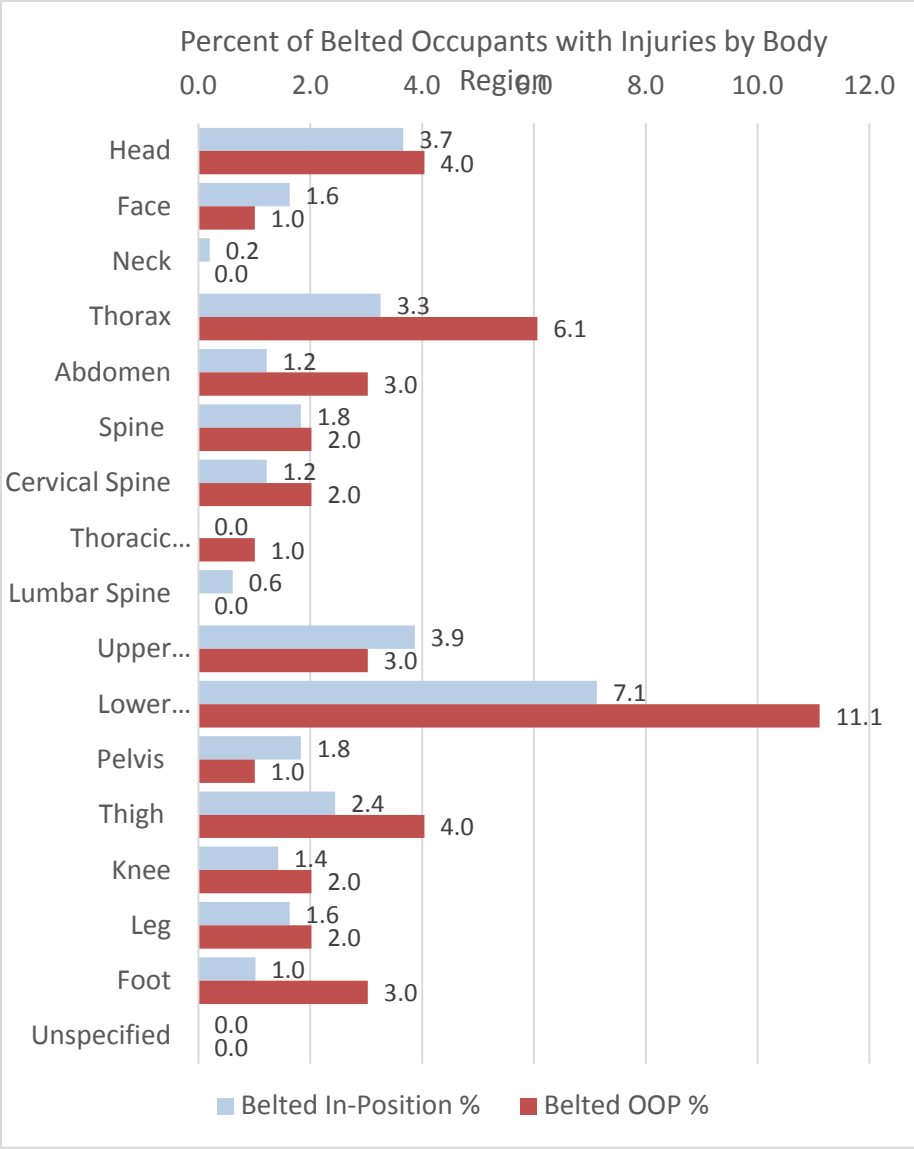


Figure 14. Percent of belted occupants with AIS 2+ injuries per body region.

In contrast to the above analysis "Injury Patterns for In-Position and Out-of-Position Occupants" that suggested that OOP was a less injurious condition, the results of the matched pair study suggest that, for most body regions, being OOP may be an injury risk factor. Figure 15 indicates that foot, abdomen, thorax, cervical spine, and thigh injuries are particularly more likely for OOP occupants. The finding that both abdominal and cervical spine injuries may be associated with OOP is consistent with the injury pattern often reported for submarining that is more likely for reclined postures (Figure 2).

Limitations

Using the matched pair approach allowed a comparison between in-position and OOP injury distribution without the complication of different cohort characteristics such as age. However, the approach could not address the low number of injured OOP subjects per body region. For example, in most of the body region categories there are fewer than four occupants (Table 13). When considering only those body regions with four or more occupants (thorax, lower extremity, and thigh) the results suggest that the OOP condition is more injurious. Although there appears to be a tendency for an increased risk of injury in the OOP occupants, we do not have the statistical power to test for trends or demonstrate statistical significance in the differences.

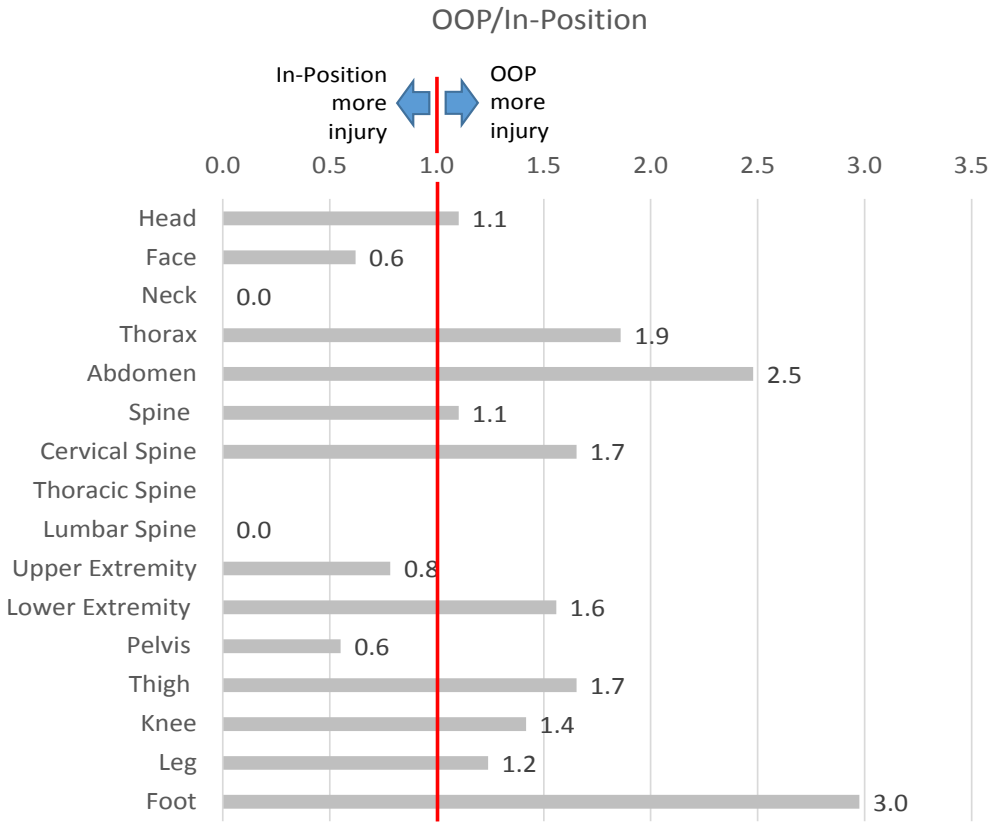


Figure 15. Ratio of the percentage of OOP and in-position occupants with AIS 2+ injuries by body region.

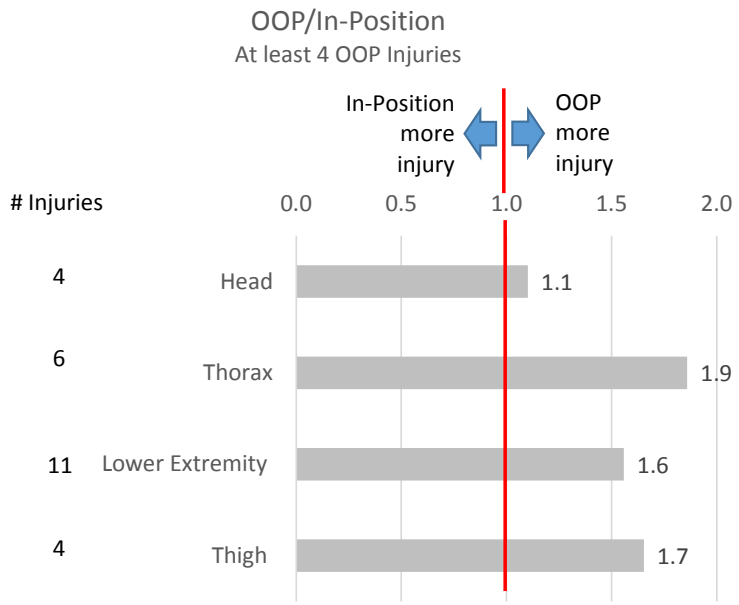


Figure 16. Ratio of the percentage of OOP and in-position occupants with AIS 2+ injuries by body region only for body regions with four or more injured occupants.

Discussion

6.3 Injury Patterns for Reclined Occupant Posture

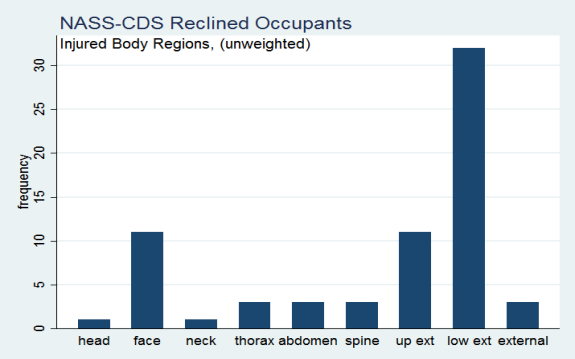
This analysis examined a limited number of cases in which the CIREN and NASS occupants were reported to be in a reclined posture (Table 14).

Table 14. CIREN and NASS Case Search Criteria

Search Criteria	CIREN	NASS Query
Age	≥13yr	≥13yr
Case year enrolled	2000-2014	2000-2014
Seating position	All	RFP
Crash type	All planar (no rollover)	Frontal (0 ± 40deg)
Restraint use	Belted, unbelted	Belted, unbelted
Occupant posture	Reclined	Reclined
Total # of cases	16	40

Results

Figures 17 and 18 present the results of the searches relative to body region. Figure 18 plots the body region injuries by AIS severity level. Note that the total number of injuries exceeds the total number of case subjects (16+40=56) as some subjects sustained multiple injuries.



Note: External – burns, asphyxiation, etc.

Figure 17. AIS 1+ injuries by body region for reclined occupant – NASS-CDS

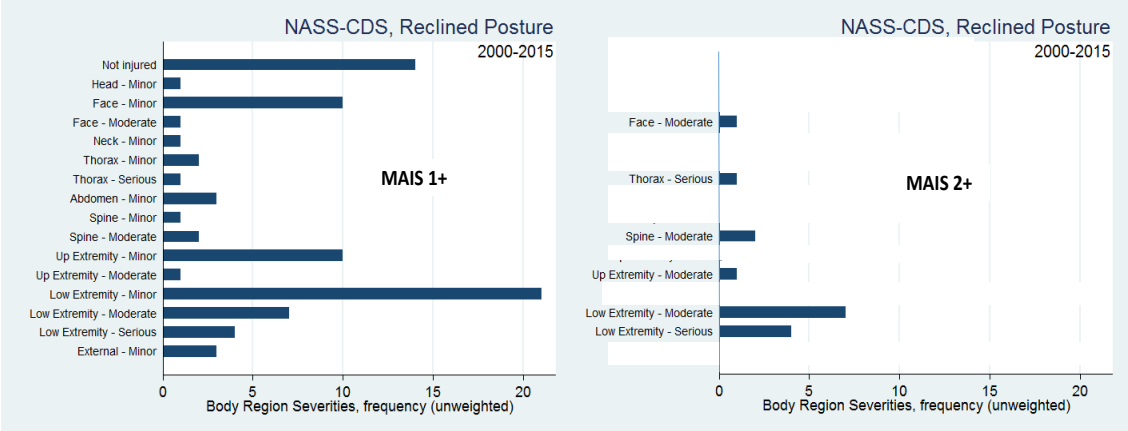


Figure 18. Injuries by body region and by severity for reclined occupant – NASS-CDS. The left chart includes all injuries, AIS 1-3. The right chart is restricted to only moderate (AIS 2) and severe (AIS 3) injuries.

Discussion

As expected, more CIREN subjects had higher MAIS levels than NASS subjects (Table 13). This is because entry to the CIREN database requires a MAIS of 3 or greater in most cases. The NASS database requires only that one of the vehicles involved in a crash be towed. There is no minimum injury level for the occupants explaining why 33 percent have no injury.

As per the "Injury Patterns for In-Position and Out-of-Position Occupants: Matched Pair Analysis" above, lower extremity injuries dominate the results of the frequency analysis both when considering injuries of all severities and only moderate and severe injuries (Figure 17 and 18). We found no AIS 2 or 3 abdominal injuries. This is surprising given that reclined posture increases the risk of submarining and exposure of the abdomen to lap belt loading.

Limitation

This analysis included only 56 subjects reported to be reclined.

6.4 Injury Patterns for Reclined Occupant Posture: Seatback Slightly Reclined Versus Seatback Completely Reclined

This investigation used a subset of the 56 case subjects identified using the Table 14 search criteria in order to compare occupants who sat in a normal posture with those who sat reclined. Search criteria in addition to those listed in Table 14:

- Coded post-crash seatback angle,
- 1st row belted passenger, and
- Injury with AIS level 2+.

We used reported post-crash seatback angle as a surrogate for occupant posture. Most occupants considered to be in a normal posture ride with the seatback slightly reclined (Manary et al., 1998).

Results

Table 15 lists the 15 injuries for the six subjects reported to have a slightly reclined seat and the 31 injuries for the six subjects in a completely reclined seat. Figures 19-21 present the injury distribution.

Discussion

The average number of injuries per subject for the completely reclined seatback group was twice that of the slightly reclined group (5.2 versus 2.5). This is consistent with past research and the findings of our Match Pair Study that found OOP to be associated with higher injury risk. The greatest difference in injury distribution was for the head. For subjects in the completely reclined seatback the 5 head injuries represented 16 percent of the total injuries recorded while those in the slightly reclined seat sustained only 1 head injury, 7 percent of the injury total. The percentage of head injuries for the completely reclined group was 2.4 that of the slightly reclined group (Figure 20 and 21). We found one case study in the literature in which the reclined posture was considered a contributing factor for a sub arachnoid hemorrhage and a cerebral contusion (Thorbole et al., 2015). The proposed mechanism is rapid rotation of the head when the upper torso and neck is arrested by the shoulder belt.

The completely reclined group also sustained proportionally fewer thoracic injuries. This finding contradicts that of the "Injury Patterns for In-Position and Out-of-Position Occupants: Matched Pair Analysis" that found that reclined occupants were more likely to sustain thoracic injuries.

We did not find a substantially greater proportion of abdominal injuries for the completely reclined occupants as would be expected if the reclined posture facilitated submarining and abdominal loading by the lap belt. In addition, neither cervical spine injuries nor lower extremity injuries, also associated with submarining, were proportionally higher for the completely reclined.

Limitations

This analysis included only 12 subjects. Any conclusions drawn from the results should be corroborated by additional investigation.

Table 15. Injury Distribution by Seatback Recline

	Seatback Slightly Reclined		Seatback Completely Reclined	
Body Region	**Injury**	**Count**	**Injury**	**Count**
Number of Subjects	6		6	
Head	Cerebral concussion	1	Skull fracture	1
			Vault skull fracture	1
			Brain stem laceration	1
			Cerebellum subarachnoid hemorrhage	1
			Cerebrum subarachnoid hemorrhage	1
	Subtotal	1		5
Face	-		-	
Neck	-		-	
Thorax	Clavicle fracture	1	Clavicle fracture	1
	Lung contusion	1	Lung laceration	1
	Rib cage fracture	1	Rib cage fracture	1
			Flail chest	1
	Subtotal	3		4
Abdomen	Jejunum-ileum laceration	2	Liver laceration	2
	Colon contusion(OIS Grade I)	1	Mesentery laceration	2
	Colon laceration	1	Pancreas laceration	1
	Spleen laceration	1	Diaphragm laceration	1
			Spleen laceration	1
			Colon contusion	1
			Jejunum-ileum contusion	1
			Liver contusion	1
			Stomach contusion	1
	Subtotal	5		11
Spine				
Cervical Spine	C Spine fracture	2	C-spine fracture	2
			C-spine cord laceration	1
Thoracic Spine			T-spine fracture	1
Lumbar Spine	Vertebra, L-spine fracture	1	Vertebra, L-spine fracture	1
	Subtotal	3		5
Upper Extremity			Ulna fracture	1
Lower Extremity				
Pelvis	Pelvis fracture	1	Pelvis fracture	1
			Sacroilium fracture	1
Thigh	Femur fracture	2	Femur fracture	1
Knee				
Leg			Tibia fracture	1
			Leg fracture NFS leg or ankle fracture NFS	1

	Seatback Slightly Reclined		Seatback Completely Reclined	
Body Region	**Injury**	**Count**	**Injury**	**Count**
Foot				
	Subtotal	3		5
Total number of injuries		15		31

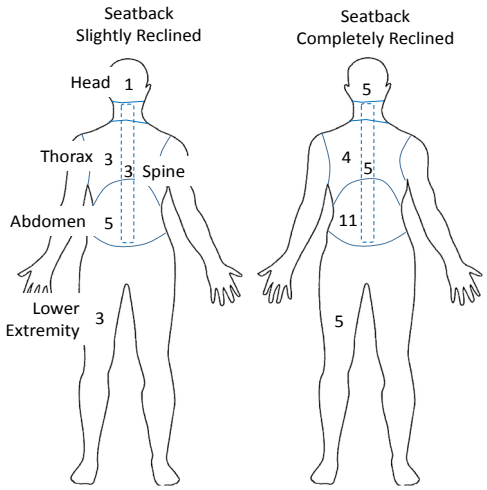


Figure 19. Injury map showing number of injuries per body region.

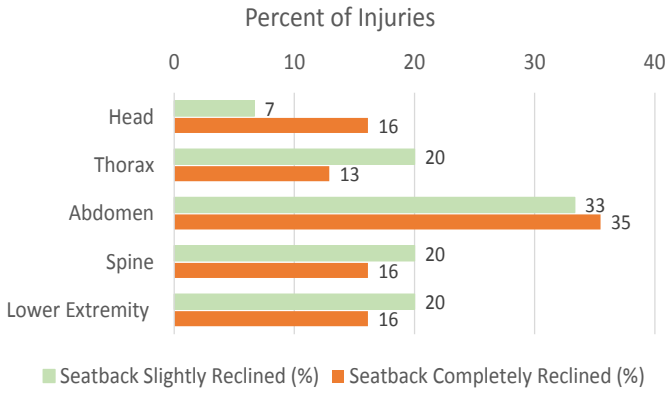


Figure 20. Injury distribution by percent.

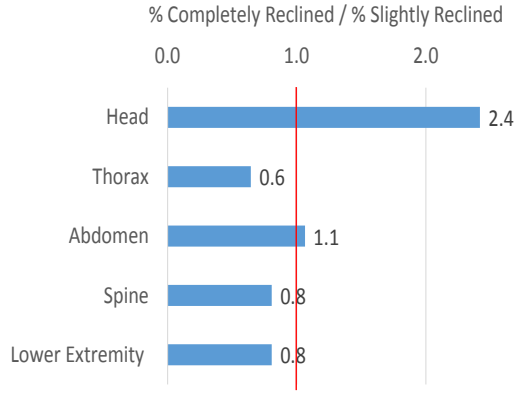


Figure 21. Ratio of injury distribution by percent.

6.5 Injury Patterns Summary

Table 16 summarizes the findings and limitations of the four injury pattern studies. The findings are inconsistent from study-to-study and inconsistent both with our other studies in this report and with prior research publications. For example, the first study found that OOP subjects had fewer injuries than in-position subjects for the head, neck, thorax, upper extremity, and pelvis. This finding was inconsistent with that of the second study that used matched pair method to ensure similar subject characteristics between the two groups.

Assuming that many OOP subjects sit reclined and that a reclined posture increases the chance for submarining and the associated injuries to the abdomen due to lap belt loading, to the neck and cervical spine due to shoulder belt loading, and to the lower extremities due to a poorly restrained lower body, we expected all of our studies to find increased abdominal, neck, and lower extremity injuries. The results were mixed with only the second study finding an increase in of injuries for all of these body regions. Study three, while finding an increase in OOP lower extremity injuries, did not find an increase in abdominal injuries, most commonly associated with submarining. Study four identified head injuries as much more common for OOP occupants. As head injuries, at least those sustained when the head whips forward over the shoulder belt, may occur for a submarining occupant, the fact that this study did not find an increase in abdominal injuries was puzzling.

While the findings were inconsistent, there was a consistent limitation for the four studies. All suffered from a low number of OOP subjects and subject injuries. Studies three and four included only 56 and 12 subjects respectively. Even study two, which we consider to have produced the most defensible results due to the matched pair strategy, was limited by often single digit numbers of OOP occupants per body region. The low number of OOP subjects and subject injuries limited the statistical power to test for trends or to demonstrate statistical significance in the differences between OOP and in-position occupant injury patterns using the CIREN and NASS databases. Therefore, the findings of all four studies should be used with caution.

Table 16. Injury patterns for occupants out of position

Study	Findings	Limitations
1) Injury Patterns for In-Position and Out-of-Position Occupants	The weighted injury frequency was lower for OOP subjects for the head, neck, thorax, upper extremity, and pelvis. We found no neck injuries for OOP occupants no increase in the frequency of cervical spine injuries for OOP occupants as has been reported for fully reclined submarined occupants.	Differences between the in-position and OOP occupants such as age might explain this unexpected finding. Low numbers of OOP subjects limits the statistical power of identifying differences relative to in-position occupants.
2) Injury Patterns for In-Position and Out-of-Position Occupants: Matched Pair Analysis	For most body regions, especially the foot, abdomen, thorax, cervical spine, and thigh, being OOP may be an injury risk factor. The finding that both abdominal and cervical spine injuries may be associated with OOP, is consistent with the injury pattern often reported for submarining that is more likely for reclined postures.	Low number of OOP subjects per body region results in insufficient statistical power to test for trends.
3) Injury Patterns for Reclined Occupant Posture	Lower extremity injuries dominate the results of the frequency analysis. We found no AIS 2 or 3 abdominal injuries. This is surprising given that reclined posture increases the risk of submarining and exposure of the abdomen to lap belt loading.	This analysis included only 56 subjects reported to be reclined.

Study	Findings	Limitations
4) Injury Patterns for Reclined Occupant Posture: Seatback Slightly Reclined Versus Seatback Completely Reclined	The percentage of head injuries for the completely reclined group was 2.4 that of the slightly reclined (normal posture) group. The completely reclined group also sustained proportionally fewer thoracic injuries. We did not find a substantially greater proportion of abdominal injuries for the completely reclined occupants as expected.	This analysis included only 12 subjects.

7. Acknowledgments

NHTSA provided funding support for this study. Javier Ferro and Fran Lopez-Valdes shared sleeping posture images of their research volunteers.

8. References

Battaglia, S., Kietlinski, K., Unger, M., van der Made, R., & Bours R., (2013). *Occupant behavior during a one-lane change maneuver resulting from autonomous emergency steering*. (Paper 13-0383). Proceedings of the 23rd International Technical Conference on the Enhanced Safety of Vehicles, Seoul, Korea.

Braver, E., R., Scerbo, M., Kufera, JA., Alexander, M., T., Volpini, K., & Lloyd, J. P., (2008). Deaths among drivers and right-front passengers in frontal collisions: redesigned air bags relative to first-generation air bagsAir bagAir bag. *Traffic Injury Prevention, 9*(1): 48-58.

Carter, P. M., Flannagan, C. A. C., Reed, M. P., Cunningham, R. M., & Rupp, J. D., (2014). Comparing the effects of age, BMI and gender on severe injury (AIS 3+) in motor vehicle crashes. *Accident Analysis and Prevention, 72*: 146-160.

Department of Transportation. (2001). The 2001 National Household Travel Survey, daily trip file [Database]. Author.

Dissanaike, S., Kaufman, R., Mack, CD., Mock, C., & Bulger, E., (2008). The effect of reclined seats on mortality in motor vehicle collisions. *Journal of Trauma, 64*(3): 614-619.

Fagnant, D., & Kockelman, K. M. (2013). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. Eno Center for Transportation.

Fox, A. D., & Dickinson, E. T., (2010). Neck & neck. Seat belt sign on the neck is as serious a finding as on the abdomen. *JEMS: A Journal of Emergency Medical Services, 35*(4): 36-37.

Fukui, T.., Koyota, N.., Isonaga, K.., Kamiji, K.., & Ino, T., (2001). Occupant position detection system (OPDS) for side aAir bag system. *JSAE Review, 22*(1): 69-74.

Gaewsky, J. P., Weaver, A. A., Koya, B., & Stitzel, J. D. (2015). Regional-level injury risk sensitivity to pre-crash driver position within simplified real world motor vehicle crash reconstructions. Proceedings of the Injury Biomechanics Symposium, Ohio State University, Columbus, OH.

Harberl, J., Ritzl, F., & Eichinger, S. (1989, May 29-June 1). *The effect of fully seat-integrated front seat belt systems on vehicle occupants in frontal crashes*. Proceedings of the 12th International Technical Conference on Experimental Safety Vehicles, 1138-1145; Göteborg, Sweden.

Hayes, B. (2011). Leave the driving to it. *American Scientist, 99*: 362-366.

Jeffery, R. S., & Cook, P. L., (1991). Seat belts and reclining seats. *Injury-International Journal of the Care of the Injured, 22*(5): 416-417.

Levinson, D. (2015). Climbing Mount Next: The effects of autonomous vehicles on society. *Minnesota Journal of Law, Science & Technology, 16*(2): 787-810.

Litman, T. (2016, January 11-15). *Autonomous vehicle implementation predictions: Implications for transport planning*. Transportation Research Board 94th Annual Meeting, Washington DC.

Lopez-Valdes, F. J., Fernandez-Bolanos, M. M., Alvarez Ruiz-Larrinaga, A., & Segui-Gomez, M. (2011). Reduction in the exposure to being out-of-position among car occupants who used a sleeping device. *Injury Prevention, 18*(3): 165-169.

Manary, M., Reed, M., Flannagan, C., & Schneider, L. (1998, November 2-4). *ATD positioning based on driver posture and position* (Paper No. P-337). 42nd Stapp Car Crash Conference Proceedings, Tempe, AZ.

National Transportation Safety Board. (1988). Safety Recommendation H-88-009. Author.

Pickrell, T. M., & Li, R. (2016, February). *Seat belt use in 2015 - Overall results* (Traffic Safety Facts Research Note. Report No. DOT HS 812 243). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812243

Rashidy, M., Deshpande, B., Lindberg, J., Morris, R., Munson, R., Summers, L., & Gunasekar, T. J. (2001, June 4-7). *Analytical evaluation of an advanced integrated safety seat design in frontal, rear, side, and rollover crashes*. Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles. Amsterdam, The Netherlands.

Rehm C. G., & Goldman, R. K., (2001). Seat belt and car seat in a reclined position: A dangerous combination. *Journal of Trauma, 51*(6): 1189-1191.

Rubin, D. B. (1980). Bias reduction using Mahalanobis-metric matching. *Biometrics, 36*(2):293-298.

Schöeneburg, R., Baumann, Kh., & Justen R., (2003, May 19-22). Pre-safe - The next step in the enhancement of Vehicle Safety. Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan.

Singhvi, A., & Russell, K. (2016, July 12). *Inside the self-driving Tesla fatal accident*. New York Times. www.nytimes.com/interactive/2016/07/01/business/inside-tesla-accident.html

Sivak, M., & Schoettle, B. (2015, January)., Road safety with self-driving vehicles: General limitations and road sharing with conventional vehicles, sustainable worldwide transportation program (Report No. UMTRI-2015-2). University of Michigan Transportation Research Institute.

Stigson H., Kullgren A., & Rosen E., (2012). Injury risk functions in frontal impacts using data from crash pulse recorders. *Annals of Advances in Automotive Medicine, 56*: 267-276.

Thorbole, C. K. (2015, November 13-19). *Dangers of seatback recline in a moving vehicle: How seatback recline increases the injury severity and shifts injury pattern*. ASME 2015 International Mechanical Engineering Congress and Exposition, IMECE 2015, Houston, TX. DOI: 10.1115/IMECE2015-51809

Appendix A: Sleeping Postures

The authors of a study that tracked head position while sleeping in the front passenger seat of a moving car (Lopez-Valdes et al., 2011) shared a subset of the subject videos. A researcher associated with the study, Javier Ferro, selected six of the 41 subject videos to illustrate the observed variety of sleeping postures assumed by male and female subjects with an average age of 44 years and BMI of 27.

Test conditions

The same mid-range car (Citroen C4 HDI) was used in all the tests. The passenger seat was placed as far back as possible and was reclined at an angle of 30° from the vertical plane, with the height of the headrest adjusted to the passenger head. All subjects wore a 3-point belt.

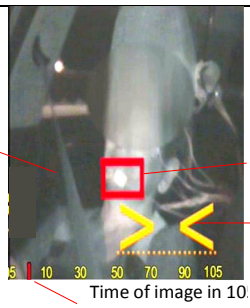
Results

Table A1 presents select images from the subject videos. The necessarily low light level and attempts to conceal facial features to protect subject identity reduced the image quality. However, head and upper body position is visible. The initial face/head position was designated by a red rectangle drawn around a white marker placed on the chin. The yellow arrows indicate the initial position of an identifiable landmark on the upper torso. Downward movement of the landmark relative to the arrows indicates that the subject's torso moved down during the session.

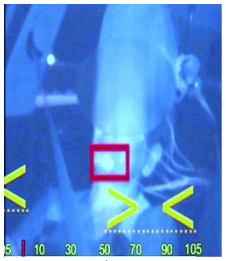
Table A1. Sleep Study Subject Images

Notes
A – Head position
B – Comment

Key:



(Subject) 10b



Neutral [A]
Initial position [B]

Neutral

Right
Torso moved down

14b

Neutral (neck pillow)
Initial position

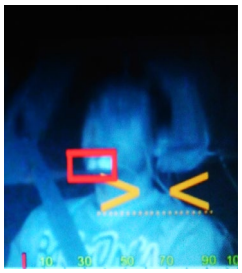
Left leaning

Left, forward

Neutral, rear

Forward

22b



Neutral
Initial position

Right
Face in front of shoulder belt. Shoulder moved down.

