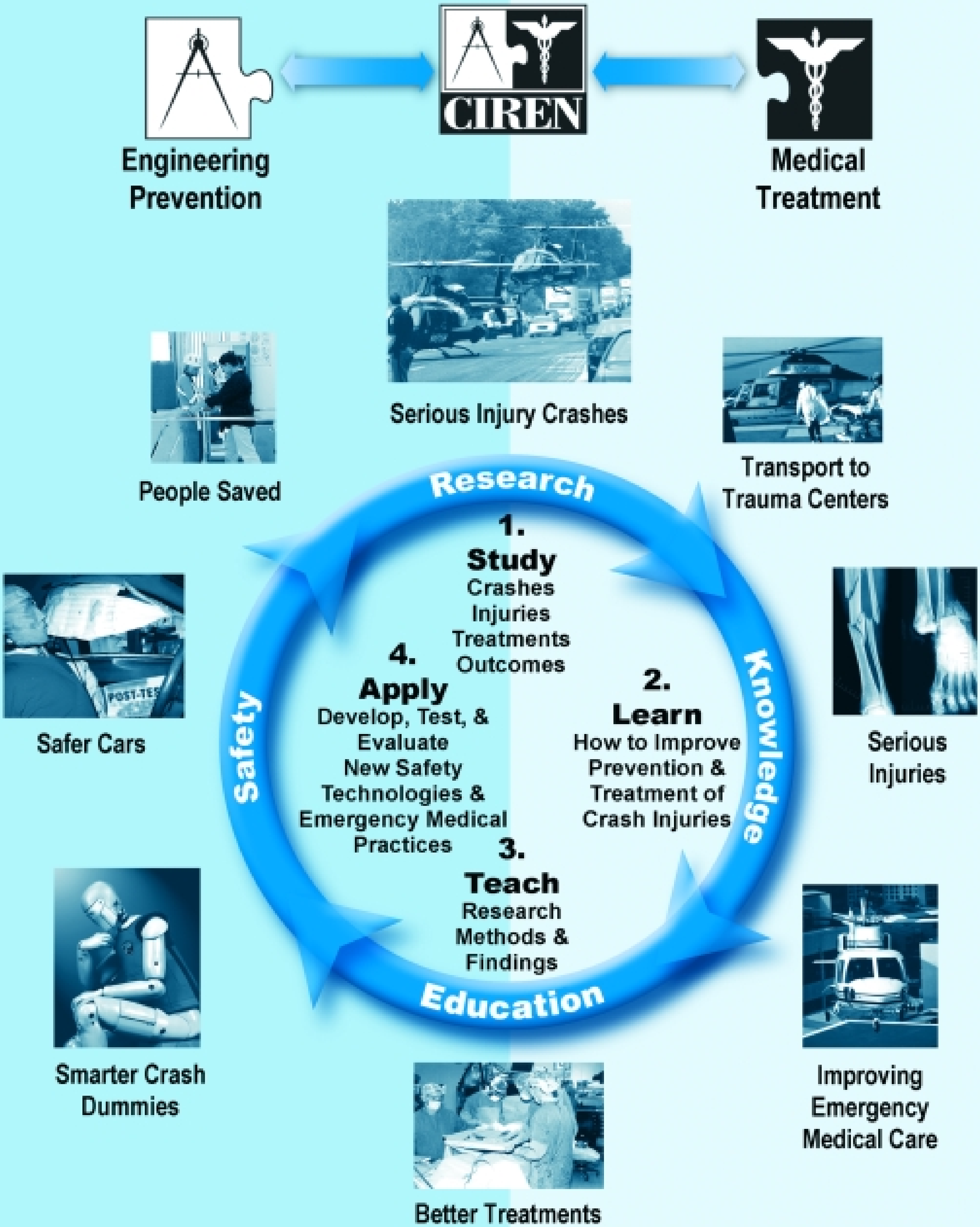
CIREN

Crash Injury Research and Engineering Network

The NHTSA Learning Laboratory for Lifesaving



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16. Abstract

The National Highway Traffic Safety Administration has created the Crash Injury Research and Engineering Research (CIREN) program for the purpose of conducting multidisciplinary research on serious crash injuries. The mission of CIREN is to improve the prevention, treatment, and rehabilitation of motor vehicle crash injuries to reduce deaths, disabilities, and human and economic costs. The goal of NHTSA/CIREN research is to identify opportunities for improvement in the prevention and treatment of crash injuries. This is accomplished through coordinated efforts of medical and engineering researchers. This report provides a description of the NHTSA CIREN Network, each of the 10 CIREN centers, the research teams, and their work. The report summarizes the contributions to auto safety produced by NHTSA CIREN center researchers.

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Table of Contents

CIREN Program Report, 2002

National Highway Traffic Safety Administration (NHTSA)

Introduction

This is the second NHTSA CIREN Program Report. The report provides a description of the research conducted by CIREN center multi-disciplinary research teams. CIREN research teams consist of trauma surgeons, emergency physicians, medical examiners, trauma nurses, epidemiologists, crash investigators, engineers, sociologists and computer data analysts.

The medical members of the team study the injuries, treatments and outcomes. The engineers study the crashes, vehicles, safety equipment, occupant kinematics and injuries. CIREN multidisciplinary research provides NHTSA, the auto safety engineering community, and the medical profession with the ability to jointly study "real-world" cases of serious injuries.

> *The CIREN Mission*
>
> *The mission of the NHTSA Crash Injury Research and Engineering Network (CIREN) is to improve the prevention, treatment, and rehabilitation of motor vehicle crash injuries to reduce deaths, disabilities, and human and economic costs.*

The individual centers have been operating for varying periods of time. While some current CIREN centers were performing hospital crash injury studies prior to the formation of CIREN, others have been established more recently.

CIREN researchers are key contributors to the Agency's study of the medical and engineering aspects of serious crash injuries. CIREN "hands on" studies of crashes, injuries, treatments, and outcomes examine better ways to prevent and treat serious crash injuries. CIREN provides the safety community with a high-powered scientific "microscope" for the study of these crash injuries in the real world, and in near real time—in part, through regular public meetings.

NHTSA's CIREN program works to increase the discovery, development, and delivery of improvements in the prevention and treatment of serious crash injuries.

The Safety Problem: Deaths, Disabilities, and Human & Economic Costs

The magnitude of the safety problem that the CIREN program addresses is summarized in national crash statistics. Every year there are nearly 42,000 crash deaths (almost half of the victims die without transport to a medical treatment facility) [1], 250,000 life-threatening injuries [2], 500,000 hospitalized [3], 2,000,000 disabled by injuries [4], and 4,000,000 emergency department visits [5]. Annually in America, motorists are involved in nearly 17 million crashes involving nearly 28 million vehicles [6]. Each year crash injuries result in approximately $145 billion in economic costs, or $340 billion in comprehensive costs that include value for pain and suffering [7]. These figures do not include costs of crashes due to property damage and traffic delay.

Since the advent of the automobile, more than 3 million people have been killed and 300 million injured in vehicle highway crashes in America – more than 3 times the number of Americans killed, and 200 times the number wounded, in all wars since 1776 [8].

If the current rate continues, NHTSA has projected that the current toll of 42,000 crash deaths each year could increase by 50 percent by 2020. [3]

Many of the people killed in crashes are young. Half are under age 34, and the average is 40 years of age for all crash deaths [1]. As the U.S. population ages, the average age of crash deaths is also increasing. The population of Americans over age 65 will increase from 34 million to 53 million by 2020 [3]. Crash fatalities and serious injuries have devastating physical and financial impacts on families. Many children, uninjured physically in crashes, are hurt in other ways such as loss of one or both parents, grandparents, siblings, or other loved ones. No count of this tragic toll on children is kept, but serious crash injuries often result in long-term physiological, psychological, and sociological consequences. Crash deaths and disabilities often have devastating impacts on individuals, families, and society.

Motor vehicle crashes cause large numbers of life-threatening and disabling injuries. National estimates for the number of serious crash injuries occurring each year during the 1995–97 period [9] are given below:

- 70,000 Brain Injuries
- 4,400 Neck and Spinal Cord Injuries
- 80,000 Chest & Abdominal Injuries: Heart, Lungs, Spleen, Liver, & Kidneys

- 18,000 Hip and Pelvic Injuries
- 35,000 Leg, Ankle and Foot Injuries

The above statistics are for serious injuries based on data from light vehicle towaway crashes and do not include a much larger number of less serious injuries occurring each year. Nor do these statistics include injuries to pedestrians, motorcyclists, and heavy truck occupants, for which statistics on serious injuries are not available in the NASS database.

The $145 billion in economic costs for crash injuries incurred each year is comparable with the $172 billion in costs for cancer and the $350 billion in costs for heart disease. The annual federal budget for highway safety research however is $205 million, compared to $5 billion for cancer research and $2 billion for heart disease research. [7, 18–21]

> *"Science begets knowledge."*
>
> Hippocrates, 460-377 BC

The CIREN Program: Research to Reduce Fatal and Serious Injuries in Crashes

The NHTSA CIREN Program focuses medical and engineering research on finding ways to reduce crash deaths and critical injuries that have life altering consequences. CIREN researchers are working to improve both the prevention and treatment of crash injuries. Through CIREN research, NHTSA is examining questions of life and death importance for many Americans such as:

- Why do 20,000 people, nearly half of all crash fatalities, die each year without being taken to a medical treatment facility?
- How can we do a better job of getting seriously injured people the correct level of medical care they need – in time to prevent deaths and disabilities?
- What information will help the emergency medical system work "faster and smarter" in providing optimal care and delivering seriously injured crash victims to trauma centers?
- How do we learn to better evaluate crash data to improve patient outcomes?
- How can new safety and communications technologies be used to improve triage, transport, and treatment decisions?
- How do we develop new medical protocols to assure widespread deployment for improved triage, transport, and treatment of seriously injured crash victims?
- How do we educate and train the emergency medical care community to apply the latest lifesaving techniques for improved care of seriously injured crash victims?
- As air bags, belts and child seats save more lives each year, what are the residual injuries and their consequences?
- How, and to what extent, are new safety technologies working to save lives and reduce disabilities?
- To what extent can we reduce lifetimes of suffering from brain and spinal cord injuries through improvements in prevention and treatment?
- What biomechanics research can be done to prevent potentially fatal thoracic, and hip injuries?
- What can be done to prevent leg, ankle, and foot injuries and their resulting disabilities?
- How do we improve detection and treatment of traumatic brain injuries when diagnostic imaging studies often reveal negative clinical findings for lesions, but adverse behavioral consequences later become manifest?

CIREN Research – Serious, or compelling, injuries are characterized by their severity, i.e., requiring urgent or specialized critical care to prevent death and disability. In their work investigating serious crashes, injuries, treatments, and outcomes, CIREN researchers are producing a growing body of data and scientific research. Over the past decade, the CIREN Centers have published more than 100 scientific research papers in national and international medical and engineering journals. [10]

> *"Injury is not an insoluble problem. Exciting opportunities to understand and prevent injuries and reduce their effects are available."*
>
> Injury in America*, 1985*

The CIREN Program, through 2002, now has a database of 1,752 cases of people involved in serious injury crashes. Among these are 1,180 cases of people suffering serious injuries, and 218 cases where the vehicle occupant ultimately died with the balance of the cases involving injuries of lesser severity.

CIREN Study Criteria – CIREN cases involve people so severely injured in motor vehicle crashes that they must be transported to a Level 1 trauma center. Case selection criteria are listed in Table 1.

Inclusion criteria also permit addition of any case of special interest. Beginning in 2003, more rollover crashes will be included as the two quarter turns limit will be removed.

The CIREN study case inclusion criteria were formulated to enable medical and safety engineering researchers to focus on the injuries that are most threatening to people's lives. Currently, case selection is restricted to restrained (air bag and/or belts) occupants.

Table 1. CIREN Case Inclusion Criteria for 2002

Crash Type	Crash Direction	Vehicle Year	Restraint Used	Occupant	Occupant Position	AIS Severity
Frontal	10 to 2 o'clock PDOF full or offset	LMY	AB, B, AB+B, CRS	Child/ Infant	Front	AIS>=1
					Rear	AIS >=2
				Adult	Front	AIS>=3*
Side, Near	8 to 10 2 to 4	1993 or later	Any and all	Child/infant	Any	AIS>=2
				Adult		AIS>=3*
Rear	4 to 8	1985 or later	rear-facing CRS	Infant only	Any	AIS>=2
Rollover	<= two quarter turns	LMY	AB,B, AB + B, CRS	All	Any	AIS>=2
Fire	All	LMY	N/A	All	Any	AIS>=2
All	All	All	CRS 1990 or later	Child/infant	Any	Any

Legend:
A: Airbag
B: Seat Belt
CRS: Child Restraint Seat
LMY: Late Model Year (the current year less 6)
PDOF: Principal Direction of Force

*or 2 or more AIS>=2 and of medical significance, or one or more AIS>=2 disabling injuries to the ankle or foot.

Abbreviated Injury Scale (AIS) is used to classify injuries generally according to their degree of severity based on threat-to-life. The AIS classification scale is as follows:
AIS 1 - Minor AIS 2 - Moderate AIS 3 - Serious AIS 4 - Severe AIS 5 - Critical AIS 6 - Maximum

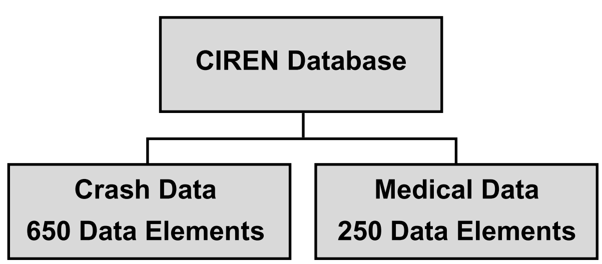
CIREN Data – The CIREN database consists of the NASS CDS set of 650 data elements plus an additional 250 medical and injury data elements. The NASS CDS data set contains variables that describe an automotive crash such as:

- Crash Type
- Vehicle Make, Models, and Body Types
- Collision deformation classification (CDC)
- Crush Profiles
- Delta Vs
- Intrusions
- Occupant Contacts

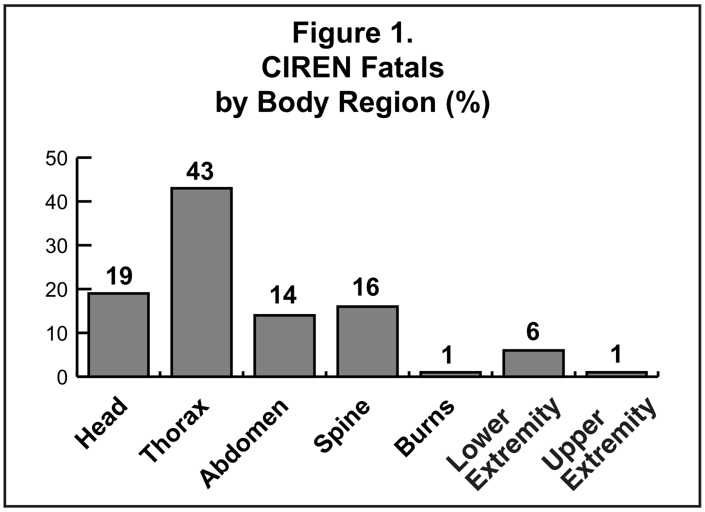
The CIREN medical and injury data elements include tables for:

- Co-morbidity
- Diagnostic Procedures
- Complications
- Operative Procedures
- Medical Images
- Disability Measurements
- Emergency Medical Response
- Emergency Medical Treatment
- Vital Signs
- Physiologic Measurements
- Injury Location
- Ventilation Periods
- Intensive Care Unit Stays

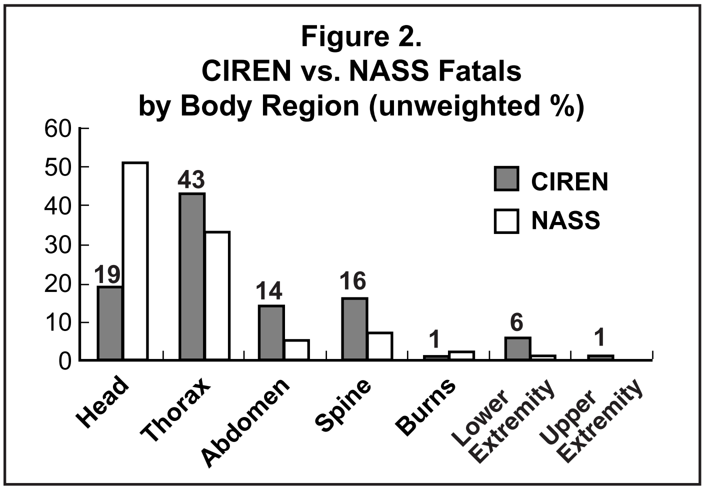
CIREN Database Structure



CIREN Cases – CIREN researchers now have detailed data on 218 people who ultimately expired from their injuries in crashes compiled from 1996–2002. Figure 1 shows the distribution of fatalities in CIREN by the body region where the most serious injury was located. Injuries to the thorax, head, spine, and abdomen were the leading primary causes of death in fatal CIREN cases.



CIREN and NASS – Figure 2 shows how the distribution of CIREN fatal cases by body region currently compare with the distribution of all fatalities in NASS. The proportionally fewer fatalities associated with head injuries in CIREN, in part, is due to the effects of CIREN case selection criteria differing from NASS. Specifically: (a) CIREN cases are limited to restrained occupants protected by air bag and/or belts, (b) in late model year vehicles with the latest safety features, and (c) crash victims have access to the highest quality emergency medical care at CIREN facilities which are Level 1 Trauma Centers. In contrast, NASS cases are statistically representative of all occupants (both restrained and unrestrained), in all model year vehicles.



The CIREN Centers have conducted research on more than 1,000 life-threatening injuries that did not result in fatality, but are significant in the level of threat to life and/or long-term consequences.

These serious injury studies provide insights on potential improvements in prevention and treatment. Figure 3 shows the distribution, by body region, of compelling injuries in the CIREN database. The distribution shows that these compelling injuries in crashes are occurring primarily to the head, thorax, and lower extremities.

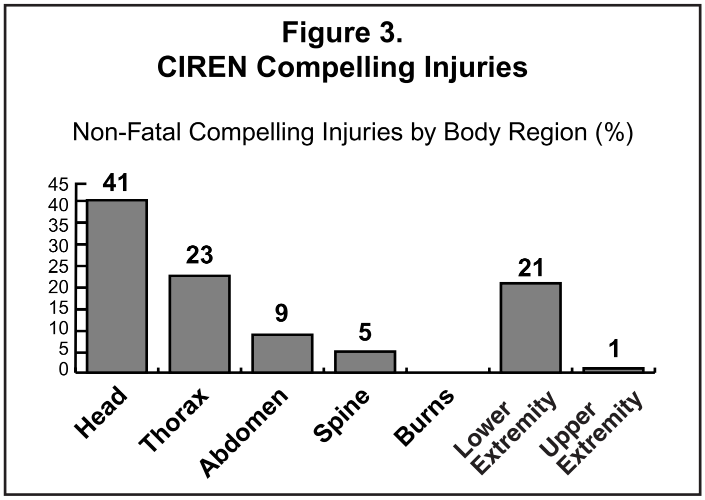
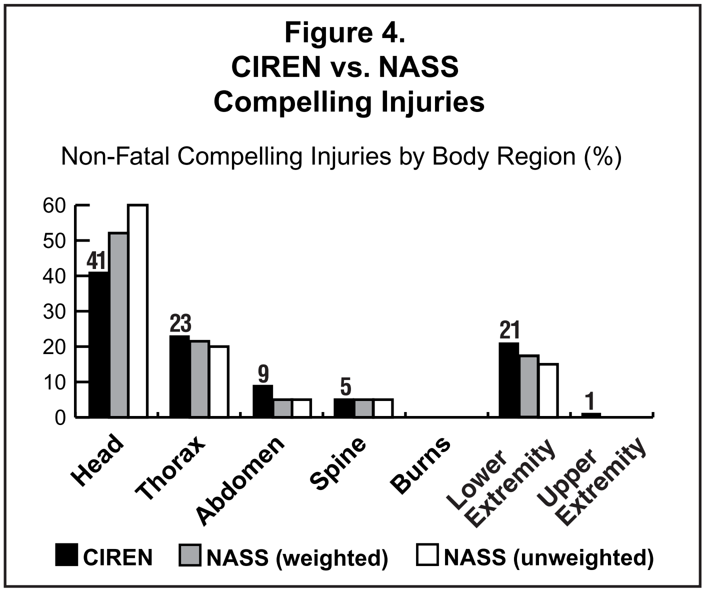


Figure 4 shows that the distribution of non-fatal compelling injuries treated at CIREN Centers is closely tracking the non-fatal compelling injuries being found in NASS. Thus CIREN is studying precisely the types of serious crash injuries that are occurring nationally – and doing so, in near real-time as the injuries are being treated. This illustrates how CIREN complements NASS.



CIREN is not a nationally representative sample of all crash injuries. It is designed to be a high powered tool for conducting research on serious injuries. CIREN is used to both generate and examine hypotheses through detailed studies of serious crashes, injuries, treatments, and outcomes.

CIREN is a complementary tool to NASS. NASS provides estimates of the broad national incidence of all crash injuries.

Thus, for example, CIREN may have more crashes of a particular crash type than would be obtained under case selection criteria designed to create a nationally representative sample of all crash injuries. The CIREN case selection process has the strength of being able to detect — early on — new serious injury patterns, and studying them in great detail.

CIREN studies injuries to people who have suffered a wide variety of injuries ranging in severity from moderately life-threatening to fatal. NHTSA estimates that out of a total 5,300,000 people injured each year in crashes, about 650,000 people suffer moderately life-threatening to fatal injuries each year. More than 95 percent of the injured people in CIREN cases suffered such serious injuries. The injuries specifically studied by CIREN represent 12 percent of all crash injuries, but because of their seriousness, result in about 77 percent of the total economic costs of crash injuries. These serious injuries, being studied by the NHTSA CIREN research program, nationally incur about $112 billion in economic costs each year.

The work process employed by CIREN researchers has involved the following steps:

1. Observations of potential injury patterns at the CIREN center
2. Examination of NASS files to develop estimates of national incidence
3. Recommendation of potential next steps in continuous improvement cycles that have improved:
   a. data collection, storage, and analysis e.g., crash investigation, data elements, and software
   b. test equipment such as crash test dummies e.g., load measurement capabilities in the THOR dummy for acetabular and abdominal injuries
   c. biomechanical injury criteria and test configurations, e.g., for knee, thigh, and hip injuries
   d. standards for the protection of lower extremity injuries e.g., THOR Lx
   e. air bags with features to lower deployment injury incidence
   f. EMS triage, transport, and treatment decision-making capabilities with URGENCY software to help distinguish the one crash with high probability of serious injuries from the 100 crashes without serious injury.

The ten CIREN Centers bring to the nation the benefits of a broad geographic distribution of serious crash injury problems relating to vehicles, environmental conditions, roadways, driver behaviors, and medical practices. The CIREN researchers, some of the nation's foremost traumatologists from a variety of specialties, bring a wide diversity of injury experience and medical and engineering expertise. They apply their rich multidisciplinary expertise to the many serious crash injuries they treat in their facilities and share their knowledge with NHTSA and the wider safety community. This combination of major medical facilities and researchers provides NHTSA and the safety community with a powerful microscope for the study of the prevention and treatment of serious crash injuries.

CIREN Research Progress

CIREN researchers continue to study the safety benefits of occupant restraint systems (air bags, seat belts, and their combination). New vehicles are increasingly being equipped with safety features such as: air bags with multi-stage deployment capabilities; safety belts with crash tensioning retractors, adjustable anchorage points; and belt force limiters. Because CIREN researchers study serious injury crashes, the vehicles, the resulting injuries, treatments, and outcomes; they are able to document both safety technology successes as well as needed improvements in prevention and treatment.

CIREN research is leading to improved understanding of the changing patterns of serious crash injuries. This research is leading to recognition of successful safety technologies and opportunities to improve both the engineering of safer vehicles and the medical treatment of seriously injured crash victims.

CIREN research is showing the benefits of:

Improving Safety Research:

Over the years, through both papers and presentations, CIREN researchers have brought to the safety community's attention the need for greater attention to several important aspects of improving the prevention and treatment of injuries:

- The importance of long-term consequences and costs of serious injuries such as brain and spinal cord injuries on individuals, families, and society. [Siegel, Augenstein, Burgess, Cushing, et al.]
- The significance of lower extremity injuries that may have a low threat-to life but high costs and life-long consequences for quality of life in pain and suffering. [Siegel, Augenstein, Burgess, Cushing, et al.]
- The many particular problems that occupant age, gender and habitus (young and old) present biomechanically and medically to reducing deaths and disabilities from crash injuries. [All Centers]
- The need for improvement in measures of injury burdens beyond AIS threat to life scales and economic costs. [Burgess, Siegel, et al.]
- The value of long-term follow-up outcome studies. [Siegel, Burgess, Cushing, Dischinger, Read, et al.]

Improving Auto Safety:

- Air bags reducing the incidence and severity of brain injuries [Siegel, et al.]
- New air bag designs reducing aggressive deployments [Augenstein, et al.]
- 3-point belts in rear seats to better protect children and adults from lethal abdominal injuries and crippling spinal cord injuries [Eichelberger, et al.]
- Safer child seats and their proper installation and use [Eichelberger, et al.]
- Safer vehicle structures to protect people from leg and hip injuries in frontal offset crashes [Burgess, et al.]
- Safer air bags and belts designed to protect older people in frontal impact crashes [Augenstein, et al.]
- Safer vehicle structures and side air bags designed to protect the head, thorax, and pelvis in side impact crashes [Mock, et al.]

> *"Serious crashes happen every day, more than half of them in rural areas where the ability to rapidly contact 9-1-1 and the capability of responders to quickly reach the scene can mean the difference between life and death. New technologies such as wireless E9-1-1, automatic collision notification and emergency vehicle route navigation are available that will make emergency access more reliable and help deliver faster and better emergency care."*
>
> NHTSA Administrator Jeffrey W. Runge, MD

Improving Emergency Medical Care:

- Saving lives by faster and more accurate diagnoses and treatments of crash injured occupants [All CIREN Centers]
- Improving diagnostic tools to recognize occult, or hidden, internal injuries – especially for vehicle occupants who are older, female, of short stature, or large girth
- Educating police, fire, and EMS care providers to recognize crash victims that demand a higher index of suspicion for internal injuries and transport to a trauma center for treatment
- Designing, developing, and validating URGENCY software for faster and smarter emergency medical care for crash victims
- Improving Automatic Crash Notification (ACN) systems for better decisions in triage, transport, and treatment of crash victims
- Improving communications and organization of trauma systems for better care of crash victims

The work of CIREN researchers has contributed to some recent noteworthy steps toward a Safer America:

- The American College of Emergency Physicians has adopted the following language based, in part, on CIREN research: "The American College of Emergency Physicians (ACEP) supports the development and implementation of programs, policies, legislation, and regulations that promote the use of automatic crash notification (ACN) and intelligent transportation systems (ITS) technologies." [12]
- General Motors Corporation announced on July 31, 2002, that it would offer an Advanced Automatic Crash Notification system on about 400,000 vehicles in 2003 and more in subsequent years. [13] CIREN researcher Dr. Jeffrey Augenstein, who has contributed to the development of Advanced ACN, was quoted praising this GM decision "This is an extraordinarily significant decision for emergency medicine…It is a breakthrough that will eventually save thousands of lives a year."
- Ford Motor Company announced on August 3, 2002 it installed enhanced Automatic Crash Notification (ACN) technology in a test fleet of 500 police cars in the Houston area. [14] This is the first deployment of enhanced ACN technology by a major motor vehicle manufacturer. Ford is testing technology that was developed, using CIREN research. The Ford announcement quoted CIREN researcher Dr. Stewart Wang "Delays in medical treatment are directly associated with higher fatality rates and worse outcomes from serious injuries in crashes…This post-crash technology can be especially effective in two cases – rural areas, where a crash is not always quickly seen by passersby and response times are often greater than 1 hour, and urban areas during off-peak driving times."

Promising Prospects – Researchers at Johns Hopkins University (JHU)Applied Physics Laboratory have conducted an independent evaluation of ACN for NHTSA and reviewed CIREN research on the subject [Augenstein, Cushing, Siegel et al.]. Recently NHTSA published the JHU report that estimated the medical benefits "the ACN system could offer an approximate 20% reduction in fatalities from motor vehicle collisions." [15]

Figure 5 shows that in more than 10 percent of all the fatal crashes in 2001, it took more than 45 minutes to get 4,013 crash victims to a medical treatment facility, not necessarily a trauma center, that could properly treat potentially fatal injuries. Note that these figures are based only on the 24 percent of all fatalities where times from crash to hospital arrival are reported. Therefore, these figures tend to understate the magnitude of the national problem of getting seriously injured crash victims into operating rooms for definitive medical care within the "Golden Hour." CIREN data show that, among the Nation's leading trauma centers, in cases of fatal and potentially serious injuries 1 out of every 4 cases received the benefit of air medical services.

Figure 5.
Fatal Crashes by EMS Times from Crash to Hospital Arrival, FARS 2001

Minutes	Fatal Crashes
≤45 Minutes	5,099
>45 Minutes	*4,013*
*Unknowns & Dead at Scene	28,683
Totals	**37,795**

*Includes 23,005 fatalities not taken to a medical treatment facility

CIREN Centers are researching the life-saving potential of improving emergency medical care. The Maryland CIREN Center, for example, has the longest history of leading emergency medical research and education of emergency care providers.

CIREN center researchers [Augenstein, Cushing, Siegel, et al.], the NHTSA, the automotive industry, the wireless communications industry, and emergency medical care providers are continuing to work together to develop, test, and evaluate advanced Automatic Crash Notification (ACN) technologies and URGENCY software to improve emergency rescue of people in serious injury crashes. [22]

Currently a seriously injured person must wait for a series of time critical steps before receiving optimal medical care:

- Wait for their crash to be noticed,
- Wait until they can be properly located (often difficult along rural roadways),
- Wait for the crash to be reported (often difficult if there is no cell phone available and passersby must travel to a landline phone),
- Wait for police or EMS personnel to travel over land to the crash site,
- Wait for EMS to make a medical assessment and then either take them to a local medical facility or call and wait for an air medical rescue team to warm up the helicopter (about 5 minutes), launch, fly to the crash scene, and find an appropriate landing site,
- Wait for transport to a Level 1 Trauma Center,
- Wait for appropriate tests and diagnoses to receive optimal medical treatment.

CIREN center researchers [Augenstein, Cushing, Siegel, et al.] have been addressing the problems involved in improving the effectiveness and efficiency of triage, transport, and treatment decision-making for crash victims. Figure 6 shows that the time between crash and arrival of emergency medical care is critical to whether or not a seriously injured crash victim is taken to a medical treatment facility for care. The chance of dying at the crash site grows rapidly as time passes waiting for emergency rescue.

In the future, information transmitted, instantly and automatically, from the scene of the crash is expected to enable faster and smarter emergency rescue decision-making. Timely and valuable information will improve treatment and reduce medical errors in the delivery of pre-hospital and hospital emergency care for life and death decisions:

- **What is the URGENCY level of this crash?**
  – Low Probability (0-10%) of Serious Injury?
  – Moderate Probability (11-49%) of Serious Injury?
  – High (50+%) Probability of Serious Injury?
- **What rescue resources need to be dispatched?**
  – Ambulance (Basic or Advanced Life Support Teams)?
  – Extrication teams and equipment?
  – Helicopter?
  – Trauma team activation?
- **Where should injured people be taken for medical care?**
  – Rural Clinic?
  – Closest Hospital?
  – Trauma Center?

Figure 6.
Percent Fatalities: Taken vs. Not Taken by Time Between Crash and EMS Arrival at Scene (All Roads)

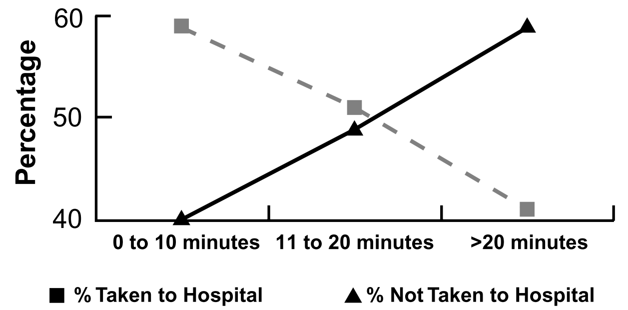
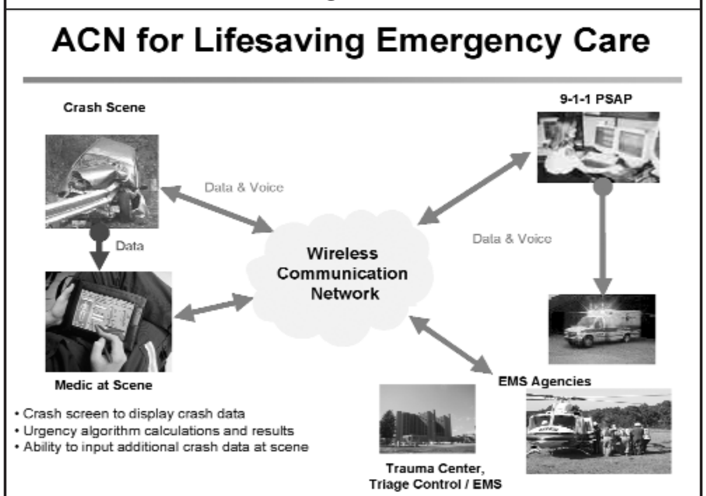


Figure 7

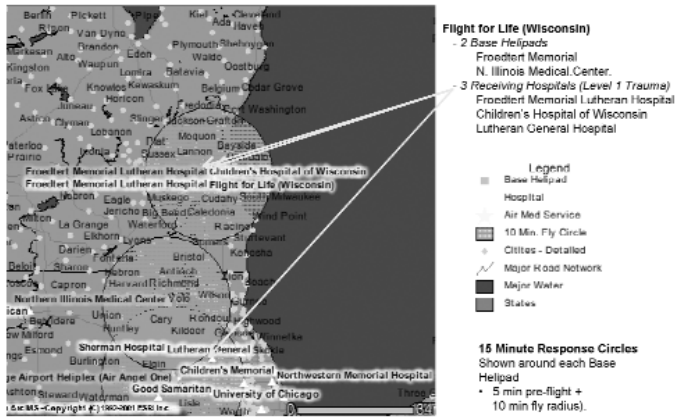


Following and building upon CIREN research, researchers at the Center for Transportation Injury Research (CenTIR) are working with CIREN Center researchers, and the Association of Air Medical Services (AAMS) to develop software to improve emergency dispatch of helicopter rescue teams for people involved in serious injury crashes. [Augenstein, Siegel, Rue, et al.] Dispatch decisions in the future will have the benefit of information from ACN URGENCY and SCENE URGENCY software packages to more effectively and efficiently respond to emergencies. [16] Figure 8 below illustrates this work with respect to the area around the Wisconsin CIREN Center. This work is being performed for use with all air medical services in the nation (see Figure 9).