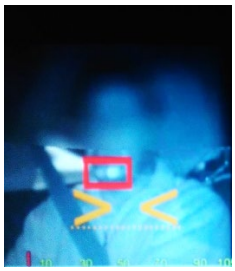
Left

Right

Neutral

Right
7 min. after this, moved back to neutral

25a

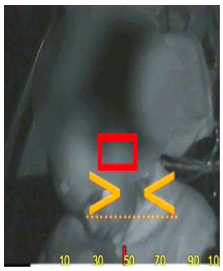


Neutral
Initial position

Rear
midline

Neutral

Forward



Forward right
Head forward of
shoulder belt

30a

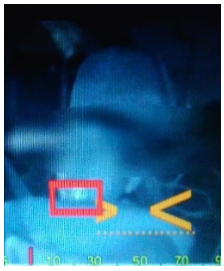
Neutral
Initial position

Left
Shoulders lower.

Right

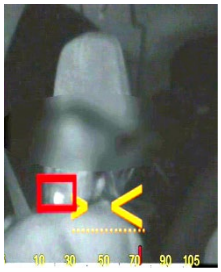
Right
Shoulder belt in
front of face

33b

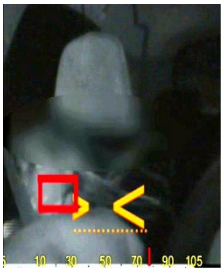


Neutral
Initial position

Right
Face in front of
shoulder belt



Neutral



Right
Shoulder belt in
front of face

Observations

1. All subjects moved during the 105 minutes driving session. Most rotated and/or leaned their head left and right while others rotated their head rearward and forward. Subject 22b was particularly restless.
2. One subject, 10b, maintained a relatively stable head position but appeared to slide down in his seat at about 7 minutes into the session.

3. Subjects 30a and 33b both leaned their heads far enough to the right to place their face behind the shoulder belt. Subject 33b's face was both in front of and then behind the belt. Subjects 22b and 25a slept with their face in front of the shoulder belt.
4. All but subject 14b leaned right at some point in the driving session. This posture appeared to place the neck near the shoulder belt.
5. While some of the subjects leaned their heads to the left (inboard), we did not observe inboard torso lean sufficient enough to move the right shoulder inboard of the shoulder belt path.
6. Subject 14b used a neck pillow that may have reduced lateral leaning but did not control forward and rearward motion.
7. The seatback angle of 30 degrees reclined is approximately 6 degrees more than that selected by the average vehicle occupant. While this additional recline is associated with a more relaxing sitting position with the head resting on the headrest, it was not sufficient to prevent two of the subjects (14b, 25a) from hanging their head forward in a chin-to-chest posture.
8. Not evident in the still images was the effect on subject posture of vehicle motion. Although the car was driven sedately in order to not disturb the subjects' sleep, nonetheless, the videos showed involuntary head movement in response to vehicle maneuvers and/or roadway topography.

Discussion

Although subjects leaned laterally, we found no cases in which the head was against the side glass or resting on the top of the door. In the case of the downward deploying curtain air bag, a head against the window posture could result in the air bag deploying inboard of the head. Occupants who sit near the door risk being in the path of deploying seatback and curtain air bags (Lopez-Valdes et al., 2011). Javier Ferro, one of the sleep study researchers, has documented children test subjects who slept in these postures during driving sessions (Figure A1) (Javier Ferro personal communication, January 17, 2017). The potential for injury from deploying air bags has motivated Honda to develop a system that prevents deployment of the seatback bolster air bag if a short-stature passenger leans into the path of the air bag (Figure A2) (Fukui et al., 2001).

The videos did not show the position of the lower body or lower extremities. However, the upper torso of three subjects, 10b, 22b, and 30a, moved downward during the session. This may have indicated that they assumed a slouched position with a posteriorly rotated pelvis. This posture increases the chance of submarining under the lap belt in the event of a frontal crash.

Belt loading injuries attributed to postures associated with sleeping such as a reclined torso include submarining injuries (abdomen and lumbar spine) and neck injuries (soft tissue and cervical spine) (NTSB, 1988, Rehm & Goldman, 2001, Thorbole, 2015). In this review, 5/6 subjects slept with their neck near the shoulder belt and potentially more susceptible to shoulder belt loading of the lateral neck in a frontal crash. Such loading has been associated with blunt carotid artery injury (BCAI) and blunt vertebral artery injury (BVAI) that may result in a life-threatening stroke (Fox & Dickinson, 2010).

The finding that even sleeping occupants assume a series of non-midline, non-erect postures supports the need for restraint systems that continually adapt to a range of occupant positions.

Figure A1. Child subject sleeping with head on top of the door. Source: Personal communication, Javier Ferro, January 17, 2017.

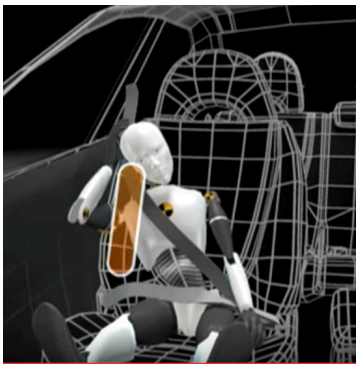


Figure A2. Occupant position seat sensor (Fukui, 2001).

Appendix B: Defining the Reclined Sitting Position

CIREN and NASS databases have fields that allow the coding of both pre-crash occupant posture and post-crash seatback angle. In some cases, there are post-crash interior photos that show seatback orientation. However, the coded information is qualitative. The pre-crash occupant posture variable includes only one code for reclined posture "Lying back in a reclined position." The seatback variable includes only "slightly reclined" and "fully reclined." In order to quantify occupant posture, we have conducted a pilot study to measure the post-crash seatback recline using CIREN and NASS interior photos. The study also provided information on how occupant torso angle relates to seatback angle.

Method to estimate seatback reclined angle

Seatback angles were estimated by using case photos from CIREN and NASS-CDS database. Seatback angle, as recorded in many New Car Assessment Program (NCAP) reports, is taken on the rear surface of the seatback (Figure B1).

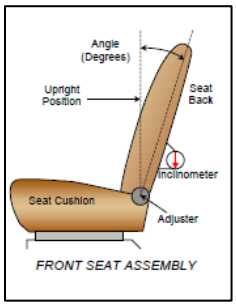


Figure B1. Measurement technique of seat reclined angle from NCAP

Method:

1. A reference lines (line 2) is drawn parallel to the top of the door in a lateral view photo of an exemplar vehicle as shown in right hand side of Figure B2. A horizontal line (line 1) is drawn parallel to the ground so that angle α between line 1 and 2 can be determined.
2. Right front passenger area is shown on the left-hand side of Figure B2. Reference line 3 is drawn parallel to the window section. Line 4 is drawn along the seatback and angle β can be determined between line 3 and line 4.
3. By assuming a fully upright seat has 0° seat reclined angle, the seatback recline angle is determined by summing angle α and angle β minus 90°.

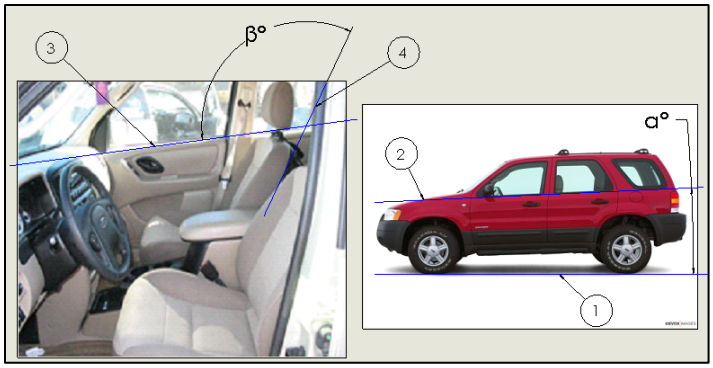


Figure B2. Seatback recline angle estimation

Sources of Error:

1. Line 4 was drawn on the rear border of the seatback when it was visible. In most photos, however, it was not visible and the front surface of the seatback cushion was used (Figure B3).
2. Judgement was required in drawing the line that was intended to represent the average angle of the seatback that was comprised of two or more segments with different inclinations.
3. Although we rejected case photos taken at noticeably oblique angles (>~15 degrees) relative to the vehicle, the position of the camera relative to the vehicle and seatback varied from case to case and this variability introduced an unknown error due to parallax.

Figure B3. Seatback recline angle estimation on the seatback rear surface (left) and the front surface (right)

Error estimation and reduction strategy

We photographed and measured seatback angles for three vehicles, a sedan, an SUV, and a minivan, to:

1) compare the angle of the front surface of the seatback to the rear surface (NCAP standard angle measurement); and
2) estimate the error associated with parallax and our error in judgement when drawing the line on the photos.

A) Inclinometer Measurements:

Comparison of Rear of Seatback to Front Surface of Seatback Angle

For each vehicle, the rear surface of the seatback (B1) and three locations on the front surface of the seatback cushion (C1, C2 and C3) were measured with an inclinometer in three locations (Figure B4). The seatback was placed in its most upright position.

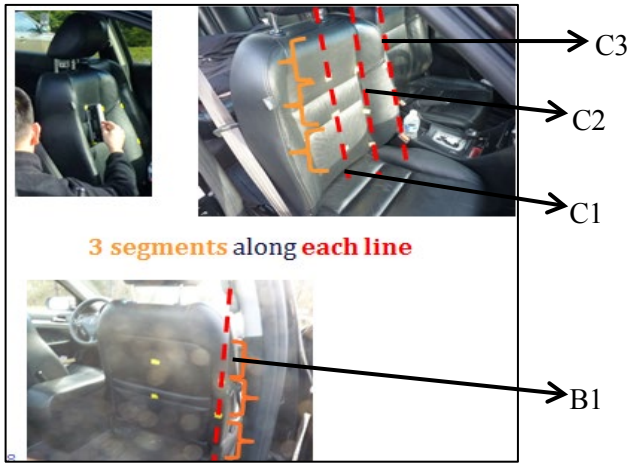


Figure B4. Illustration of seatback reclined angle measurement along seatback and seatback cushion using inclinometer

The results are presented in Figure B5 and Table B1. The seatback bolster (C3) has the largest average angle difference (13 deg.) due to its variable curvature. However, C1 and C2 overestimated B1 by only 2 -3 degrees.

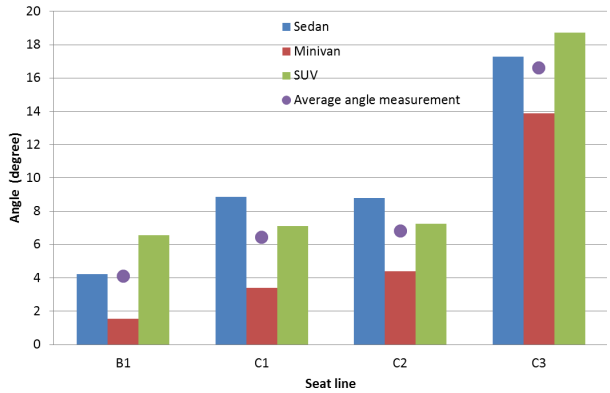


Figure B5. Average measured seatback angle versus seatback line at 0° reclined seatback

Table B1. Details of measured angle at different seat line for the 3 vehicles

	Sedan	Minivan	SUV	Average angle (degree)	Average angle difference relative to B1
Angle at B1 (degree)	4	2	7	4	0
Angle at C1 (degree)	9	3	7	6	2
Angle at C2 (degree)	9	4	7	7	3
Angle at C3 (degree)	17	14	19	17	13

A) Inclinometer Measurements versus Lines Drawn on Photos on the Rear Surface of the Seatback

In this analysis, that included four views taken with a camera perpendicular to the vehicle we compared angles estimated from lines drawn along the rear surface of the seatback (B1) with the inclinometer measurement (Figure B6). Figure B7 shows that the photo method overestimates the inclinometer (actual) angle by an average of 9 degrees.

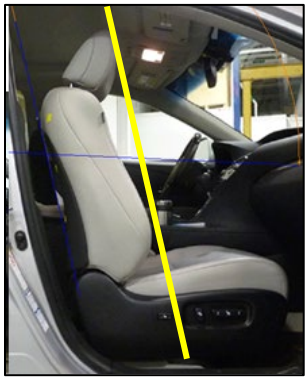


Figure B6. Estimated angle of rear surface of seatback

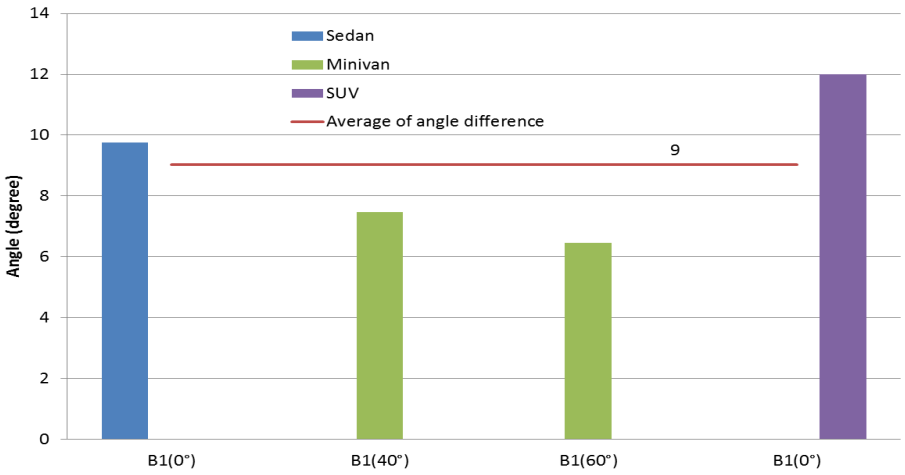


Figure B7. Angle difference between inclinometer measurement and photo method for B1

B) Inclinometer Measurements versus Lines Drawn on Photos on the Front Surface of the Seatback

For three locations on the seatback cushion front surface we used and inclinometer in three locations along each line and estimated the angle of these lines from a photo (Figure B8). The seatbacks were placed erect and in three recline positions, 20, 40, and 60 degrees relative to vertical.

Note that the photos were taken at 25 deg. relative to the long axis of the vehicle (Figure B9). Because we had rejected case photos taken obliquely with an angle greater than ~15 degrees, we expect that parallax errors associated with the 25 deg. test photos would bound those of the case photos.

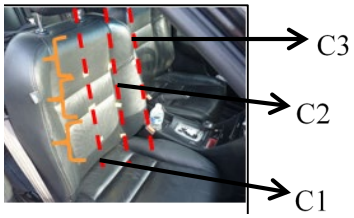


Figure B8. Locations on the front of the seatback

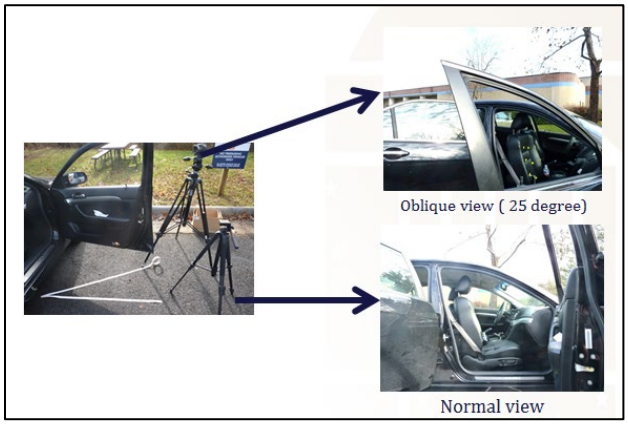


Figure B9. Cameras setup for photo taking at normal and oblique view

Figure B10 presents the results of the inclinometer versus the photo method of angle estimation. The photo method overestimates the actual (inclinometer) angle for the front of the seatback cushion (C1, C2 and C3) an average of 7, 9, and 7 degrees respectively. These differences include errors associated with parallax and with judgement errors in selecting the appropriate line on the photo.

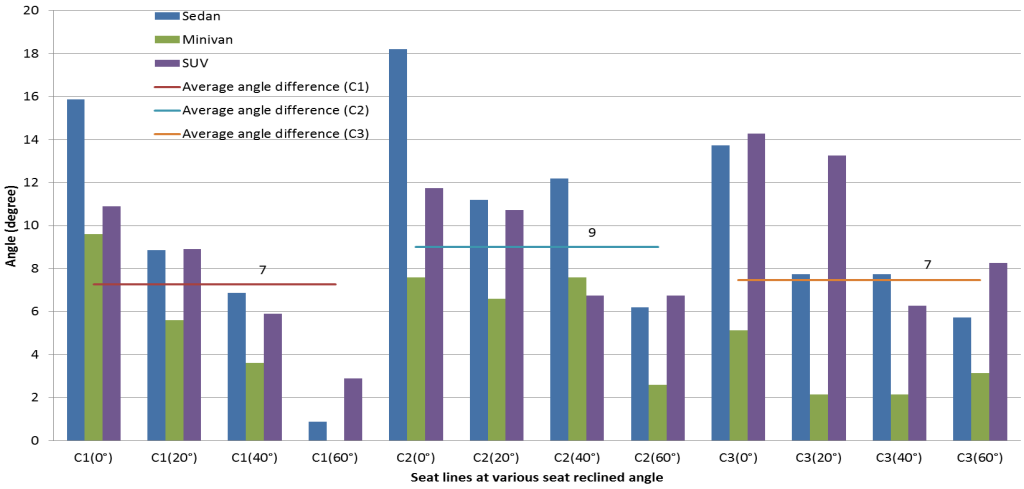


Figure B10. Difference between seatback cushion angle measured by an inclinometer and by the photo method at three locations (C1, C2 and C3)

Error Reduction for Angles Estimated Using the Photo Method for CIREN and NASS-CDS Case Photos

In order to estimate the angle of the NCAP standard rear of the seatback angle for the CIREN and NASS case photos we applied correction factors according to where the line was drawn to estimate seatback angle (Table B2). Note that the correction values are subtracted from the original estimated angles.

For example, a case photo with an estimated angle of a line drawn at C1 would overestimate the angle of the front of the seatback by an average of 7 degrees (Figure B10). In order to convert this angle to the rear of the seatback requires an additional subtraction of 2 degrees (Table B2). In this case the original case photo seatback angle would be adjusted by subtracting a total of 9 degrees.

Table B2. CIREN and NASS Case Photos Location of Estimate Seatback Angle Lines and Applied Correction to Yield Rear Surface Seatback Angle

	# of Cases	Applied Correction (deg)	Source of Correction
B1	10	9	Figure 6
C1	14	2 + 7 = 9	Table 1, Figure 10
C2	0	-	
C3	2	13 + 7 = 20	Table 1, Figure 10

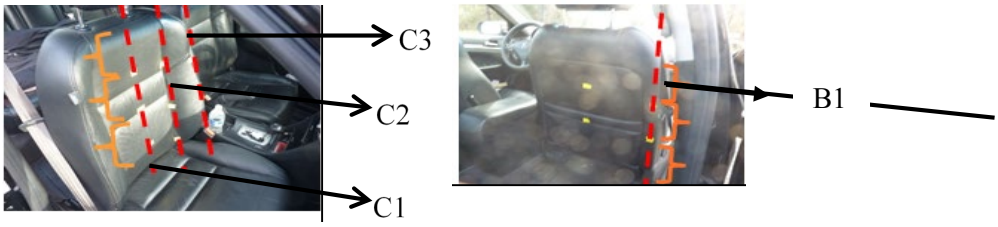


Figure B11 presents the case seatback angles adjusted in this manner and estimate the recline angle of the rear surface of the seatback. Seatback angles described in the databases as "slightly reclined" range from 13° to 35° and seatback angles greater than 33° are described as "completely reclined." There is a 2 degree overlap region (33° to 35°) for the slightly reclined and completely reclined descriptions at which the seatback angle lies in between. The maximum seatback recline angle measured is 62°. The most common seatback angle for front passengers, "usual seatback angle," is approximately 24° (Manary et al., 1998).

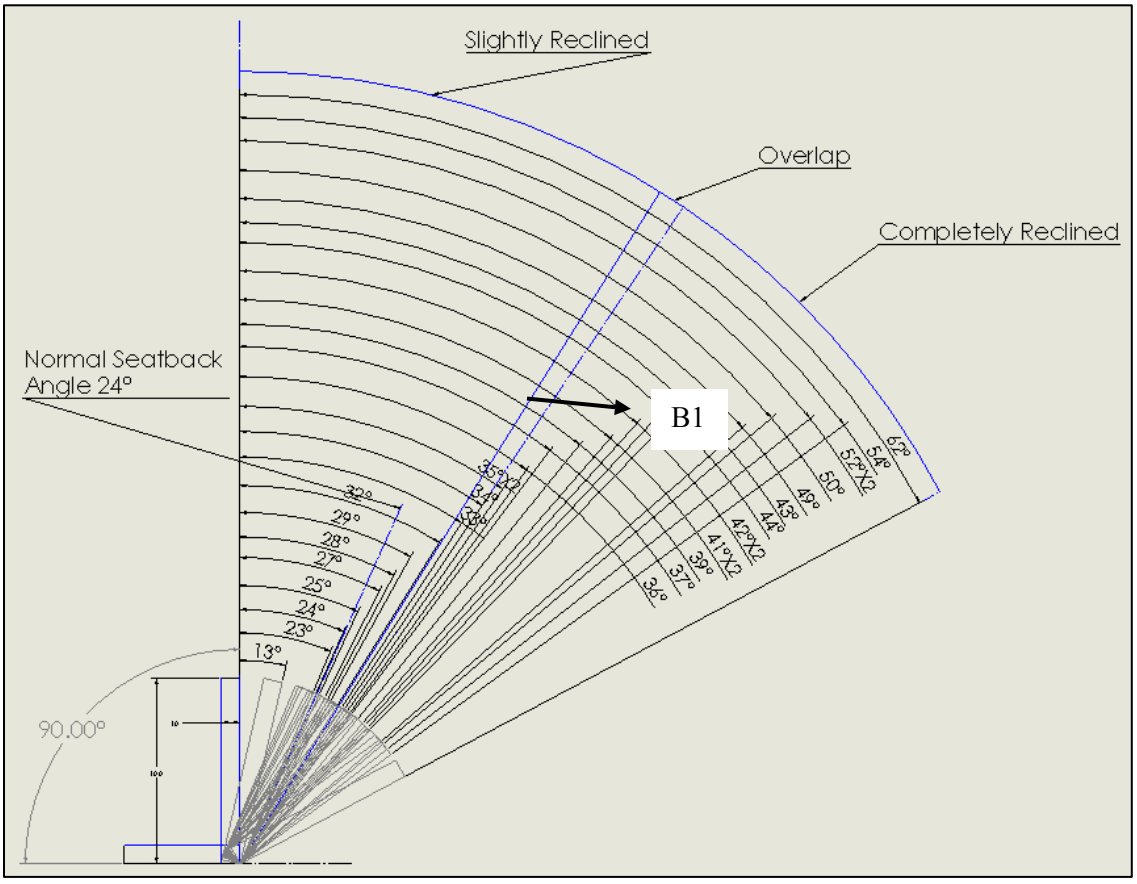


Figure B11. Distribution CIREN and NASS case seatback rear surface inclination angles

Relationship between occupant torso and seatback angle

Using CIREN and NASS post-crash photos to estimate seatback angle is useful only if seatback angle is related to occupant torso angle. We conducted a simple and very limited study (one volunteer ~50th male 67.5 kg (148lbs) and 176cm (5'9")) in which we measured sternal angle and correlated it with the angle of the rear of the seatback (B1) (Figure 12).

An inclinometer was placed on the subject's sternum while the subject sat at reclined angles of 0°, 20°, and 40° in each vehicle (i.e. sedan, minivan, and SUV). Figure B12 illustrates the subject sitting in the minivan at the three different seat reclined angles.

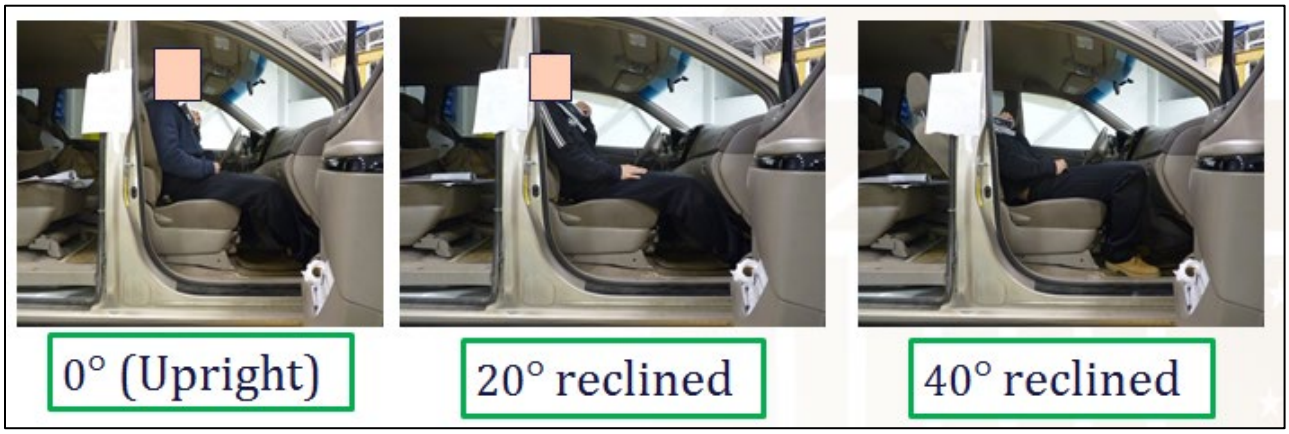


Figure B12. Subject sitting in the minivan at 3 different seatback reclined angles

Table B3 and Figure B13 show an approximately linear relationship of sternum angle relative to the seat-back (B1) as a change of seatback angle produces a similar change in sternal angle. However there is a large difference (~30 degrees) between the two angles.

Table B3. Sternal Angle Relative to Seatback Angle

Degrees	Seatback Angle Relative to Vertical	Sternal Angle Relative to Vertical	Change in Seatback Angle	Change in Sternal Angle
Sedan	4	35		
	20	49	16	14
	40	77	20	28
Minivan	1	31		
	19	46	18	16
	39	74	20	27
SUV	1	30		
	20	52	19	22
	40	81	21	28

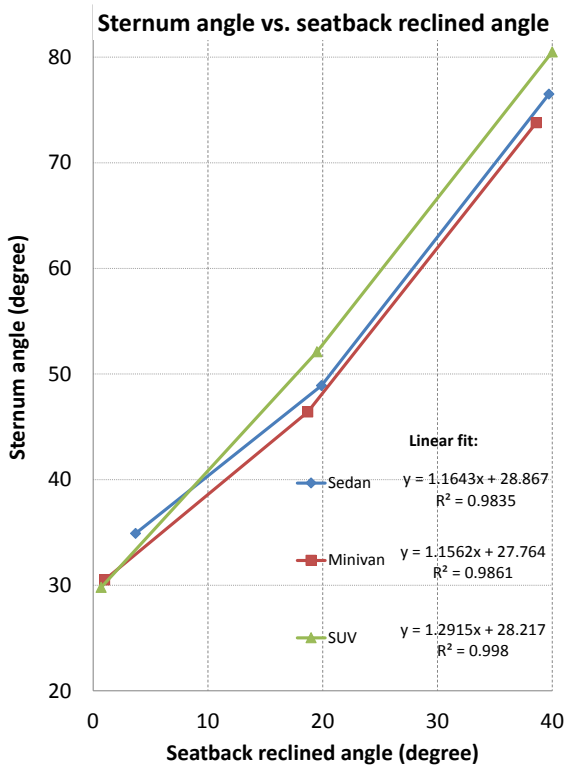


Figure B13. Sternum angle versus seatback reclined angle

Discussion

Our study of CIREN cases found that it is possible that an occupant assumed a lying back posture despite the seatback not being fully reclined. This means that "occupant posture" and "seatback recline" are not interchangeable terms as assumed by Dissanaike et al. (2008). Our NASS Study found that 90 percent of the seatbacks coded as "fully reclined" had occupants coded as "lying back." However 0.2 percent of the seatbacks coded as "slightly reclined" also had occupants coded as "lying back." This means that, while a few occupants may have assumed more of a reclined posture than suggested by the seatback angle, most who rode reclined also reclined their seatback. Therefore, seatback angle is usually a reasonable surrogate for occupant torso angle.

This was a pilot study designed to provide more information on seatback recline and how it relates to occupant torso recline in order to inform the subsequent task work including FE human body modeling. It was not intended to comprehensively investigate the relationship between seatback angle and the occupant torso angle. This relationship is complicated by the topography of the seatback cushion, the variable geometry of the human torso including spinal curvature, and how far the occupant sits back in the seat. We measured only one volunteer subject.

Despite the study's limitations, it provided useful information:

1. The seatback angle estimated using lines drawn on the rear of the seatback and along the centerline of the front of the seatback on CIREN and NASS case photos overestimated the actual angle of NCAP standard rear of the seatback by no more than 9 degrees. This error bound is acceptable given objectives of the overall project, namely to explore FE models and their ability to simulate a variety of non-standard postures.

2. Using the lateral seatback bolster contour to estimate seatback angle is not recommended due to the potential for greater error (20 degrees).
3. While there is considerable difference between the volunteer's sternal angle and the seatback angle, a change in the seatback angle produced a similar change in the sternal angle.

This information will help in the FE field data case simulation task by providing specific ranges of seatback angles corresponding to qualitative descriptions available for CIREN and NASS cases (Figure B11). It also will provide a real-world check for positioning the human FE models in various reclined postures.

Appendix C: CIREN Case Study: Laying-Back Posture Cases

Case 286014504

The 66-year old female case occupant, 155 cm (61 in) in height and 62 kg (137 lb) in weight, was the right front passenger of a 2004 Acura TL 4-door sedan that was involved in a moderate frontal impact crash with another passenger car. The PDOF was 12 o'clock (350 deg.). Estimated delta V was -28 km/h. The speed limit on the 2-lane rural highway was 89 km/h (55 mph).

Restraint: She was restrained by a 3-point lap/shoulder belt. Belt position described as "lap belt is snugged and low across hips; shoulder belt across the collarbone and over shoulder with extra "slack room"." The frontal air bag deployed but the pretensioner did not actuate.

Seat track position and seatback recline: Her seat base adjustment was coded as "middle track position" and her seatback was described as "reclined all the way back."

Occupant posture: She was reported to be sleeping.

Vehicle and Occupant Motion: "On impact, the case occupant moved forward relative to the vehicle."

Occupant Loading / Occupant Injuries, ICS, IPC: "The occupant's torso loaded the shoulder part of the belt flexing her neck over the shoulder belt. She sustained a cervical spine (C1) left anterior arch fracture extending into left lateral mass. The injury causation was coded with a confidence level of possible. She sustained a thoracic spine (T12) burst fracture, anterior and mid column with 6mm retropulsion into spinal cord. The injury causation was coded with a confidence level of probable. Both injuries were attributed to flexing over the shoulder belt. The shoulder belt loading to the abdomen caused the Grade II right lobe liver laceration along with the right rib fracture (# 8). The injury causation was coded with a confidence level of certain. For these three injuries, the evidence of the causation scenario was the occupant's initial seating posture determined through occupant interview, kinematics and vehicle principal direction of force. The case occupant also sustained non-displaced left skull fracture to the occipital bone and left proximal ulnar fracture. The sources for these injuries are unknown."