Seriously injured crash victims will benefit from ACN and URGENCY software being developed in CIREN to expedite and improve emergency medical care:

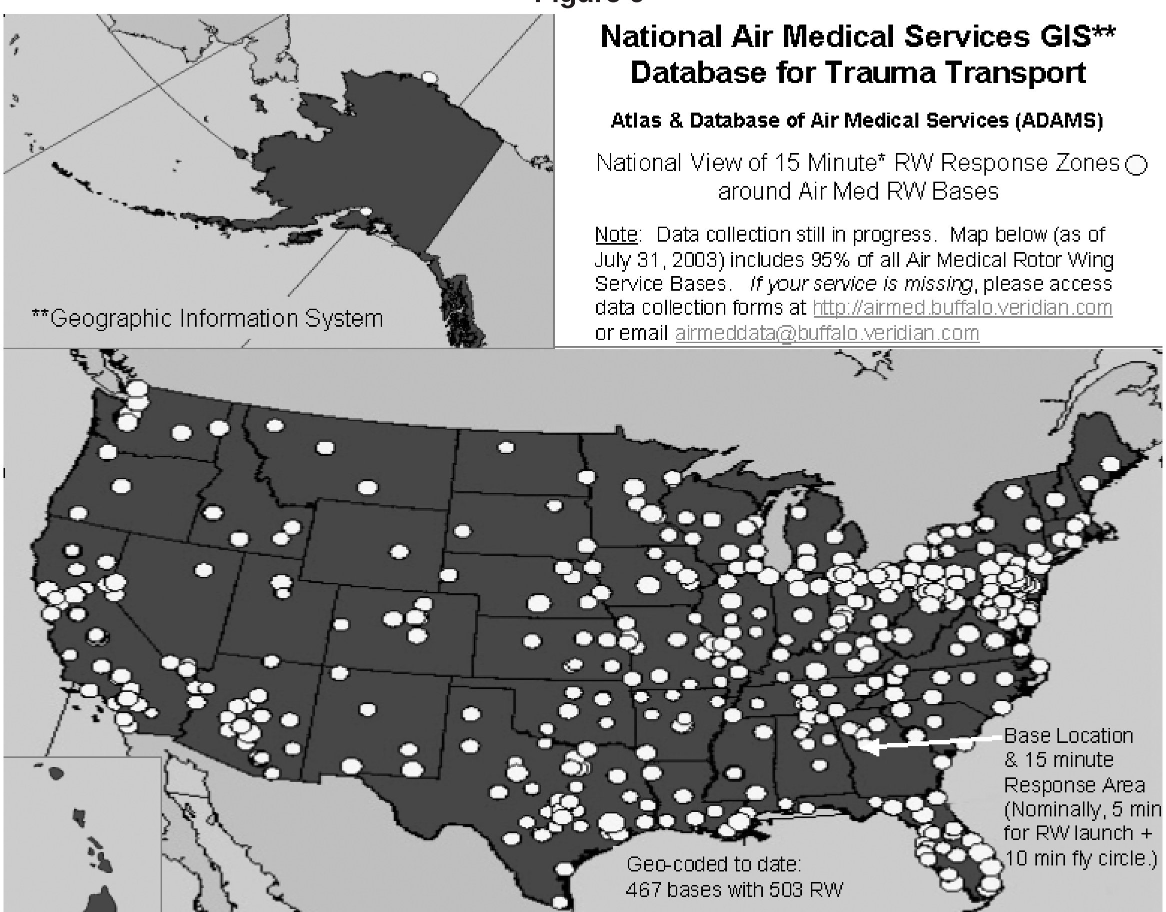
- Instant and automatic wireless transmission of life-saving information on the occurrence, location, and severity of their crash will be communicated to the appropriate rescue authorities.
- EMS will be able to immediately send the most advanced rescue teams for fastest transport and optimal care.
- Trauma teams of emergency physicians, nurses, neurosurgeons, thoracic and orthopedic surgeons will be simultaneously alerted at the Trauma Center. With timely and pertinent point-of-care information the trauma teams will be able to better prepare to deliver optimal care for incoming patients.

Figure 8



Receiving Hospitals (White) are also displayed.

Figure 9



CIREN Center researchers [Augenstein, Siegel, Rue, et al.] are working to update, refine, test and validate URGENCY software. In the future, CIREN research will lead to faster and smarter emergency medical responses to crash victims. CIREN research will help trauma care systems to anticipate injuries based on transmitted crash information, and to find better ways of treatment and rehabilitation of serious crash injuries through continuous performance improvement programs.

To summarize, CIREN is working to fulfill its promise as noted in the National Academy of Sciences (NAS) report, *Reducing the Burden of Injury:*

"CIREN links trauma center clinicians and crash investigators in a nationwide computerized network. This enables engineers to better understand injury-producing mechanisms and to develop better criteria for vehicle safety design, while informing clinicians about emerging injury patterns, and thereby facilitating triage, diagnosis, and treatment of crash injuries." [17]

The nation's investment in the CIREN multi-center research program is producing advances in scientific understanding that are being applied to develop safety technologies, safer products, and improved delivery of emergency care. The result will be a safer future for motorists on America's roads.

References:

1. NHTSA, Fatality Analysis Reporting System, www-fars.nhtsa.dot.gov
2. NHTSA, National Automotive Sampling System, www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/nass.html
3. NHTSA, NHTSA 2020 Report, DOT HS 808 665, September 1997, p. 1-4.
4. National Safety Council, Injury Facts, 2001, p. 2.
5. National Safety Council, Injury Facts, 2001, p. 28.
6. NHTSA, The Economic Impact of Motor Vehicle Crashes, 2000, p. 9.
7. NHTSA, The Economic Impact of Motor Vehicle Crashes, 2000, p. 8, 62.
8. National Safety Council, Accident Facts 1994, p. 70.
9. NHTSA, National Automotive Sampling System, Crashworthiness Data System, 1995–1997, DOT HS 809 203, 2001.
10. Bibliography of CIREN research available at: http://www-nrd.nhtsa.dot.gov/departments/nrd-50/ciren/CIRENpubs.html
11. Sampalis JS, Boukas S, Nikolis A, Lavoie A, "Preventable Death Classification: Interrater Reliability and Comparison with ISS-Based Survival Probability Estimates," Accident Analysis and Prevention, Vol. 27, No. 2, 1995, pp. 199-206.
12. American College of Emergency Physicians, "Automatic Crash Notification and Intelligent Transportation Systems," ACEP Policy Statements, Approved February 2002, available at http://www.acep.org/1,5069,0.html, accessed 12/9/02.
13. GM, "GM Advanced Automatic Crash Notification Announcement," Press Release July 31, 2002, available at http://www.gm.com/company/gmability/safety/news_issues/releases/onstar_072902_lang.html, accessed 12/09/02
14. Greater Harris County 9-1-1 Emergency Network, "Ford Telematics Delivers Crash Information in Less Than 60 Seconds." Press Release Houston, Texas, August 28, 2002, available at http://www.911.org/news/release13.asp, accessed 12/09/02
15. Bachman LR, Preziotti GR, "Automated Collision Notification (ACN) Field Operational Test (FOT) Evaluation Report," National Highway Traffic Safety Administration, US DOT HS 809 304, February 2001, pp. 6-7.
16. Blatt A, Flanigan M, Association of Air Medical Services (AAMS), description of project available at http://www.aams.org/GISdatabase.htm
17. Committee on Injury Prevention and Control, Institute of Medicine, National Academy of Sciences, Reducing the Burden of Injury, Advancing Prevention and Treatment, Washington, DC, 1999, pp. 1-17, 32]
18. National Cancer Institute, "Plans and Priorities for Cancer Research," available at www.plan.cancer.gov/budget/2004.htm
19. American Cancer Society, "Cancer Facts and Figures, 2003," available at www.cancer.org/downloads/STT/CAFF2003 PWsecured.pdf, p. 3.
20. Department of Health and Human Services, NIH, National Heart, Lung, and Blood Institute, "FY 2004 Budget Justification," available at www.nhlbi.nih.gov/funding/fromdir/cong/cj.htm
21. American Heart Association, "Heart Disease and Stroke Statistics – 2003 Update," available at www.americanheart.org/downloadable/heart/104612078 52142003HDSStatsBook.pdf, p. 40.
22. Champion HR, Augenstein JS, Blatt AJ, Cushing B, Digges KH, Hunt RC, Lombardo LV, Siegel JH, "Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Vehicles in Crashes to EMS," *Proceedings, 18th International Technical Conference on the Enhanced Safety of Vehicles*, May 2003, DOT HS 809 543, available at www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv18/cd/files/18esv-000406.pdf

The following chapters were prepared by researchers at the CIREN Centers. The opinions, findings and conclusions expressed are those of the author(s) and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration.

Children's National Medical Center

A Pediatric CIREN Center

CIREN Program Report

Children's National Medical Center (CNMC) is one of the frontline advanced scientific resources for understanding the significance and consequences of serious motor vehicle crash injuries in children. CNMC has been participating in government-funded crash reconstruction research since 1991. The detailed study of 286 children involved in motor vehicle crashes has resulted in the prevention, and the detection, diagnosis, and treatment of serious injuries. The following chapter outlines our research including past successes and future goals.

The Value of CIREN Research – Improving Diagnosis and Treatment of Children Injured in Crashes

Management of the injured pediatric crash victim requires immediate stabilization of the airway and restoration of circulation, followed by specific interventions directed at life-threatening injuries. However, the proper diagnosis of internal injuries despite a focused, accurate history, thorough physical exam, and excellent clinical judgment is extremely difficult even for the most experienced physicians.

Given the unique anatomy and physiology of children, diagnosis of injury is a challenge. Children have efficient compensatory mechanisms for volume loss; consequently, initial vital signs may be within normal limits though blood loss is present from internal injury. In addition, the decision to obtain radiographs is often based on external evidence of trauma, but internal injuries in children frequently occur without such external evidence. Moreover, abnormalities are not always evident on initial radiographs and findings may be non-specific because interpretation of radiographs is complicated by a large number of anatomical and physiological variations normal to child development.

Significant morbidity and mortality occurs in young children who are victims of crash-related injury, because the indications of internal injury in the pediatric patient are often so subtle that diagnosis is delayed, or worse yet, missed completely. For example, determination of the stability of the cervical spine in children can be particularly problematic; pre-vertebral soft tissues often mimic edema on radiographs, incompletely ossified vertebral bodies of the cervical spine result in anterior wedging mimicking C2-C3 compression fractures, and ligamentous laxity results in a widened predental space. Similarly, detection of intra-abdominal injury is complicated by the limitations of plain radiographic evaluation and by a paucity of specific findings. Diagnosis of thoracic injury is also difficult because immature skeletal structures have greater compliance, and, unlike adults, significant abdominal and pelvic visceral injuries in children usually occur in the absence of fractures.

CNMC has been recognized throughout the country as a premier level 1 pediatric trauma center. How did we establish this reputation? How are our physicians able to detect occult injuries so quickly? Why do we search diligently for internal injury based solely on mild-to-moderate localized tenderness during palpation or percussion? What prompts our surgeons to obtain an abdominal computed tomography (CT) scan on a hemodynamically stable child with normal initial radiographs and an unremarkable physical examination ultimately resulting in the identification of a life-threatening bowel injury? In other institutions, abdominal CT scans play a pivotal role in triaging and managing pediatric trauma victims with suspected intra-abdominal injury. Why do our radiologists often encourage exploratory laparotomy when abdominal CT scans reveal subtle and non-specific findings such as trace amounts of peritoneal fluid, or the smallest amount of mucosal edema? What pieces of information increase our index of suspicion for injury? We know that it is not feasible to perform plain radiographs, flexion/extension radiographs, CT scans, or

MRI images on every child involved in a motor vehicle crash. So why is it that we perform seemingly unnecessary procedures on children and "just happen" to find serious injuries requiring treatment?

The common answer to all these questions is that our institution has an integrated, multi-disciplinary approach to the study of crash-related injury in children – CIREN. This research has helped us do a better job of diagnosing and treating injuries in the pediatric crash victim. In general, diagnostic and treatment procedures are performed based solely on clinical indications of injury. And if those clinical indications fail to exist, a conservative "wait and watch" approach often is the only treatment method implemented. Few physicians understand the importance of elucidating the specific mechanism of injury and most fail to obtain valuable pre-hospital predictors of injury such as type of restraint used (automatic shoulder belt only, lap belt only, forward-facing car seat) and direction of impact (frontal, side, rear). The CIREN research conducted at our institution over the past 10 years has resulted in dramatic improvements in our approach to caring for the pediatric trauma patient. When combined with clinical and physical signs and symptoms, elucidation of the mechanism of injury provides our clinicians with a compass in the search for occult injuries. CIREN research allows us to go beyond standard practices to do a better job saving the lives of children. More importantly, the CIREN project enables us to share and disseminate our knowledge nationally and internationally, and to many different disciplines. It is impossible to make such progress in preventing crash-related death and disability without such a multidisciplinary research approach.

Seatbelts

CIREN data enables NHTSA to monitor changing injury patterns associated with current restraint systems. In the early 1990's, our CIREN center was instrumental in contributing to the literature on seatbelt syndrome in children: lumbar spine fracture or subluxation, abdominal organ injury, perforation of intestinal viscera, and a belt-shaped ecchymosis on the abdomen pattern the seatbelt syndrome.

CIREN data revealed that young children restrained by seatbelts consistently sustained these injuries when involved in frontal crashes. By combining detailed medical and crash data, we were able to elucidate the specific occupant kinematics resulting in these injuries. In addition, we have become more skilled in identifying risk factors for internal injury. The combination of a history of a frontal impact crash for children restrained in 2 or 3 point seatbelts, abdominal pain or tenderness, and belt-shaped abdominal ecchymosis is highly suggestive of intra-abdominal injury and requires prompt, aggressive surgical work-up. Lateral spine x-rays and laparotomy based on CT findings and physical examination result in a more accurate diagnosis and a subsequent decrease in morbidity and mortality. This is one of the examples where CIREN research has assisted us in identifying seatbelt syndrome in children earlier in their presentation and allowed us to put into motion a course of treatment that might have otherwise been delayed or not implemented at all.

Child Restraint Systems

Many recent changes have been made to restraints and to the federal motor vehicle safety standards that govern them, but little is known about the performance of these technologies in protecting children during real-life crash situations. As technology changes, continued monitoring of restraint performance is needed, especially for children whose anatomy, stature, and physiology make their risk of injury very different than those of their adult counterparts.

There are a number of issues relating to the use of child restraint systems in motor vehicles including child seats that are not used correctly or are inappropriate for the weight and height of the child. CIREN data aids in identifying problems associated with the incorrect or inappropriate use of child restraint systems so that child passenger safety recommendations can be revised and new technologies developed.

Federal Motor Vehicle Safety Standard (FMVSS) 213 sets minimum performance standards that all child restraints must meet. FMVSS 213 is currently being updated to reflect modern vehicle designs, new child restraint systems, and real-world crash scenarios. CIREN is capable of monitoring the effectiveness of FMVSS 213 as it exists now and as better performance standards are implemented.

A. Shield Boosters

Shield booster seats were originally designed for use in vehicles with lap belts in the rear seating position and were certified for use in children 30-60 pounds. In 1996, FMVSS 213 was updated so that child restraints marketed for use in children over 40-pounds had to meet crash test standards using a 6-year old, 47-pound dummy rather than the 3-year old, 33-pound dummy previously used. This important change resulted in the de-certification of shield boosters for children over 40 pounds. However, current research indicates that shield boosters comprise 50-68% of all boosters in circulation. Although shield booster seats meet FMVSS 213 standards for use with children 30-40 pounds, our real-world crash data indicates that shield boosters are not appropriate for use by these children. Recently, our CIREN center analyzed data to assess the performance of the shield booster seats.

Case Example A. Top Tether Used with Forward-Facing Child Safety Seat

Case A. Occupant & Vehicle Information
— 2-year-old female (33 pounds)
— Left Rear Seating Position
— Safety Seat 5-Point Harness
— Top Tether Anchored Correctly
— 2000 Subaru Outback Limited
— Frontal Impact
— Delta-V of 31.7 mph

Case Seat with Top Tether

Case A. Injury Analysis
— Slight Diastasis Fracture at C2-C3
— Bilateral Shoulder Abrasions
— Injury Severity Score = 5
— Maximum AIS = 2
— Length of Stay = 1 day

No Contact to Seatback

Among our CIREN cases, there were 16 children less than 40-pounds restrained in shield booster seats. Today, all forward-facing child safety seats are certified for use in children up to 40 pounds and provide better protection to children in this weight range. An analysis of CIREN data revealed that when compared to children restrained in forward-facing child safety seats, children in shield booster seats suffered more serious injuries, had longer hospital stays, higher acute care charges, and poorer outcomes. Shield booster cases also had a higher frequency of severe injury to the abdomen/pelvic region and to the thoracic cavity. These findings were presented to physicians at the Pediatric Academic Societies' Meeting and submitted for publication in Pediatrics so that pediatricians can help counsel patients on booster seat selection. Furthermore, our data was presented to NHTSA personnel in hopes that efforts will be made to remove shield booster seats from the market.