Case 317118807

The 49-year old male case occupant, 180 cm (71 in) in height and 86 kg (190 lbs) in weight, was the right front passenger of a 2012 Chevrolet Impala 4-door sedan involved in a severe frontal impact with a ditch. The driver of V1 swerved to avoid impact with a deer but lost control and departed the right side of the road. V1 traveled down a small embankment and struck a ditch with its frontal plane. The PDOF was 12 o'clock (10 deg.) and the estimated delta V was -13 km/h longitudinal and -2 km/h lateral. The posted speed limit for the interstate highway was 113 km/h (70 mph).

Restraint: He was restrained by a 3-point lap/shoulder belt with the D-ring in mid position. Belt position note: "Occupant reclined fully - shoulder belt not touching shoulder or chest." The belt retractor pretensioner and the frontal air bag deployed.

Seat track position and seatback recline: His seat base adjustment was coded as "rear most track position" and his seatback was coded as "completely reclined."

Occupant posture: He was reported to be "asleep in a fully reclined position."

Vehicle and Occupant Motion: "On impact the case occupant moved forward and outboard (towards the right front door) in relationship to the vehicle…."

Occupant Loading: Not reported.

Occupant Injuries, ICS, IPC: "…middle chest abrasions extending towards his right shoulder and a left seventh rib fracture both caused by the seat belt. The L1 burst fracture was attributed to the pelvis contacting the seat pan. The knee was pocketed by the knee bolster and at the same time the lap belt was contacting the abdomen causing the flexion and compression of the L-spine. A probable confidence level was assigned to the L1 burst fracture."

Case 359458609

The 29-year old female case occupant, 157 cm (62 in) in height and 62 kg (137 lbs) in weight, was the right front passenger of a 2009 Mazda Mazda3 4-door sedan that was involved in a moderately severe frontal impact. Estimated delta V -38 km/h ; PDOF = 12 o'clock (10 deg).

Restraint: She was restrained by a 3-point lap/shoulder belt with a retractor type pretensioner that activated during the crash. The D-ring adjuster in the full down position. The frontal air bag deployed.

Seat track position and seatback recline: Her seat base adjustment was coded as "between forward and middle seat track position" and her seatback was described as "fully reclined."

Occupant posture: Not reported. She was reported to be "in a fully reclined position per interview."

Vehicle and Occupant Motion: "Her body …. moved forward"

Occupant Loading: "…the belt webbing had loading evidence from restraining her torso. Both knees contacted and scuffed the glove box door. Her seat pan and cushion deformed downward from loading of her buttocks."

Occupant Injuries, ICS, IPC: "This patient suffered a grade III liver laceration, a grade III splenic laceration, and multiple bilateral rib fractures at the level of the 5th - 8th anterior and lateral ribs. The abdominal injuries and rib fractures were all due to compression from the seat belt as certain. Her posture of being fully reclined contributed to this mechanism and location of the belt loading into the upper abdomen and mid torso."

Observation: Not sure if this meant submarining - all injuries could have been due to shoulder belt. Not sure how recline changed injury pattern

Case 385166433

The 29-year old female case occupant, 168 cm (66 in) in height and 70 kg (155 lbs) in weight, was the right front passenger of a 2010 Mazda CX-7 SUV, which was involved in a moderately severe frontal impact with a concrete culvert/embankment area. The PDOF was 1 o'clock. Estimated delta V was not provided. The speed limit on the 2-lane rural highway was 89 km/h (55 mph).

Restraint: She was restrained by a 3-point lap/shoulder belt with retractor type pretensioners that activated during the crash. Frontal, right seatback, and curtain air bags deployed.

Seat track position and seatback recline: Her seat base adjustment was described as "rear seat track position" and her seatback was described as "reclined (at or greater than 45 degrees)."

Occupant posture: She was reported to be "sleeping in a somewhat reclined position …., resulting in an incorrect positioning of both the lap and shoulder portions of the seat belt."

Vehicle and Occupant Motion: "Just prior to impact, Vehicle 1 departed an embankment and pitched downward while rolling slightly right along the longitudinal axis, causing the case occupant to move upward, in reference to the vehicle, and slightly inward. At impact, the case occupant was projected mostly forward and upward and somewhat right, in reference to the vehicle."

Occupant Loading: "She heavily loaded the lap portion of the seat belt webbing with her abdominal/hip area, while her chest struck and loaded the shoulder portion of the belt. She flexed about the belt, possibly striking the forward right area of the roof panel (scuffed) with her head, while her right shoulder/upper arm possibly engaged the right roof side rail (shoulder/arm interaction with the shoulder belt is also possible)."

Occupant Injuries, ICS, IPC: "The case occupant's injuries include: anterior occipitocervical dislocation (C1-C2), a non-displaced dens fracture (C2), distraction of the atlas and axis, and an anterior arch avulsion fracture (C1), all the result of contact with the roof panel (probable) or windshield header area (possible). Injuries to the thoracic region include: a left breast contusion, a central manubrium/sternum fracture, bilateral lower rib fractures, a right anterior pneumothorax, a right anterior pulmonary contusion and a spleen laceration, all are the result of certain contact with the shoulder portion of the seat belt. Injuries to the abdominal region include: a lower abdominal contusion, an abdominal wall rupture (anterior), a small bowel injury, a mesentery laceration, and an abdominal aorta injury, all are the result of certain loading of the lap portion of the seat belt. A distraction injury of the T8-T9, though in the thoracic region, was also associated with the abdominal injuries and loading of the lap belt. The case occupant also sustained a right humeral head dislocation (probable contact with the roof side rail or possibly the shoulder portion of the belt webbing), bilateral hip contusions (certain contact with the lap portion of the seat belt), a right, lower leg contusion (probable contact with the knee bolster/lower instrument panel), and bilateral foot contusions (possible contact with the toe pan). The maximum Abbreviated Injury Scale (AIS) for this case occupant was AIS 4."

Case 407063518

The 59-year-old male case occupant, 183 cm (72 in) in height and 82 kg (180 lbs) in weight, was the right front passenger of a 1999 Saturn SL sedan that was involved in a moderately severe frontal impact with a boulder. The PDOF was 12 o'clock. The longitudinal delta V recorded by the EDR was 60.7 km/h (-37.7 mph). His estimated travel speed on four-lane interstate highway was 113 km/h (70 mph).

Restraint: He was restrained by a 3-point lap/shoulder belt with the D-ring in mid position and with a retractor pretensioner that activated during the crash. The frontal air bag also deployed.

Seat track position and seatback recline: His seat base adjustment was described as "rearmost location" and his seatback was described as "reclined between the mid and full back position" although coded as "slightly reclined."

Occupant posture: He was reported to be "sleeping with his legs stretched out into the floorboard and arms relaxed at his side. It is likely that the subject awoke prior to impact due the uneven physical nature of the crash site."

Vehicle and Occupant Motion: "The driver allowed the vehicle to drift to the left where the left side tires traveled off of the roadway. This prompted the driver to steer to the right to regain the roadway that she did. However, the vehicle began to rotate clockwise and the driver corrected to the left. The vehicle again traveled off of the left side of the road, this time going over the embankment and onto the desert floor. The vehicle continued to travel west on the desert surface until striking a large boulder with its front plane."

Occupant Loading: "Due to his distance from the instrument panel, the subject apparently did not make contact with the air bag. Rather, the subject loaded heavily into the belt restraint system."

Occupant Injuries, ICS, IPC: "Kinematics suggested that the subject's head flexed over the belt resulting in a C7 facet fracture. The force of the subject's deceleration also caused a concussion. There was a right shoulder contusion attributed to the shoulder aspect of the restraint. There was also a right scapular abrasion. The subject's abdomen loaded the lap aspect of the restraint system resulting in a splenic tip avulsion, a deserosalization injury to the ascending colon, small bowel perforations (x 2), a sigmoid colon contusion and a right lower abdominal contusion. The subject's lower spine flexed over the lap aspect causing an L2 vertebral body anterior column fracture. There was a left flank abrasion that was also attributed to the lap belt. The subject sustained a right shin abrasion as a result of his lower legs loading the right side instrument panel."

Case 551110814

The 31-year old female case occupant, 150 cm (59 in) in height and 57 kg (126 lb) in weight, was the right front passenger of a 2003 Chevrolet Cavalier sedan that was involved in a severe frontal impact with a minivan. The PDOF was 12 o'clock (0 deg.). Estimated delta V was -44 km/h. The speed limit on the 6-lane divided highway was 113 km/h (70 mph).

Restraint: She was restrained by a 3-point lap/shoulder belt with the D-ring in the full up position and with an emergency locking retractor but no pretensioner. The frontal air bag deployed.

Seat track position and seatback recline: Her seat base adjustment was coded as "rear most track position" and her seatback was described as "fully reclined."

Occupant posture: Coded as "lying back in a reclined position."

Vehicle Motion: "V1 locked up the brakes leaving 180 feet of skid marks measured by police before the front of V1 struck head on with V2. V1 rotated clockwise on to the left shoulder and then rolled over on to its left side in the grassy median."

Occupant Loading: "There was loading on the seat belt."

Occupant Injuries, ICS, IPC: "Injuries included a T-12 vertebral body fracture with 25 percent vertebral body loss consistent with fracture. The spinal fracture mechanism was noted as a flexion-distraction type. This was felt to be due to buckling over the lap and shoulder belt at a level of probable. There appeared to be a role of the reclining seat position in this injury mechanism as the body moved forward and then made contact with the seat belt that acted as the fulcrum across the chest. Lower extremity injury included a femur fracture of a spiral type. This was felt to be due to contact of the knee with the door panel at the corner with the glove box. It appeared that the right knee had pocketed here. This mechanism was given a level of certain as substantiated by a finding of a scuff in this location. There may have been a role of rotation of the knee due to her reclining position in the causation of the spiral nature of the fracture."

Case 852122288

The 65-year-old female, 170 cm (67 in) in height and 136 kg (300 lbs) in weight, was the right front passenger of a 2006 Scion TC 2-door hatchback that was involved in a severe frontal impact collision with a large tree. The PDOF was 12 o'clock (0 deg.). Estimated delta V was -48 km/h (30 mph).

Restraint: She was restrained by a 3-point lap/shoulder belt with retractor pretensioner that activated during the crash. There was no D-ring adjustment mechanism. The position of the belts were described as "lap belt across abdomen and "other" position for shoulder belt." The frontal air bag deployed.

Seat track position and seatback recline: Her seat base adjustment was described as "seat at middle track position" and her seatback was described as "fully reclined."

Occupant posture: "Being fully reclined the upper body was not in contact with the shoulder belt portion."

Vehicle and Occupant Motion: "V1 approached behind the stopped traffic and then swerved to the right off south side of the highway across a paved driveway to avoid a collision with the stopped vehicles. V1 started to brake as it crossed the paved driveway leaving tire yaws marks that continued off the pavement into a grassy area before the front left half of V1 struck a large tree. V1 came to final rest against the tree and rotated slightly counterclockwise. ….This case occupant moved forward in response to a 12 o'clock direction of force…"

Occupant Loading: "… the left knee struck the center instrument panel and the left edge of the glove box door that were both found deformed and scuffed. The right knee contact and deformed the glove box. As the occupant moved forward some loading on the webbing was noted from her upper body as well as a smudge mark on the shoulder belt that may have occurred when the upper body made contact."

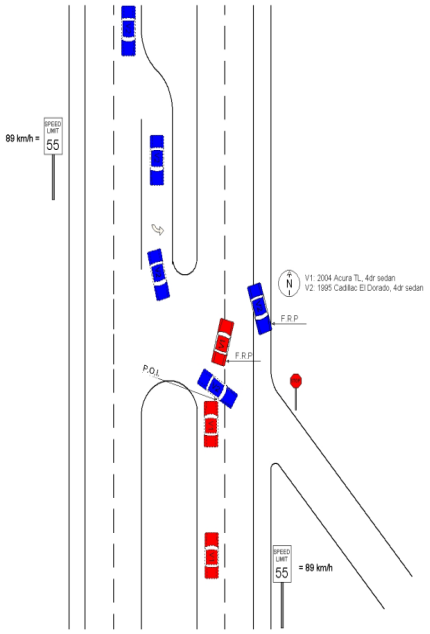
Occupant Injuries, ICS, IPC: "This patient suffered head and cervical spine injuries that resulted in death. These included an atlanto-occipital fracture, subarachnoid hemorrhage, a laceration to the medulla and spinal cord with surrounding hematoma. These head, brain and cervical injuries resulted from deceleration shearing forces, which occurred as her head moved rapidly forward after sustaining contact with the shoulder belt into the upper chest. She suffered multiple bilateral rib fractures including ribs 6-10 on the right and 2-8 on the left with deep abrasions across her chest in the pattern of the shoulder belt as she came in contact with the shoulder after beginning in a reclined position. Thus we attribute the chest wall injuries to compression from the seat belt impact. The patient was also found to have multiple mesenteric lacerations and a pelvic fracture involving the sacroiliac joint. These are attributable to the compression force applied by the lap belt. These mechanisms were rated as certain for the mesenteric injury and possible for the pelvic fracture."

Appendix D: CIREN Case Study: Case Summaries

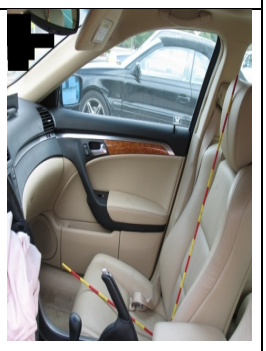
UVA CAB OOP Study

CIREN Case Summary

Case ID: 286014504

Crash Scenario:	**Scene:**
Case Vehicle 1: 2004 Acura TL Object Struck: Vehicle Impact Type: Front ***Conditions***: Not mentioned ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 66-year-old female ***Stature/Mass***: 155 cm and 62 kg ***Restraint Employed***: Lap and shoulder belt available, lap belt is snugged and low across hips; shoulder belt across the collarbone and over shoulder with extra "slack room" ***Air Bags Deployed***: Top instrumental panel Maximum Crush: 29 @ C3 ***PDOF*** (degrees): 350 (12 o'clock) ***CDC***: FDEW01 ***DV***: 28 kph MAIS: 3 ***ISS***: 22	

Vehicle Images



Crash Summary

The case involves a frontal impact to the case vehicle resulting in serious injuries to right front seated case occupant.

Vehicle 1 (V1 - case vehicle), a 2004 Acura TL 4-door car was traveling north on a north bound roadway. Vehicle 2 (V2), a 1996 Cadillac El Dorado, 2-door car was traveling south and made a left-hand turn at the intersection. The crash occurred at the intersection. The roadway is level and there is no controlled traffic signs or light. The frontal plane of V1 struck the right side plane of V2. V1 was facing north in its final rest position on the north bound roadway. V2 rotated counterclockwise and came to a final rest position facing south.

The driver of V1 is a 60-year-old male restrained by a 3-point manual belt and the frontal air bag deployed during the crash. He sustained minor injuries and was transported to a nearby hospital by ground transportation. A 66-year-old female case occupant was seated in the right front seat of V1 and was restrained by a manual 3-point belt and the frontal passenger air bag deployed. She was sleeping and the seatback was reclined all the way back. She sustained severe injuries resulting in hospitalization. She was initially transported to the nearby hospital and was later flown to a level 1 trauma center.

A 77-year-old female driver was driving the V2. Her restraint status and injuries are unknown.

Injury Analysis

A 66-year-old female passenger, height 155 cm (61 inches) weighing 61 kilograms (137 pounds), located in the right front seat of a 2004 Acura TL, 4-door sedan was involved in a moderate frontal impact crash (principal direction of force = 12 o'clock) with a 1996 Cadillac Eldorado 2-door sports car. The case occupant was seated (sleeping) in a reclined posture and was using the manual lap and shoulder belt and the passenger frontal air bag deployed.

On impact the case occupant moved forward relative to the vehicle. The occupant's torso loaded the shoulder part of the belt flexing her neck over the shoulder belt. She sustained a cervical spine (C1) left anterior arch fracture extending into the left lateral mass. The injury causation was coded with a confidence level of possible. She sustained a thoracic spine (T12) burst fracture, anterior and mid column with 6mm retropulsion into spinal cord. The injury causation was coded with a confidence level of probable. Both injuries were attributed to flexing over the shoulder belt.

The shoulder belt loading to the abdomen caused the Grade II right lobe liver laceration along with the right rib fracture (# 8). The injury causation was coded with a confidence level of certain. For these three injuries, the evidence of the causation scenario was the occupant's initial seating posture determined through occupant interview, kinematics and vehicle principal direction of force.

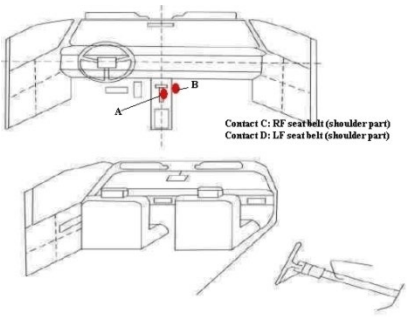
The case occupant also sustained non-displaced left skull fracture to the occipital bone and left proximal ulnar fracture. The sources for these injuries are unknown.

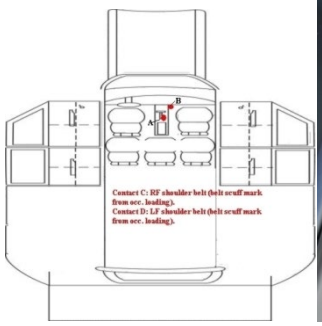
Relevant Intrusions

No Intrusion

Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Center lower instrument panel (inc	2	Lower Leg - Left	Scuffed	Probable
B	Interior	Center console first row	2	Lower Arm - Left	Scuffed	Probable
C	Interior	Belt restraint webbing/buckle	1	Chest	Scuffed	Certain
D	Interior	Belt restraint webbing/buckle	2	Chest	Combination (Specify)	Certain





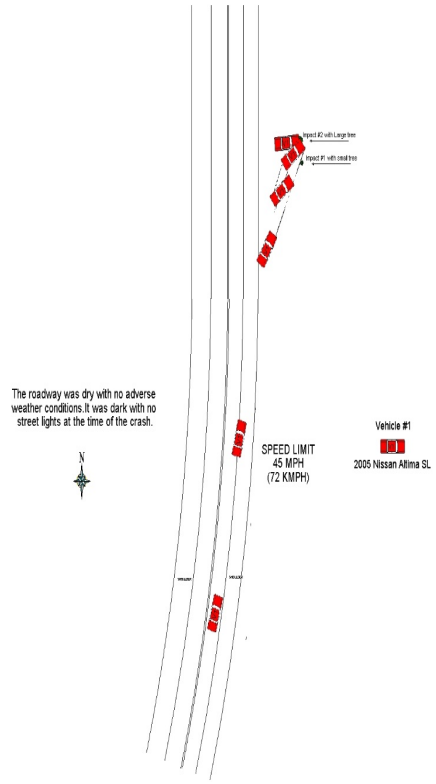
Injuries

Version	AISCODE	Description	Aspect	Rank
1998	6502243	Cervical Spine fracture lamina	C1;Posterior/Back/Dorsal	1
1998	6504343	Thoracic Spine fracture vertebral body major compression	T12;Superior/Upper	2
1998	1504022	Vault skull fracture closed	Posterior/Back/Dorsal;Left	3
1998	5418222	Liver laceration minor (OIS Grade I or II)	Right	
1998	7532022	Ulna fracture closed	Left	
1998	4502121	Rib cage fracture 1 rib	R Rib 8	
1998	8902021	Lower Extremity Skin abrasion	Knee;Right	
1998	8902021	Lower Extremity Skin abrasion	Knee;Left	
1998	8904021	Lower Extremity Skin contusion	Knee;Left	
1998	8904021	Lower Extremity Skin contusion	Knee;Right	

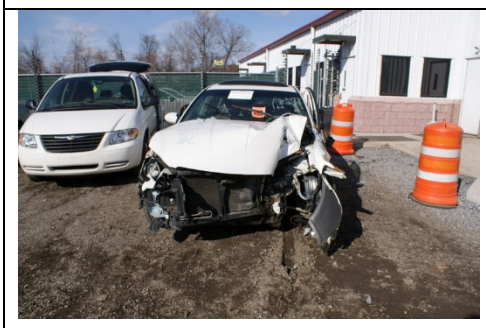
UVA CAB OOP Study

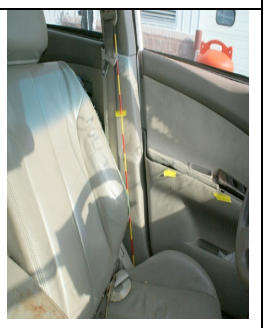
CIREN Case Summary

Case ID: 286036974

Crash Scenario:	**Scene:**
Case Vehicle 1: 2005 Nissan Altima ***Object Struck***: Tree (> 10 cm in diameter) Impact Type: Head-on ***Conditions***: Clear/Dark, Dry, bituminous roadway ***Occ. Position:*** Driver (1st-row-left-side) ***Age/Gender***: 48-year-old female ***Stature/Mass***: 180 cm and 99 kg ***Restraint Employed***: Lap and shoulder belt are available but both were not used ***Air Bags Deployed***: Steering wheel hub, seatback, roof side rail Maximum Crush: 44 @ C2 ***PDOF*** (degrees): 340 (11 o'clock) ***CDC***: FLEN02 ***DV***: 40 kph MAIS: 3 ***ISS***: 17	

Vehicle Images





Crash Summary

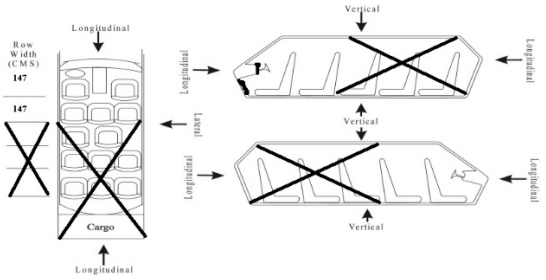
Vehicle 1 (V1-case vehicle), a 2005 Nissan Altima, 4-door sedan was traveling in the northbound lane of a two-lane, two-way roadway. It was dark (no street lights), the weather was clear and the bituminous roadway was dry. As V1 completed a left curve in the roadway, it traveled off the right-side road edge into a wooded area. The front of V1 struck a small 14-cm tree with the front right corner, and then struck a 40-cm tree with its front left. After striking the larger tree with its front bumper, V1 rotated 90 degrees in a clockwise direction before traveling to its final resting position facing east. The 48-year-old female driver (case occupant) of V1 was not using her available three-point seat belt (pretensioner fired in the not used position) and the available driver's air bags (front, seatback-mounted thorax, and side curtain) all deployed as a result of the impact with the large tree (Event 2). The driver (case occupant) was transported from the scene to a regional level-one trauma center with serious injuries. V1 was towed from the scene due to disabling vehicle damage. There were no other occupants in the case vehicle.

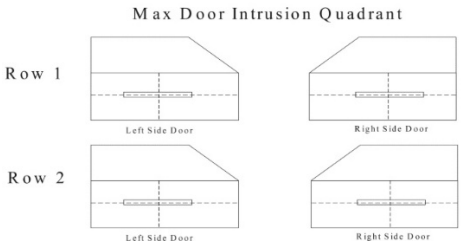
Injury Analysis

This case involves a 48-year-old female of height 180 cm (71 in) and weighing 99 kg (218 lbs). The case occupant was the driver of a 2005 Nissan Altima 4-door sedan involved in a moderate frontal impact with a 14-cm tree (principal direction of force unknown) and a 40-cm tree (principal direction of force = 11 o'clock). The case occupant was not using the available 3-point lap and shoulder belt. The frontal, side curtain, and seat-mounted thorax air bags deployed for her seating position. The crash occurred when the driver of the case vehicle failed to navigate a slight left curve, causing the vehicle to depart the roadway to the right. The case vehicle struck a 14-cm diameter tree with its front bumper, then struck a 40-cm tree with its left front bumper, causing the vehicle to rotate to the left around the tree. The initial impact with the smaller tree caused the unbelted occupant to move out-of-position, and the secondary impact with the larger tree caused the occupant to move forward and to the left. Her thorax contacted the seat-mounted side air bag. The case occupant's head contacted the air bag cover flap and deploying air bag, as evidenced by the presence of a major forehead laceration, scalp contusion, forehead contusion, and right eyelid contusion. The case occupant also sustained a C5-C6 unilateral facet dislocation, a C5 lamina fracture, and a minor compression fracture to the body of C6. These injuries were all attributed to spine flexion at the point of head contact; this injury causation scenario was given a confidence of probable. The case occupant's cervical spine lamina fracture injury caused a right vertebral artery occlusion at the area of fracture (confidence of certain). Upon EMS arrival, the case occupant was still in the vehicle. She was awake and alert, but amnestic to crash events. Her GCS was assessed at 15. She was transported by ground to a Level 1 trauma center in 70 minutes.

Relevant Intrusions

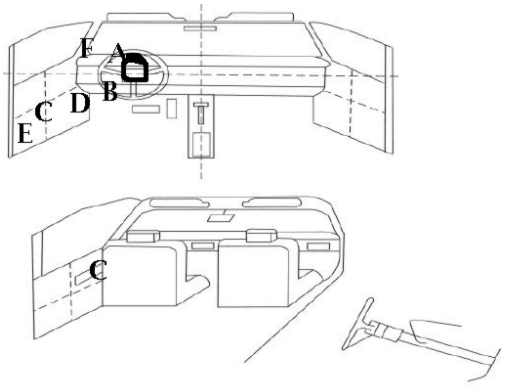
Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Left	Instrument panel left	186	183		>= 3 to < 8 cms	Longitudinal
Front Seat	Left	Toe pan	200	195		>= 3 to < 8 cms	Longitudinal





Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
B	Steering w heel hub/spoke	1	Hand - Left	Cracked	Possible
C	Left armrest/hardw are in forw ard upper quadrant	1	Thigh - Left	Deformed	Probable
D	Left forw ard low er quadrant	1	Knee - Left	Cracked	Probable
E	Left armrest/hardw are in rear upper quadrant	1	Hip - Left	Deformed	Probable
F	Left Instrument Panel	1	Knee - Left	Deformed	Possible
G	Left B-pillar	1	Hip - Left	Cracked	Possible
A	Air bag-driver side	1	Face	Transfer	Possible



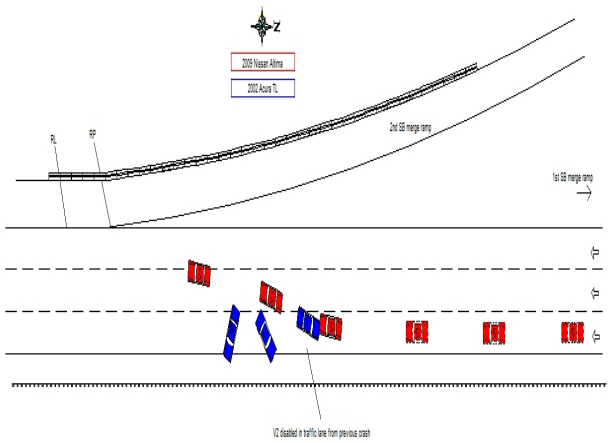
Injuries

			Injury Causation Scenario (ICS)		Involved Physical Component (IPC)		
Injury #	**AIS Name**	**Aspect**	**Source of Energy**	**ICS confidence**	**IPC Status**	**Involved Component**	**IPC Confidence**
1	Vertebral artery, neck, thrombosis (occlusion) secondary to trauma from any lesion but lacerationVertebral artery thrombosis (occlusion) secondary to trauma	Right;	N/A	Certain	Primary	N/A	Unknown
2	Cervical Spine dislocation facet unilateral	Posterior/Back/Dorsal; C5C6;	Crash (pick)	Probable	Primary	Air bag	Possible
3	Cervical Spine fracture lamina	C5;	Crash (pick)	Probable	Primary	Air bag	Unknown
4	Scalp contusion/subgaleal hematoma	Posterior/Back/Dorsal;	Crash (pick)	Possible	Primary	Air bag	Possible
5	Scalp laceration major	Whole Region; Anterior/Front/Ventral;	Crash (pick)	Probable	Primary	Air bag compartment cover	Probable
6	Facial Skin contusion	Central; Superior/Upper;	Crash (pick)	Probable	Primary	Air bag	Probable
7	Eyelid contusion	Right;	Crash (pick)	Probable	Primary	Air bag	Probable
8	Vertebra, cervical spine, fracture with or without dislocation but no cord involvement, vertebral body (""burst"" fracture), minor compression (<=20% loss of anterior height)Cervical Spine fracture vertebral body minor compression	C6;	Crash (pick)	Probable	Primary	Air bag	Unknown
9	Vertebra, thoracic spine, fracture with or without dislocation but no cord involvement, transverse processThoracic Spine fracture transverse process	T7;	Crash (pick)	Probable	Primary	Air bag	Probable

UVA CAB OOP Study

CIREN Case Summary

Case ID: 317086764

Crash Scenario:	**Scene:**
Case Vehicle 1: 2009 Nissan Altima Object Struck: Vehicle Impact Type: Front ***Conditions***: Night on a lighted interstate divided, dry concrete roadway ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 36-year-old female ***Stature/Mass***: 173 cm and 105 kg ***Restraint Employed***: Lap and shoulder belt available, but both are not used ***Air Bags Deployed***: Top instrumental panel Maximum Crush: 65 @ C2 ***PDOF*** (degrees): 350 (12 o'clock) ***CDC***: FYEW04 ***DV***: 45 kph MAIS: 4 ***ISS***: 33	
Vehicle Images	
  	

Crash Summary

This case involved a 36-year-old female unrestrained front right passenger of a 2009 Nissan Altima 4-door sedan (V1). The driver, a 43-year-old unrestrained male, was the only other occupant of V1. Both the driver and passenger frontal air bags deployed as well as the left side impact and head curtain air bags. The available right side air bags did not deploy. The other vehicle involved in the crash was a 2002 Acura TL 4-door sedan (V2).

The crash occurred at night on a lighted interstate divided highway. The dry concrete roadway was straight and level with three northbound and three southbound lanes. The impact took place at the area of an interchange merging ramp. The posted speed limit was 97 kph (60 mph).

Prior to the crash with V1, V2 was attempting to merge from the right merge lane onto the interstate when the driver lost control and traveled across the three southbound lanes and struck a guardrail with its left rear. V2 was disabled and came to rest in the left southbound lane facing north and the occupants exited the vehicle. V1 was traveling south in the left lane at an unknown speed when the impact with V2 occurred. The front of V1 struck the front of V2 in a left offset configuration. V2 was pushed rearward to final rest in the left traffic lane while V1 continued forward and into the center lane for final rest. Both vehicles were towed due to disabling damage.

The front right passenger of V1 (case subject) was lying back in a reclined position at the time of the crash. She received fatal injuries and was pronounced dead on the scene. The driver of V1 was transported by ground ambulance to a level one trauma center for treatment of unknown injuries.

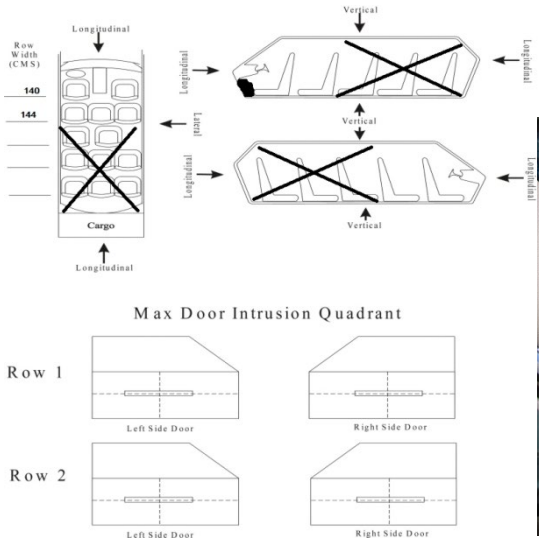
Injury Analysis

This case involved a 36-year-old female, unrestrained, right front passenger of a 2009 Nissan Altima 4- door sedan. She was 173 centimeters (68 inches) tall and weighed 105 kilograms (231 pounds) with a body mass index of 35.1. The case vehicle was involved in a severe level frontal impact with a 2002 Acura TL 4-door sedan. The principal direction of force was 12 o'clock. There was a top instrument panel-mounted air bag that deployed in the front right passenger position. The case subject was pronounced dead at the scene by the medical examiner. She was riding in a fully reclined position and asleep.

On impact the unrestrained case occupant moved forward and slightly to the left in relationship to the vehicle. She sustained an inferior vena cava laceration, bilateral hemothoraces, right diaphragm laceration, multiple rib fractures, and a pericardial sac laceration that were attributed to contact with the instrument panel under the air bag with a confidence of probable. She also sustained splenic lacerations, liver lacerations, stomach and colon lacerations that were all attributed to contact with the glove box with a confidence level of probable.

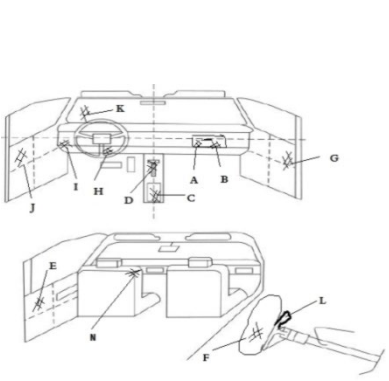
Relevant Intrusions

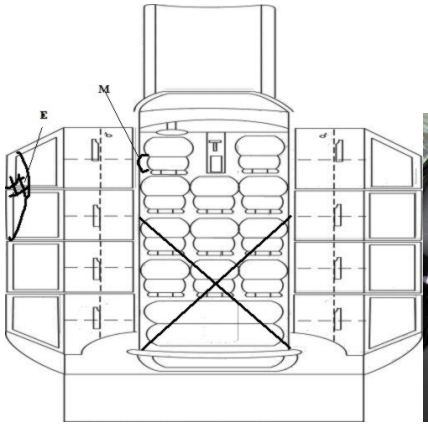
Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Left	Interior	Windshield	96	84	12	>= 8 to < 15 cms	Longitudinal
Front Seat	Left	Interior	Toe pan	107	101	6	>= 3 to < 8 cms	Longitudinal
Front Seat	Left	Interior	Instrument panel left	76	72	4	>= 3 to < 8 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Glove compartment door	2	Knee - Left	Scuffed	Certain
B	Front	Glove compartment door	2	Knee - Right	Scuffed	Certain
C	Interior	Center console first row	2	Shoulder - Left	Deformed	Probable
D	Floor	Floor or console mounted transmis	2	Thigh - Left	Deformed	Probable
E	Air Bag	Other air bag (specify)	1	Head	Blood	Probable
F	Air Bag	Air bag-driver side	1	Face	Blood	Probable
G	Right Door Pa	Right armrest/hardware in rear up	2	Head	Blood	Possible
H	Front	Left lower instrument panel (incluc	1	Knee - Left	Deformed	Probable
I	Front	Left lower instrument panel (incluc	1	Knee - Right	Scuffed	Probable
J	Left Door Pan	Left rear upper quadrant	1	Upper Arm - Left	Blood	Probable
K	Front	Windshield	1	Unknown	Cracked	Probable
L	Front	Steering wheel rim	1	Chest	Deformed	Certain
M	Air Bag	Other air bag (specify)	1	Unknown	Blood	Possible
N	Interior	Seat, back support	1	Unknown	Blood	Probable





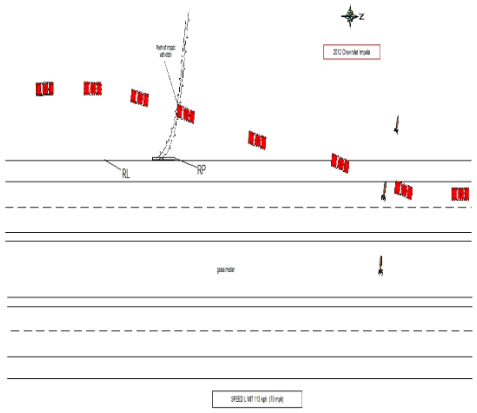
Injuries

Version	AISCODE	Description	Aspect	Rank
2005	5212064	Vena Cava, inferior, laceration; perforation; puncture, major; rupture; transection; segmental lo	Superior/Upper	1
2005	4422014	Thoracic injury, hemothorax, major; >1000cc blood loss on at least one side	Bilateral	2
2005	5442264	Spleen, laceration, involving segmental or hilar vessels producing major devascularization of >	Left	3
2005	4406063	Diaphragm, laceration, <=10cm [OIS II, III]	N/A	
2005	4502033	Rib fracture or fractures, without flail, any location unilateral or bilateral, >=3 ribs [OIS II]	L Rib 10;L Rib 1;L Rib 2;L Rib 4;L Rib 9;P	
2005	5408243	Colon (large bowel), laceration, perforation; full thickness; >=50% circumference without transe	Inferior/Lower	
2005	5418243	Liver, laceration, >3cm parenchymal depth; major duct involvement; blood loss >20% by volur	Right Lobe;Right	
2005	4416022	Pericardium, laceration; puncture	Central	
2005	5444222	Stomach, laceration, no perforation; partial thickness [OIS I]	Superior/Upper	
2005	4104021	Skin/subcutaneous/muscle, thorax, contusion; hematoma	Left;Lateral Wall	
2005	5402991	Adrenal gland injury NFS	Left	
2005	7104021	Skin/subcutaneous/muscle, upper extremity, contusion; hematoma	Forearm;Left	
2005	8104021	Skin/subcutaneous/muscle, lower extremity, contusion; hematoma	Bilateral;Hip;Thigh	
2005	8106021	Skin/subcutaneous/muscle, lower extremity, laceration, minor; superficial	Left;Thigh;Buttock	

UVA CAB OOP Study

CIREN Case Summary

Case ID: 317118807

Crash Scenario:	**Scene:**
Case Vehicle 1: 2012 Chevrolet Impala/Caprice ***Object Struck***: Fixed object - ditch or culvert Impact Type: Front ***Conditions***: Dark, unlit interstate highway. The dry asphalt roadway was straight and level and there were no adverse weather conditions at the time of the crash. ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 49-year-old male ***Stature/Mass***: 180 cm and 86 kg ***Restraint Employed***: Lap and shoulder belt available, lap belt is snugged and low across hips; shoulder belt position is "Unknown" ***Air Bags Deployed***: Top instrumental panel Maximum Crush: 3 @ C6 ***PDOF*** (degrees): 10 (12 o'clock) ***CDC***: FREW01 ***DV***: 13 kph MAIS: 3 ***ISS***: 11	
Vehicle Images	
  	

Crash Summary

This case involved the 49-year-old restrained male front right passenger of a 2012 Chevrolet Impala 4-door sedan (V1). The only other occupant of V1 was the 43-year-old female driver who was also restrained by the manual lap and shoulder belt. The case subject (front right passenger) was wearing the available lap and shoulder belt, but was asleep in a fully reclined position at the time of the crash. Both the driver and passenger frontal air bags deployed upon impact.

The crash occurred on a dark, unlit interstate highway. The dry asphalt roadway was straight and level and there were no adverse weather conditions at the time of the crash. The highway ran north and south with two travel lanes for each direction divided by a grass median. The posted speed limit was 113 kph (70 mph).

V1 was traveling south in the right lane when a deer ran onto the roadway. The driver of V1 swerved to the right and avoided impact with the animal, but lost control and departed the right side of the road. V1 traveled down a small embankment and struck a ditch with its frontal plane. V1 continued forward and came to rest approximately 41 meters from point of impact. V1 was towed from the scene due to disabling damage.

The driver was not injured, but the front right passenger (case subject) received serious injuries and was taken by ground ambulance to a local hospital. He was later transferred to a level one trauma center for treatment of his injuries.

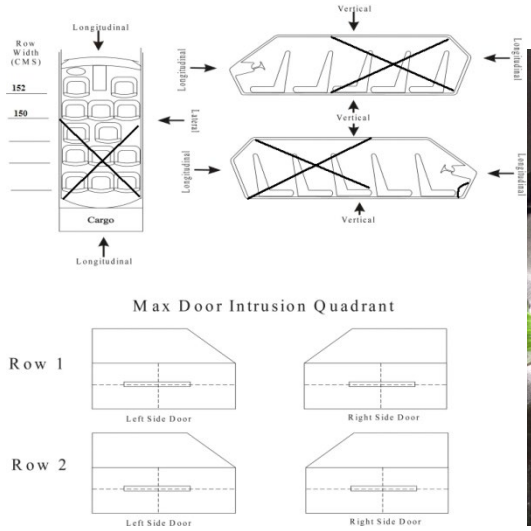
Injury Analysis

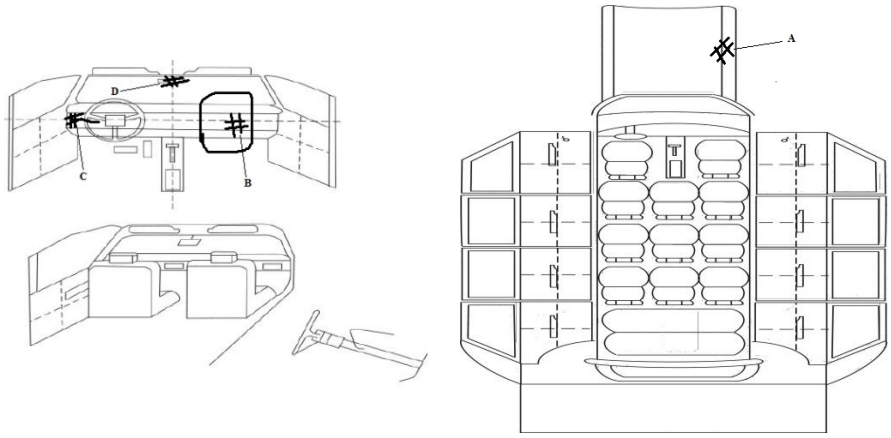
This case involves a 49-year-old, 180 centimeters (5 feet 11 inches) tall, male weighing 86 kilograms (190 pounds). He was the right front passenger of a 2012 Chevrolet Impala 4-door sedan involved in a severe level frontal impact with a ditch. The principal direction of force was 12 o'clock. He was wearing his 3-point manual seat belt and had the benefit of a deployed frontal top instrument panel mounted air bag.

On impact the case occupant moved forward and outboard (towards the right front door) in relationship to the vehicle as evident by the middle chest abrasions extending towards his right shoulder and a left seventh rib fracture both caused by the seat belt. The L1 burst fracture was attributed to the pelvis contacting the seat pan. The knee was pocketed by the knee bolster and at the same time the lap belt was contacting the abdomen causing the flexion and compression of the L-spine. A probable confidence level was assigned to the L1 burst fracture.

Relevant Intrusions

Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Right	Interior	Toe pan	107	103	4	>= 3 to < 8 cms	Longitudinal





Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Roof	Roof right side rail	2	Head	Other (Specify)	Possible
B	Right Air Bag	Right top instrument panel	2	Unknown	Blood	Possible
C	Front	Steering column,transmission sele	1	Knee - Left	Other (Specify)	Probable
D	Front	Mirror	1	Unknown	Other (Specify)	Probable

Injuries

Version	AISCODE	Description	Aspect	Rank
2005	6506343	Vertebra, lumbar spine, fracture with or without dislocation but no cord involvement, vertebral	Inferior/Lower;Unstable;L1	1
2005	4502011	Rib fracture or fractures, without flail, any location unilateral or bilateral, one rib [OIS I]	Left;L Rib 7;Anterio-lateral Rib	2
2005	4102021	Skin/subcutaneous/muscle, thorax, abrasion	Right Front;Central	3

UVA CAB OOP Study

CIREN Case Summary

Case ID: 317510255

Crash Scenario:

Case Vehicle 1:

2011 Chrysler 200

Object Struck: Non-fixed object-animal

Impact Type: Front

Conditions: Dark, dry, two-way, two-lane asphalt road. There were no adverse weathers conditions.

Occ. Position: Passenger (1st-row-right-side)

Age/Gender: 38-year-old male

Stature/Mass: 180 cm and 86 kg

Restraint Employed: Lap and shoulder belt available, but both were not used

Air Bags Deployed: Top instrumental panel

Maximum Crush:

Profile #	Event#	Direct Damage Location	Field L Location	Max Crush
1	1	Front - overlapping	None Used - overlapping	Unknown
2	2	Begins 136cm fwd rear axle (extends	None Used	Center of direct
3	3	Undercarriage	None Used	Unknown
4	4	Begins 22cm Right of dmg ctr end pla	Bumper Support - corner to corner	C3
5	5	Entire Frontal Plane	None Used	Unknown

PDOF (degrees): 0 (12 o'clock)

CDC:

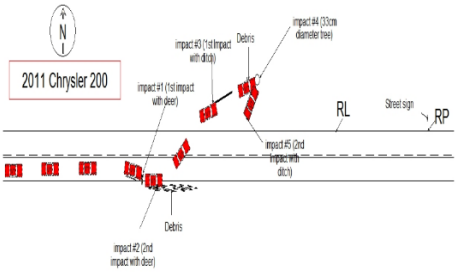
Event	Object Contacted	Force Dir	Location	Total	Long	Lateral	Energy	Impact	Barrier	Est	Rank
1	Animal	0	12F99999	999	999	999	-9999	999	999	3	2
2	Animal	90	03RPEW01	999	999	999	-9999	999	999	2	4
3	Ditch or culvert	0	12UDDW01	999	999	999	-9999	999	999	7	5
4	Tree(> 10 cm in diamete	0	12FYEW03	75	-75	0	382870	998	75	1	1
5	Ditch or culvert	180	06BDLW01	999	999	999	-9999	999	999	3	3

DV: 999

MAIS: 3

ISS: 9

Scene:



Vehicle Images

Crash Summary

This case focuses on a 38-year-old unrestrained right front male passenger in a 2011 Chrysler 200 sedan (V1). V1 was also occupied by an unrestrained female driver. V1 was equipped with dual side curtains, dual frontal and dual side air bags. The front air bags were the only air bags to deploy during the crash.

The crash occurred on a dark, dry, two-way, two-lane asphalt road. There were no adverse weathers conditions. The posted speed limit for the road was 72 kph (45 mph).

V1 was traveling east in the eastbound lane when the driver noticed a deer in V1's travel lane. The driver attempted to avoid the collision by braking (with lock-up) and steering right. V1 contacted the deer with its front. After the initial impact with the deer, V1 continued and made additional contact to the deer with its right side. After contacting the deer V1 partially departed its travel lane onto the right roadside. The driver steered hard left in an attempt to maneuver her vehicle back onto the road. V1 crossed the center lane line and continued across the opposing lane onto the left roadside. While on the roadside V1 contacted a ditch with its undercarriage. After contacting the ditch V1 continued and contacted a tree with its front. V1 came to rest on the roadside facing northeast. V1 was towed from the crash scene due to disabling damage.

The driver of V1 did not sustain injury. The front right passenger was transported to local hospital by ground; however, he was later transferred to a level one trauma center where he received treatment for serious injuries that he sustained in the crash.

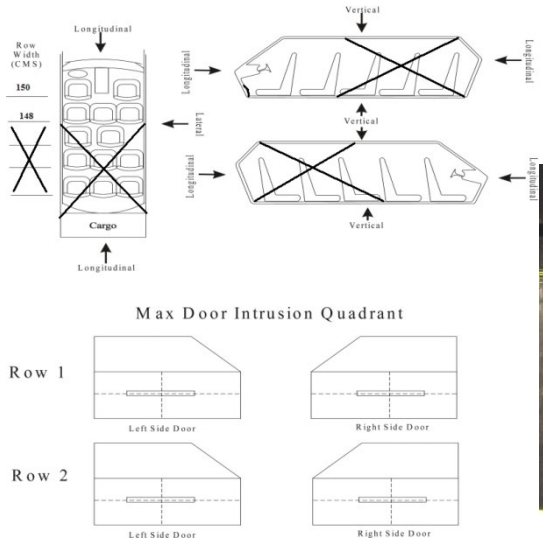
Injury Analysis

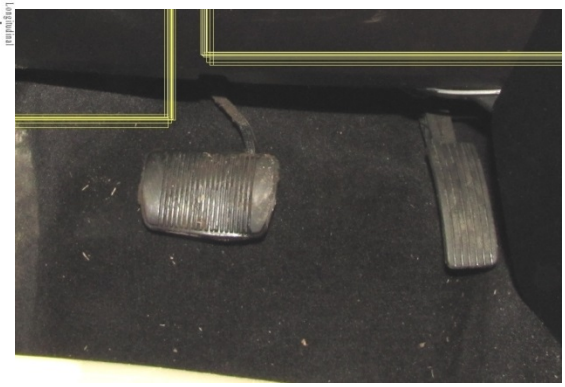
This case involves a 38-year-old male 180 centimeters (5 foot 11 inches) tall and weighing 86 kilograms (190 pounds). He was the unrestrained right front seat passenger of a 2011 Chrysler 200 sedan. The front air bags were the only air bags to deploy during the crash.

The right distal femur fracture was attributed to contact with the glove box with a certain confidence level. The right distal tibia and right talus fractures were attributed to contact with the toe pan with a certain confidence level. The left iliac spine fracture was attributed to contact with the center console with a probable confidence level.

Relevant Intrusions

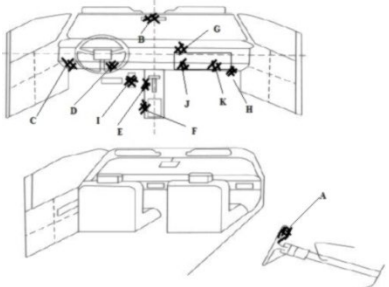
Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Left	Interior	Toe pan	58	54	4	>= 3 to < 8 cms	Longitudinal

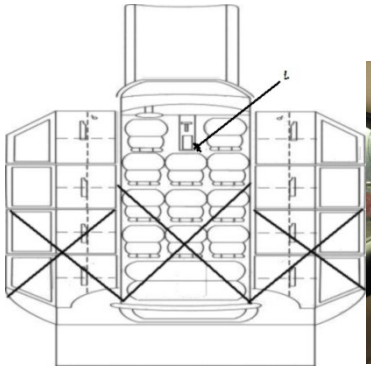




Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Steering wheel rim	1	Chest	Bent	Certain
B	Front	Mirror	1	Hand - Right	Other (Specify)	Certain
C	Front	Left lower instrument panel (incluc	1	Knee - Left	Scuffed	Certain
D	Front	Left lower instrument panel (incluc	1	Knee - Right	Scuffed	Certain
E	Interior	Center console first row	1	Thigh - Right	Other (Specify)	Certain
F	Interior	Center console first row	1	Hip - Right	Other (Specify)	Certain
G	Front	Right Instrument Panel	2	Chest	Deformed	Certain
H	Front	Right lower instrument panel (incl	2	Knee - Right	Scuffed	Certain
I	Floor	Foot controls including parking br	1	Ankle - Right	Other (Specify)	Possible
J	Front	Glove compartment door	2	Knee - Left	Scuffed	Possible
K	Front	Glove compartment door	2	Knee - Right	Scuffed	Possible
L	Interior	Center console first row	2	Hip - Left	Scuffed	Certain





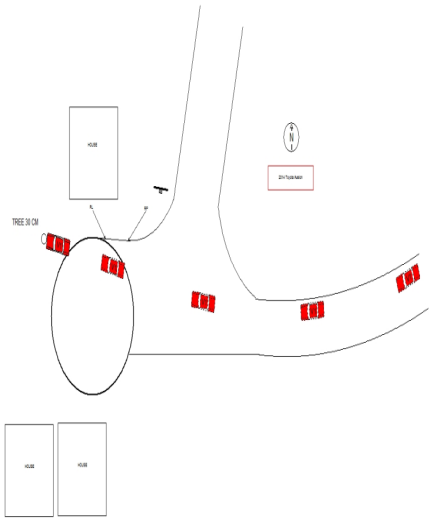
Injuries

Version	AISCODE	Description	Aspect	Rank
2005	8533613	Femur fracture, distal, partial articular; condylar; Hoffa	Right	1
2005	8543512	Tibia fracture, distal, extra-articular; isolated medial malleolus	Right	2
2005	8561512	Pelvic ring fracture, posterior arch intact; isolated fracture not destroying the integrity	Left Ilium;Central	3
2005	8544712	Fibula [malleoli] fracture, above joint (suprasyndesmotic); isolated shaft, head or neck	Right	
2005	8572512	Talus fracture, extra-articular; talus neck	Right	

UVA CAB OOP Study

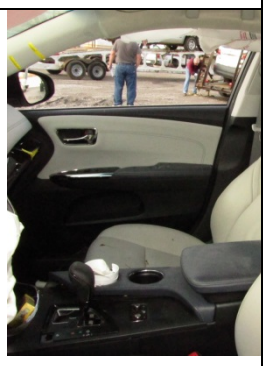
CIREN Case Summary

Case ID: 317643885

Crash Scenario:	**Scene:**
Case Vehicle 1: 2014 Toyota Avalon ***Object Struck***: Fixed object-Tree(>10 cm in diameter) Impact Type: Front ***Conditions***: Daylight hours in a residential area on a two-way, two-lane asphalt road. There were no adverse weather or road conditions. ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 57-year-old female ***Stature/Mass***: 168 cm and 125 kg ***Restraint Employed***: Lap and shoulder belt available, but both were not used ***Air Bags Deployed***: Top instrumental panel, bottom instrumental panel, Roof side rail Maximum Crush: 62 @ C4 ***PDOF*** (degrees): 0 (12 o'clock) ***CDC***: FCEN03 ***DV***: 51 km/h MAIS: 3 ***ISS***: 10	

Vehicle Images





Crash Summary

This case involves a 65-year-old unrestrained female driver and a 57-year-old unrestrained female right front passenger in a 2014 Toyota Avalon (V1). V1 was equipped with dual frontal air bags, dual knee bolster air bags, dual first row side air bags, dual side curtains, and dual second row side air bags. The driver's steering mounted air bag, passenger instrument panel mounted frontal air bag, dual frontal knee bolster air bags, and dual side rail curtains all deployed during the crash.

The crash occurred during the daylight hours in a residential area on a two-way, two-lane asphalt road that had an uphill grade and curved to the right. The posted speed limit was 32 kph (20 mph). There were no adverse weather or road conditions.

V1 was traveling to the west in the westbound lane of the roadway while negotiating a right curve and traveling up a steep hill. The driver lost control of the vehicle causing an end departure of V1 off the roadway at a cul-de-sac. After departing the roadway, V1 contacted a large tree with its front and came to rest. V1 faced north at its final rest. It was towed from the crash scene due to disabling damage.

Both occupants in V1 were transported from the crash scene to a level one trauma center. The driver was treated for moderate injuries that she sustained in the crash and had an extended hospital stay. The front right passenger sustained serious injuries and was also hospitalized.

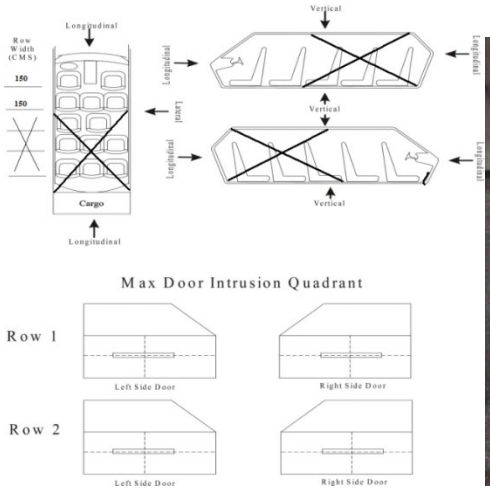
Injury Analysis

This case involves a 57-year-old female 168 centimeters (5 foot 6 inches) tall and weighing 125 kilograms (275 pounds). She was the unrestrained right front passenger in a 2014 Toyota Avalon involved in a frontal crash with a tree. Her seatback was fully reclined during the crash.

The right femoral shaft and trochanter fractures were attributed to the right knee contacting the knee bolster.

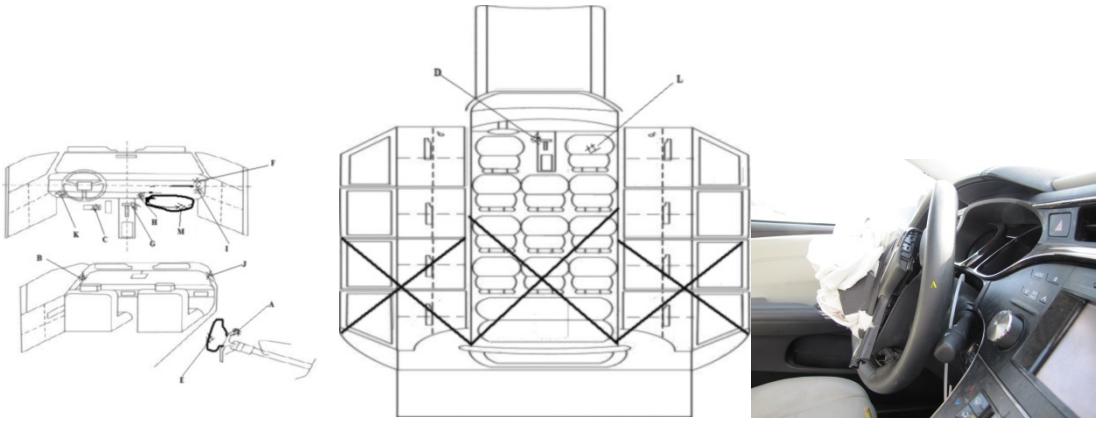
Relevant Intrusions

Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Right	Interior	Toe pan	61	50	11	>= 8 to < 15 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Steering wheel rim	1	Abdomen	Deformed	Certain
B	Left Side	Left A (A 1/A2)-pillar	1	Hand - Left	Scratched	Possible
C	Floor	Foot controls including parking br	1	Foot - Right	Other (Specify)	Possible
D	Interior	Center console first row	1	Lower Leg - Right	Scuffed	Possible
E	Left Air Bag	Steering wheel hub	1	Abdomen	Scuffed	Certain
F	Front	Right Instrument Panel	2	Hand - Right	Cracked	Certain
G	Interior	Center console first row	2	Lower Leg - Left	Scuffed	Certain
H	Front	Right lower instrument panel (inclu	2	Knee - Left	Combination (Specify)	Certain
I	Front	Right lower instrument panel (inclu	2	Knee - Right	Combination (Specify)	Certain
J	Right Side	Right A (A 1/A2)-pillar	2	Unknown	Transfer (Specify)	Certain
K	Front	Left lower instrument panel (incluc	1	Knee - Left	Scuffed	Certain
L	Interior	Seat, back support	2	Buttock - Right	Transfer (Specify)	Certain
M	Right Air Bag	Right bottom instrument panel	2	Knee - Right	Transfer (Specify)	Certain



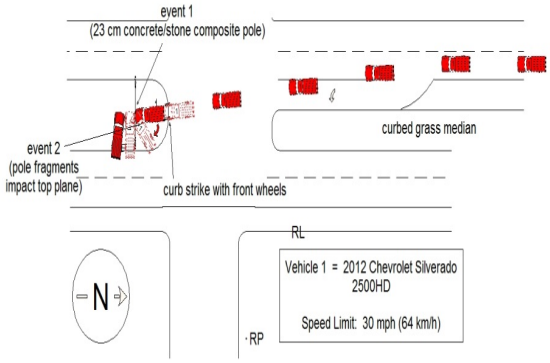
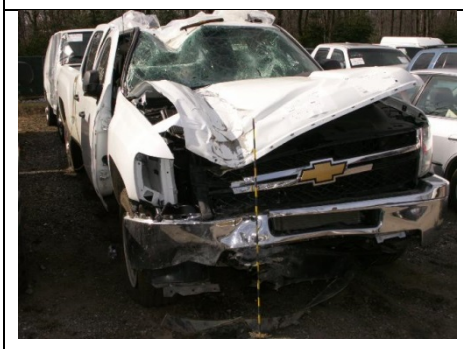
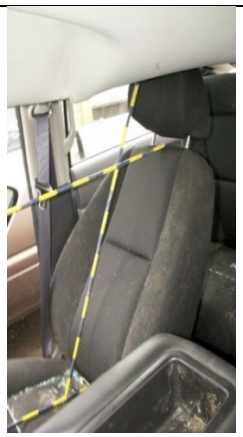
Injuries

Version	AISCODE	Description	Aspect	Rank
2005	8532723	Femur fracture, shaft, complex; comminuted; segmental; Winquist IV, open	Right	1
2005	8531513	Femur fracture, proximal, trochanteric; intertrochanteric	Right	2
2005	7526631	Phalange fracture, one of lateral four fingers, partial articular	Right	3
2005	8102021	Skin/subcutaneous/muscle, lower extremity, abrasion	Knee;Left	

UVA CAB OOP Study

CIREN Case Summary

Case ID: 352209899

Crash Scenario:	**Scene:**
Case Vehicle 1: 2012 CHEVROLET C, K, R, V-Series Pickup ***Object Struck***: Nonbreakaway pole or post(>10 cm but <= 30 cm in diameter) ***Impact Type***: Object off road ***Conditions***: Weather was clear and the roadway surfaces were dry ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 39-year-old male ***Stature/Mass***: 185 cm and 98 kg ***Restraint Employed***: Lap and shoulder belt available but both belts were not used ***Air Bags Deployed***: Top instrument panel Maximum Crush: 23 @ C5 ***PDOF*** (degrees): 0 (12 o'clock) ***CDC***: FREN01 ***DV***: Unknown MAIS: 3 ***ISS***: 14	
Vehicle Images	
	
	

Crash Summary

Case Focus: The focus of this case is on a 38-year old, right front, male passenger of a 2012 Chevrolet Silverado 2500 HD pickup truck, which was primarily involved in a frontal collision with a pole.