B. Infant and Child Car Seats

The frequencies of various types of child restraint misuse have been well documented, but little information exists on the consequences of such misuse. CNMC CIREN has been instrumental in documenting the injuries that result from improper installation of child safety seats. For example, analysis of our car seat cases revealed that incorrectly restrained children experienced a significantly higher mean Injury Severity Score (ISS) and significantly higher medical charges than correctly restrained children. Because child restraint misuse drastically increases the risk of injury to children in crashes, NHTSA has mandated that all new vehicles be designed with the Lower Anchors & Tethers for Children (LATCH) system in the outboard rear seating positions. LATCH is a restraint system designed to work independently of the vehicle seat belt system to simplify child safety seat installation and reduce misuse. Used properly, the system is expected to save up to 50 lives a year and prevent close to 3,000 crash-related injuries. As with any new technology, evaluation is essential and CIREN will play an important part of that process.

Belt-positioning booster seats

As our knowledge on seatbelt syndrome in children has continued to grow, new child passenger safety recommendations have been implemented. Over the past several years, national efforts have been made to increase the use of booster seats among school-aged children. Part of the difficulty in increasing usage stems from the lack of real-world

Case Example B. High-Back Booster

Case B. Occupant & Vehicle Information
— 6-year old female (48 pounds)
— Left Rear Seating Position
— High-Back Booster
— Booster used with 3-Point Belt
— 2000 Pontiac Bonneville
— Frontal Impact
— Delta V of 28 mph

Case B. Injury Analysis
— Two Right Rib Fractures
— Grade I Liver Laceration
— Thigh Laceration
— Injury Severity Score = 9
— Maximum AIS = 2

Shoulder Contusion

Thigh Laceration

Rib Fracrures

Case Example C. Seatbelt

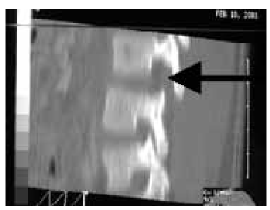
Case C. Occupant & Vehicle Information

— 7-year old female (49 pounds)
— Left Rear Seating Position
— 3-Point Belt
— Shoulder belt positioned under arm
— 1999 Dodge Avenger
— Frontal Impact
— Delta V of 30 mph

Case C. Injury Analysis

— L3-L4 Lumbar Spine Distraction
— Avulsed Lumbar Nerve Roots
— Two Large Colon Perforations
— Paraplegia
— Injury Severity Score = 26
— Maximum AIS = 5

Post-Operative Incision



L3-L4 Distraction

data on booster seat effectiveness, but as usage increases, CIREN will be an important resource in evaluating their performance. Above is a comparison of the booster seat case (Case B) with a similarly sized child in a seatbelt (Case C). In the near future, we hope to provide more definitive feedback regarding booster seat effectiveness.

Vehicle Safety

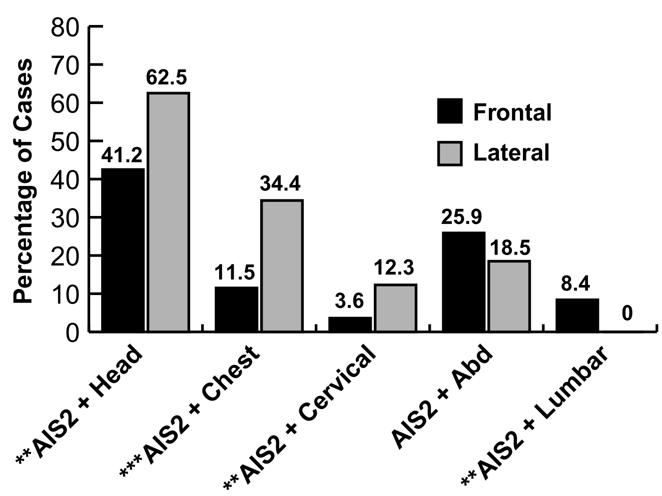
Side impact syndrome

Side impact collisions cause a significant percentage of deaths to children. We recently identified a new distinct pattern of injury for restrained children involved in side impact crashes. This information can also provide a useful tool in the differential diagnosis of children injured in motor vehicle collisions. Information on the direction and severity of crash, restraint use, and seating position can supplement vital signs and physical findings when determining the need for further diagnostic testing. Furthermore, identifying injury patterns to children involved in side impact collisions can help improve vehicle safety. In the past, the interior padding of the automobile instrument panel and other surfaces were designed with the adult passenger in mind. While children's shorter stature may lessen the likelihood of vehicle contact in frontal collisions, it may put them at increased risk of certain types of intrusion-related injury from side impact collisions.

The Transportation Recall, Enhancement, Accountability, and Documentation (TREAD) Act requires NHTSA to upgrade Federal Motor Vehicle Safety Standard No. 213, Child Restraint Systems, to include side and rear-end impacts. NHTSA recently released an Advanced Notice of Proposed Rulemaking (ANPRM) to address requirements for side impact collisions. According to NHTSA, one of the severe challenges in modifying FMVSS 213 to address side impact collisions is that little or no data exists describing the medical nature of child injuries in side impact crashes. CIREN has an important role in elucidating some of the injury mechanisms associated with side impact collisions. Preliminary analysis of approximately 65 CIREN side impact cases describes the specific patterns of injury for restrained children – *side impact syndrome*:

- Children in side impact crashes experienced higher overall morbidity than children in frontal crashes, despite a lower mean total delta V.
- Lateral impact crashes resulted in a higher frequency of intrusion/intrusion-related injury (p<. 05).
- Children in side impact crashes are more than three times as likely to have an ISS>15 than children in frontal crashes. Furthermore, side impact collisions result in greater risk of sustaining an AIS2+ head injury, AIS2+ cervical spine injury, and AIS2+ chest injury.

Figure 1. Injured Body Region by Direction of Impact.



All frontal cases (n=166) compared to all lateral cases (n=65). *p<.05; **p<.01, ***p<.001.

In addition to FMVSS 213, NHTSA has made changes to FMVSS 214, side impact collisions, that require reinforcement of side door panels and other protective measures. Side impact airbags are also becoming more prevalent because they can provide significant supplemental safety benefits to adults. However, children who are seated in close proximity to a side air bag may be at risk of serious or fatal injury, especially if the child's head, neck, or chest is in close proximity to the air bag at the time of deployment. In the coming years, CIREN will have an important role in demonstrating the effectiveness of the new side-impact safety standards and advanced technologies like side impact airbags.

Biomechanical Research

Data on pediatric injury tolerance is scarce since practical and moral constraints make research using pediatric cadavers unfeasible. Measures of head excursion and head injury criteria values are available for pediatric dummies restrained in safety seats, but due to lack of information on pediatric injury tolerances, considerable uncertainty exists regarding how these measurements relate to injury risk.

The CNMC CIREN center funded a child restraint misuse research project at the University of Virginia Automotive Safety Laboratory. Sled tests and computer modeling were used to explore all combinations of correct/incorrect and appropriate/inappropriate seating conditions in 4 different aged dummies (6 month old, 12 month old, 3-year old, 6-year old). A total of 38 sled tests were performed, and multi-body models (MADYMO) of 3 dummies in more than 10 restraint conditions were constructed.

The parametric studies in this project allowed for joint stiffness to be varied in the models to show the effect on kinematics, forces, and moments. This is important because there is a lack of constitutive data for children, particularly joint stiffness, which influences dummy designs. For example, results from this project indicate that the Hybrid III 6-year old dummy has a non-biofidelic thorax which causes high loads in the dummy's neck (2002 AAAM paper). A submitted paper (2003 SAE) studied the effect of modern restraint countermeasures (force limiting belt, active pretensioners) on the 6-year old child in a booster seat. The sled tests allowed for comparison between belt and LATCH restrained child seats. Additionally, data on the 6-year old dummy from these tests was used in comments to NHTSA on their proposed changes to federal regulations. Occupant and restraint positions (incorrect usage) demonstrated which positions place the child at the most risk of injury. The kinematics identified in the sled tests and the subsequent computer models are being used to improve understanding of the biomechanics of injury among CIREN cases since the models allow for different restraint conditions to be studied.

New Triage, Transport, & Treatment Tools

CIREN has greatly increased our knowledge of injury patterns to restrained children in crashes. In the foreseeable future, we anticipate that these findings will be incorporated into Automatic Crash Notification systems so that injured occupants can be triaged more effectively and transported to a trauma center in a more timely fashion. Child fatalities due to airbag deployment have been well documented. Recently, automobile manufacturers have begun utilizing a sensor technology that can monitor the size and positioning of riders inside vehicles. The systems are able to read the pressure pattern and weight distribution of a person or object to determine if a child seat is placed in the front passenger seat. If so, the front-passenger frontal airbag will automatically turn off and not deploy during a crash. Using a collection of strategically located sensors, these systems can automatically call for help if the vehicle is involved in a moderate to severe frontal, rear or side-impact crash, regardless of air bag deployment. We hope that in the future, valuable findings from CIREN will be incorporated into these notification systems. For example, the system would provide crash severity information to 911 centers such as impact direction, delta V, airbag deployment, child use of seatbelt, child seat anchored to LATCH system, etc., helping to quickly determine the appropriate combination of emergency personnel, equipment and medical facilities needed. This technology is especially promising in many rural areas, where there are fewer motorists to report crashes and less access to state-of-the-art urban trauma centers to treat crash victims.

Pediatric Outcomes

Long-term consequences of motor-vehicle crashes not only affect physical functioning but psychosocial functioning as well. Long-term outcome research is vital in assessing the impact of the injury on children and their families. Although CIREN obtains detailed information regarding a child's condition at discharge, no long-term quality of life information has been collected in the past. In the near future, CNMC will begin assessing quality of life for all CIREN cases at baseline and at 6-months post-discharge. The questionnaire is designed to provide reliable information about the everyday functioning and well-being of children. It asks questions about the child's physical wellness, his/her feelings, behavior, and activities at school and with family and friends. CNMC is about to implement long-term outcomes research into the CIREN data collection process. Interview with both child and parent will be conducted at baseline to assess pre-crash functioning and again at 6-months and 1-year post-discharge to assess the post-crash functioning. Questions will assess functioning in each of the following areas:

> Physical Functioning, Social Functioning, Psychosocial Functioning, Emotional Functioning, and School Functioning.

Publications 2001–2002

Sherwood CP, Shaw CG, van Rooij L, Kent RW, Gupta PK, Orzechowski KM. Prediction of Cervical Spine Injury Risk for the 6 Year Old Child in Frontal Crashes. Association for the Advancement of Automotive Medicine

Platform /Poster Presentations 2001–2002

Orzechowski KM, Edgerton EA, McLauglin PM, Eichelberger MR. Pediatric Motor Vehicle Crash Injuries Associated with Restraint Misuse. Third National Congress on Childhood Emergencies. Dallas, TX, April 2002

Orzechowski KM, Edgerton EA, McLauglin PM, Eichelberger MR. CIREN: A Multidisciplinary Approach to the Prevention of Motor Vehicle Crash Injuries. Third National Congress on Childhood Emergencies. Dallas, TX, April 2002

Orzechowski KM, Edgerton EA, Eichelberger MR. Injury Trends Among Improperly Restrained Booster Seat Age Children Involved in Motor Vehicle Crashes. American Academy of Pediatrics 2001 National Conference and Exhibition, San Francisco, CA, October 2001

Literature Cited

i Durbin DK, Kallan MJ, Winston FK. Trends in Booster Seat Use Among Young Children in Crashes. Pediatrics. 2001, December: 108 (6): E109.

ii Advanced Notice of Proposed Rulemaking (ANPRM) To Add A Side Impact Test to FMVSS No. 213 Washington, DC: Office of Regulatory Analysis and Evaluation Plans and Policy, National Highway Traffic Safety Administration, U.S. Department of Transportation, February 2002

University of Maryland
National Study Center for Trauma and EMS
R Adams Cowley Shock Trauma Center
CIREN Program Report

The Mechanism of Lower Extremity Injuries in Real-World Crashes

Real-world crashes provide important insights into the mechanism(s) of lower extremity injury. These injuries are frequent, disabling, and costly. Many of these injuries are sustained in crashes with little or no intrusion. Accident investigations, crash test data, and simulation results suggest that factors such as vehicles' change in velocity and rate and timing of intrusion must be considered in examining mechanisms of injury to the lower extremities.

Introduction

Motor vehicle crashes are a major cause of lower extremity injuries. These injuries are costly, frequently result in lifetime impairments, and are preventable. Although current information on the biomechanics of these injuries is still insufficient, it is known that they occur most often in frontal and offset frontal collisions, that seatbelts may be ineffective with respect to their prevention, and that vehicular intrusions of the toepan and instrument panel have been implicated as possible causes [1]. Many collisions resulting in these injuries occur at delta v's well within the purview of current regulatory standards. With the increasing availability of airbags and resultant decrease in life-threatening head and thoracic injuries, the relative importance of lower extremity injuries will increase.

Data from NHTSA's National Accident Sampling System (NASS) reveal that lower extremity injuries account for 32% of all AIS>2 injuries for belted occupants (24% for unbelted). Injuries to the ankle/foot complex account for 33% of the AIS>2 injuries for belted occupants (24% for unbelted), and are the most prevalent lower extremity injury [2]. Among patients admitted to trauma centers following motor vehicle crashes, approximately 20% of drivers had at least one lower extremity fracture; the highest incidence rate for a specific fracture is 5.7% for ankle injuries [3]. Surveys suggest that foot and ankle injuries account for 8-12% of all moderate-to-serious injuries sustained by motor vehicle occupants involved in frontal collisions [4-6]. In a study of the one-year treatment charges for persons hospitalized in Maryland with motor vehicle-related injuries, lower extremity injuries accounted for 40% of the treatment charges [7].

Lower extremity injuries sustained in car crashes tend to be high-energy injuries, which have a poorer prognosis than comparable low-energy injuries caused by slips and falls [8]. Because they involve weight-bearing surfaces and joints, knee and ankle fractures often result in prolonged reductions in mobility. Proximal foot fractures (talus, calcaneus) involve the complex weight-bearing joints of the ankle and hindfoot and may also result in long-term impairment and disability. However, their low scores on injury severity scales, which are usually designed to reflect threat to life, not to predict nonfatal outcomes, do not reflect the disabling nature of these injuries.

In a follow-up study of patients admitted to trauma centers, it was noted that, among individuals with moderate or severe injuries to the extremities, only 58% had returned to work at one year [9]. Another study of functional outcomes after lower extremity fracture revealed that a significant

proportion of patients hospitalized for treatment of a unilateral fracture of the lower extremity remained physically impaired at 6 months after discharge from the hospital. Most affected was the ankle joint: 55% of the patients had evidence of abnormal dorsi/plantar flexion [10]. At 12 months, half of the patients still reported minor to moderate disabilities. Six- to 12-month improvements were noted for patients with both single and multiple metaphyseal or shaft fractures in one limb. Patients with foot fractures, however, showed no improvement. Measures of patient-oriented functional outcomes were worse for persons with three or more fractures to the same extremity and for fracture patterns typical of high energy forces [11].

With increasing survival rates among drivers in high-speed crashes, as a result of the availability of both seatbelts and airbags, it is anticipated that there will be a relative increase in serious lower extremity injuries among people who previously would have died of multiple trauma, including head, thoracic, abdominal, and lower extremity injuries [12]. From in-depth crash reconstruction studies, it is possible to learn more about the mechanism of these injuries and thus, working with biomechanics experts, address scientific strategies for prevention [13].

We present data on 1,345 cases studied as part of NHTSA's Crash Injury Research and Engineering Network (CIREN), 751 (56%) of which received at least one lower extremity fracture (table 1).

Table 1 summarizes the comparison of injury severity scores and delta v for CIREN cases with and without lower extremity fractures (LEF). It is apparent that, compared to those not resulting in LEF, LEF crashes occur at significantly higher delta v's. Thus, injured occupants with LEF also have, on average, higher injury severity scores. Additionally, the median total charges were double for those with lower extremity fractures compared to those without such fractures.

Table 1. Median Injury Severity Score (ISS), and Delta V by Lower Extremity Fractures (1345 cases)

	Lower Ext. Fracture (n=751)	No Lower Ext. Fracture (n=594)	P-value
ISS (25%–75%)	17 (10–29)	14 (9–26)	<0.001
Total Delta V (25%–75%)	43 (31–57)	33 (24–45)	<0.001
Total Charges	$41,042	$19,569	<0.001

A total of 1,754 lower extremity fractures were documented for these 1,345 cases. The frequencies of individual fractures are listed in Table 2. Pelvic fractures were most common (26%), followed by tibia/fibula fractures (23%) and femur fractures (21%).

Table 2. Distribution of Fracture Type (1754 cases)

Pelvic	26%
Tibia/Fibula*	23%
Femur	21%
Ankle/Hindfoot	13%
Tarsal/Metatarsal	7%
Patella	4%
Other	7%

*Excluding ankle/hindfoot

Table 3 identifies the injury source associated with a particular fracture type. For pelvic and femur fractures, the major source of injury was the instrument panel. Tibia/fibula fractures were associated with the instrument panel and toepan, while ankle/foot fractures were primarily attributed to the toepan and foot controls.

Post-trauma Outcomes

Despite the low AIS scores associated with injuries to the lower extremities, many patients who survive these high-energy crashes experience physical and psychological problems. Difficulties such as depression, post-traumatic stress, behavioral and cognitive changes can impede recovery and a return to pre-injury functional status. Results from the Short Form Health Survey (SF36) presented in the 2001 annual report clearly indicated a decline in both physical and psychological functioning at 6 months post trauma, with gradual improvement at one year, but significantly lower functional status than at baseline for all patients. This report will discuss only a few LEI outcomes as they pertain to patients with ankle/foot fractures and those with mild brain injury.