Collision Sequence

Pre-Crash: This single-vehicle collision occurred during the afternoon hours (daylight), of a winter weekday, on a north/south trafficway, at the location of a crossover area. The southbound roadway is composed of three travel lanes (two southbound through lanes and one dedicated left-turn lane), while the northbound roadway has two through lanes. Both roadways are straight and level, with a raised grass median separating the two travel directions. The speed limit for the southbound travel direction is 30 mph (48 km/h). At the time of the crash, the weather was clear and the roadway surfaces were dry. Vehicle 1, the 2012 Chevrolet Silverado 2500HD pickup truck, was being operated by a male driver, in the left southbound through lane, approaching a crossover area from the north. Occupying the right front seating position was the 38-year old male case occupant. Neither occupant was restrained by their available 3-point, lap/shoulder belts, but the vehicle was noted to be equipped with advanced frontal air bags. The driver of Vehicle 1 intended to continue traveling southbound.

Crash: As Vehicle 1 traveled south, it drifted left out of its travel lane and crossed into the left turn lane. Vehicle 1 continued to drift left as it traveled southbound and entered the crossover area. At this time, Vehicle 1 passed through the crossover area, while traveling south, and entered the south median where it subsequently struck a lamp pole (stone/concrete composite) with its frontal plane. At this time, Vehicle 1 started to rotate clockwise as the pole yielded and upper portions started to shear. Due to the impact, upper portions of the pole fell and struck the top plane of Vehicle 1 (hood and roof panel areas). Vehicle 1 came to rest in the median, after rotating approximately ninety degrees clockwise, facing a westerly direction. As a result of its initial impact with the pole, Vehicle 1's frontal air bags deployed.

Post-Crash: The driver of Vehicle 1 was reported as uninjured; however, the 38-year old right front passenger of Vehicle 1 (case occupant) was transported from the scene, by land unit, to a local trauma center and hospitalized with minor to serious injuries. Vehicle 1 was towed from the scene due to damage sustained in the crash.

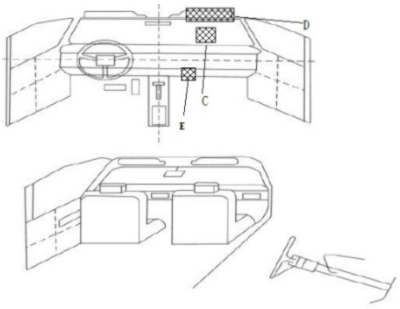
Injury Analysis

This 39-year old male case occupant was the unbelted, right front passenger of a 2012 Chevrolet Silverado 2500HD pickup truck, which was primarily involved in moderate, 12 o'clock frontal impact with a street light pole (Note: sections of the damaged pole eventually fell upon the top plane at the case occupant seating area). The case occupant was unbelted and sleeping/resting in a moderately reclined seating position. His bucket seat was adjusted to the rear most seat track position. Noted air bag deployments for the impact included the driver's frontal air bag. At the time of the crash, the case occupant was 73 inches (185 cm) in height and weighed 215 pounds (98 kg). During the primary impact with the pole (Event 1), the case occupant was projected mostly forward, in reference to the vehicle. However, given his reclined position and the rearward seat track position of his seat, he was still moving forward when portions of the roof panel intruded inward due to the falling remnants of the pole (Event 2). He contacted the roof panel with head/face (scuff marks present), but without firm confirmation if the contact took place further back on the panel (scuff mark present) or closer to the sun visor area (although his sun visor exhibited evidence of possible contact damage, this damage could be related to the intruding roof panel). Regardless, the case occupant continued forward and probably contacted the windshield glazing with his right hand, just behind the deflating frontal air bag (skin deposit at windshield glazing). Based upon injury, it is believed that his lower left leg contacted the lower instrument panel/knee bolster. It should be noted that a potential skin deposit was seen at the central header/map light console, but this potential contact could be the result of the driver and not the case occupant. The case occupant came to rest within his respective seating area, but his post-crash posture is unknown. The case occupant's injuries include: a left forehead abrasion, a left eyelid abrasion, a left orbit floor fracture and a left chin

abrasion, all of which are probably due to contact with the roof panel. Unilateral fractures of the 10th through 12th ribs (left posterior) were due to possible contact with the seatback rest during a rebound movement. A right hand laceration was attributed to the windshield glazing (certain), while a lower leg abrasion was the probable result of contact with the lower instrument panel. The maximum Abbreviated Injury Scale (AIS) for this case occupant was AIS 3.

Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
F	Roof or convertible top	2		Other	Inferred Contact
A	Roof maplight/console	2	Hand - Left	Combina-tion	Probable
B	Roof or convertible top	2	Head	Scuffed	Possible
C	Windshield	2		Transfer	Probable
D	Sunvisor	2	Head	Other	Possible
E	Right lower instrument panel (includes knee bolster)	2	Lower Leg - Left	Other	Inferred Contact



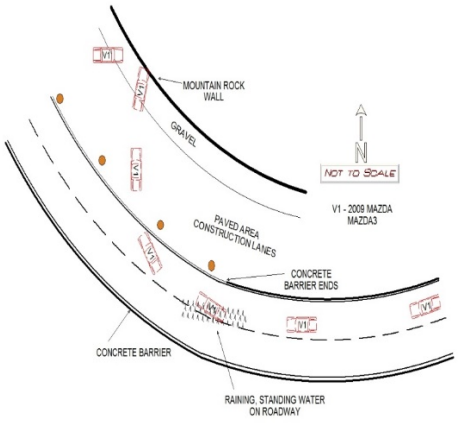
Injuries

Injury #	AIS Name	Aspect	Injury Causation Scenario (ICS)		Involved Physical Component (IPC)			Rank
1	Rib fracture or fractures, without flail, any location unilateral or bilateral, >=3 ribs [OIS II]	Left; L Rib 10; L Rib 11; L Rib 12; Posterior Rib;	**Source of Energy**	**ICS confidence**	**IPC Status**	**Involved Component**	**IPC Confidence**	1
			Crash (pick)	Possible	Primary	Seat, back support	Possible	
2	Orbit fracture, orbital floor, ""blow out"" fracture	Left;	Crash (pick)	Probable	Primary	Roof or convertible top	Probable	2
3	Skin/subcutaneous/muscle, face, abrasion	Left; Chin;	Crash (pick)	Probable	Primary	Roof or convertible top	Probable	3
4	Skin/subcutaneous/muscle, face, abrasion	Left; Eyelid;	Crash (pick)	Probable	Primary	Roof or convertible top	Probable	4
5	Skin/subcutaneous/muscle, face, abrasion	Left; Left Forehead;	Crash (pick)	Probable	Primary	Roof or convertible top	Probable	5
6	Skin/subcutaneous/muscle, upper extremity, laceration, minor; superficial	Right; Hand/Digits;	Crash (pick)	Certain	Primary	Windshield	Certain	6
7	Skin/subcutaneous/muscle, lower extremity, abrasion	Left; Lower Leg;	Crash (pick)	Probable	Primary	Right lower instrument panel (includes knee bolster)	Probable	7

UVA CAB OOP Study

CIREN Case Summary

Case ID: 359458609

Crash Scenario:	**Scene:**
Case Vehicle 1: 2009 Mazda3 ***Object Struck***: Other fixed object Impact Type: Head-on ***Conditions***: Raining and the roadway was wet with standing water ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 29-year-old female ***Stature/Mass***: 157 cm and 62 kg ***Restraint Employed***: Lap and shoulder belt available, only lap belt across abdomen and unknown for shoulder belt ***Air Bags Deployed***: Top instrument panel, Seatback, Roof side rail Maximum Crush: 53 @ C6 ***PDOF*** (degrees): 10 (12 o'clock) ***CDC***: FDEW03 ***DV***: 38 km/h MAIS: 3 ***ISS***: 19	
Vehicle Images	
 	

Crash Summary

This moderate severity frontal crash involved a case occupant who was a 29-year-old female and restrained with a lap/shoulder belt and frontal air bag, and was in a reclined seatback position. She sustained severe injuries and transported to the trauma center. This crash occurred on two, one-way lanes of a divided freeway in a construction area at night with no lights in the area. It was raining and the roadway was wet with standing water. Vehicle 1 (V1), a 2009 Mazda Mazda3 4-door sedan, was westbound in lane one of the two-lanes that were bordered by concrete barriers on both sides as the roadway curved to the right. After the curve the right side shoulder barrier ended and opened up to a large new paved area that was bordered on the north side by a mountain, rock wall. V1 was negotiating this curve right and started to hydroplane on some standing water on the roadway and lost control. V1 then departed the roadway to the right after the barrier ended, crossed over the open paved area and struck the front of V1 into the mountain, rock wall. V1 then rotated clockwise and came to final rest facing north near the wall. V1 was towed and disable. The case occupant is the front right passenger who is a 29-year-old female. She was wearing the lap/shoulder belt and the retractor pretensioners fired plus a frontal air bag deployed. She was in a fully reclined position per interview and vehicle inspection. She sustained severe injuries and was taken to an outside hospital before being transported to the trauma center. The driver and one child were also in the vehicle. The driver was a 23-year-old male who was wearing a lap/shoulder belt with pretensioners actuating plus the steering column air bag deployed. He had minor injuries, and did not receive any treatment. The child was a seven month old male in an unknown type child seat in the second row center seat location, and was not injured and reported to have no treatment.

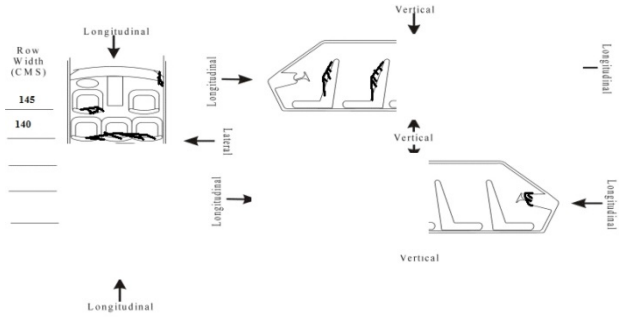
Injury Analysis

This 29-year-old female (157 cm/62 kg, 5'2"/137lbs) was the front right passenger of a 2009 Mazda Mazda3 4-door sedan that was involved in a moderate severity frontal collision. The principal direction of force was 12 o'clock (10 degrees). She had her seatback fully reclined and was using the manual lap/shoulder seat belt. On impact the belt retractor pretensioner actuated, and the frontal instrument mounted air bag deployed. Her body then moved forward and the belt webbing had loading evidence from restraining her torso. Both knees contacted and scuffed the glove box door. Her seat pan and cushion deformed downward from loading of her buttocks. This patient suffered a grade III liver laceration, a grade III splenic laceration, and multiple bilateral rib fractures at the level of the 5th to 8th anterior and lateral ribs. The abdominal injuries and rib fractures were all due to compression from the seat belt as certain. Her fully reclined posture contributed to this mechanism and the location of the belt loading into the upper abdomen and mid torso.

Relevant Intrusions

Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Right	Side panel - forward of the A1/A2 pillar	57	55		<= 2 cms	Lateral
Front Seat	Left	Front seatback	50	47		>= 3 to < 8 cms	Longitudinal
Front Seat	Right	Instrument panel right	73	69		>= 3 to < 8 cms	Longitudinal
Second Seat	Left	Second seatback	90	87		>= 3 to < 8 cms	Longitudinal

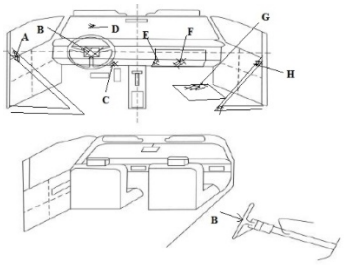
Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Second Seat	Middle	Second seat-back	90	86		>= 3 to < 8 cms	Longitudinal
Second Seat	Right	Second seat-back	90	86		>= 3 to < 8 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
A	Belt restraint webbing/buckle	1		Other	Certain
B	Steering wheel (combination of codes 004 and 005)	1	Chest	Other	Certain
C	Left lower instrument panel (includes knee bolster)	1	Knee - Right	Scuffed	Certain
D	Windshield	1	Hand - Unknown	Cracked	Probable
E	Glove compartment door	2	Knee - Left	Scuffed	Possible

Contact	Component	Occ	Body Region	Evidence	Confidence
F	Glove compartment door	2	Knee - Right	Scuffed	Certain
G	Seat, back support	2	Buttock - Both	Deformed	Certain
H	Belt restraint webbing/buckle	2		Other	Certain



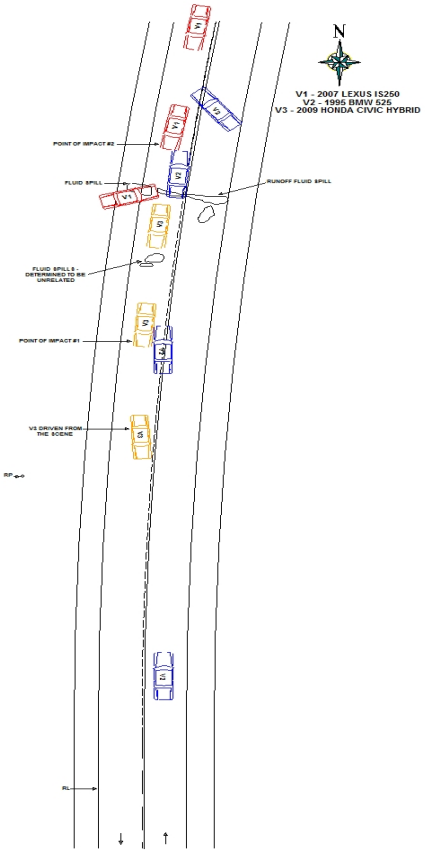
Injuries

Injury #	AIS Name	Aspect	Injury Causation Scenario (ICS)		Involved Physical Component (IPC)			Rank
1	Liver, laceration, >3cm parenchymal depth; major duct involvement; blood loss >20% by volume; moderate [OIS III]Liver laceration moderate (OIS Grade III)	Right; Left Lobe;	**Source of Energy**	**ICS confidence**	**IPC Status**	**Involved Component**	**IPC Confidence**	1
			Crash (pick)	Certain	Primary	Belt restraint webbing/buckle	Certain	
2	Rib fracture or fractures, without flail, any location unilateral or bilateral, >=3 ribs [OIS II]	Bilateral; R Rib 5; R Rib 6; L Rib 5; L Rib 6; L Rib 7; L Rib 8; Lateral Rib;	Crash (pick)	Certain	Primary	Belt restraint webbing/buckle	Certain	2
3	Spleen, laceration, simple capsular tear <=3cm parenchymal depth and no trabecular vessel involvement; minor; superficial [OIS I, II]Spleen laceration minor (OIS Grade I or II)	Left;	Crash (pick)	Certain	Primary	Belt restraint webbing/buckle	Certain	3
4	Skin/subcutaneous/muscle, upper extremity, abrasion	Left; Elbow;	Crash (pick)	Unknown	Primary	Injured, unknown source	Unknown	4
5	Skin/subcutaneous/muscle, abdomen, [except rectus abdominus], contusion; hematoma	Left; Left Front;	Crash (pick)	Certain	Primary	Belt restraint webbing/buckle	Certain	5
6	Skin/subcutaneous/muscle, lower extremity, contusion; hematoma	Left; Knee;	Crash (pick)	Certain	Primary	Glove compartment door	Certain	6
7	Skin/subcutaneous/muscle, lower extremity, contusion; hematoma	Right; Lower Leg;	Crash (pick)	Certain	Primary	Glove compartment door	Certain	7
8	Skin/subcutaneous/muscle, lower extremity, contusion; hematoma	Right; Hip;	Crash (pick)	Probable	Primary	Belt restraint webbing/buckle	Probable	8

UVA CAB OOP Study

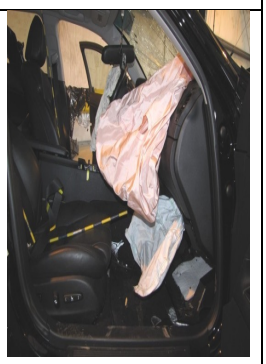
CIREN Case Summary

Case ID: 359551218

Crash Scenario:	**Scene:**
Case Vehicle 1: 2007 Lexus Es-250/300/330/350 Object Struck: Vehicle Impact Type: Front ***Conditions***: Evening hours in darkness on a two-lane, two-way roadway. At the time of the crash, there were clear weather conditions and dry travel lanes ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 52-year-old male ***Stature/Mass***: 196 cm and 98 kg ***Restraint Employed***: Lap and shoulder belt available, lap belt was snugged and low across hips; shoulder belt snugly across the collarbone and over shoulder ***Air Bags Deployed***: Top instrumental panel, Bottom instrumental panel Maximum Crush: 34 @ C1 ***PDOF*** (degrees): 340 ***CDC***: FYEW02 ***DV***: 37 km/h MAIS: 3 ***ISS***: 10	

Vehicle Images





Crash Summary

This three vehicle crash involves two case occupants in the same vehicle. The first case occupant is a 54-year-old female driver, wearing the available manual lap/shoulder belt, involved in a moderate frontal collision with frontal and knee air bag deployments. The second case occupant is a 52-year-old male front right passenger who was wearing the manual lap/shoulder belt and also had frontal and knee air bag deployments. Both sustained serious injuries and were hospitalized at the trauma center.

This crash occurred during evening hours in darkness on a two-lane, two-way roadway. At the time of the crash, there were clear weather conditions and dry travel lanes. In the area where the crash occurred, the asphalt lanes are level and curve to the left for southbound vehicles. There are paved shoulders present on both sides of the roadway. Vehicle 1 (V1 – case vehicle), a 2007 Lexus IS250 4-door sedan, was southbound in the southbound lane. Vehicle 2 (V2), a 1995 BMW 525 4-door sedan, was traveling north in the northbound lane. Vehicle three (V3), a 2009 Honda Civic hybrid 4-door sedan, was traveling south ahead of V1. As V2 approached the curved section of roadway, V2 departed its lane, crossed the center lane lines and the front of V2 sideswiped the left side of V3. V2 continued a short distance north and the front of V2 struck the front of V1, resulting in the actuation of V1's front row seat belt retractor pretensioners and the deployment of the dual frontal and knee air bags. V1 rotated counterclockwise and came to final rest on the west shoulder, facing northeast. V2 rotated counterclockwise and came to final rest facing northwest in the roadway. V3 came to final rest facing south in the southbound lane and was driven from the scene. V1 and V2 were towed due to damage.

The first case occupant in V1 is the 54-year-old female driver who was wearing the available manual lap/shoulder belt. Her seat belt retractor pretensioner actuated and her steering column mounted frontal air bag and bottom instrument panel mounted knee air bags both deployed during the crash. She sustained serious injuries and was transported to the trauma center. The second case occupant is the 52-year-old male front right passenger who was wearing the available manual lap/shoulder belt. His seat belt retractor pretensioner actuated and his instrument panel mounted frontal air bag and bottom instrument panel mounted knee air bag both deployed. Both case occupants sustained serious injuries and were taken to the trauma center for treatment. The drivers of V2 and V3 reportedly had minor injuries.

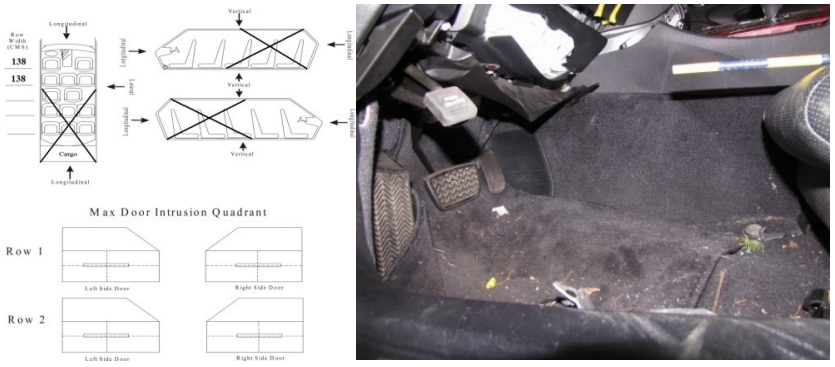
Injury Analysis

This 52-year-old male (196 cm/98 kg, 6'4"/215 lbs) was the front right passenger of a 2007 Lexus IS250 4-door sedan that was involved in a moderate severity frontal crash. He was wearing the lap/shoulder seat belt and on impact the belt pretensioners actuated, plus the frontal steering column mounted and knee bolster mounted air bags both deployed. The principal direction of force was 11 o'clock at 340 degrees. On impact his body moved forward and slightly to the left. His seat belt restrained his body with loading evidence documented on the webbing and latch plate. His left hip and thigh contacted and deformed the center console.

This patient suffered an abdominal injury involving jejunal perforations that required surgery. This was attributed to the compression and rate of compression of the seat belt into his abdomen. His previous abdominal surgery was noted to be a contributing factor.

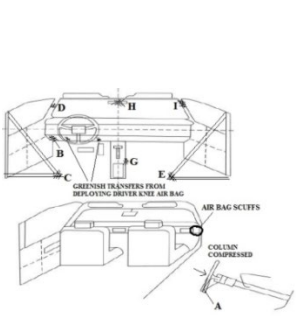
Relevant Intrusions

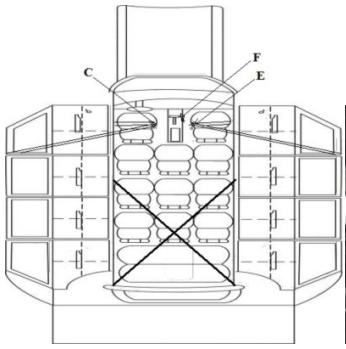
Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Left	Interior	Floor pan (includes sill)	110	102	8	>= 8 to < 15 cms	Vertical
Front Seat	Left	Interior	Other interior componer	62	51	11	>= 8 to < 15 cms	Lateral
Front Seat	Left	Interior	Toe pan	63	53	10	>= 8 to < 15 cms	Longitudinal
Second Seat	Left	Interior	Floor pan (includes sill)	110	104	6	>= 3 to < 8 cms	Vertical

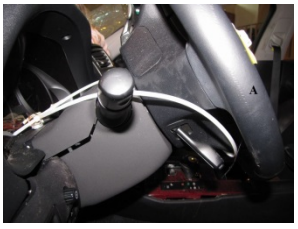


Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Steering wheel (combination of cc	1	Chest	Combination (Specify)	Certain
B	Front	Left lower instrument panel (incluc	1	Knee - Left	Combination (Specify)	Certain
C	Interior	Belt restraint webbing/buckle	1	Multiple Regions (spe	Other (Specify)	Certain
D	Left Side	Left A (A 1/A2)-pillar	1	Wrist - Left	Transfer (Specify)	Possible
E	Interior	Belt restraint webbing/buckle	2	Multiple Regions (spe	Other (Specify)	Certain
F	Interior	Center console first row	2	Multiple Regions (spe	Deformed	Certain
G	Interior	Other interior object (specify)	2	Lower Leg - Left	Scuffed	Possible
H	Front	Mirror	2	Head	Combination (Specify)	Possible
I	Right Side	Right A (A 1/A2)-pillar	2	Unknown	Scuffed	Probable







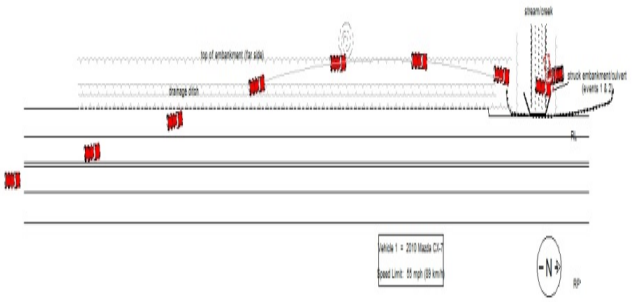
Injuries

Version	AISCODE	Description	Aspect	Rank
2005	5414243	Jejunum-ileum (small bowel), laceration, perforation; full thickness; >=50% circumferer	Inferior/Lower	1
2005	8104021	Skin/subcutaneous/muscle, lower extremity, contusion; hematoma	Hip;Left	2
2005	5104021	Skin/subcutaneous/muscle, abdomen, [except rectus abdominus], contusion; hemat	Left Front;Left	3
2005	7104021	Skin/subcutaneous/muscle, upper extremity, contusion; hematoma	Upper Arm;Left	4
2005	2102021	Skin/subcutaneous/muscle, face, abrasion	Cheek;Right	5
2005	7102021	Skin/subcutaneous/muscle, upper extremity, abrasion	Hand/Digits;Right	6

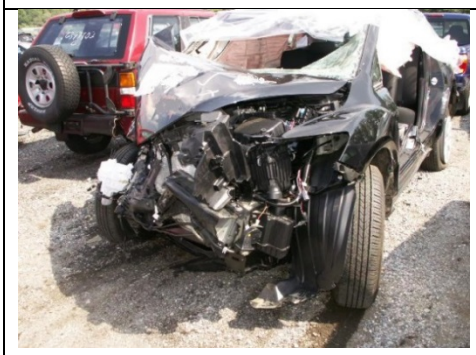
UVA CAB OOP Study

CIREN Case Summary

Case ID: 385166433

Crash Scenario:	**Scene:**
Case Vehicle 1: 2010 MazdaCX-7 Object Struck: Embankment ***Impact Type***: Object off road ***Conditions***: Weather conditions were clear and the bituminous roadway surface was dry ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 29-year-old female ***Stature/Mass***: 168 cm and 70 kg ***Restraint Employed***: Lap and shoulder belt available, only lap belt across abdomen and "other" position for shoulder belt ***Air Bags Deployed***: Top instrument panel, Seatback, Roof side rail Maximum Crush: 48 @ C5 ***PDOF*** (degrees): Non-horizontal ***CDC***: FZEW03 ***DV***: unknown MAIS: 4 ***ISS***: 34	

Vehicle Images



Crash Summary

Case Focus: The focus of this case is on a 29-year old, right front, female passenger (case occupant), of a 2010 Mazda CX-7, which was involved in a moderate, frontal impact, with an embankment/concrete culvert.
Collision Sequence

Pre-Crash: This single-vehicle collision occurred during the early morning hours (dark), of a late summer weekday, on a straight, two-lane roadway. This bituminous roadway runs north and south and has a downhill grade for the northbound travel direction. The overall environment is rural in nature. At time of the crash, the weather conditions were clear and the roadway surface was dry. The speed limit of the east/west roadway is 55 mph (89 km/h). A 31-year-old male driver was operating Vehicle 1 (V1 – case vehicle), the 2010 Mazda CX-7, in the northbound travel lane. He intended to continue traveling north. The 29-year old female passenger (case occupant) occupied the right front seating position. Both occupants of Vehicle 1 were utilizing their respective 3-point lap/shoulder belts (retractor type pretensioners present); however, the female case occupant was reportedly sleeping in a somewhat reclined position at the time, resulting in an incorrect positioning of both the lap and shoulder portions of the seat belt. Vehicle 1 is noted to be equipped with advanced frontal air bags, front seat backrest mounted side impact air bags and roof side rail curtains.

Crash: As Vehicle 1 traveled north, it drifted left and departed the west edge of the roadway. Vehicle 1 climbed a grass embankment and traveled north, parallel to the roadway for some distance. At this time, Vehicle 1 traveled through some minor brush and just left of a guardrail at the area of a small stream. Vehicle 1 continued off the near embankment of the stream, crossed over the stream and pitched downward (with a slight roll to the right about the longitudinal axis) before striking the embankment area on the far side with its frontal plane and striking the concrete culvert with its top/right side plane (front fender extending to the right A-pillar) in a non-horizontal fashion. Vehicle 1 rotated clockwise, along both the lateral and longitudinal axis, and came to rest at the far embankment, facing a southerly direction. As a result of the impact, Vehicle 1's front retractor type pretensioners actuated, while the frontal air bags and side curtains deployed.

Post-Crash: The driver of Vehicle 1 was able to exit the vehicle under his own power. The 29-year old, right front, female case occupant tried to exit the vehicle, but was unable to do so. She was found, by the responding emergency medical systems personnel with her feet in the driver's foot well, her back against the instrument panel and her upper torso at or near the right front foot well area. The left side doors and B-pillar were removed by fire/rescue personnel and the 29-year old female driver of Vehicle 1 was removed. She was transported, by air unit, to a local trauma center and hospitalized with minor to severe injuries. The driver of Vehicle 1 was transported to a local hospital where he was treated and released. Vehicle 1 was towed due to damage sustained in the crash.

Injury Analysis

This 29-year old female case occupant was the right front passenger of a 2010 Mazda CX-7, which was involved in a moderate, 01 o'clock, frontal impact with a concrete culvert/embankment area. At the time of the crash, she was sleeping, in a somewhat reclined position, which resulted in an improper positioning of her body in reference to her 3-point lap/shoulder belt (retractor type pretensioner actuated). As noted above, her bucket seat was adjusted to the rear seat track position, while her seat backrest was reclined (at or greater than 45 degrees). Due to impact, her advanced frontal air bag and the right, roof side rail curtain deployed. At the time of the crash, the case occupant was 168 cm (66 in) in height and weighed 155 lbs (70 kg). Just prior to impact, Vehicle 1 departed an embankment and pitched downward while rolling slightly right along the longitudinal axis, causing the case occupant to move upward, in reference to the vehicle, and slightly inward. At impact, the case occupant was projected mostly forward and upward and somewhat right, in reference to the vehicle. She heavily loaded the lap portion of the seat belt webbing with her abdominal/hip area, while her chest struck and loaded the shoulder portion of the belt. She flexed about the belt, possibly striking the forward right area of the roof panel (scuffed) with her head, while her right shoulder/upper arm possibly engaged the right roof side rail (shoulder/arm interaction with the shoulder belt is also possible). She came to rest mostly in her seating area, but her post-crash posture was likely abnormal due to her pre-impact posture

and the vehicle dynamics associated with the crash. The case occupant's injuries include: anterior occipitocervical dislocation (C1-C2), a non-displaced dens fracture (C2), distraction of the atlas and axis, and an anterior arch avulsion fracture (C1), all the result of contact with the roof panel (probable) or windshield header area (possible). Injuries to the thoracic region include: a left breast contusion, a central manubrium/sternum fracture, bilateral lower rib fractures, a right anterior pneumothorax, a right anterior pulmonary contusion and a spleen laceration, all are the result of certain contact with the shoulder portion of the seat belt. Injuries to the abdominal region include: a lower abdominal contusion, an abdominal wall rupture (anterior), a small bowel injury, a mesentery laceration, and an abdominal aorta injury, all are the result of certain loading of the lap portion of the seat belt. A distraction injury of the T8-T9, though in the thoracic region, was also associated with the abdominal injuries and loading of the lap belt. The case occupant also sustained a right humeral head dislocation (probable contact with the roof side rail or possibly the shoulder portion of the belt webbing), bilateral hip contusions (certain contact with the lap portion of the seat belt), a right, lower leg contusion (probable contact with the knee bolster/lower instrument panel), and bilateral foot contusions (possible contact with the toe pan). The maximum Abbreviated Injury Scale (AIS) for this case occupant was AIS 4.

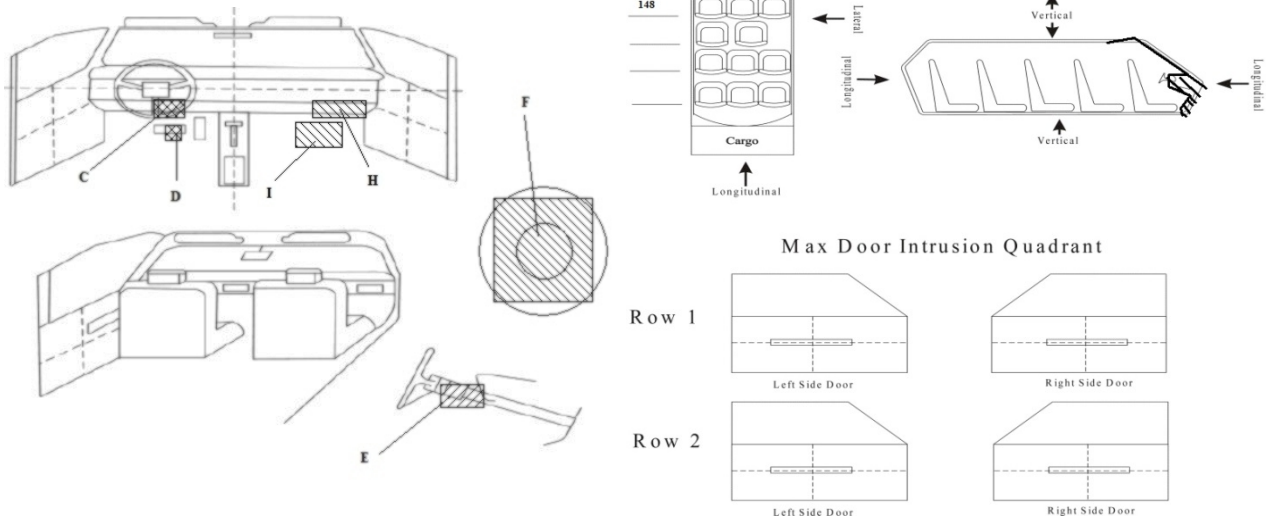
Relevant Intrusions

Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Middle	Instrument panel center	0	4		>= 3 to < 8 cms	Lateral
Front Seat	Middle	Instrument panel center	Unknown	Unknown		Unknown	Longitudinal
Front Seat	Right	Toe pan	69	63		>= 3 to < 8 cms	Longitudinal
Front Seat	Right	Instrument panel right	160	154		>= 3 to < 8 cms	Longitudinal
Front Seat	Right	A (A1/A2)-pillar	174	171		>= 3 to < 8 cms	Longitudinal
Front Seat	Right	Windshield header	0	2		<= 2 cms	Longitudinal

Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
A	Belt restraint webbing/buckle	1		Stretched	Certain
B	Belt restraint webbing/buckle	2		Stretched	Certain
C	Left lower instrument panel (includes knee bolster)	1	Knee - Right	Deformed	Probable

Contact	Component	Occ	Body Region	Evidence	Confidence
D	Foot controls including parking brake	1	Foot - Right	Scuffed	Possible
E	Steering column, transmission selector lever, other attachment	1	Chest	Deformed	Possible
F	Air bag-driver side	1	Chest	Other	Inferred Contact
G	Roof or convertible top	2	Unknown	Scuffed	Possible
H	Right lower instrument panel (includes knee bolster)	2	Lower Leg - Right	Other	Inferred Contact
I	Floor (including toe pan)	2		Other	Inferred Contact



Injuries

Injury #	AIS Name	Aspect	Injury Causation Scenario (ICS)		Involved Physical Component (IPC)			Rank
			Source of Energy	ICS confidence	IPC Status	Involved Component	IPC Confidence	
1	Aorta, abdominal, intimal tear, no disruptionAorta, abdominal intimal tear, no disruption	Central;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	1
2	Lung, contusion, unilateral, major; >=1 lobe	Right;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	2
3	Mesentery, laceration, majorMesentery laceration major	Inferior/Low er;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	3
4	Rib fracture or fractures, w ithout flail, any location unilateral or bilateral, >=3 ribs [OIS II]	Bilateral;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	4
5	Vertebra, cervical spine, dislocation [subluxation], no fracture, no cord involvement, atlanto-axial	Posterior/Back/Dorsal; Stable;	Crash (pick)	Certain	Primary	Roof or convertible top	Probable	4
					Alternate	Win. incl. 1/+:fr header,A(A1/A2)-pillar,instr. panel,or mirror(passenger)	Possible	
6	Vertebra, cervical spine, fracture w ith or w ithout dislocation but no cord involvement, odontoid	Posterior/Back/Dorsal; Stable;	Crash (pick)	Certain	Primary	Roof or convertible top	Probable	5
					Alternate	Win. incl. 1/+:fr header,A(A1/A2)-pillar,instr. panel,or mirror(passenger)	Possible	
7	Spleen, laceration, no hilar or segmental parenchymal disruption or destruction; >3cm parenchymal depth or involving trabecular vessels; moderate [OIS III]Spleen laceration moderate (OIS Grade III)	Left;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	6
8	Thoracic injury, pneumothorax NFS	Right;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	7
9	Sternum, fracture [OIS II, III]Sternum fracture (OIS Grade II or III)	Central;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	8
10	Rectus Abdominus rupture NFS	Inferior/Low er;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	9
11	Skin/subcutaneous/muscle, abdomen, [except rectus abdominus], laceration, avulsion, major; >100cm2	Inferior/Low er; Whole Front;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	10
12	Jejunum-ileum contusion (OIS Grade I)Jejunum-ileum (small bow el), contusion; hematoma [OIS I]	Inferior/Low er;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	11
13	Vertebra, cervical spine, dislocation [subluxation], no fracture, no cord involvement, atlanto-	Posterior/Back/Dorsal; Stable;	Crash (pick)	Certain	Primary	Roof or convertible top	Probable	13
					Alternate	Win. incl. 1/+:fr header,A(A1/A2)-pillar,instr. panel,or mirror(passenger)	Possible	
14	Vertebra, cervical spine, fracture w ith or w ithout dislocation but no cord involvement, vertebral	Posterior/Back/Dorsal; C1; Stable;	Crash (pick)	Certain	Primary	Roof or convertible top	Probable	14
					Alternate	Win. incl. 1/+:fr header,A(A1/A2)-pillar,instr. panel,or mirror(passenger)	Possible	
15	Vertebra, thoracic spine, dislocation [subluxation], no fracture, no cord involvement, facet, unilateral	Superior/Upper; T8T9;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	15
16	Humerus fracture, proximal, extra-articular, unifocal [either one of the tuberosities or the metaphysis]; single	Right;	Crash (pick)	Probable	Primary	Roof right side rail	Probable	16
					Alternate	Belt restraint w ebbing/buckle	Possible	
17	Shoulder (glenohumeral) joint, dislocation	Right;	Crash (pick)	Probable	Primary	Roof right side rail	Probable	17
					Alternate	Belt restraint w ebbing/buckle	Possible	
18	Skin/subcutaneous/muscle, thorax, contusion; hematoma	Left; Left Front;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	18
19	Skin/subcutaneous/muscle, abdomen, [except rectus abdominus], contusion; hematoma	Inferior/Low er; Central Front;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	19
20	Skin/subcutaneous/muscle, low er extremity, contusion; hematoma	Right; Low er Leg;	Crash (pick)	Probable	Primary	Right low er instrument panel (includes knee bolster)	Probable	20
21	Skin/subcutaneous/muscle, low er extremity, contusion; hematoma	Bilateral; Hip;	Crash (pick)	Certain	Primary	Belt restraint w ebbing/buckle	Certain	21
22	Skin/subcutaneous/muscle, low er extremity, contusion; hematoma	Bilateral; Foot/Toes;	Crash (pick)	Probable	Primary	Floor (including toe pan)	Probable	22

UVA CAB OOP Study

CIREN Case Summary

Case ID: 407063518

Crash Scenario:

Case Vehicle 1:

1999 Saturn SL

Object Struck: Fixed object-other

Impact Type: Front

Conditions: Clear and dry at the time of the daylight (dawn) crash

Occ. Position: Passenger (1st-row-right-side)

Age/Gender: 59-year-old male

Stature/Mass: 183 cm and 82 kg

Restraint Employed: Lap and shoulder belt available, both were used properly

Air Bags Deployed: Mid instrumental panel

Maximum Crush:

Profile #	Event#	Direct Damage Location	Field L Location	Max Crush
1	1	FL corner - inward	Entire front	C2 / C3
2	2	Right rear wheel	Same	NA

PDOF (degrees): 0 (12 o'clock)

CDC:

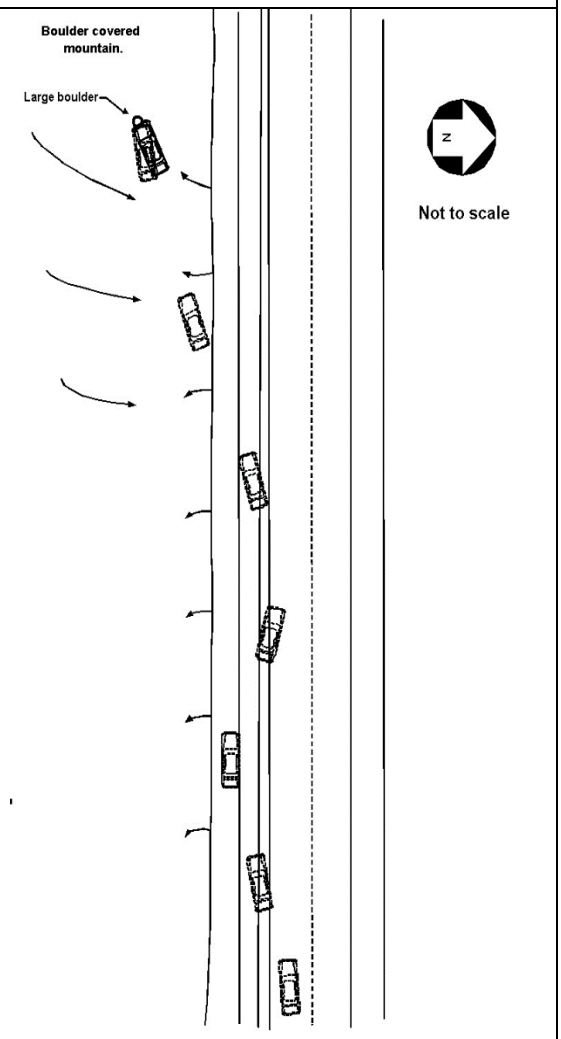
Event	Object Contacted	Force Dir	Location	Total	Long	Lateral	Energy	Impact	Barrier	Est	Rank
1	Other fixed object (speci	0	12FDEW04	51	-51	0	124554	998	51	1	1
2	Ground	90	03RBWN02	999	999	999	-9999	999	999	7	2

DV: 51 kph

MAIS: 3

ISS: 19

Scene:



Vehicle Images

Crash Summary

This crash occurred on a four-lane, divided, east/west interstate freeway. The westbound lanes are separated from the eastbound lanes at the incident location. The bituminous/concrete roadway is straight with an approximate 6 percent incline at the point of departure. It was clear and dry at the time of the daylight (dawn) crash. The left roadside profile at this point consists of an asphalt shoulder (with a curb, drain, lip) and a 1.2 m dirt shoulder that drops 1.8 m down an embankment to the rocky desert floor. The case vehicle was traveling westbound in the number two lane (left) at a reported (estimated) speed of 113 kph. The driver allowed the vehicle to drift to the left where the left side tires traveled off of the roadway. This prompted the driver to steer to the right to regain the roadway, which she did. However, the vehicle began to rotate clockwise and the driver corrected to the left. The vehicle again traveled off of the left side of the road, this time going over the embankment and onto the desert floor. The vehicle continued to travel west on the desert surface until striking a large boulder with its front plane. The vehicle sustained a minor impact to its right rear wheel, presumably as it rotated counterclockwise subsequent to the impact. The vehicle came to rest facing west against the rock and was towed due to damage. All three occupants of the vehicle were transported with varying degree of injury.

Injury Analysis

The case vehicle was equipped with 3-point manual lap and shoulder belts, with pretensioners, in the front outboard positions. There were also front row air bags that deployed upon impact. The vehicle inspection, interview and associated injuries agreed that the subject was using the belt restraint system.

The 183 cm. (6'), 82 kg (180 lb) 59-year-old male subject was seated in the front right side passenger seat. The subject's seat cushion was adjusted to the rearmost location and the seatback was reclined between the mid and full back position. The subject was sleeping with his legs stretched out into the floorboard and arms relaxed at his side. It is likely that the subject awoke prior to impact due the uneven physical nature of the crash site.

Upon impact the air bags deployed, the 3-point manual belt pretensioners actuated and the subject began loading forward. Due to his distance from the instrument panel, the subject apparently did not make contact with the air bag. Rather, the subject loaded heavily into the belt restraint system.

Kinematics suggested that the subject's head flexed over the belt resulting in a C7 facet fracture. The force of the subject's deceleration also caused a concussion.

There was a right shoulder contusion attributed to the shoulder aspect of the restraint. There was also a right scapular abrasion.

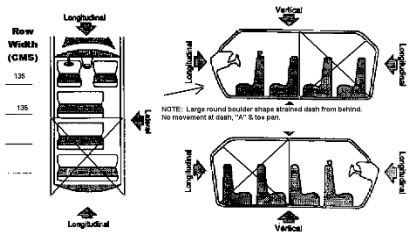
The subject's abdomen loaded the lap aspect of the restraint system resulting in a splenic tip avulsion, a deserosalization injury to the ascending colon, small bowel perforations (x 2), a sigmoid colon contusion and a right lower abdominal contusion.

The subject's lower spine flexed over the lap aspect causing an L2 vertebral body anterior column fracture. There was a left flank abrasion that was also attributed to the lap belt.

The subject sustained a right shin abrasion as a result of his lower legs loading the right side instrument panel.

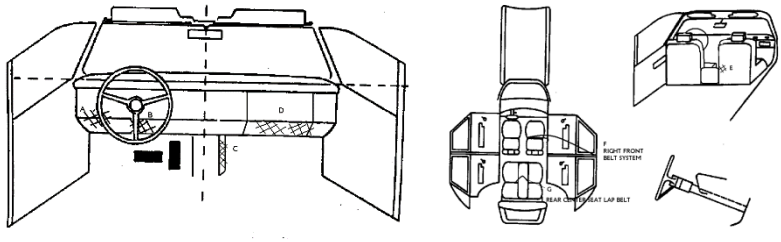
Relevant Intrusions

Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Middle	Interior	Instrument panel center	82	77	5	>= 3 to < 8 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Left instrument panel and below	3	Unknown	Scuffed	Certain
B	Front	Knee bolster	3	Unknown	Scuffed	Certain
C	Front	Center instrument panel and belo	1	Unknown	Deformed	Possible
D	Front	Right instrument panel and below	1	Lower Leg - Right	Scuffed	Certain
E	Interior	Seat, back support	2	Unknown	Scuffed	Certain
F	Interior	Belt restraint webbing/buckle	1	Abdomen	Other (Specify)	Certain
G	Interior	Belt restraint webbing/buckle	2	Abdomen	Stretched	Certain



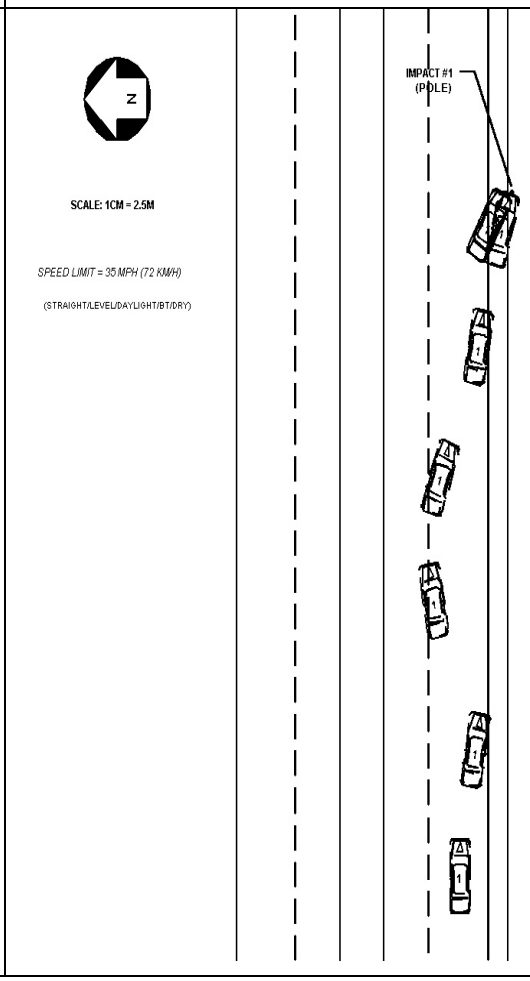
Injuries

AISCODE	Description	Aspect	Injury Source	confidence	Rank
5414243	Jejunum-ileum laceration perforation (OIS Grade III)	Inferior/Lower	Belt restraint webbing/buckle	Probable	1
6502223	Cervical Spine fracture facet	C6C7;Posterior/Back/Dorsal	Other noncontact injury source (specify)	Probable	1
1610002	Cerebral Concussion	Whole Region	Other noncontact injury source (specify)	Probable	2
5408102	Colon contusion (OIS Grade I)	Inferior/Lower	Belt restraint webbing/buckle	Probable	2
5408202	Colon laceration NFS	Inferior/Lower	Belt restraint webbing/buckle	Probable	2
5442222	Spleen laceration minor (OIS Grade I or II)	Left	Belt restraint webbing/buckle	Probable	2
6506322	Lumbar Spine fracture vertebral body minor compression	L1L2;Inferior/Lower	Other noncontact injury source (specify)	Probable	2
5902021	Abdomen Skin abrasion	Left	Belt restraint webbing/buckle	Probable	3
5904021	Abdomen Skin contusion	Right	Belt restraint webbing/buckle	Certain	3
6902021	Back Skin abrasion	Superior/Upper;Right	Injured, unknown source	Unknown	3
7904021	Upper Extremity Skin contusion	Upper Arm;Right	Belt restraint webbing/buckle	Probable	3
8902021	Lower Extremity Skin abrasion	Lower Leg;Right	Right instrument panel and below	Certain	3

UVA CAB OOP Study

CIREN Case Summary

Case ID: 438034143

Crash Scenario:	**Scene:**
Case Vehicle 1: 1995 Oldsmobile Delta 88 ***Object Struck***: fixed object--non-breakaway pole or post(>30 cm in diameter) Impact Type: Front ***Conditions***: The bituminous road was straight, level and dry at the time of the crash. ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 75-year-old female ***Stature/Mass***: 163 cm and 73 kg ***Restraint Employed***: Lap and shoulder belt available, both were used properly ***Air Bags Deployed***: Top instrumental panel Maximum Crush: 79 @ C5 ***PDOF*** (degrees): 0 (12 o'clock) ***CDC***: FREN03 ***DV***: 46 kph MAIS: 4 ***ISS***: 36	

Vehicle Images

Crash Summary

This case involves a front right seat, belted, female passenger responding to a frontal impact into a wooden utility pole with air bag deployment.

This single-vehicle crash took place on a four-lane trafficway divided by a curbed median. Eastbound traffic consisted of two travel lanes and a bicycle lane to the right. The right roadside consisted of a mountable curb and concrete sidewalk with a wooden utility pole positioned next to the roadway. The bituminous road was straight, level and dry at the time of the crash.

Vehicle 1 (V1 – case vehicle), a 1995 Oldsmobile 88 Royale 4-door sedan, driven by a 75-year-old male, was traveling east in the number one lane (right) at an undetermined speed. The driver of V1 reportedly lost consciousness preceding the crash due to an underlying medical condition. Witnesses stated that V1 slowed and began a steering maneuver to the right until it contacted the south curb edge of the roadway. V1 then swerved to the left and into both travel lanes before swerving back to the right. V1 exited the right roadway (north) as its front right contacted a power pole adjacent to the south curb edge. After impact, V1 rebounded rearward and came to rest in close proximity to the point of impact facing southeast.

The vehicle was towed due to disabling damage. The driver and right front seat passenger were airlifted to a local trauma center for treatment of their injuries. The driver had police-reported moderate injuries. The passenger (case occupant) had severe injuries and died hours after hospital admission.

Injury Analysis

The 163 cm (64 in), 73 kg (161 lb), 75-year-old female front right passenger of the 1995 Oldsmobile 88 Royale 4-door sedan was restrained by the available 3-point manual lap and shoulder belt system, in an upright posture with the seat track found at a mid-to-rear position. Following the two swerving maneuvers, the occupant may have been out-of-position relative to her seat belt.

At impact, the front right passenger initiated a forward motion in response to the 12 o'clock principal direction of force and loaded the manual restraint system, glove compartment door, floor pan, and deployed front right passenger air bag.

Loading of the manual restraint resulted in a contusion of the lateral right cheek that crossed the angle of the jaw into the right neck, an abrasion of the right jaw and a laceration to right cheek overlying the inferior orbital ridge.

Seat belt loading also resulted in oblique patterned contusions/abrasions across the chest and abdomen, along with underlying extensive internal trauma. Thoracic trauma consisted of fractures of the right 1st rib, fractures of the posterolateral left 1st - 9th ribs, numerous left pleural lacerations, and a left diaphragmatic laceration. Abdominal trauma involved multiple contusions to the large/small bowel, gastric stretch-type lacerations, mesentery laceration, splenic lacerations, pancreas laceration, and a liver contusion. Seat belt loading was also responsible for her right clavicle fracture. These injury mechanisms were evidenced by the location and extent of the injury along the belt path, relative to the occupant kinematic response pattern.

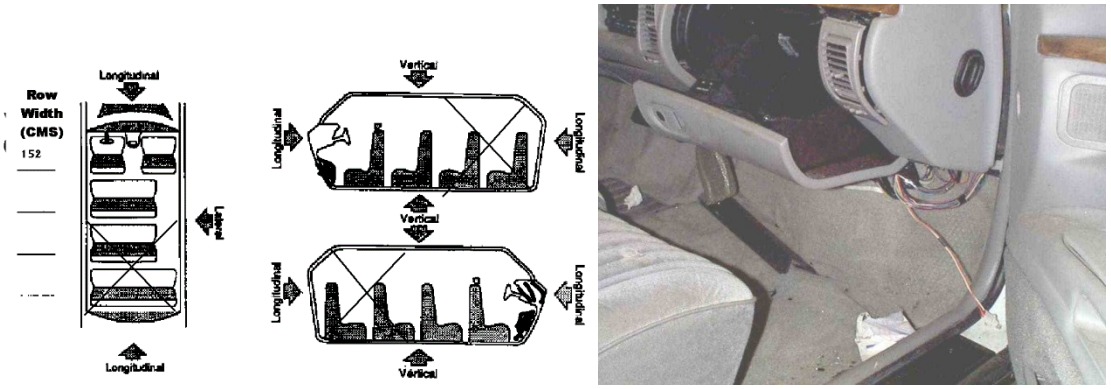
Contact with the glove compartment door possibly resulted in the abrasion and contusion to her posterior medial left calf, multiple contusions to anterior lateral left thigh, and contact with the right instrument panel may have been responsible for lacerations and ecchymosis of the dorsal aspect of the left index and ring fingers, and multiple contusions to the ulnar and dorsal aspects of the distal right forearm.

The abrasion of the dorsal aspect of the right toes was probably a result of contact with the (intruded) toe pan.

She also sustained a left occipital scalp contusion and multiple contusions to the right elbow. The case occupant expired 5.75 hours after admission to the trauma center from her injuries and underlying medical condition.

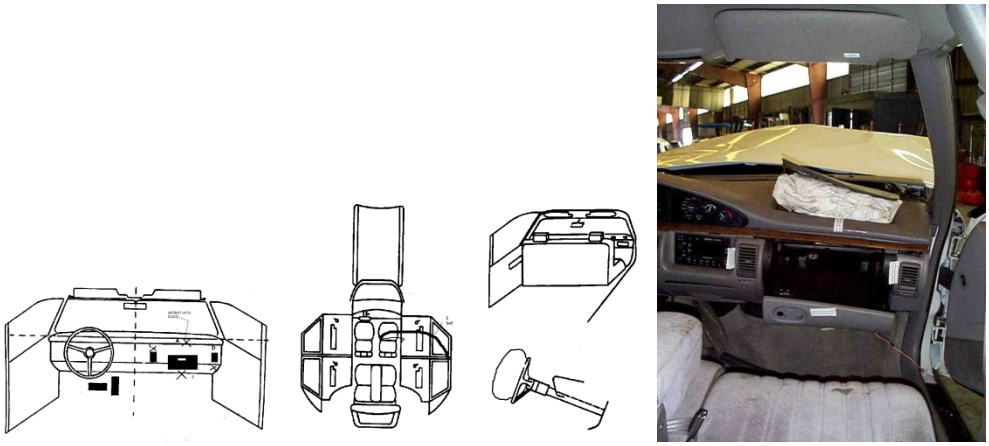
Relevant Intrusions

Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Right	Interior	Toe pan	122	110	12	>= 8 to < 15 cms	Longitudinal
Front Seat	Right	Interior	Instrument panel right	67	63	4	>= 3 to < 8 cms	Longitudinal
Front Seat	Left	Interior	Toe pan	125	120	5	>= 3 to < 8 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Right instrument panel and below	1	Lower Arm - Right	Imprint	Certain
B	Front	Glove compartment door	1	Multiple Regions (spe	Deformed	Certain
C	Front	Right instrument panel and below	1	Hand - Left	Scuffed	Possible
D	Front	Right instrument panel and below	1	Unknown	Scuffed	Probable
E	Interior	Belt restraint webbing/buckle	1	Multiple Regions (spe	Combination (Specify)	Inferred Contac



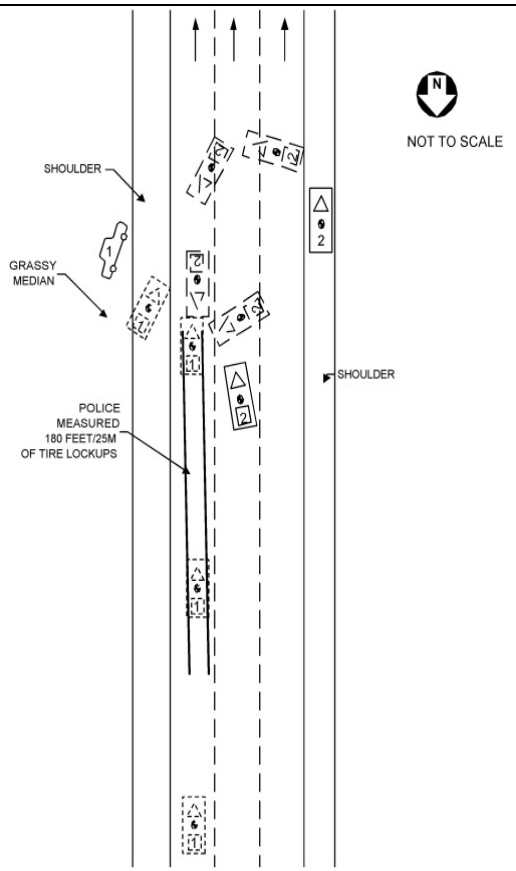
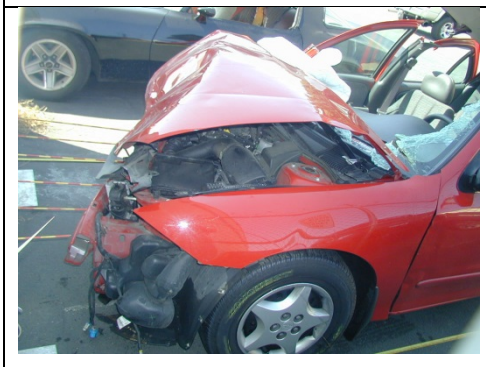
Injuries

AISCODE	Description	Aspect	Injury Source	confidence	Rank
4502604	Rib cage flail chest NFS (OIS Grade III or IV)	Left;Right;L Rib 2;L Rib 9;L Rib	Belt restraint webbing/buckle	Certain	1
5428264	Pancreas laceration moderate if involving ampulla (OIS	Superior/Upper	Belt restraint webbing/buckle	Certain	1
4406043	Diaphragm laceration (OIS Grade II thru IV)	Inferior/Lower	Belt restraint webbing/buckle	Probable	2
4414143	Lung laceration NFS with or without hemo-/pneumothora	Unknown;Left	Rib cage flail chest NFS (OIS Grade III or IV)	Probable	2
5420243	Mesentery laceration major	Inferior/Lower	Belt restraint webbing/buckle	Certain	2
5442243	Spleen laceration moderate (OIS Grade III)	Left	Belt restraint webbing/buckle	Certain	2
5408102	Colon contusion (OIS Grade I)	Inferior/Lower	Belt restraint webbing/buckle	Certain	3
5414102	Jejunum-ileum contusion (OIS Grade I)	Inferior/Lower	Belt restraint webbing/buckle	Certain	3
5418102	Liver contusion NFS	Right	Belt restraint webbing/buckle	Certain	3
5420202	Mesentery laceration NFS	Inferior/Lower	Belt restraint webbing/buckle	Certain	3
5444102	Stomach contusion (OIS Grade I)	Superior/Upper	Belt restraint webbing/buckle	Certain	3
5444222	Stomach laceration no perforation (OIS Grade I)	Superior/Upper	Belt restraint webbing/buckle	Certain	3
7522002	Clavicle fracture (OIS Grade I or II)	Right	Belt restraint webbing/buckle	Certain	3
1904021	Scalp contusion/subgaleal hematoma	Left		Unknown	4
2902021	Facial Skin abrasion	Right	Belt restraint webbing/buckle	Certain	4
2904021	Facial Skin contusion	Right	Belt restraint webbing/buckle	Certain	4
2906021	Facial Skin laceration minor	Right	Belt restraint webbing/buckle	Probable	4
4902021	Chest Skin abrasion	Right	Belt restraint webbing/buckle	Certain	4
4904021	Chest Skin contusion (OIS Grade I)	Left	Belt restraint webbing/buckle	Certain	4
5902021	Abdomen Skin abrasion	Left;Right	Belt restraint webbing/buckle	Certain	4
5904021	Abdomen Skin contusion	Left;Right	Belt restraint webbing/buckle	Certain	4
7904021	Upper Extremity Skin contusion	Unknown	Right instrument panel and below	Possible	4
7904021	Upper Extremity Skin contusion	Elbow;Right		Unknown	4
7906021	Upper Extremity Skin laceration minor	Hand/Digits;Left	Right instrument panel and below	Possible	4
8902021	Lower Extremity Skin abrasion	Foot/Toes;Right	Floor (including toe pan)	Probable	4
8902021	Lower Extremity Skin abrasion	Lower Leg;Left	Glove compartment door	Possible	4

UVA CAB OOP Study

CIREN Case Summary

Case ID: 551110814

Crash Scenario:	**Scene:**
Case Vehicle 1: 2003 Chevrolet Cavalier Object Struck: Vehicle Impact Type: Head on ***Conditions***: night with no lights and clear, dry weather conditions ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 31-year-old female ***Stature/Mass***: 150 cm and 57 kg ***Restraint Employed***: Lap and shoulder belt available, "unknown" position for lap belt and "Other" position for shoulder belt ***Air Bags Deployed***: Top instrument panel Maximum Crush: 60 @ C6 ***PDOF*** (degrees): 0 (12 o'clock) ***CDC***: FDEW03 ***DV***: 44 kph MAIS: 3 ***ISS***: 19	
Vehicle Images	
 	

Crash Summary

This crash occurred on a six-lane divided freeway at night with no lights and clear, dry weather conditions. The posted speed limit is 70 mph/113 kph. Vehicle 1 (V1 – case vehicle), a 2003 Chevrolet Cavalier 4-door sedan, was travelling southbound in lane 3 of three lanes. Vehicle 2 (V2), a 1990 Ford Aerostar minivan, was southbound and pulled to the right shoulder, made a U-turn and began travelling northbound in lane 3 of the southbound lane. V1 locked up the brakes leaving 180 feet of skid marks measured by police before the front of V1 struck head on with V2. V1 rotated clockwise on to the left shoulder and then rolled over on to its left side in the grassy median. V2 rotated clockwise and ended up facing southbound in lane 2. Both vehicles were disabled and damaged. The driver and front right passenger in V1 are both case occupants with no other passengers in V1. The driver is a 29-year-old female who was wearing her lap/shoulder belt and the frontal air bag deployed. The front right passenger is a 31-year-old female who was wearing the lap/shoulder belt and the frontal air bag deployed. The front right passenger had the seatback fully reclined at impact. Both subjects were transported to the trauma center.