Table 3. Most Common Injury Source by Fracture Type						
Rank	**Pelvic**	**Tibia/ Fibula**	**Femur**	**Ankle/ Hind Foot**	**Tarsal/ Metatarsal**	**Patella**
1	Knee bolster	Floor/ toe pan	Knee bolster	Floor/ toe pan	Floor/ toe pan	Knee bolster
2	Left side interior surface	Left instrument panel	Left instrument panel	Foot controls	Foot controls	Left instrument panel
3	Left side interior surface	Knee bolster	Glove compartment door	Non-contact injury source	Unknown injury source	Glove compartment door
4	Right side interior surface	Foot controls	Center instrument panel	Right side interior surface	Non-contact injury source	Steering column
5	Left instrument panel	Center instrument panel	Right instrument panel	Left instrument panel	Right side interior surface	Center instrument panel

At the Maryland CIREN center, a clinical interview is conducted with the patient and family shortly after admission to the trauma center to obtain pre-injury information, and at 6 months and 1 year post trauma in order to assess cognitive, economic, physical and psychosocial outcomes of injury. A total of 90 patients have completed the interview process through one year. Of those, 65 patients (72%) sustained lower extremity injuries. Lower extremity injuries were defined as a fracture of the pelvis or lower limbs, including femur, patella, tibia fibula and bones of the ankle and foot (International Classification of Diseases 9th Revision [ICD-9] codes 808.0-808.9, 820.0-829.9). Using CDC criteria, traumatic brain injuries were defined as fracture of the vault or base of the skull; other and unqualified and multiple fractures of the skull; and intracranial injury, including concussion, contusion, laceration, and hemorrhage (ICD-9 codes 800.0-801.9, 803.0-804.9, and 850.0-854.1) as reported at the scene by paramedics and recorded in the medical record and by the patient when total amnesia to the event and /or loss of consciousness was indicated.

Analysis of 65 Maryland CIREN Cases

Crash and injury characteristics of 65 patients with lower extremity injury are displayed in Table 4. Most (91%)of the patients were drivers, of whom 69% were deemed culpable for their crash according to the crash investigation review. The majority were involved in frontal crashes (89%) and were belted, with airbag deployment (80%). Fifty-five percent of the patients suffered an ankle or foot fracture, and 37% sustained fractures to both lower extremities.

In addition to the lower extremity fractures, 28% had an associated traumatic brain injury (TBI) even though most of the patients (88%) had an admission Glasgow Coma Score (GCS) of 15.

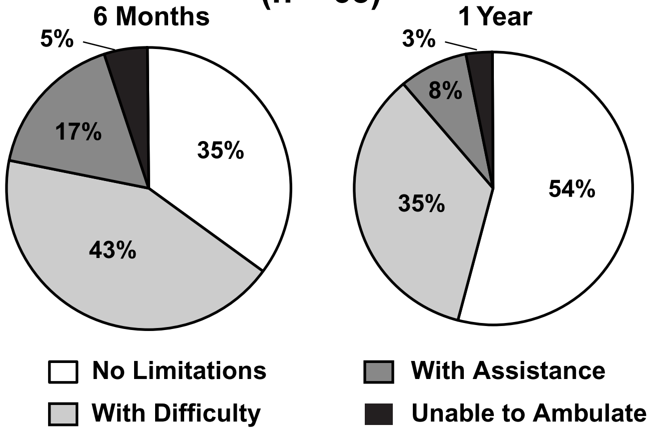
Following acute care hospitalization, many patients with LEI were discharged to an inpatient rehabilitation facility (44%) where they remained, on average, three weeks for intensive therapy. Additional outpatient therapy lasted approximately 12 weeks. At 6 months post-trauma, the majority of patients reported serious problems with ambula-

Table 4. Crash and Injury Characteristics of Patients With Lower Extremity Injury* (N = 65)

	n	**%**
Drivers	59	91
Culpable	41	69
Restraint Use		
Airbag with Seatbelt	52	80
Airbag Only	9	14
Seatbelt Only	3	5
Point of Impact		
Frontal	57	89
Lateral	6	9
Injuries		
Left LEI Fracture	33	56
Right LEI Fracture	45	76
Bilateral Fractures	22	37
Ankle/Foot Fracture	36	55
Maximum AIS for LEI = 2	42	65
Associated TBI	18	28
Admission GCS		
3–8	4	6
9–12	4	6
14–15	57	88

*due to ‘other’ responses, numbers may not add to 65 tion due to a slow, uneven, or painful gait, foot drag or limp, often requiring assistance such as a cane, walker or use of a wheelchair. One-year following injury, 35% continued to have difficulty walking, 8% required the aid of a walker or cane and 3% were unable to walk (Figure 1).

Figure 1. Ambulation (n = 65)



Patients who sustain ankle or foot fractures or bilateral extremity injury report significant ambulation problems and are less likely to return to work or activities, such as driving, compared to those without such injuries (Table 5). Among those who worked full time prior to the crash, only 58% of patients with ankle/foot injuries were back to full time work at one year compared to 87% of patients without ankle/foot injuries. (This was similar to the group with bilateral fractures). Over half of those with ankle/foot fractures or bilateral injuries experienced interfering pain, limited range of motion and more pronounced gait abnormalities, compared with 34% of those without such injuries at one year following injury.

Table 5. Ankle/foot Fracture vs. No Ankle/foot Fracture

	A/F Fracture (N=36)		No A/F Fracture (N=29)	
	n	%	n	%
Cannot return to driving				
6 months	15	42	6	21
1 year	9	25	4	14
Cannot return to work				
1 year	8	22	1	3
*p<0.05				

Additional injury, such as mild traumatic brain injury (TBI) also influences long term outcome and frequently exacerbates the recovery process, especially for patients with LEI who must endure multiple surgeries and lengthy rehabilitation. Although the majority of LEI patients who sustained a TBI had a Glasgow Coma Score of 14 /15 (89%) on admission, 28% had an associated TBI as evidenced by follow-up interviews at six months. Some of the consequences of TBI include physical problems (headaches, dizziness, balance); emotional or behavioral concerns (altered mood, increased irritability, depression); and cognitive problems (slowed ability to process information, memory, concentration). Of those who sustained a TBI, 44% exhibited behavioral problems at one year compared to 9% of those not diagnosed with such injury (Figure 2). At one year, 61% of the TBI group reported cognitive problems versus 15% of the non-TBI group (Figure 3). Depression remained high for all patients at one year but especially for the TBI group (56%) vs. 30% for the non-TBI patients.

Figure 2. TBI vs. No TBI Behavioral Changes

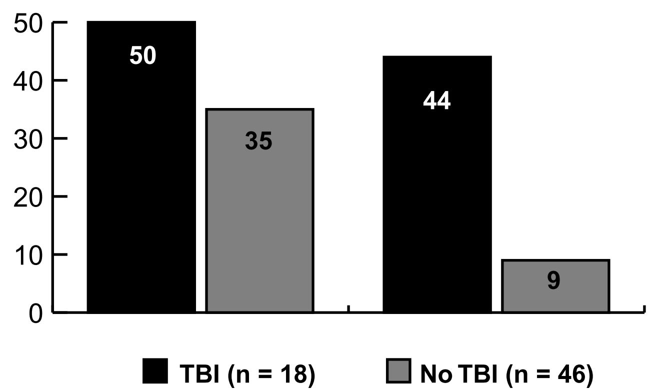
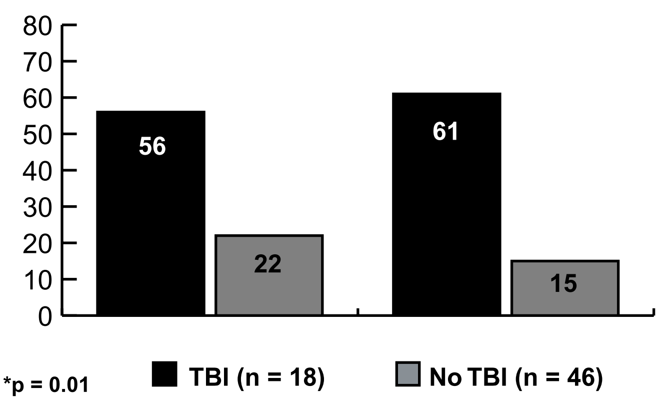


Figure 3. TBI vs. No TBI Cognitive Problems



*p = 0.01
**p < 0.001

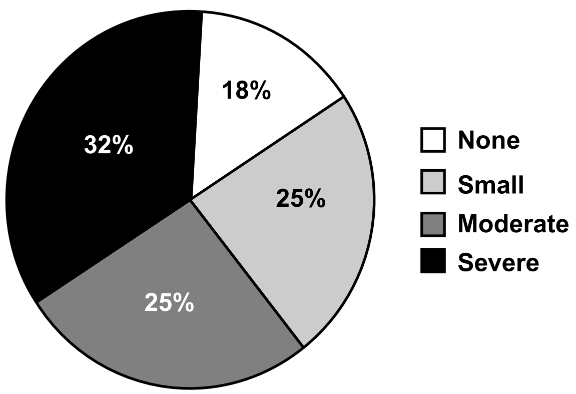
Costs

Although most of the patients had insurance to cover their medical costs, (64% private/HMO and 22% medicare/ medicaid), 32% of these patients felt the financial impact of their injury was severe and caused hardships for themselves and their families. Another 25% stated that the financial impact was moderate due to less income and large deductibles and co-pays. As illustrated in Table 6, total median costs (hospital, professional and rehabilitation) for those patients who were admitted to an in-patient rehab facility following their acute care was over $10,000 higher than costs for patients discharged to home. Moreover, these costs do not include re-hospitalization or further rehabilitative care. Thirty-four percent of patients were re-hospitalized in the first 6 months and 20% of the patients were re-hospitalized between 6 and 12 months post-trauma (data not shown).

Table 6. Median Costs and Financial Impact (N = 65)

Median Costs	
Hospital & Professional	$44,068
Inpatient Rehabilitation	$16,238
Outpatient Rehabilitation	$3,500

Financial Impact



It is apparent that lower extremity injuries have a major impact on individuals which manifests itself in several ways, including physical mobility, a patient's ability to return to work and pre-injury functional status, and the need for extensive surgical procedures and rehabilitative efforts. Those with ankle/foot injuries have the most difficult challenge, in that complete recovery may never be attained, since disruption of the complex ankle articular surfaces may never be restored. Associated mild brain injury also can impede a return to pre-injury status. In addition, lower extremity injuries add a considerable burden to the health care system

Discussion

Since the majority of cases collected so far, as part of CIREN, include occupants with modern restraint systems (usually both belts and bags), it is not possible to address questions regarding the effectiveness of these systems with regard to prevention of lower extremity injuries. However, many of the cases presented had no major injuries except for those to the lower extremities. Not long ago, individuals involved in high-speed crashes would have suffered serious multiple trauma to the head, chest, and abdomen as well as their lower extremities [14,15]. Thus, these are "success stories", since most of the patients survived. However, even with the protection afforded by seatbelts and airbags, it is apparent that patients admitted to trauma centers have still sustained serious lower extremity injury, necessitating treatment in a trauma center [12,16].

The CIREN consortium represents an opportunity to study the causes and outcomes of these injuries in greater detail. However, it is necessary to take a step beyond descriptive analyses, such as those presented here, and address more in-depth questions, such as the actual mechanism of injury, especially for the most disabling and costly of all lower extremity injuries—ankle and foot fractures. Previous findings from this research conducted at the University of Maryland in conjunction with the University of Virginia revealed that (1) not all foot and ankle injuries are associated with vehicular intrusion [17], (2) axial load (often with associated inversion or eversion forces) plays a significant role in the causation of these injuries [18,19], and (3) driver anthropometry [20] and foot placement [21] are important factors. With the evolution of CIREN, it will be possible to address such questions at multiple centers, allowing for the collection of much larger numbers of cases.

Based on the real-world findings noted among patients admitted to trauma centers, CIREN engineering/biomechanics experts can try to replicate these injuries, using tools such as computer simulation or dummy crash test experiments. Moreover, engineers from the automotive industry can provide important insights into the dynamics of a crash from the perspective of vehicle standards and performance. Many lower extremity injuries are sustained in crashes with little or no intrusion. However, accident investigations, crash test data, and simulation results suggest that factors such as a vehicle's change in velocity and rate and timing of intrusion must be considered when examining mechanisms of injury to the lower extremities. Based on engineering input, CIREN data collection protocols may be tailored to obtain more detailed measurements, for example, of toepan intrusion. Primary prevention of these common, costly, and disabling injuries should be a major goal of the automotive and medical communities encompassed by CIREN.

References

1. Proceedings, International Conference on Pelvic and Lower Extremity Injuries. Washington DC, December, 1995.
2. Morgan RM, Eppinger RH, Hennessey BC. Ankle Joint Injury Mechanism for Adults in Frontal Automotive Impact, Proc 35th Stapp Car Crash Conf, SAE Paper No. 912902, 1991.
3. Dischinger PC, Cushing BM, Kerns TJ. Lower extremity fractures in motor vehicle collisions: Influence of direction of impact and seatbelt use. 38th Annual Proceedings, Association for the Advancement of Automotive Medicine, 1992, pp. 319-325.
4. Otte D, Rhheinbaben H, Zwiipp H. Biomechanics of injuries to the foot and ankle joint of car drivers and improvements for an optimal car floor development. Proc 36th Stapp Car Crash Conference, SAE 922514, 1992.
5. Crandall JR, Klopp GS, Klisch S, Sieveka E, Pilkey W, Martin P. Research program to investigate lower extremity injuries. In-Depth Accident Investigations—Trauma Team Findings in Late Model Vehicle Collisions. Society of Automotieve Engineers, SAE Paper No. 940711, 1994.
6. Kruger HJ, Heuser G, Kraemer B, Schmitz A. Foot loads and footwell intrusion in an offset frontal crash. Paper 94-S4-0-03. 14th ESV Conference, Berlin, Germany, 1994.
7. MacKenzie EJ, Shapiro S, Siegel JH. The economic impact of vehicular trauma: One-year treatment related expenditures. 32nd Annual Proceedings, Association for the Advancement of Automotive Medicine, 1988: pp 53-68.
8. States JD. Adult occupant injuries of the lower limb. In: Biomechanics and Medical Aspects of Lower Limb Injuries. Warrendale, PA: Society of Automotive Engineers, Inc.; 1986: pp 97-107.
9. MacKenzie EJ, Siegel JH, Shapiro S, Moody M, Smith RT: Functional recovery and medical costs of trauma: an analysis by type and severity of injury. J Trauma 28:281-298, 1993.
10. MacKenzie EJ, Cushing BM, Jurkovich GJ, Morris JA, Burgess AR, deLateur BJ, McAndrew MP, and Swiontkowski MF. Physical impairment and functional outcomes six months after severe lower extremity fractures. J Trauma 34: 528-539, 1993.
11. Mock C, Jurkovich G, MacKenzie E, Swiontkowski M, Burgess A, Cushing B, deLateur B, McAndrew M, Morris J. Long-term functional outcome in trauma patients: assessment using the sickness impact profile (SIP). Proc 22nd Annual Mtg, American Public Health Association, 1994: p 158
12. Burgess AR, Dischinger PC, O'Quinn TD, Schmidhauser CB. Lower extremity injuries in drivers of airbag-equipped automobiles: Clinical and crash reconstruction correlations. Journal of Trauma 35:920-931, 1993
13. Bents FD, Dischinger PC, and Siegel JH. Trauma center based crash investigation research: Methodologies and applications. SAE Paper No. 940709, 1994.
14. Siegel JH, Mason-Gonzalez S, Dischinger PC, Read KM, Cushing BM, Badellino MC, Goodarzi S, Smialek JE, Heatfield BM, Robinson RM, Parkinson K, Hill JH, Jackson JW, Livingston DJ, Bents FD, Clark CC. Causes and costs of injuries in multiple trauma patients requiring extrication from motor vehicle crashes. Journal of Trauma 35(6): 920-931.
15. Siegel JH, Mason-Gonzalez S, Dischinger PC, Cushing BM, Read K, Robinson R, Smialek, J, Heatfield, B, Hill W, Bents F, Jackson J, Livingston D, and Clark CC. Safety belt restraints and compartment intrusions in frontal and lateral motor vehicle crashes: mechanisms of injuries, complications, and acute care costs. J Trauma 34:736-759, 1993.
16. Loo GT, Siegel JH, Dischinger PC, Rixen D, Addis MD, O'Quinn TO, McCammon L, Schmidhauser CB, Marsh P, Hodge PA, Burgess AR, and Bents FR. Airbag protection versus compartment intrusion effect determines the pattern of injuries in multiple trauma motor vehicle crashes. J Trauma 41:935-951, 1996.
17. Crandall JR, Martin PG, Sieveka EM, Klopp GS, Kuhlmann TP, Pilkey WD, Dischinger PC, Burgess AR, O'Quinn TD, Schmidhauser CB. The influence of footwell intrusion on lower extremity response and injury in frontal crashes. 39th Annual Proceedings, Association for the Advancement of Automotive Medicine, pp 1-18, 1995.
18. Dischinger PC, Burgess AR, Cushing BM, et al. Lower extremity trauma in vehicular front-seat occupants: patients admitted to a Level I trauma center. In In-Depth Accident Investigation: Trauma Team Findings in Late Model Vehicle Collisions. Warrendale, PA Society of Automotive Engineers, 1994, pp 11-18.
19. Dischinger PC, Burgess AR, Cushing BM, et al: Lower extremity trauma in vehicular front-seat occupants. In Proceedings of the 4th Annual Injury Prevention through Biomechanics Symposium, Detroit, Wayne State University, 1994, pp 29-42.
20. Pilkey WD, Sieveka EM, Crandall JR, Klopp G. The influence of foot placement and vehicular intrusion on occupant lower limb injury in full-frontal and frontal-offset crashes. Paper No. 94 S4 W31, presented at the International ESV Conference, 1994.
21. Dischinger PC, Kerns TJ, Kufera JA. Lower extremity fractures in motor vehicle collisions: the role of driver gender and height. Accid Anal Prev. 27:601-606, 1995.