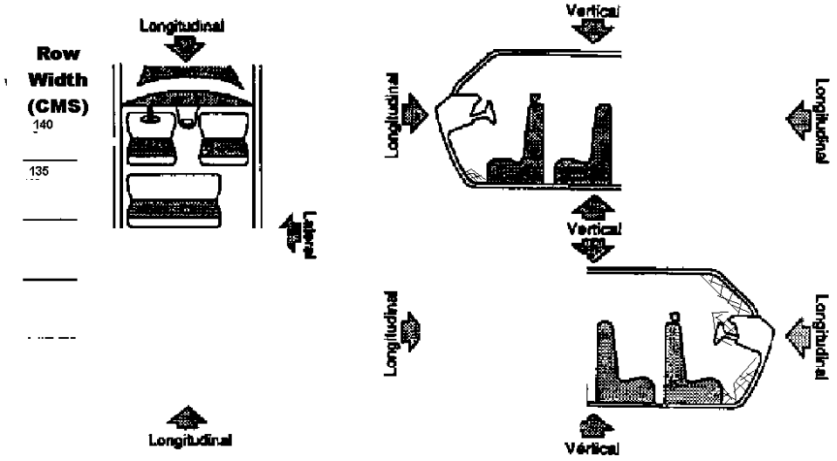
Injury Analysis

This case involved a 31-year-old female, the right front passenger in a 2003 Chevrolet Cavalier that was involved in a severe frontal crash. Lap and shoulder belts were used. There was an air bag deployment. An interview with the subject and inspection of the vehicle revealed that her seat had been in the fully reclined position at the time of the crash. Injuries included a T-12 vertebral body fracture with 25 percent vertebral body loss consistent with fracture. The spinal fracture mechanism was noted as a flexion-distraction type. This was felt to be due to buckling over the lap and shoulder belt at a level of probable. There was loading on the seat belt. Seat reclining position appeared to play a role in this injury mechanism as the body moved forward and then made contact with the seat belt that acted as the fulcrum across the chest. Lower extremity injury included a femur fracture of a spiral type. This was felt to be due to contact of the knee with the door panel at the corner with the glove box. It appeared that the right knee had pocketed here. This mechanism was given a level of certain as substantiated by a finding of a scuff in this location. The rotation of the knee due to her reclining position may have played a role in the causation of the spiral nature of the fracture.

Relevant Intrusions

Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Right	Instrument panel right	67	52		>= 15 to < 30 cms	Longitudinal
Front Seat	Left	Floor pan (includes sill)	38	31		>= 3 to < 8 cms	Vertical
Front Seat	Right	Toe pan	120	99		>= 15 to < 30 cms	Longitudinal
Front Seat	Right	Side panel - forward of the A1/A2 pillar	84	78		>= 3 to < 8 cms	Longitudinal
Front Seat	Right	Floor pan (includes sill)	38	32		>= 3 to < 8 cms	Vertical

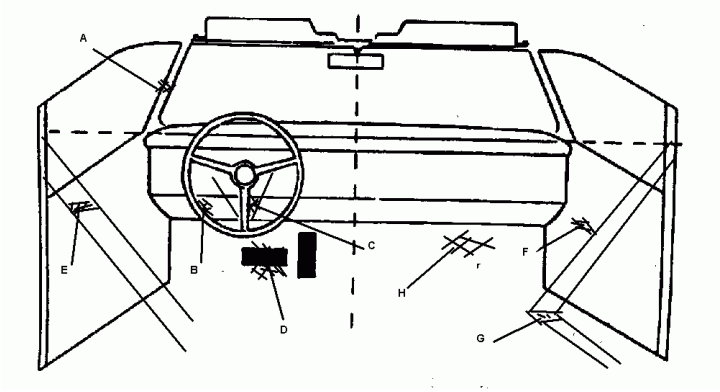
Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Right	A (A1/A2)-pillar	83	70		>= 8 to < 15 cms	Longitudinal
Front Seat	Right	Windshield	80	70		>= 8 to < 15 cms	Longitudinal
Front Seat	Middle	Instrument panel center	67	55		>= 8 to < 15 cms	Longitudinal
Front Seat	Left	Instrument panel left	67	59		>= 8 to < 15 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
A	Left A (A 1/A2)-pillar	1	Lower Arm - Left	Scuffed	Probable
B	Knee bolster	1	Knee - Left	Scuffed	Certain
C	Steering column,transmis-sion selector lever, other attachment	1	Knee - Right	Scuffed	Certain
D	Foot controls including parking brake	1	Foot - Right	Bent	Certain
E	Belt restraint web-bing/buckle	1	Chest	Transfer	Certain
F	Right side interior surface excl hardware or armrests	2	Knee - Right	Scuffed	Probable

Contact	Component	Occ	Body Region	Evidence	Confidence
G	Belt restraint web-bing/buckle	2	Chest	Transfer	Probable
H	Floor (including toe pan)	2	Foot - Unknown	Transfer	Probable



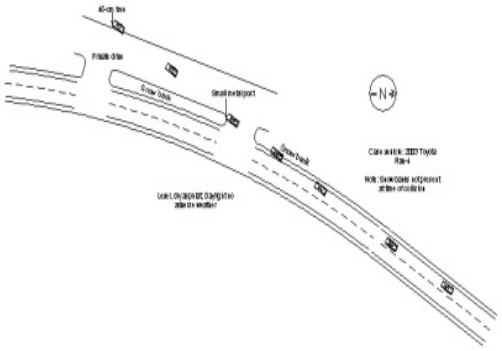
Injuries

AIS Code	AIS Name	Aspect	Injury Source	Confidence	Rank
6504343	Vertebra, thoracic spine, fracture w ith or w ithout dislocation but no cord involvement, vertebral body (""burst"" fracture), major compression (>20% loss of anterior height)Thoracic Spine fracture vertebral body major compression	Superior/Upper; T12;	Belt restraint w ebbing/buckle	Probable	1
8518143	Femur fracture shaft	Right;	Right side interior surface, excluding hardw are or armrests	Certain	2
8904021	Low er Extremity Skin contusion	Right; Thigh; Low er Leg;	Right side interior surface, excluding hardw are or armrests	Certain	3
7510101	Shoulder (glenohumeral joint) contusion	Left;	Belt restraint w ebbing/buckle	Possible	4
7904021	Upper Extremity Skin contusion	Left;	Belt restraint w ebbing/buckle	Probable	5
4904021	Chest Skin contusion (OIS Grade I)	Left;	Belt restraint w ebbing/buckle	Probable	6
2974021	Eyelid contusion	Left;	Air bag-passenger side	Possible	7

UVA CAB OOP Study

CIREN Case Summary

Case ID: 608028951

Crash Scenario:	**Scene:**
Case Vehicle 1: 2003 Toyota Rav-4 ***Object Struck***: Tree(> 10 cm in diameter) ***Impact Type***: Object off road ***Conditions***: daylight and there was no adverse weather ***Occ. Position:*** Passenger (2nd-row-left-side) ***Age/Gender***: 20-year-old female ***Stature/Mass***: 163 cm and 56 kg ***Restraint Employed***: Lap and shoulder belt available, "un-known" position for both lap and shoulder belt ***Air Bags Deployed***: Top instrument panel, steering wheel hub Maximum Crush: 73 @ C2 ***PDOF*** (degrees): 0 (12 o'clock) ***CDC***: FLEW04 ***DV***: 61 km/h MAIS: 5 ***ISS***: 45	
Vehicle Images	
  	

Crash Summary

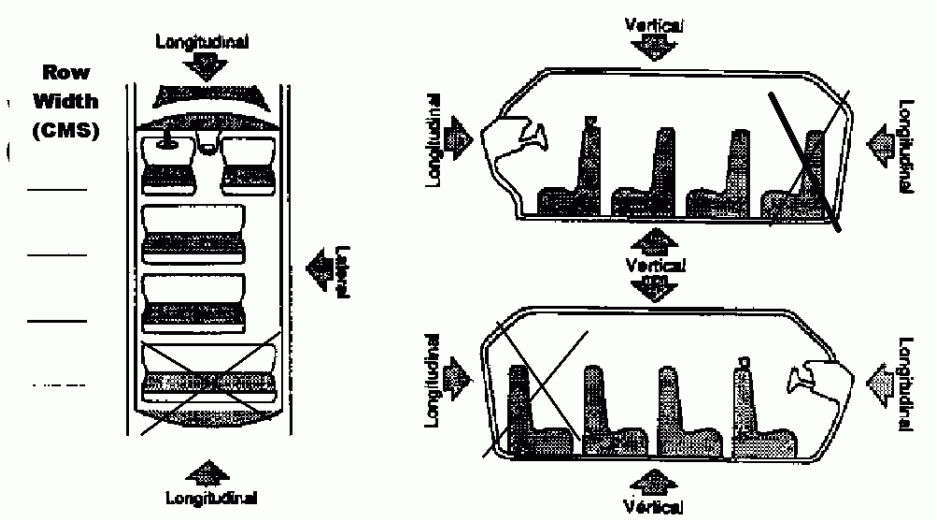
The case vehicle, a 2003 Toyota Rav-4 SUV was south bound on a dry, level, two-lane asphalt roadway approaching a left-sweeping curve. It was daylight and there was no adverse weather. The driver stated he dozed-off and the case vehicle drifted off the west side of the road, traversed a private drive, stuck a small post and struck a 46-cm tree with the left side of its front end. The case vehicle came to rest facing southwest against the tree. The case vehicle was towed due to damage. The 24-year-old male driver and the 24-year-old female right-front passenger were both restrained by three-point belts. The steering-wheel and top-mounted instrument panel air bags deployed. They were transported to a local hospital and treated and released. The 20-year-old female left-rear passenger was restrained by a three-point belt, but her seatback was in a reclined position. She was transported to a local hospital with critical injuries. She was transferred to a level-one trauma center and enrolled as a case occupant.

Injury Analysis

The restrained 20-year-old female left-rear passenger of the 4-door 2003 Toyota Rav-4 SUV had the seatback in a reclined position that appears to have placed the belt somewhat away from her chest as she moved forward because of the severe 12 o'clock impact with a tree. Her reclined position also appears to have permitted her to partially submarine the lap-belt portion of the belt restraint. The loss of consciousness for less than one hour is possibly due to contact with the left-front seatback. Right pulmonary contusion, bilateral ribs fractures, right 5th-10th posterolateral and left 5th-9th with some comminuted and displaced concurrent with bilateral hemo-pneumothorax, an abrasion to the left upper to right lower chest, are due to occupant loading the shoulder belt. As she loaded the lap belt, she sustained a spinal cord contusion with fracture and dislocation involving compression fractures of T11 and T12 with wedging of T12. These fractures were associated with grade I anterolisthesis (25%), complete disruption of the ligaments at T11/12 producing a subluxation at T11/12, with the T12 vertebral body compromising cord inducing impaired sensory and motor function. The infraumbilical contusion to the anterior lower abdomen, the Grade IV laceration of the inferior aspect of right lobe of the liver, the Grade III laceration right kidney were also due to the occupant loading the lap belt. The contusion to the right leg is possibly due to contact with back side of the center console.

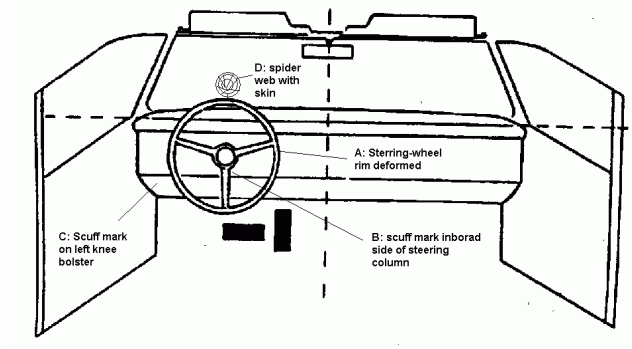
Relevant Intrusions

Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Left	Instrument panel left	70	67		>= 3 to < 8 cms	Longitudinal
Front Seat	Left	Steering Assembly	54	52		<= 2 cms	Longitudinal
Front Seat	Left	Toe pan	98	88		>= 8 to < 15 cms	Longitudinal
Front Seat	Middle	Instrument panel center	64	63		<= 2 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
A	Steering wheel rim	1	Chest	Deformed	Certain
B	Steering column,transmission selector lever, other attachment	1	Knee - Right	Scuffed	Probable
C	Left instrument panel and below	1	Knee - Left	Scuffed	Probable
D	Windshield	1	Head	Cracked	Certain
E	Seat, back support	3		Other	Probable
F	Belt restraint webbing/buckle	1	Chest	Other	Certain
G	Belt restraint webbing/buckle	2	Chest	Other	Certain
H	Belt restraint webbing/buckle	3		Other	Certain



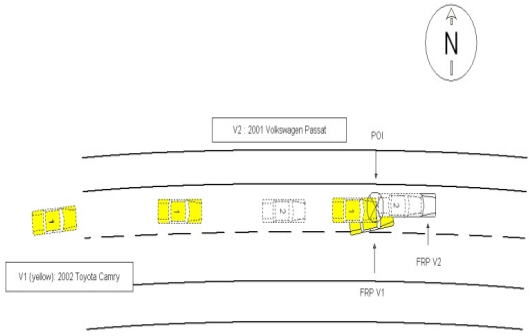
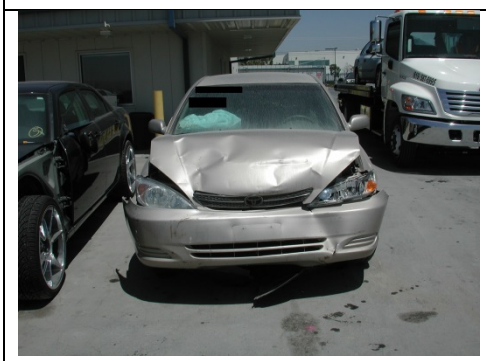
Injuries

AIS Code	AIS Name	Aspect	Injury Source	Confidence	Rank
4502425	Rib cage fracture >3 ribs on each of two sides, with hemo-/pneumothorax	Bilateral; R Rib 5; R Rib 6; R Rib 7; R Rib 8; R Rib 9; R Rib 10; L Rib 5; L Rib 6; L Rib 7; L Rib 8; L Rib 9;	Belt restraint webbing/buckle	Certain	1
5418264	Liver, laceration, parenchymal disruption <=75% hepatic lobe; multiple lacerations >3cm deep; ""burst"" injury; major [OIS IV]Liver laceration major (OIS Grade IV)	Right;	Belt restraint webbing/buckle	Certain	2
6404184	Cord contusion, thoracic spine, [includes the diagnosis of compression, or epidural or subdural hemorrhage within spinal canal documented by imaging studies or autopsy], incomplete cord syndrome (preservation of some sensation or motor function; includes Thoracic Spine cord contusion incomplete cord syndrome with fracture and dislocation	Superior/Upper; T11; T12;	Belt restraint webbing/buckle	Certain	3
5416243	Kidney, laceration, >1cm parenchymal depth of renal cortex, no collecting system rupture or urinary extravasation; moderate [OIS III]Kidney laceration moderate (OIS Grade III)	Right;	Belt restraint webbing/buckle	Certain	4

UVA CAB OOP Study

CIREN Case Summary

Case ID: 781130572

Crash Scenario:	**Scene:**
Case Vehicle 1: 2002 Toyota Camry Object Struck: Vehicle Impact Type: Rear end ***Conditions***: weather was clear and the concrete lanes dry during the afternoon, weekday crash ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 76-year-old male ***Stature/Mass***: 168 cm and 67 kg ***Restraint Employed***: Lap and shoulder belt available, lap belt snug and low across hip and "unknown" position shoulder belt ***Air Bags Deployed***: Top instrument panel Maximum Crush: 22 @ C2 ***PDOF*** (degrees): 0 (12 o'clock) ***CDC***: FDEW02 ***DV***: 29 kph MAIS: 3 ***ISS***: 22	
Vehicle Images	
	

Crash Summary

This case involved a belted male front right passenger of a mid-sized car responding to a “moderate' frontal impact with the back of another similar vehicle. The subject's frontal impact air bag deployed. This two-vehicle crash occurred on the eastbound side of a four-lane, divided interstate traveling through a rural area. The two eastbound lanes were divided from the westbound lanes by a natural median, were level and curved gently right. The weather was clear and the concrete lanes dry during the afternoon, weekday crash. Vehicle 1 (V1 – case vehicle), a 2002 Toyota Camry, 4-door sedan, was traveling eastbound in the second (left) lane. The vehicle was equipped with lap and shoulder belts and first row frontal impact air bags. There were two occupants in V1. The 75-year-old female driver and the 76-year-old male front right seat passenger (case subject) were both using the belt restraints. Vehicle 2, (V2), a 2001 Volkswagen Passat, 4-door sedan, was also traveling eastbound in the second lane further ahead of V1. V2 was slowing in the second lane at an approximated/estimated lower speed. The driver of V1 did not realize that V2, to her front, had been gradually slowing and was now close in front of her. The driver braked, but struck the back plane of V2 with its front. V1's frontal impact air bags deployed. The impact brought V1 to a stop within close proximity of the point of impact, facing northeast in the second lane. V2 came to rest facing east in the second lane as well. Both vehicles were towed due to disabling damage. The occupants of V1 (subject, front right seat passenger) were both transported to a trauma facility due to serious injury for the case subject. The driver of V2 was not injured.

Injury Analysis

This 76-year-old male right front passenger is 168 cms (5' 6" inches) tall and weighing 67 kilograms (148 pounds) with BMI of 24. This individual has a history of osteoporosis and prior spinal fusion of C5 and C6. The case occupant was riding in a 2002 Toyota Camry, 4-door sedan involved in a moderate severity frontal crash with a 2001 Volkswagen Passat, 4-door sedan. The principal direction of force was 12 o'clock. The case occupant was properly restrained with a 3-point manual belt and had a dash mounted air bag available to him, which deployed as a result of the crash. Prior to the crash, the case occupant recognized the situation, was sitting upright and forward looking while bracing with both legs extended against the floor. On impact, he moved forward and right toward the 12o'clock principal direction of force. The case occupant sustained multiple left sided anterior and lateral rib fractures (5-8) from compression caused by contact with the seat belt. With the thorax restrained, the case occupant sustained flexion injuries of the cervical spine. The head moved forward and the neck flexed probably resulting in the Type III odontoid fracture, which extended into the left transverse foramen where there is an associated vertebral artery filling deficit (intimal tear). The vertebral artery intimal injury may have been caused by the displacement of the fractured vertebrae or the displacement of the spinal column. The case occupant also sustained a right elbow contusion and distal radial fracture of the left arm from unknown sources.

Relevant Intrusions

No intrusion

Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
B	Air bag-passenger side	2		Combination	Inferred Contact
C	Belt restraint webbing/buckle	1		Combination	Certain
A	Belt restraint webbing/buckle	2		Combination	Inferred Contact

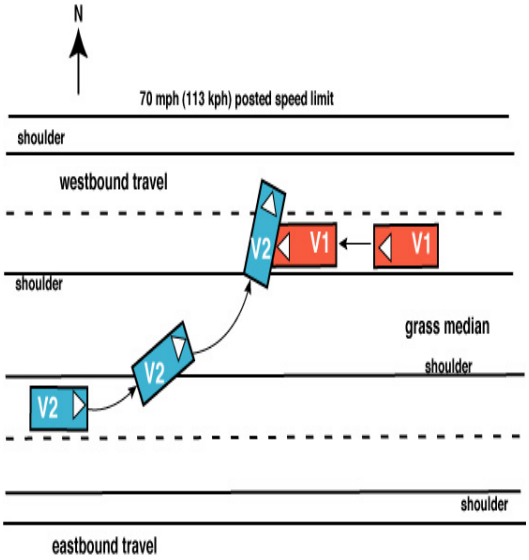
Injuries

AIS Code	AIS Name	Aspect	Injury Causation Scenario (ICS)		Involved Physical Component (IPC)			Rank
6502283	Vertebra, cervical spine, fracture with or without dislocation but no cord involvement, odontoid (dens)Cervical Spine fracture odontoid (dens)	Posterior/Back/Dorsal;	**Source of Energy**	**ICS confidence**	**IPC Status**	**Involved Component**	**IPC Confidence**	1
			Crash (pick)	Probable	Primary	Belt restraint webbing/buckle	Probable	
4502303	Rib cage fracture >3 ribs on one side and <=3 ribs on the other side, stable chest or NFS	L Rib 5; L Rib 6; L Rib 7; L Rib 8;	Crash (pick)	Certain	Primary	Belt restraint webbing/buckle	Probable	2

UVA CAB OOP Study

CIREN Case Summary

Case ID: 830068012

Crash Scenario:	**Scene:**
Case Vehicle 1: 1998 Pontiac Bonneville/Catalina/Parisienne Object Struck: Vehicle Impact Type: Front ***Conditions***: dark, snowing, and the bituminous roadway was snow-covered and icy. ***Occ. Position:*** Passenger (1st-row-right-side) ***Age/Gender***: 54-year-old female ***Stature/Mass***: 163 cm and 82 kg ***Restraint Employed***: Lap and shoulder belt available, both were used properly ***Air Bags Deployed***: Top instrumental panel Maximum Crush: 82 @ C6 ***PDOF*** (degrees): 340 (11 o'clock) ***CDC***: FDEW03 ***DV***: 60 kph MAIS: 3 ***ISS***: 10	
Vehicle Images	
 	

Crash Summary

Vehicle 1 (V1 - case vehicle), a 1998 Pontiac Bonneville, 4-door sedan was traveling west in the inside west-bound lane of a four-lane, divided, limited access freeway (two lanes eastbound, grassy median, two lanes westbound). Vehicle 2 (V2), a 2001 Isuzu Rodeo, 4-door SUV (case vehicle) was traveling east in the inside eastbound lane of the same freeway. It was dark, snowing, and the bituminous roadway was snow-covered

and icy. For an unknown reason, the driver of V2 lost control and entered the snow covered median while beginning a counter-clockwise rotation. V2 crossed the median and entered the inside westbound lane. The driver of V1 was unable to avoid V2 and the front of V1 struck the right-side of V2 in a T-type configuration. After impact, V2 rotated clockwise and came to rest in the inside westbound lane facing south-east. After impact, V1 rotated clockwise approximately 180 degrees, but remained in the inside westbound lane facing east. V1 and V2 were towed from the scene due to disabling vehicle damage. The 55-year-old male driver of V1 was using the available three-point seat belt and the steering-wheel air bag deployed. The 53-year-old female right-front passenger of V1 (case occupant) was using the available three-point seat belt and the dash-mounted air bag deployed. The 32-year-old male driver of V2 (case occupant) was using the available three-point seat belt and the steering-wheel air bag deployed. Both occupants of V1 and the driver of V2 were transported via ground ambulance to a regional level-one trauma center.

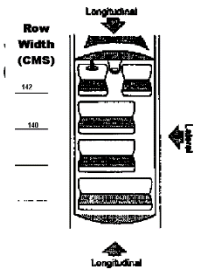
Injury Analysis

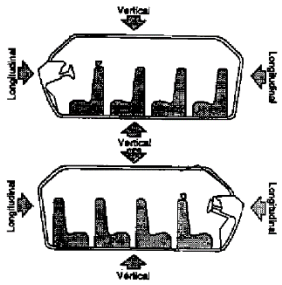
The case occupant is the 163 cm (5' 4"), 82 kg (181 lb), 53-year-old female right-front passenger of a 1998 Pontiac Bonneville 4-door sedan that struck the right side of a 2001 Isuzu Rodeo 4-door SUV. The Rodeo rotated across the grassy median and entered the case vehicle's path of travel. The impact was classified as severe. The WinSmash reconstruction program calculated a delta V of 60 kph (37 mph), which appeared to be consistent with the vehicle damage. The case occupant was reportedly fully reclined in the right-front seat. She was using the available three-point seat belt, and the dash-mounted air bag deployed.

In response to the 11 o'clock direction of force, she moved forward and slightly to her left, relative to the vehicle interior. She sustained a left femoral neck fracture, left mid-shaft femur fracture, and a left supracondylar femur fracture probably from contact with the glove compartment door/knee bolster.

Relevant Intrusions

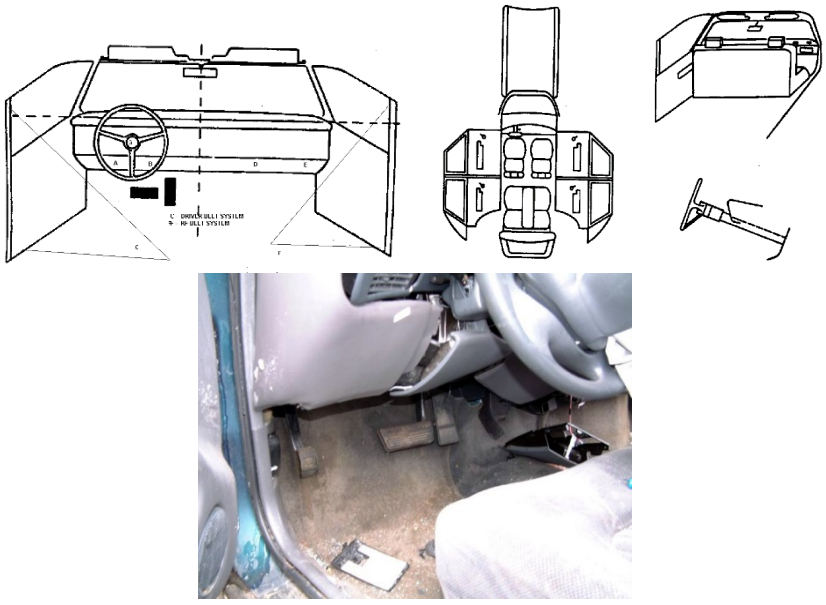
Row	Position	Area	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Right	Interior	Toe pan	101	86	15	>= 15 to < 30 cms	Longitudinal
Front Seat	Left	Interior	Toe pan	101	92	9	>= 8 to < 15 cms	Longitudinal
Front Seat	Right	Interior	Instrument panel right	82	72	10	>= 8 to < 15 cms	Longitudinal
Front Seat	Left	Interior	Instrument panel left	82	80	2	<= 2 cms	Longitudinal





Case Occupant Contact (Nass Form):

Contact	Area	Component	Occ #	Body Region	Evidence	Confidence
A	Front	Knee bolster	1	Knee - Left	Deformed	Probable
B	Front	Knee bolster	1	Knee - Right	Deformed	Probable
C	Interior	Belt restraint webbing/buckle	1	Chest	Transfer (Specify)	Probable
D	Front	Knee bolster	2	Knee - Left	Deformed	Probable
E	Front	Knee bolster	2	Knee - Right	Deformed	Probable
F	Interior	Belt restraint webbing/buckle	2	Chest	Transfer (Specify)	Certain
G	Air Bag	Air bag-driver side	1	Face	Blood	Probable



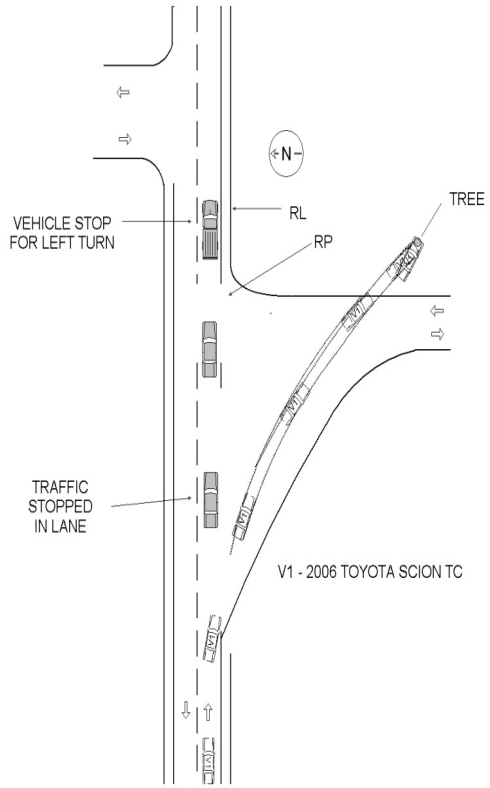
Injuries

AISCODE	Description	Aspect	Injury Source	confidence	Rank
8518123	Femur fracture neck	Left	Glove compartment door	Probable	1
8518223	Femur fracture supracondylar	Left	Glove compartment door	Probable	2
8518143	Femur fracture shaft	Left	Glove compartment door	Probable	3
2906021	Facial Skin laceration minor	Inferior/Lower;Central	Same occupant contact (specify) [ex- knee]	Possible	4
8906021	Lower Extremity Skin laceration minor	Knee;Left	Glove compartment door	Probable	5
4904021	Chest Skin contusion (OIS Grade I)	Left	Injured, unknown source	Unknown	6
7904021	Upper Extremity Skin contusion	Hand/Digits;Left	Same occupant contact (specify) [ex- knee]	Possible	7
5902021	Abdomen Skin abrasion	Inferior/Lower;Left	Belt restraint webbing/buckle	Probable	8
5902021	Abdomen Skin abrasion	Inferior/Lower;Right	Belt restraint webbing/buckle	Probable	8

UVA CAB OOP Study

CIREN Case Summary

Case ID: 852122288

Crash Scenario:	**Scene:**
Case Vehicle 1: 2006 Toyota Scion TC (<2012) ***Object Struck***: Tree (> 10 cm in diameter) ***Impact Type***: Object off road ***Conditions***: Daylight with clear, dry conditions ***Occ. Position:*** Passenger (1st-row right-side) ***Age/Gender***: 65-year-old female ***Stature/Mass***: 170 cm and 136 kg ***Restraint Employed***: Lap and shoulder belt available, lap belt across abdomen and "other" position for shoulder belt ***Air Bags Deployed***: Top instrument panel Maximum Crush: 81 @ C1 ***PDOF*** (degrees): 0 (12 o'clock) ***CDC***: FYEW04 ***DV***: 48 kph MAIS: 6 ***ISS***: 75	
Vehicle Images	
 	

Crash Summary

This crash occurred on a two-lane, two-way highway during daylight with clear, dry conditions. Vehicle 1 (V1 – case vehicle), a 2006 Scion TC 2-door hatchback, was eastbound on this highway. Side roadways and driveways intersect along the highway and traffic in the eastbound lane was stopped behind a vehicle that was waiting to make a left turn at an uncontrolled intersection. V1 approached behind the stopped traffic and

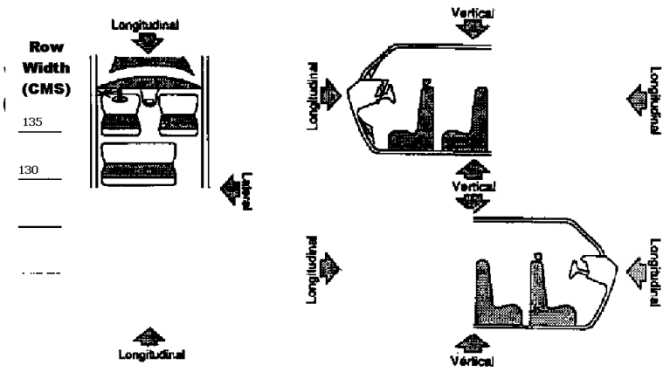
then swerved to the right off the south side of the highway across a paved driveway to avoid a collision with the stopped vehicles. V1 started to brake as it crossed the paved driveway leaving tire yaws marks that continued off the pavement into a grassy area before the front left half of V1 struck a large tree. V1 came to final rest against the tree and rotated slightly counterclockwise. V1 had significant frontal damage and was towed. V1 included two case occupants who were the only passengers. The driver, a 70-year-old male, was wearing the manual lap and shoulder belt with the pretensioners firing at impact. The front steering column mounted and knee bolster air bags deployed in this driver's position. The case driver was transported to the trauma center with serious injuries. The front right passenger, a 65-year-old female, was wearing the manual lap and shoulder belt with the pretensioners firing. The front instrument panel mounted air bag deployed. This case occupant had the seatback fully reclined at the time of impact and was fatally injured and died on scene.