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Fatal Versus Potentially Survivable Motor Vehicle Crash (MVC) Aortic Injuries (AI): The Ratio of Deceleration Energy to Change in Velocity on Impact and the Presence of Associated Injuries as Determinants of Outcome

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Abstract

Objective: To examine the difference in force mechanisms between fatal and potentially survivable MVC aortic injuries (AI) compared to non-AI severe thoracic injuries (ST). **Methods:** Of 324 autopsied MVC driver or front seat passenger fatalities (1997-2000), there were 43 fatal AI (36 scene deaths, 7 hospital deaths) and 5 additional AI survivors. **Results:** Of the 48 AI, there was only a 42% survival for those reaching hospital alive. 80% of AI survivors had isthmus lesions and all had no or minimal brain injury (GCS >= 13), no cardiac injury and only 20% ribs 1-4 fx or shock; of AI non-survivors reaching hospital alive, 67% had GCS <= 12, 50% cardiac injury, 83% ribs 1-4 fx and 83% shock; AI scene deaths had 78% severe brain injury, 56% cardiac injury, 69% lung injury and 78% ribs 1-4 fx. Quantifying forces in AI scene mortality: the **Instantaneous Velocity on Impact** of the subject vehicle (delta V1) and the Impact Energy Dissipated (IE) on the subject vehicle (V1) in joules demonstrated a linear regression in fatal **car** MVC AIs: **Energy dissipated (joules) = –56.65 x (delta V1)^2 + 15972 x delta V1 – 454661**, $r^2 = 0.83$. However, for 27 patients with non-AI but severe thoracic (ST) injury (AIS>=3), the relationship of IE to delta V1 had a linear regression of Energy dissipated (joules) = -5.0787 x (delta V1)2 + 4282.1 x delta V1 - 57182 1, r2 = 0.84, with the slope difference between the regression for AI scene deaths and that of ST and AI survivors being significant ($p<0.05$). Based on these relationships, a Critical Zone limited by MVC Impact Energy level of 336,000 joules and a delta V1 of 64 kph appears to be the limit of potential survivability in MVCs producing aortic injuries. All AI above these thresholds died. In contrast, ST had greater use of seatbelts (AI 10% vs all ST 60%) and airbags (AI 50% vs all ST 72%), and an 83% survival. **Conclusion:** The data suggest different mechanisms of force delivery and injury patterns in fatal vs potentially survivable AI, and vs ST MVCs. They suggest that an approach to improving vehicle safety measures for AI may involve better safety devices and mechanisms for reducing that fraction of Impact Energy dissipated on V1 for a given delta V1 which is focused on the upper portion of the subject's thoracic cage between the levels of ribs1-8.

Introduction

A variety of mechanisms have been proposed as determinants of motor vehicle crash induced aortic injuries. These include shearing stresses secondary to differential decelerations of the aorta and the thorax at the time of impact [Zehnder, 1956; Sevitt, 1977; Feczko, Lynch, Pless *et al*, 1992; Shkrum, McClafferty, Green *et al*, 1999] as a function of the direction of the motor vehicle crash, frontal versus lateral [Ben-Menachem, 1993; Katyal, McLellan, Brenneman *et al*, 1997; Careme, 1989] chest wall compression in a cephalic direction with a “shoveling effect” on the heart and proximal aorta with tethering at the aortic isthmus by the ligamentum arteriosum in frontal crashes [Voigt, Wilfert, 1969] and a similar compression of the chest wall with lateral movement of the more mobile heart relative to the fixed proximal descending aorta in lateral MVCs [Viano, 1983; Nahum, Kroell, Schneider, 1971]; an “osseous pinch” effect whereby the proximal descending aorta is caught between the sternum or upper ribs and the vertebral bodies [Crass, Cohen, Motta *et al*, 1990]; and an intravascular “water hammer” effect due to a sudden rise in intravascular arterial pressure when the external compression effect occurs at a critical point in the cardiac ejection cycle, thus bursting the aorta at its weakest point [Lundevall, 1964; Lasky, Nahum, Siegel, 1969; Saylam, Melo, Ahmad *et al*, 1980]. In addition to these theories as to causation, a major component of the literature has focused on the differences in mechanisms between aortic disruption survivors and deaths in the group of patients who reach hospital alive [Turney, Attar, Ayella et al, 1976; Fabian, Richardson, Croce *et al*, 1997]. Conversely, a number of important studies of aortic injury have confined themselves solely to autopsy series of scene-fatal medical examiner cases [Shkrum et al, 1999; Ben-Menachem, 1993; Dischinger, Cowley, Shankar et al, 1988; Williams, Graff, Uku *et al*, 1994].

While all of these theories have some merit, very few studies have combined their clinical or post mortem patient observations with professional crash reconstruction-derived data regarding the mechanism and direction of the MVC, the calculation of the impact deceleration velocity (delta V1) and the estimated impact energy (IE) dissipated upon the patient’s vehicle (V1), and the identification of the passenger compartment structure responsible for the delivery of these physical factors to the patient’s thorax and the modulating or contributing factors induced by seat belts and/or airbag deployment. Moreover, it is essential to identify the nature and severity of any other associated injuries and their physiological consequences, which may convert a potentially survivable aortic injury into a fatal one, regardless of the timing and proficiency of the aortic reconstruction surgery. Finally, there is a need to examine the entire demographic distribution of scene fatal versus potentially survivable aortic injuries within a given geographic region, since the qualitative mechanisms and quantitative forces may be quite different in these two groups, or within subgroups, of these patients. The present study was designed to consider all of these factors by obtaining detailed crash reconstruction compared to anatomic/physiologic data on a specific group of aortic injury patients, front seat drivers and passengers who remained in the vehicle after the MVC, to include all aortic injury patients encountered during a continuous time period, hospital survivors, hospital deaths and medical examiner scene fatalities.

Methods

All cases of fatal aortic injury (AI) occurring between 1997 and 2000 in either drivers or front seat passengers of cars, sport utility vehicles or light pickup trucks in the three county area (Essex, Passaic, & Hudson) which falls under the administrative authority of the Regional Medical Examiners Office (ME) of Newark, New Jersey, and those patients surviving their AI injury long enough to be admitted to the Level I Trauma Center at the New Jersey Medical School University Hospital, also located at Newark, were included in this study. All of the fatal AI cases were autopsied under the authority of the ME and the cases surviving to reach hospital who were treated by surgical therapy had clinical, radiological and operative confirmation of the nature, location and outcome of their AI, as well as diagnosis and appropriate therapy for any associated anatomic or physiologic injuries. Thus, there were three categories of AI: Scene Deaths autopsied by the Medical Examiner (ME), Hospital Deaths (H), and Hospital Survivors (S). The pathologic anatomic findings of all injuries were documented by direct contemporaneous observation (autopsy or surgical/radiological procedures), the physiologic consequences of all injuries in patients surviving long enough to reach hospital alive were directly observed (shock, Glasgow Coma Scale, evidence of organ dysfunction and length of hospital and ICU stay) and documented, as was the final outcome of the patient’s AI (survival or death). In all cases, crash scene reconstruction was done by examination of police and EMS reports, as well as by direct questioning by the study EMS Coordinator of the EMS personnel involved in transporting the hospital directed cases. In the Scene Deaths (ME cases), no vehicle could be moved, nor could the corpse be removed until the ME’s office photographer had documented the exact location of the vehicles and the position of the bodies.

Following the identification of each crash which met the criteria of the study, with the assistance of the study’s EMS Coordinator, the study Crash Investigation Team located the vehicle (V1) of the AI victim and the crashing vehicle(s) (V2, V3, etc.), or the fixed object impacted by V1. The team made detailed measurements of the vehicle deformities and identified the location of the occupant contact sites within the passenger compartment, which had been made by the subject at the time of the crash. The deployment of any frontal airbags was noted, as was the use of any type of seatbelt restraints. None of these vehicles were equipped with side airbags or air curtains. From these measurements, wherever possible the change in velocity on impact (delta V1) and the deceleration energy dissipated on impact (IE) were estimated using the National Highway

Traffic Safety WINSMASH 1.2.1 program.

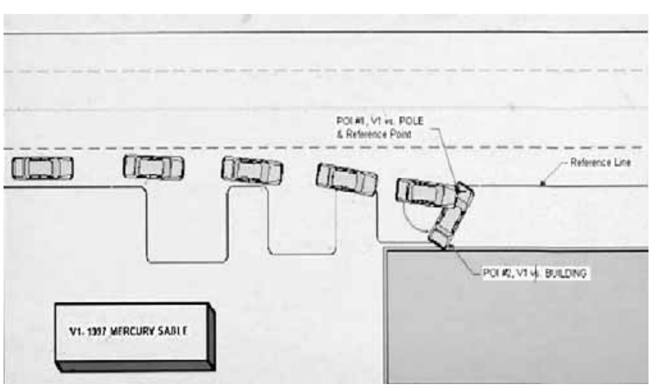
In addition, for purposes of comparison with those AI patients reaching hospital alive, a group of patients who sustained severe thoracic trauma of AIS 3 or greater (mean AIS for most severe thoracic injury=3.6) (ST), similar in all respects save AI, were studied in the identical manner with regard to injury identification, hospital course and crash and vehicle reconstruction with delta V1and IE also being calculated from the WINSMASH program supplied by NHTSA. In all patients reaching hospital alive, an informed consent to record the patient data and to examine the vehicle approved by the UMDNJ: IRB was obtained from the patient or next of kin. In the Scene Deaths (ME), the autopsy findings and crash reconstruction were obtained under the legal authority of the Medical Examiner. However, in all cases (ME, H, & S), all patient and vehicle identifiers, protected by a Certificate of Confidentiality, were removed and each sanitized case was identified only by a randomly selected case identification number. These sanitized data were entered into a computer generated relational data base and the data interrelationships were analyzed for patterns and significance with ANOVA and regression techniques by the use of a standard statistical program (SAS). A value of $p<0.05$ was used as the minimum basis for significance.

Results

As examples of the CIREN methodology two representative cases are presented. The first is an example of a proximal aortic rupture in a front seat passenger produced by a frontal motor vehicle crash (MVC) impact of a sedan into a telephone pole and the second is an example of a descending aortic laceration sustained by the driver of a sedan also in a frontal MVC with a delivery truck. Both subjects were immediate deaths and consequently were autopsied immediately after the MVC by the Regional Medical Examiner.

In the first case, the patient was a 73 year old male who was the unrestrained front seat passenger in a 1997 Mercury Sable (1676 kg). He weighed 90kg (198lbs) and was 5ft 11inches (180cm) in height. As shown in the scene diagram (Figure 1), the driver lost control of the vehicle and it impacted a telephone pole at the side of the road on the drivers side with a primary direction of force (PDOF) of 350o, and then rotated in a counter clockwise direction.

Figure 1



The Delta V was 73kph (41mph) and the maximum crush was 81cm at C2 (Figure 2). The passenger airbag deployed on impact, but because the passenger was unrestrained and the primary impact was on the driver's side at 350o PDOF, the patient missed the airbag and impacted his anterior left chest wall and sternum on the left side of the central instrument panel (Figure 3).

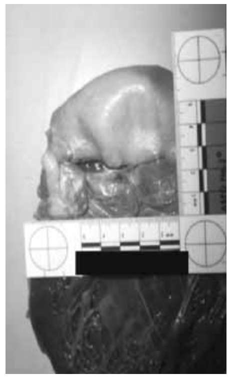
Figure 2

Figure 3

As a result of the impact, the patient sustained a bursting type of rupture of the proximal aorta on the anterior aspect just above the aortic valve (Figure 4). On inspection, after opening the aorta and the left ventricular chamber (Figure 5), it can be seen that the transverse rupture lies just above the aortic valve ring and the coronary artery cusps close to the right coronary artery orifice in the aorta. This type of lesion is unfortunately always fatal, since the high-pressure stream of blood ejected from the left ventricle immediately enters the pericardium with acute pericardial tamponade and if there is also a rent in the pericardium, rapidly fills the thoracic cavity with the entire cardiac output with consequent acute hypovolemic shock and subsequent cardiac arrest.

Figure 4

Figure 5



The second case example, which demonstrates a shearing type of rupture of the descending aorta, was a 51 year old female, 62 kg (135 lbs), 5ft 4 inch (163cm) unrestrained driver of a 1985 Ford Thunderbird (1505 kg) who apparently lost control of her vehicle at a curve in a four lane undivided roadway and crossed the mid-line to sustain a frontal impact with a 1996 International CBE/490 delivery truck (14923 kg) (Figure 6 and Figure 7).

Figure 6

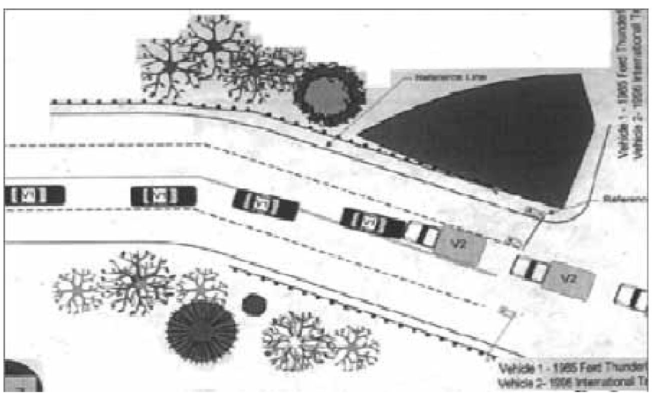


Figure 7

The impact occurred at a Delta V of 60 kph (33 mph) with a maximum crush of 76cm at C6. There was a major degree of bumper override of the delivery truck with the sedan, so that the engine was driven back toward the passenger compartment with intrusion of the steering wheel into the driver's space (Figure 8).

Figure 8

As there was no airbag to deploy and the patient was unrestrained, she impacted with the steering wheel hub with her left anterior chest wall (Figure 9). The force of this unbuffered impact produced fractures of the first through the fifth ribs on the left, just to the left of the costal-sternal junction (Figure 10).

Figure 9

Figure 10

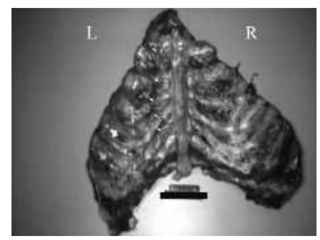


Figure 11

This impact produced a shearing type of complete transverse laceration of the aorta in the freely mobile isthmus region below the take-off of the left subclavian artery and just proximal to the aortic orifices of the third intercostals arteries which fix the descending aorta to the vertebral column. The leading edge of the disruption appeared to be at the point of fixation of the aorta to the left pulmonary artery by the ligamentum arteriosum. This rupture was not contained by the posterior mediastinal tissues, and consequently the entire cardiac output was ejected into the left thoracic cavity, with immediate death of the patient at the scene of the MVC (Figure 11).

Demographics of Aortic Injury

Of 324 autopsied MVC drivers and front-seat passenger fatalities (1997-2000), there were 43 fatal aortic injuries, or 13% of these fatalities (Table 1).

Table 1. Survival of Aortic Injury Cases	
Total aorta injury cases:	48
Dead at scene:	36 (75%)
Potentially survivable:	12 (25%)
Hospital deaths:	7 (15%)
Actual survivors:	5 (10%)

Of the fatal AI, 36 were scene deaths (ME) and 7 were hospital deaths (H). In addition there were 5 AI who were hospital discharge survivors (S). Thus, AI represented 13.3% of all fatally injured front seat MVC occupants. Moreover, it is discouraging to note that 75% of all AI patients were dead at the scene of the crash; only 25% were sufficiently vital to be able to reach the hospital alive in spite of brief urban transport times, and of these potential survivors less than half, 42%, (but representing only 10% of the total MVC induced aortic injuries) actually left the hospital alive.

With regard to the mechanism of the MVC induced AI, of the 48 cases, two cases were in so massive an MVC that the exact direction of the crash could not be assigned with certainty. Of the remaining 46, 74% were caused by Frontal (F) MVCs and 26% by Lateral (L) MVCs. Seatbelt restraints were used by only 12% of the Frontal crash AI and 36% of the Lateral crash AI patients. Airbag deployment occurred in 50% of the Frontal crashes, but surprisingly, in 36% of the Lateral crashes the airbag actually deployed, either due to the sudden arrest of the subject vehicle's forward motion, or due to the massive deformity of the subject vehicle consequent to the force of the Lateral impact. As a result, 74% of the Frontal-MVC and 82% of the Lateral MVC were ME cases. Neither seatbelt use nor airbag deployment appeared to influence the final outcome in patients with AI. However, when compared to a group of 27 crash study patients admitted to the hospital with similar severe thoracic injuries (ST), but without AI, there was a significant difference ($p< 0.05$) with respect to a greater use of seatbelts (AI 10% vs ST 60%) and a higher incidence of airbag deployment (AI 50% vs ST 72%) in the non AI thoracic injury patients. Possibly as a result of the use and/or deployment of these protective devices, there was a significantly ($p<0.05$) higher survival rate in the ST patients (83%) compared to the potentially survivable AI patients, where only 42% of the AI patients who reached the hospital while still viable actually left the hospital alive.

Location of Aortic Injuries

The sites of the primary aortic injuries is shown in Figure 12, with the majority of the patients who reached the hospital alive and the actual hospital survivors having their main lesion in the isthmus region or the descending thoracic aorta.

However, there were frequently multiple areas of aortic injury, some of which did not result in a complete disruption of the aorta, but were limited to the intima and the media of the aortic wall.

Figure 12

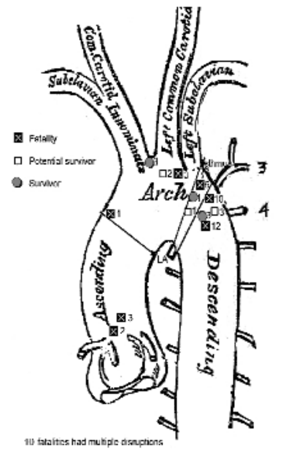


Table 2. Location of Aortic Injuries			
(24% had multiple lesions)	**Survival**	**Hospital deaths**	**Dead at scene**
N	5	7	36
Proximal aorta injury	1 (2%)*	0	6 (13%)
Aortic arch injury	1 (2%)	3 (6%)	12 (25%)
Descending aorta injury	4 (8%)	4 (8%)	29 (60%)

The site of the principal aortic injury appeared to play a major role in the type of outcome. As shown in Table 2, while 13% of the AI (all were ME cases) had a major proximal aortic injury, only one* of the hospital survivor AI cases in this series sustained such a lesion and it was only a small non-ruptured bulge with the primary pseudoaneurysm occurring at the aortic isthmus. Of the total AI, 33% had an injury to the aortic arch, only one of whom survived (2%), but of those with an aortic arch injury 25% were scene death ME cases. However, 76% of the AI had an aortic injury at the aortic isthmus, or just below the ligamentum arteriosum in the proximal descending aorta, but of these 37 cases, only 4 actually left the hospital alive. There were 29 ME cases, representing 60% of the total AI patients, who had their lesion in a similar location. In regard to the sites of AI, it is important to emphasize that in 24% of all the cases there were multiple sites including various combinations of proximal, arch and isthmus lesions.

In addition to the general direction of the MVC (Frontal vs Lateral), the Principal Direction of Force (PDOF) appeared to play some important role in the mechanism and location of the aortic injury. In 30 of the cases, a precise PDOF could be related to the site (or sites) of the aortic injury.

These data are shown in Figure 13 where it can be seen that all of the proximal aortic (P) and most of the aortic arch injuries (A) occurred in frontal MVCs in which the PDOF was between 0 and 30 degrees to the right, or between 360 and 330 degrees to the left of the vehicle's front center point (0/360 degrees). Moreover, all of those cases in which there were multiple sites (PA, PD, AD)

Figure 13. Sites of Aortic Injury by Direction of Impact Force

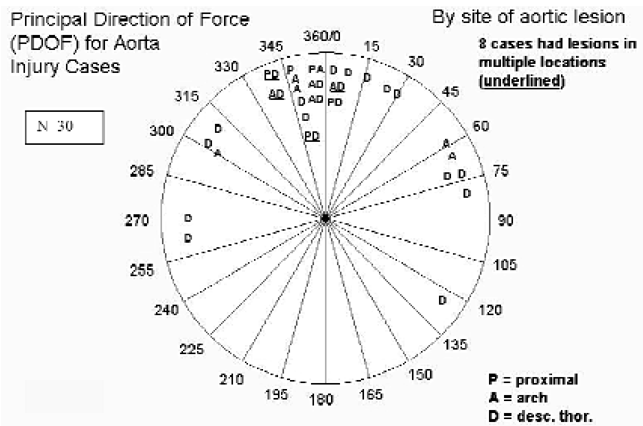
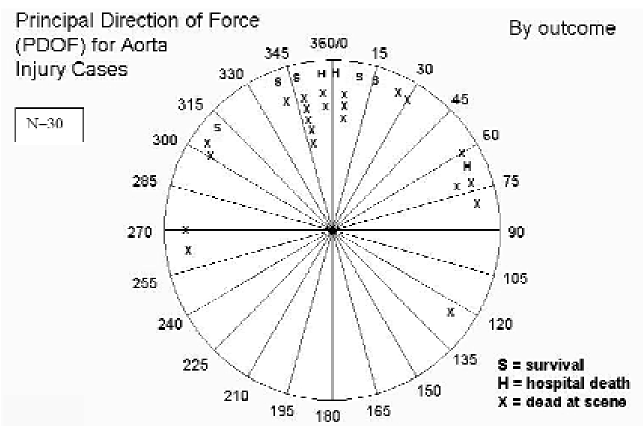


Figure 14 - Sites of Aortic Injury by Outcome

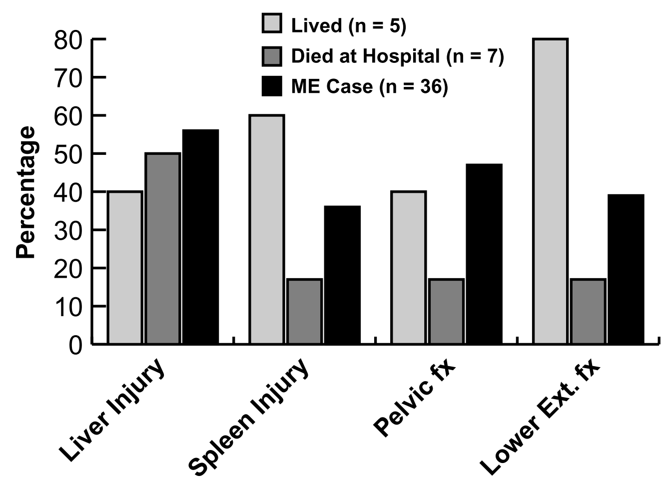


resulted from impacts within this range of PDOFs. However, while 3 of the 4 Frontal MVC hospital survivors (S) had their major lesion in the isthmus or proximal descending aorta (Figure 14), one also had a small contained lesion of the proximal aorta. The only Frontal MVC AI survivor who did not have an isthmus or proximal descending aortic lesion had a small pseudoaneurysm contained within the adventitia of the aortic arch between the innominate artery and the left carotid artery. The majority of the patients whose AI resulted from a Lateral MVC had their lesion in the isthmus or descending aorta. There was no proximal AI in this group.

In weighing the major factors which contributed to the final outcome of those patients with AI who did not instantly exsanguinate from their injury, there are two critical relationships which must be considered. The first, although not necessarily the most important variable, is age. While the incidence of aortic injury was greatest among the younger age groups, with a peak in the 26 to 35 year range (13 cases), there were cases seen steadily even in the 96 to 100 year age range and surprisingly, there were survivors even in the aged population. Not unexpectedly, the ratio of male to female AI patients was slightly more than 3:1, but in this small population the only potential survivors in the over 65-year group were male.

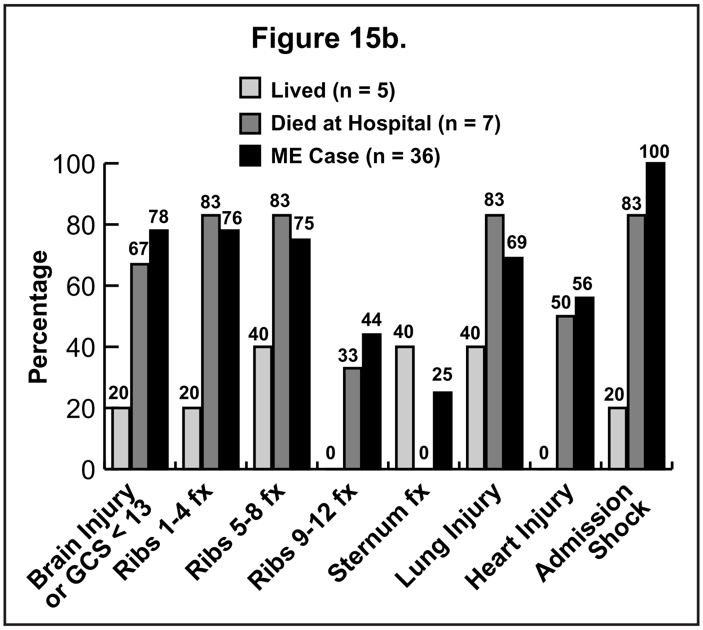
The second and undoubtedly most important factor affecting the final outcome in the AI patient is the incidence and severity of the associated injuries and their consequent physiologic complications; namely circulatory shock and severe brain injury as measured by their admission Glasgow Coma Scale (GCS) score. These data are shown in Figures 15A and 15B. Figure 15A demonstrates the incidence of major visceral (liver and spleen) and non-thoracic fracture injuries (pelvic and lower extremity fractures) in each of the three groups: hospital survivors (S), hospital deaths (H), and scene fatalities (ME). It can be seen that while the incidence of hepatic injury rose progressively from S (40%) through H (50%) to ME (59%), it was the hospital survivor group who had the highest incidence of splenic injuries (60%) and lower extremity injuries (80%) compared to the other two groups. Indeed, even in the ME cases, injuries to the spleen were only found in 35% and those to the lower extremities were only found in 38% of the cases. Pelvic fractures in the S and ME groups were of similar incidence (40% and 47% respectively) and both were higher than the incidence seen in the H group.

Figure 15a.
Visceral and Lower Extremity Injuries Associated with Aorta Injuries by Outcome



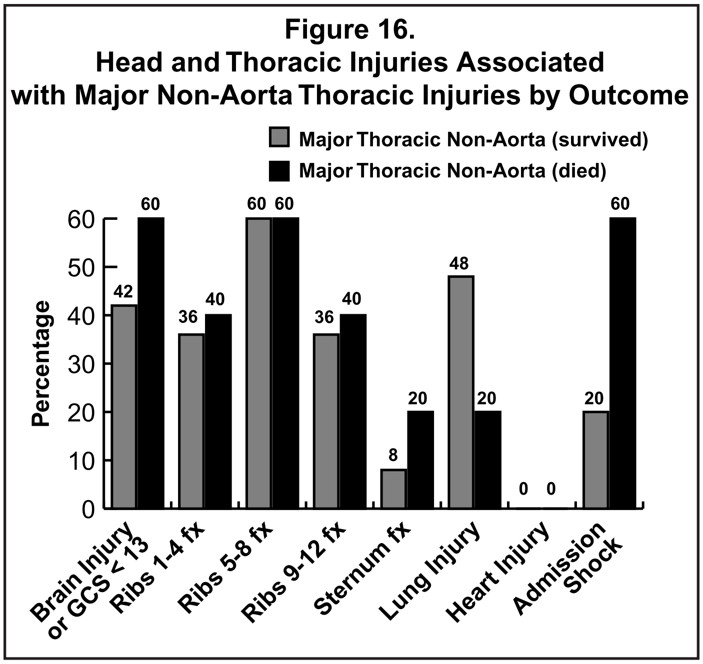
However, perhaps the most revealing differences in the pattern of injuries which separated the hospital survivor AI patients (S) from the ME and H patients is seen in Figure 15B. Here it can be noticed that the pattern of incidence of the most critical associated injuries was vastly different in the S patients compared to both the hospital death (H) and the scene death (ME) groups. The incidence of associated severe intrathoracic injuries to lung (40%) in S was substantially less than that seen in H (83%) or ME (68%) and there was no evidence of cardiac injury in S, compared to a 50% H and 56% ME incidence, respectively. As a result of this vastly reduced incidence of associated injuries to other vital organs or major skeletal systems, there was a marked decrease in the consequent state of physiologic shock in S patients (20%) compared to 83% in the hospital deaths (H), and of course all of the ME cases by definition had passed beyond shock into final irreversible physiologic collapse.

A perhaps equally important difference in the incidence of physiologic injury was seen with regard to the brain (Figure 15B). Again, only 20% of the hospital survivors (S) had a brain injury severe enough to produce a Glasgow Coma Scale (GCS) score of less than 13, while 67% of the H patients reached this level. In the ME cases, autopsy findings showed that there was a similar incidence (76%) of pathologic evidence of significant brain injury (epidural, subdural, or intraparenchymal hemorrhage, as well as brain laceration, or contusion) which would have been expected to have produced at least a similar level of brain deterioration as that represented by a GCS of <13.



Of considerable interest with regard to the site and outcome of the AI was the incidence of rib fractures at different levels of the chest wall. As also shown in figure 15B, while only 20% of the AI survivors (S) had rib fractures involving ribs 1-4, 83% of the H patients and 76% of the ME cases had fractures at this level. Indeed the one patient in the S group with rib fractures at this level was the one with a small contained rupture of the aortic arch between the innominate and right carotid artery. Also, S patients generally had a reduced incidence of rib 5-8 fractures (40%) compared to those found in the H (83%) and ME (74%) groups and no S patient among the AI survivors had a fracture involving ribs 9-12. In contrast, the AI survivors sustained a greater incidence of sternal fractures than the other two groups, but had no cardiac injuries.

Indeed as shown in Figure 16, which documents the pattern of injuries seen in the 27 patients with severe thoracic trauma not involving an aortic injury (ST), the general pattern of thoracic organ, skeletal and rib injuries is similar to the AI survivor (S) group, especially with respect to the incidence of rib 1-4 fractures and lung injuries, and the total absence of cardiac injuries. These data suggest that the main force of the MVC impact injury in the AI hospital-survivor group is delivered at a lower level on the body generally sparing the head and upper thorax, but causing a greater incidence of splenic and lower extremity injuries. The S patients also had an incidence of pelvic fractures which was greater than that found in the H patients, although it approached that seen in the ME cases.



However, both the H and ME patients generally had much more severe multitrauma than the S, as evidenced by the far greater incidence of admission shock found in H (83% vs 20% in S) and of course the 100% loss of all circulatory and cardiorespiratory function in the scene deaths (ME). Also, while the pattern of injuries in surviving AI patients might suggest a greater likelihood that these were sustained in a Lateral MVC, as seen in Figure 14, four of the five AI hospital survivors (S) had impacts delivered in the Frontal direction with PDOFs between 330 degrees to the left and 30 degrees to the right of the 0 degree front-center point of the vehicle.

The major difference between Frontal and Lateral MVCs responsible for the production of the resulting AI is the component of the passenger compartment which becomes the specific thoracic contact/intrusion site producing the AI. The incidence of these sites as the cause of the aortic disruption(s) is shown in Table 3. In 5 of the ME MVCs (4 Frontal and 1 Lateral) the impact was so catastrophic that no specific site could be identified and in 3 Frontal MVCs the identification was equivocal. However, in those Frontal MVCs where a contact/intrusion site could be identified with security, it was determined that in 53% of the cases the steering wheel assembly was responsible, in 15% of cases the AI was produced by anterior chest contact with an expanding airbag cover due to the patient's too close proximity to the SRS, and in 12% of cases there was thoracic contact with the instrument panel. In contrast, in the Lateral MVCs in which an AI occurred, all of the identified contacts productive of an AI came from crash-induced intrusions of the side-door panel and/or the B-pillar.

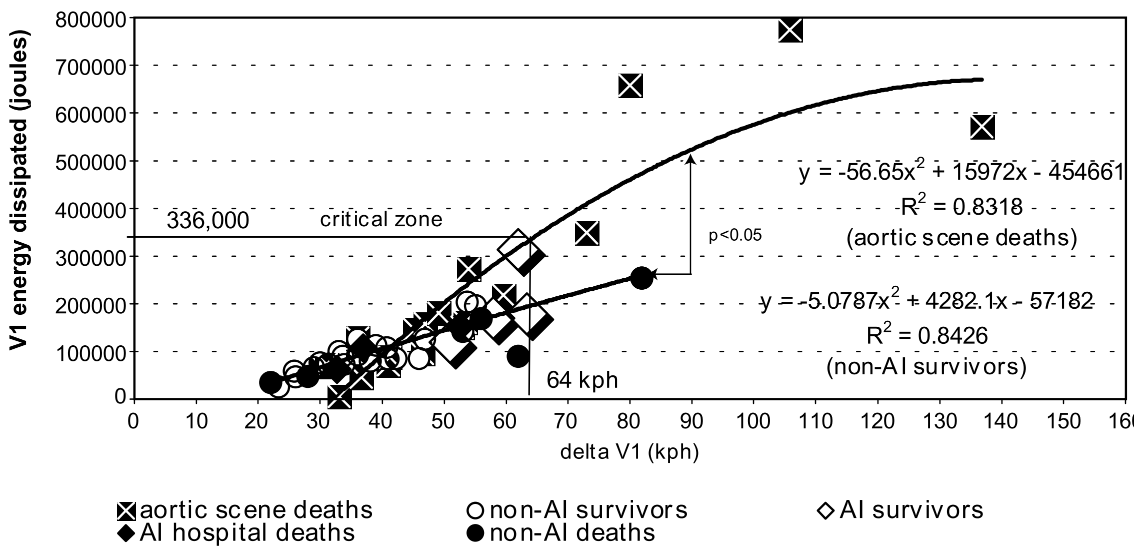
Table 3. Compartment Structure Impacts Related to Aortic Injury

	Catastrophic	Steering wheel	Air bag	Instrument panel	Side door/ B pillar	unknown
Frontal (34)	4 (12%)	18 (53%)	5 (15%)	4 (12%)		3 (9%)
Lateral (11) (6 right, 5 left)	1 (9%)				10 (91%)	

These data concerning the differing causes, sites and severities of AI, and the incidences of multiple AI lesions, as well as the different patterns of associated injuries found in the hospital survivors, compared to the in-hospital and scene deaths, suggests that a different magnitude of forces may have played a part in the creation of this lesion in these groups. To attempt to examine this question the calculated instantaneous deceleration on impact (delta V1) of the subject vehicle (V1) was evaluated with respect to the estimated deceleration energy (IE) imparted to V1 on impact, as computed from the WINSMASH program based on the direction of the MVC, the relative masses of the struck and striking vehicles and the magnitude of the V1 vehicle deformity and its stiffness characteristics. The data from all the ME scene deaths (including AI secondary to car crashes with other cars, sport utility vehicles, trucks, or fixed objects) was used to develop a linear regression which was then compared with a similar regression computed from the data of surviving front seat drivers or passengers with severe thoracic trauma (ST-survivors) who did not have an AI. These regressions, together with the data points from the AI hospital survivors and the in-hospital AI and ST deaths are shown in Figure 17.