Injury Analysis

This 65-year-old female (170 cm/136 kg, 5'7" and 300 lbs) was the front row right passenger of a 2006 Scion TC 2-door hatchback that was involved in a severe frontal impact collision with a large tree. This case occupant was wearing a manual lap and shoulder seat belt and the seat belt pretensioner actuated on impact with loading transfers found on the webbing. The frontal instrument panel mounted air bag deployed. This case occupant had the seatback fully reclined at the time of impact. Being fully reclined the upper body was not in contact with the shoulder belt portion. This case occupant moved forward in response to a 12 o'clock direction of force and the left knee struck the center instrument panel and the left edge of the glove box door that were both found deformed and scuffed. The right knee contact and deformed the glove box. As the occupant moved forward some loading on the webbing was noted from her upper body as well as a smudge mark on the shoulder belt that may have occurred when the upper body made contact. This patient suffered head and cervical spine injuries that resulted in death. These included an atlanto-occipital fracture, subarachnoid hemorrhage, a laceration to the medulla and spinal cord with surrounding hematoma. These head, brain, and cervical injuries resulted from deceleration shearing forces, which occurred as her head moved rapidly forward after sustaining contact with the shoulder belt into the upper chest. She suffered multiple bilateral rib fractures including ribs 6 to 10 on the right and 2 to 8 on the left with deep abrasions across her chest in the pattern of the shoulder belt as she came in contact with the shoulder after beginning in a reclined position. Thus we attribute the chest wall injuries to compression from the seat belt impact. The patient was also found to have multiple mesenteric lacerations and a pelvic fracture involving the sacroiliac joint. These are attributable to the compression force applied by the lap belt. These mechanisms were rated as certain for the mesenteric injury and possible for the pelvic fracture.

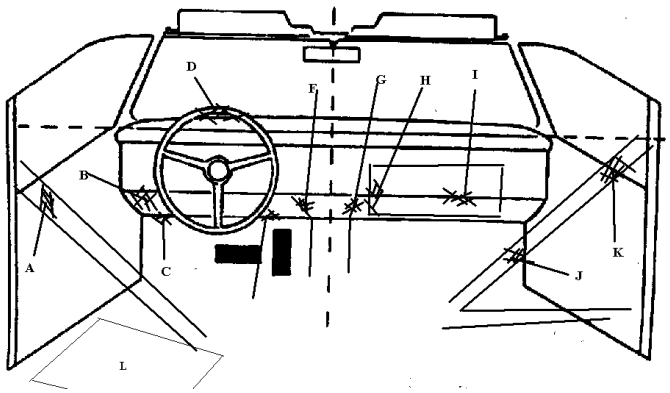
Relevant Intrusions

Row	Position	Intruded Component	Comparison	Intruded	Intrusion	Magnitude	Crush Direction
Front Seat	Left	Toe pan	58	49		>= 8 to < 15 cms	Longitudinal
Front Seat	Left	Instrument panel left	94	90		>= 3 to < 8 cms	Longitudinal
Front Seat	Left	A (A1/A2)-pillar	110	107		>= 3 to < 8 cms	Longitudinal



Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
A	Belt restraint webbing/buckle	1		Transfer	Certain
B	Knee bolster	1	Knee - Left	Deformed	Certain
C	Left instrument panel and below	1	Lower Leg - Left	Deformed	Certain
D	Steering wheel rim	1	Hand - Unknown	Deformed	Certain
E	Left instrument panel and below	1	Lower Leg - Right	Deformed	Certain
F	Center instrument panel and below	1	Knee - Right	Scuffed	Probable
G	Center instrument panel and below	2	Knee - Left	Scuffed	Certain
H	Glove compartment door	2	Knee - Left	Deformed	Certain
I	Glove compartment door	2	Knee - Right	Scuffed	Certain
J	Belt restraint webbing/buckle	2	Unknown	Transfer	Probable
K	Belt restraint webbing/buckle	2		Transfer	Certain
L	Seat, back support	1	Buttock - Both		Inferred Contact



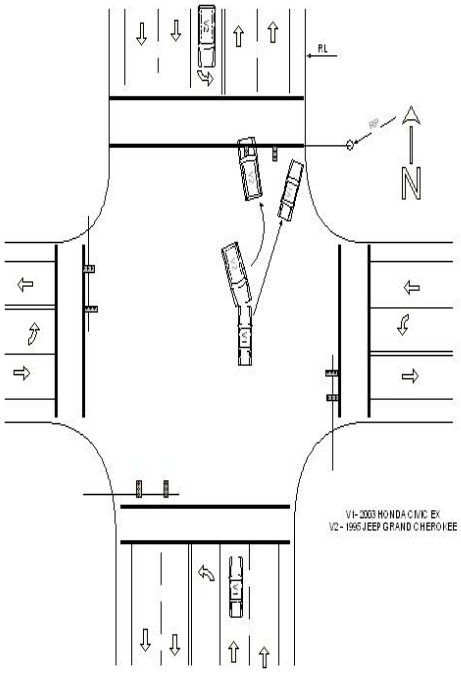
Injuries

AIS Code	AIS Name	Aspect	Injury Source	Confidence	Rank
6402726	Cord laceration, cervical spine, [includes penetrating injury, transection or crush], complete cord syndrome (quadriplegia or paraplegia with no sensation or motor function), C-3 or above, with fractureCervical Spine Cord laceration complete cord syndrome C-3 or above with fracture	Posterior/Back/Dorsal; C1; C2;	Belt restraint webbing/buckle	Certain	1
1402126	Brain stem [hypothalamus, medulla, midbrain, pons], lacerationBrain stem laceration	Inferior/Lower;	Belt restraint webbing/buckle	Certain	2
4502524	Rib cage fracture open/displaced/comminuted with hemo-/pneumothorax	Bilateral; R Rib 6; R Rib 7; R Rib 8; R Rib 9; R Rib 10; L Rib 2; L Rib 3; L Rib 4; L Rib 5; L Rib 6; L Rib 7; L Rib 8;	Belt restraint webbing/buckle	Certain	3
1404663	Cerebellum subarachnoid hemorrhage	Posterior/Back/Dorsal;	Belt restraint webbing/buckle	Certain	4
1406843	Cerebrum subarachnoid hemorrhage	Left;	Belt restraint webbing/buckle	Certain	5
5420243	Mesentery, laceration, majorMesentery laceration major	Inferior/Lower;	Belt restraint webbing/buckle	Certain	8
8528003	Sacroilium fracture	Posterior/Back/Dorsal;	Belt restraint webbing/buckle	Possible	9
8520022	Leg fracture NFSLeg or Ankle fracture NFS	Right;	Floor (including toe pan)	Probable	10
5902021	Abdomen Skin abrasion	Central;	Belt restraint webbing/buckle	Certain	11
5904021	Abdomen Skin contusion	Central;	Belt restraint webbing/buckle	Certain	12
8904021	Lower Extremity Skin contusion	Right; Ankle;	Floor (including toe pan)	Probable	13
8906021	Lower Extremity Skin laceration minor	Right; Ankle;	Floor (including toe pan)	Probable	14
2904021	Facial Skin contusion	Left; Superior/Upper;	Injured, unknown source	Unknown	15
7906021	Upper Extremity Skin laceration minor	Right;	Belt restraint webbing/buckle	Probable	16
4902021	Chest Skin abrasion	Left;	Belt restraint webbing/buckle	Certain	17
4902021	Chest Skin abrasion	Left;	Belt restraint webbing/buckle	Certain	18
4904021	Chest Skin contusion (OIS Grade I)	Central;	Belt restraint webbing/buckle	Certain	19
8904021	Lower Extremity Skin contusion	Right; Lower Leg;	Glove compartment door	Certain	20
8904021	Lower Extremity Skin contusion	Right; Lower Leg;	Glove compartment door	Certain	21

UVA CAB OOP Study

CIREN Case Summary

Case ID: 852127793

Crash Scenario:	**Scene:**
Case Vehicle 1: 2003 Honda Civic/CRX/Del Sol Object Struck: Vehicle Impact Type: Head on ***Conditions***: Night with street lights and clear, dry conditions ***Occ. Position:*** Driver (1st-row-left-side) ***Age/Gender***: 17-year-old female ***Stature/Mass***: 173 cm and 77 kg ***Restraint Employed***: Lap and shoulder belt available, both belts were not used ***Air Bags Deployed***: Steering wheel hub Maximum Crush: 45 @ C1 ***PDOF*** (degrees): 350 (12 o'clock) ***CDC***: FDEW03 ***DV***: 38 kph MAIS: 3 ***ISS***: 10	
Vehicle Images	
 	

Crash Summary

This two-vehicle crash occurred at a traffic controlled intersection during the night with street lights and clear, dry conditions. Vehicle 1 (V1 – case vehicle), a 2003 Honda Civic EX 2-door, was traveling north-bound through the intersection in lane two of a five-lane, two-way street with a center left turn lane. Vehicle 2 (V2), a 1995 Jeep Grand Cherokee 4-door, was traveling southbound in the left turn lane and was turning left through the same intersection. The front of V1 struck the front of V2 almost head on. V2 rotated counter-clockwise post impact and came to final rest on the north side of the intersection facing north. V1 continued forward and came to final rest facing northeast near the northeast corner of the intersection. Both vehicles were damaged and towed. The case occupant is the driver of V1 and was the only occupant in V1. This case driver was a 17-year-old male who was not wearing a seat belt and the front steering column mounted air bag deployed. This case occupant had serious injuries and was airlifted to the trauma center and hospitalized.

Injury Analysis

This 17-year-old male (173 cm/77 kg, 5 '8"/170lbs) was the driver of a 2003 Honda Civic EX 2-door that was involved in a moderate frontal impact collision. This driver was not belted and the frontal steering column mounted air bag deployed. This driver also had the seatback fully reclined prior to impact. On impact the driver moved forward in response to a 12 o'clock direction of force. Both knees contacted the knee bolster cover that was found scuffed and cracked. The bolster plate behind the plastic cover was deformed by the left knee contact. The right bolster plate was not deformed but had skin, fabric and blood transfers on the left edge. The lower steering rim was found deformed from contact with his chest. Some cracks and skin transfers were found on the windshield from his contact with his hand. This patient sustained a right tibial plateau fracture and left acetabular fracture with dislocation, left femur condyle fracture, and a left patella fracture. As this patient was not wearing a seat belt and was fully reclined at the time of impact he appears to have gone beneath the steering column resulting in a direct impact of the lower extremities with the knee bolsters. The lacerations on both knees confirm this along with the collapse of the left knee bolster with major deformation. This resulted in direct loading on the left lower extremity leading to all the fractures with an indirect fracture to the left acetabular with dislocation noted and a direct blow to the right lower extremity resulting in the tibial fracture. This was rated as certain. In addition he had a 5th metacarpal fracture on the left hand that was thought to be due to impact with the windshield that had intruded longitudinally from the hood.

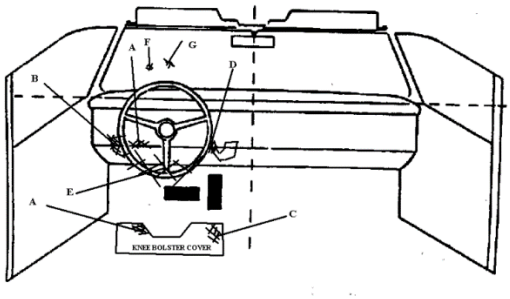
Relevant Intrusions

Row	Position	Intruded Component	Comparison	Intruded	Intru-sion	Magnitude	Crush Direction
Front Seat	Left	Windshield	115	92		>= 15 to < 30 cms	Longitudinal
Front Seat	Middle	Windshield	115	95		>= 15 to < 30 cms	Longitudinal
Front Seat	Right	Windshield	115	108		>= 3 to < 8 cms	Longitudinal
Front Seat	Left	Hood	115	92		>= 15 to < 30 cms	Longitudinal
Front Seat	Middle	Hood	115	95		>= 15 to < 30 cms	Longitudinal
Front Seat	Right	Hood	115	108		>= 3 to < 8 cms	Longitudinal

Row	Position	Intruded Component	Comparison	Intruded	Intru-sion	Magnitude	Crush Direction
Front Seat	Right	Front seat-back	85	73		>= 8 to < 15 cms	Longitudinal
Sec-ond Seat	Left	Second seat-back	60	49		>= 8 to < 15 cms	Longitudinal
Sec-ond Seat	Middle	Second seat-back	60	45		>= 15 to < 30 cms	Longitudinal
Sec-ond Seat	Right	Second seat-back	60	45		>= 15 to < 30 cms	Longitudinal

Case Occupant Contact (Nass Form):

Contact	Component	Occ	Body Region	Evidence	Confidence
A	Knee bolster	1	Knee - Left	Scuffed	Certain
B	Knee bolster	1	Knee - Left	Deformed	Certain
C	Knee bolster	1	Knee - Right	Cracked	Certain
D	Knee bolster	1	Knee - Right	Transfer	Certain
E	Steering wheel rim	1	Chest	Deformed	Certain
F	Windshield	1	Hand - Unknown	Cracked	Certain
G	Windshield	1	Hand - Unknown	Transfer	Certain



Injuries

AIS Code	AIS Name	Aspect	Injury Source	Confidence	Rank
8534083	Tibia fracture condyles open/displaced/comminuted	Right;	Knee bolster	Certain	1
8518043	Femur fracture condylar	Left;	Knee bolster	Certain	2
8526022	Pelvis fracture closed	Left;	Knee bolster	Certain	3
8506142	Hip dislocation w ithout involving articular cartilage	Left;	Knee bolster	Certain	4
8524002	Patella fracture	Left;	Knee bolster	Certain	5
8404042	Collateral ligament tear; avulsion, ankle, complete disruptionCollateral or cruciate ligament laceration knee	Right;	Knee bolster	Certain	6
7520022	Carpus or metacarpus fracture	Left;	Windshield	Certain	7
7902021	Upper Extremity Skin abrasion	Right; Hand/Digits;	Windshield	Certain	8
7902021	Upper Extremity Skin abrasion	Left; Hand/Digits;	Windshield	Certain	9
8906021	Low er Extremity Skin laceration minor	Left; Knee;	Knee bolster	Certain	10
8906021	Low er Extremity Skin laceration minor	Right; Knee;	Knee bolster	Certain	11

Appendix E: NASS Matched Pair Study: Supplemental Analysis Results

3 Comparison of Injuries

Odds ratios are given in the columns labeled `exp(coef)`.

3.1 MAIS $\geq$ 2

All matched occupants

```
Call:
clogit(I(mais >= 2) ~ outofposition + age + heightc + weightc +
    dvtotalc + strata(matchExact), data = filter(oop, !is.na(matchExact)),
    method = "efron")

                coef exp(coef) se(coef)    z       p
outofposition 0.14724   1.15863  0.20003 0.74 0.46167
age           0.03116   1.03165  0.01155 2.70 0.00697
heightc       0.01610   1.01623  0.02099 0.77 0.44315
weightc       0.00031   1.00031  0.01094 0.03 0.97740
dvtotalc      0.08984   1.09400  0.02346 3.83 0.00013

Likelihood ratio test=23.2  on 5 df, p=0.000302
n= 899, number of events= 176
   (5 observations deleted due to missingness)
```

Odds ratio confidence intervals:

```
                2.5 %   97.5 %
outofposition 0.7828515 1.714799
age           1.0085627 1.055265
heightc       0.9752621 1.058921
weightc       0.9790831 1.021997
dvtotalc      1.0448240 1.145488
```

Turned occupants

```
Call:
clogit(I(mais >= 2) ~ outofposition + age + heightc + weightc +
    dvtotalc + strata(matchExact), data = filter(oop, !is.na(matchExact) &
    matchExact %in% turnedMatches), method = "efron")

                coef exp(coef) se(coef)     z     p
outofposition -0.0701    0.9323   0.3226 -0.22 0.828
age            0.0142    1.0143   0.0188  0.76 0.449
heightc        0.0185    1.0187   0.0335  0.55 0.582
weightc       -0.0118    0.9883   0.0175 -0.68 0.499
dvtotalc       0.0760    1.0789   0.0391  1.94 0.052

Likelihood ratio test=4.57  on 5 df, p=0.47
n= 407, number of events= 76
   (4 observations deleted due to missingness)
```

Odds ratio confidence intervals:

```
                 2.5 %   97.5 %
outofposition 0.4953960 1.754530
age           0.9776777 1.052275
heightc       0.9538576 1.087844
weightc       0.9550037 1.022686
dvtotalc      0.9993291 1.164871
```

Lying occupants

```
Call:
clogit(I(mais >= 2) ~ outofposition + age + heightc + weightc +
    dvtotalc + strata(matchExact), data = filter(oop, !is.na(matchExact) &
    matchExact %in% lyingMatches), method = "efron")

               coef exp(coef) se(coef)    z      p
outofposition 0.3177    1.3740   0.2645 1.20 0.2296

age           0.0489    1.0501   0.0161 3.04 0.0024
heightc       0.0131    1.0132   0.0280 0.47 0.6406
weightc       0.0100    1.0101   0.0149 0.68 0.4992
dvtotalc      0.0992    1.1043   0.0312 3.18 0.0015

Likelihood ratio test=22.7  on 5 df, p=0.000378
n= 456, number of events= 93
   (1 observation deleted due to missingness)
```

Odds ratio confidence intervals:

```
                 2.5 %   97.5 %
outofposition 0.8182464 2.307315
age           1.0175018 1.083691
heightc       0.9590356 1.070350
weightc       0.9810877 1.039962
dvtotalc      1.0387975 1.173850
```

3.2 MAIS $\geq$ 3

All matched occupants

```
Call:
clogit(I(mais >= 3) ~ outofposition + age + heightc + weightc +
    dvtotalc + strata(matchExact), data = filter(oop, !is.na(matchExact)),
    method = "efron")

                coef exp(coef) se(coef)    z      p
outofposition 0.29479   1.34285  0.26687 1.10 0.2693
age           0.02909   1.02951  0.01686 1.72 0.0846
heightc       0.00518   1.00519  0.02787 0.19 0.8527
weightc       0.00634   1.00636  0.01474 0.43 0.6672
dvtotalc      0.07955   1.08280  0.02925 2.72 0.0065

Likelihood ratio test=12.3  on 5 df, p=0.0312
n= 899, number of events= 86
   (5 observations deleted due to missingness)
```

Odds ratio confidence intervals:

```
                 2.5 %   97.5 %
outofposition 0.7959095 2.265628
age           0.9960406 1.064109
heightc       0.9517516 1.061628
weightc       0.9777050 1.035848
dvtotalc      1.0224625 1.146690
```

Turned occupants

```
Call:
clogit(I(mais >= 3) ~ outofposition + age + heightc + weightc +
    dvtotalc + strata(matchExact), data = filter(oop, !is.na(matchExact) &
    matchExact %in% turnedMatches), method = "efron")

                  coef exp(coef) se(coef)     z    p
outofposition  0.37994   1.46219  0.40840  0.93 0.35
age            0.02794   1.02833  0.02799  1.00 0.32
heightc       -0.00958   0.99047  0.04474 -0.21 0.83
weightc       -0.02812   0.97227  0.02585 -1.09 0.28
dvtotalc       0.08345   1.08703  0.05148  1.62 0.11

Likelihood ratio test=4.05  on 5 df, p=0.542
n= 407, number of events= 36
   (4 observations deleted due to missingness)
```

Odds ratio confidence intervals:

```
                 2.5 %   97.5 %
outofposition 0.6567039 3.255655
age           0.9734462 1.086312
heightc       0.9073164 1.081239
weightc       0.9242284 1.022804
dvtotalc      0.9826956 1.202437
```

Lying occupants

```
Call:
clogit(I(mais >= 3) ~ outofposition + age + heightc + weightc +
    dvtotalc + strata(matchExact), data = filter(oop, !is.na(matchExact) &
    matchExact %in% lyingMatches), method = "efron")

               coef exp(coef) se(coef)    z     p
outofposition 0.3662    1.4422   0.3622 1.01 0.312
age           0.0283    1.0287   0.0224 1.26 0.206
heightc       0.0317    1.0322   0.0377 0.84 0.400
weightc       0.0236    1.0239   0.0189 1.25 0.211
dvtotalc      0.0884    1.0924   0.0395 2.24 0.025

Likelihood ratio test=11.9  on 5 df, p=0.0368
n= 456, number of events= 46
   (1 observation deleted due to missingness)
```

Odds ratio confidence intervals:

```
                 2.5 %   97.5 %
outofposition 0.7091488 2.932924
age           0.9845598 1.074750
heightc       0.9587908 1.111308
weightc       0.9866994 1.062499
dvtotalc      1.0109418 1.180439
```

Appendix F: NASS Study AIS 2+ Injury Distribution

Summary

Due to few OOP subjects, 11 of 16 injury category comparisons produced differences that were not statistically significant. Of the five that did produce significant differences, head, neck, thorax, upper extremity, pelvis, the weighted frequency was lower for OOP subjects.

HEAD

OutOf Position	HEAD INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	45307	23199297	98.6770	0.1335	98.3924	98.9616
0	1	2139	311044	1.3230	0.1335	1.0384	1.6076
1	0	287	119966	99.3948	0.1763	99.0191	99.7705
1	1	18	730.43453	0.6052	0.1763	0.2295	0.9809

FACE

OutOf Position	FACE INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	47018	23456049	99.7691	0.0421	99.6794	99.8588
0	1	428	54293	0.2309	0.0421	0.1412	0.3206
1	0	295	120193	99.5829	0.1914	99.1749	99.9908
1	1	10	503.46133	0.4171	0.1914	0.0092	0.8251

NECK

OutOf Position	NECK INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	Row-Lower CL	RowUpper CL
0	0	47421	23508046	99.9902	0.0037	99.9824	99.9981
0	1	25	2296	0.0098	0.0037	0.0019	0.0176
1	0	305	120697	100.000	0.0000	100.000	100.000
1	1	0	.	.	.	.	.

THORAX

OutOf Position	THORAX INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	Row-Lower CL	RowUpper CL
0	0	45577	23268130	98.9698	0.1043	98.7475	99.1921
0	1	1869	242211	1.0302	0.1043	0.8079	1.2525
1	0	286	120099	99.5050	0.1429	99.2004	99.8095
1	1	19	597.48923	0.4950	0.1429	0.1905	0.7996

ABDOMEN

OutOf Position	AB INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	46697	23448409	99.7366	0.0291	99.6745	99.7987
0	1	749	61933	0.2634	0.0291	0.2013	0.3255
1	0	298	120538	99.8687	0.0566	99.7480	99.9893
1	1	7	158.50268	0.1313	0.0566	0.0107	0.2520

SPINE

OutOf Position	SPINE INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	46511	23400148	99.5313	0.0504	99.4239	99.6387
0	1	935	110193	0.4687	0.0504	0.3613	0.5761
1	0	289	120200	99.5888	0.2121	99.1368	100.000
1	1	16	496.25298	0.4112	0.2121	0.0000	0.8632

C-SPINE

OutOf Position	CSPINE INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	47025	23463356	99.8001	0.0323	99.7312	99.8691
0	1	421	46985	0.1999	0.0323	0.1309	0.2688
1	0	299	120579	99.9026	0.0606	99.7735	100.000
1	1	6	117.58482	0.0974	0.0606	0.0000	0.2265

T-SPINE

OutOf Position	TSPINE INJ2PLUS	Fre-quency	WgtFreq	Row Percent	RowStdErr	RowLow-erCL	RowUp-perCL
0	0	47238	23481892	99.8790	0.0316	99.8117	99.9463
0	1	208	28449	0.1210	0.0316	0.0537	0.1883
1	0	300	120510	99.8450	0.1233	99.5822	100.000
1	1	5	187.13663	0.1550	0.1233	0.0000	0.4178

L-SPINE

OutOf Position	LSPINE INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	47008	23456650	99.7716	0.0431	99.6798	99.8634
0	1	438	53691	0.2284	0.0431	0.1366	0.3202
1	0	298	120483	99.8231	0.0786	99.6555	99.9906
1	1	7	213.54353	0.1769	0.0786	0.0094	0.3445

UPPER EXTREMITY

OutOf Position	UPEX INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	45471	23198687	98.6744	0.1186	98.4215	98.9273
0	1	1975	311654	1.3256	0.1186	1.0727	1.5785
1	0	292	120236	99.6181	0.1707	99.2542	99.9819
1	1	13	460.97314	0.3819	0.1707	0.0181	0.7458

LOWER EXTREMITY

OutOf Position	LOWEX INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	44481	23097233	98.2429	0.1904	97.8370	98.6488
0	1	2965	413109	1.7571	0.1904	1.3512	2.1630
1	0	271	116886	96.8426	1.7357	93.1431	100.000
1	1	34	3811	3.1574	1.7357	0.0000	6.8569

PELVIS

OutOf Position	pelvis	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	46884	23464460	99.8048	0.0154	99.7720	99.8377
0	1	562	45882	0.1952	0.0154	0.1623	0.2280
1	0	303	120638	99.9517	0.0389	99.8688	100.000
1	1	2	58.28000	0.0483	0.0389	0.0000	0.1312

THIGH

OutOf Position	thigh	Frequency	WgtFreq	Row Per-cent	RowStdErr	RowLower CL	RowUpper CL
0	0	46704	23458799	99.7808	0.0205	99.7371	99.8245
0	1	742	51542	0.2192	0.0205	0.1755	0.2629
1	0	292	120181	99.5724	0.2221	99.0989	100.000
1	1	13	516.10356	0.4276	0.2221	0.0000	0.9011

KNEE

OutOf Position	knee	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	46765	23395792	99.5128	0.0797	99.3428	99.6827
0	1	681	114549	0.4872	0.0797	0.3173	0.6572
1	0	300	120238	99.6202	0.3725	98.8262	100.000
1	1	5	458.45600	0.3798	0.3725	0.0000	1.1738

LEG

OutOf Position	leg	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	46685	23432143	99.6674	0.0249	99.6143	99.7205
0	1	761	78199	0.3326	0.0249	0.2795	0.3857
1	0	299	118542	98.2147	1.7683	94.4455	100.000
1	1	6	2155	1.7853	1.7683	0.0000	5.5545

FOOT

OutOf Position	foot	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	46637	23345682	99.2996	0.2331	98.8028	99.7964
0	1	809	164659	0.7004	0.2331	0.2036	1.1972
1	0	299	120409	99.7616	0.0896	99.5705	99.9527
1	1	6	287.75070	0.2384	0.0896	0.0473	0.4295

UNSPECIFIED

OutOf Position	UNSPEC INJ2PLUS	Frequency	WgtFreq	Row Percent	RowStdErr	RowLower CL	RowUpper CL
0	0	47439	23509782	99.9976	0.0013	99.9949	100.000
0	1	7	559.07200	0.0024	0.0013	0.0000	0.0051
1	0	305	120697	100.000	0.0000	100.000	100.000
1	1	0	.	.	.	.	.

DOT HS 812 883
May 2021

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

14612-091520-v3