Here it can be seen that each of the two regressions (ST-survivors and ME-deaths) has a coefficient of determination (R2), which explains more than 80% of the variability in the data. More important, these two regressions have significantly different slopes ($p<0.05$), with the deceleration impact energy (IE) rising to a greater extent per unit

**Figure 17.
All Non-AI Survivors Compared to All Aortic Scene Deaths,
V1 Energy Dissipated vs. Delta V1**



increase in delta V1 in the ME aortic disruption cases than in the surviving severe thoracic trauma patients (ST-survivors) who did not sustain an AI. When the data points for the potential and actual survivors of AI (H& S) are plotted on this graph, it can be seen that, with one exception, they tend to lie on, or close to, the mean regression slope for the ST survivors. This relationship suggests that, in addition to the direction of the crash, the age of the patient, and the anatomic level of the primary impact point on the patient's body, there is a critical threshold of impact energy dissipation (IE) for a given level of delta V1 which cannot be exceeded without making the incidence of AI more likely. Also to be noted is that there appears to be a Critical Zone, delimited by a level of delta V1 of 64KPH and an IE of 360,000 joules, above which the likelihood of a fatal AI secondary to a thoracic impact at MVC becomes extremely high, regardless of the direction of the crash. All AI in this series who lay above these thresholds died at the scene of the MVC. Nevertheless, even within this Critical Zone, when compared to all the ST cases (survivors and deaths), the potentially survivable AI patients, i.e., (S&H) those who reached hospital alive, had more severe brain injury (S&H 45% vs ST 17%), more fractures of ribs 1-4 (S&H 55% vs ST 27%), more injuries of heart (S&H 20% vs ST 0%) and lung (S&H 64% vs ST 43%), a higher incidence of shock (S&H 55% vs ST 27%) and a lower survival (S&H 42% vs ST 83%). However, this pattern of better outcomes even within the delta V1/IE Critical Zone also may have been facilitated by the much higher use of seatbelts (S&H 10% vs ST 60%) and the greater incidence of airbag deployment (S&H 50% vs ST 72%) in the thoracic trauma patients who did not sustain an AI, compared to the potentially survivable AI patients.

Discussion

As noted by Parmley et al (1986), the occurrence of a disruption of the thoracic aorta as the consequence of blunt trauma to the thorax was first described by Andreas Vesalius in 1557. However, it was considered a rare catastrophe until the modern era of mechanized transportation. Indeed, even as a result of domestic motor vehicle collisions, it was demonstrated to be a disease of small incidence in studies of fatal MVCs done during the Great Depression until the beginning of World War II, when the autopsy series of 7000 motor vehicle crashes done by Strassman (1947) showed an incidence of AI of only 0.73%. However, as America's love affair with cars and speed became more passionate in the quarter century of affluence beginning after 1950 which solidified the American Century, studies of fatal MVCs by Greendyke (1966) and by Sutorius, Schreiber and Helmsworth (1973) showed that the incidence of AI in fatal crashes had risen to between 10 to 15%. Similar autopsy studies carried out between 1984 - 1988 by Feczko et al (1992) and between 1980 –1985 by Williams et al (1994) in mid-sized cities surrounded by largely rural areas showed a similar incidence, 12% and 17% respectively. In contrast, Dischinger et al's (1988) observations of autopsied victims in a highly urbanized state traversed by many high speed highways demonstrated an incidence of 27% AI in MVC drivers and 19% in passengers for an overall occurrence rate of 26% of MVC fatalities. These horrifying statistics, it must be emphasized, represented an era where seatbelt use was minimal and no airbag technology had been introduced into the increasingly overpowered US automotive fleet.

Nevertheless, not dissimilar findings were seen in the 1991–1995 Canadian study carried out in metropolitan Toronto by Katyal et al (1997), where seatbelt use was legally mandatory and used by 70% of their cases. In spite of this high use of restraints, AI was found in 21% of the autopsied fatalities. However, the absence of airbag deployment was indicated as a factor by these authors. Nevertheless, they introduced an important observation into the demographics of this injury; namely, they also included the 16 additional AI cases that survived to reach hospital alive, so that the true incidence of aortic disruption in their area during this period could be ascertained. Thus, there were 97 case of AI, with a scene mortality rate of 83%. Although, the authors did no detailed crash reconstruction, they did identify the direction of the crash and the site of the primary point of impact on the subject vehicle. In this study, 49.5% of the AI resulted from a lateral impact, 50.5% were induced by a frontal MVC and in 94% of all the AI cases at least one of the aortic injuries lay in the peri-isthmic region.

It is of interest to compare these data obtained in time periods when an airbag SRS was not included as a feature of the automotive safety package, with the AI and ST patient data from the present study. In contrast to the Canadian study, done at a time when none of their AI cases appears to have had airbag protection, the present group of AI patients had airbag deployment in 50% of the Frontal MVC cases. 74% of all these cases were frontal in character. While it is not clear whether airbag deployment played a statistically significant role in preventing AI, it is of interest to note that in the Toronto study [Katyal *et al*, 1997] the overall incidence of AI averaged 24 cases per year. However, in the present study the average incidence was only 16 cases per year and the scene death rate was reduced to 75%, compared to 83% in the Canadian series. As noted earlier, the incidence of fatal AI in this study was 13%, compared to 21% in the Toronto study. Thus, both the occurrence of AI and the incidence of ME cases appear to be lower after the introduction of airbag technology into at least part of the car fleet than was found in the most immediately prior series [Katyal *et al*, 1997] analyzed before this safety device was introduced into the car fleet to any great extent.

Moreover, when the present group of AI cases is compared to a contemporaneous group of patients who sustained similar severe thoracic injuries (ST) without AI, it can be seen that the incidence of both airbag deployment and seatbelt usage were substantially greater in the ST group. Also, the data presented in Figure 3B demonstrate that those AI patients who were hospital survivors had a significantly lower incidence of moderate to severe brain injury (as defined by autopsy findings, or by clinical evidence of a GCS <13) than either the hospital deaths (H), or the ME cases. Thus, since previous studies [Loo, Siegel, Dischinger *et al*, 1996; Siegel, Loo, Dischinger *et al*, 2001] have demonstrated that airbag deployment in Frontal MVCs provides a statistically significant reduction in the functional severity of MVC induced traumatic brain injury, it seems probable that in those cases where the AI is contained within the periaortic tissues long enough to allow corrective surgical therapy, the airbag protective effect with respect to the brain may be a critical factor in increasing the potential for ultimate survival. In this regard, it is also of interest to note that four of the five hospital survivors sustained their AI in a frontal (PDOF 330 to 0 to 30 degrees) MVC, and all were airbag protected.

The importance of other associated visceral injuries seen in this series in determining the ultimate outcome in AI patients who survive the MVC long enough to reach the hospital alive is consistent with the data found in the 1993-1996 multi-institutional prospective study of blunt aortic injury patients who survived long enough to be admitted to a trauma center [Fabian *et al*, 1997]. While that 50 center study by its definition excluded ME cases, and was not stratified with respect to AI patients with or without other major visceral injuries, it can be seen that there was a similar high incidence of brain, liver, and lung injuries, as well as a 46% incidence of multiple rib fractures, and that the non AI causes of death were most heavily weighted to brain injury, Multiple Organ Failure, and Acute Respiratory Distress Syndrome, all of which would appear related to these identified organ injuries.

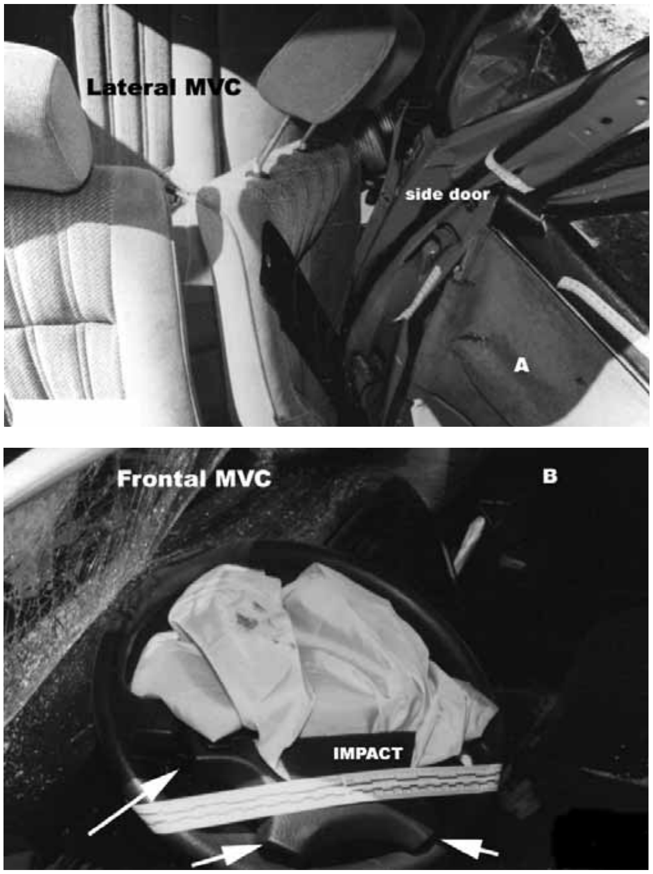
While a great deal of speculation has been made about the mechanisms involved in aortic transection injuries, it has been difficult to reproduce this injury in human cadaveric models [Eppinger, 1978; Bass, Darvish, Bush *et al*, 2001]. However, most investigators agree that a differential rate of deceleration between the fixed and mobile portions of the aorta produces a point of stress which is maximal at the isthmus. At this portion of the aorta, the arch of the aorta tethered by the major aortic arch vessels proximally is briefly free, until fixed by the third and subsequent distal intercostal arteries which arise directly from the descending aorta, and by the ligamentum arteriosum which connects the isthmus region to the left pulmonary artery. Indeed, in many of the cases of descending AI autopsied in this study, the tear appeared to begin at the ligamentum and to extend posteriorly in a circumferential manner leaving only a small bridge of intact aorta connecting the proximal and distal segments just above the intra-aortic orifices of the third intercostal arteries.

Obviously, somewhat different mechanisms have been proposed for AI secondary to frontal as opposed to lateral MVCs. Wilfert and Voigt (1971) have proposed a "shoveling" effect whereby the patient's contact with the lower portion of the steering wheel rim forces the intrathoracic cardiac and proximal aortic structures upward with a fulcrum at the isthmus. This may account for some of the distal AI injuries seen here which resulted from frontal crashes, but as seen in Figure 14 all of the proximal AI occurred in Frontal MVCs, which suggests a powerful direct anterior-posterior compression producing a bursting force. This mechanism is made more probable by the observation that in 15% of the Frontal MVCs, the AI was due to an anterior chest contact with a fully powered exploding airbag cover and in 12% of Frontal MVC cases the AI followed the chest contact of an unrestrained passenger with the instrument panel. A number of experimental studies in animal models [Moffat, Roberts, Berkas, 1966; Viano, Haut, Golocovsky et al, 1978] and using human cadaveric aortas [Bass et al, 2001; Viano, King, Melvin *et al*, 1989; Nahum, Kroell, Schneider, 1973] have explored the concept that the deceleration induced chest compression may induce extremely high intraortic pressures which may be responsible for the AI. However, in Bass's very precise studies of longitudinal and circumferential stresses induced by in vitro pressure impulse testing of human aortas, he found that pressure increases rising to more than 85kPa at rates exceeding 1000kPa/sec were more likely to produce longitudinal ruptures at the isthmus, rather than the clinically found transverse AI disruptions. Also, their studies noted that both the circumferential as well as the longitudinal stress-to-stretch ratios were most rapidly achieved in the stiffer aortas of patients older than 65 years, whereas, as widely reported in the literature, and in the present study, the vast majority of AI cases (both survivors and fatalities) occur in the young.

A great deal of comment has been made about the absence of chest wall fractures [Shkrum et al, 1999; Hossack, 1980] in many AI patients. However, as shown in Figure 15B, there appears to be a high incidence of upper rib fractures (ribs 1-4 and 5-8) in the ME and H cases, but these were less common in the hospital survivors and, since most surgical series reported deal only with patients reaching hospital alive, it is likely that the high incidence of thoracic wall bony injury has been overlooked. However, these data do not support the largely discredited "osseous pinch" theory [Crass *et al*, 1990].

Rather, they suggest that the mechanism of AI due to differential deceleration between the relatively tethered and more mobile parts of the aorta may occur in response to a

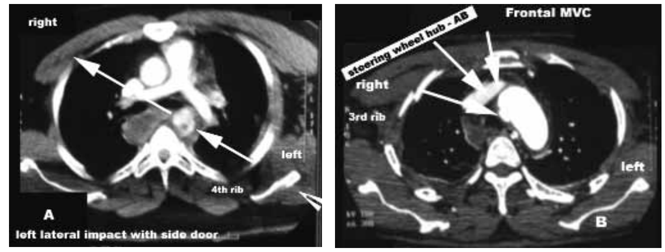
Figure 18. Site of Impact Resulting in Aortic Injury. A: Lateral MVC Left Chest Impact with Side Door and B Pillar; B: Frtonal MVC Right Chest Impact with Air Bag Cover and Steering Wheel Hub



highly focused trajectory of impact force at the time of the MVC, initiated at the precise point of the patient's bodily contact with the structures of the passenger compartment. This would appear to be a more likely mechanism in Lateral MVCs where the patient's body is in very close proximity to the intruded side door (Figure 18A) and B-pillar structures, which directly transmit the crash impact energy to the thoracic structures. However, it can also occur in Frontal MVCs when the anterior chest has a very discrete point of impact with the steering wheel hub (Figure 18B), airbag cover or instrument panel.

Evidence for this sort of mechanism can be seen in the Computer Tomographic pictures (Figures 19A and 19B) of the Lateral and Frontal MVC patients whose points of vehicle compartment contact were shown in Figures 18A and 18B, respectively. In these CT cross-sections, the level of the rib fractures which mark the site of the passenger compartment structure's impact on the body are seen to lie at a thoracic level that is in the direct line of a trajectory which passes through the point of the aortic disruption. Obviously, such a highly focused impact energy transmission need not always result in rib or sternal fractures, but

Figure 19. Computer Tomographic Images of Aortic Injury of Patients Injured in the A: Lateral and B: Frontal Impacts Shown in Figure 18



the concept that a force vector may be transmitted with a different degree of efficiency at different levels of the thorax needs further investigation. This idea is further supported by the evidence, also shown in Figure 15, that the AI hospital survivors, with or without rib 9-12 fractures, tend to have more of their associated injuries in the lower thoracic cage protected structures (i.e.: spleen) and in the pelvis and lower extremities, than do the ME and H cases.

Finally, having now introduced the issue of the Impact Energy (IE) imparted to the subject vehicle (V1) at the time of the MVC as a function of the deceleration impact velocity (delta V1) modulated by the stiffness characteristics of the motor vehicle which result in the magnitude of the vehicle and passenger compartment deformation, it is of interest to consider the data presented in Figure 17. While there are many sources of inaccuracy in the estimations of delta V1and the impact energy (IE) dissipation derived from WINSMASH, nevertheless, in the absence of direct measurements of the primary variables involved (which may come from future studies using Automatic Crash Notification sensor technology), perhaps these derived data offer some clues as to the nature and quality of the force mechanisms responsible for AI. As can be seen, when the impact energy (IE) dissipated in the MVC is considered as a function of the delta V1, there appears to be a highly significant relationship found in the AI scene death ME cases which forms an upper limit for potential patient survival.

In contrast, patients with severe thoracic MVC trauma (ST), but who did not manifest AI, had a significantly lower IE to delta V1 slope, regardless of their final outcome. However, those AI patients who survived long enough to reach hospital alive (the potential AI survivors) fell between these two regression derived slopes and in general were closer to the ST slope than to the ME one. Moreover, the deaths in the H cases were generally secondary to an interaction of the AI induced shock state with one or more of the associated organ injuries, especially that of the brain, as has been noted previously in other types of trauma cases [Siegel, Rivkind, Dalal et al, 1990]. This may be particularly relevant in two of the H cases where there was a substantial delay in definitive treatment due to a mistriage of the patient to a non-trauma center hospital before the AI was suspected. In these cases, the prolonged hypoperfusion due to their semi-contained AI, by producing an increasing oxygen debt [Siegel et al, 1990; Rixen, Raum, Bouillon et al, 2001], may have contributed to their ultimately fatal outcome.

Also, as shown in Figure 17, there appears to be a Critical Zone within which factors of associated injuries, effectiveness of field resuscitation, time to definitive therapy, etc. may play a role in influencing the final outcome. However, outside and above this IE/delta V1 threshold it would appear that there is little chance of field survival. This implies that an engineering, rather than a medical solution to this particular disease of trauma must be found, by the introduction of safety devices which will reduce the focused force thresholds below the critical level for AI and which will also prevent, or ameliorate the severity of the associated organ injuries, especially those of the brain and the heart. These engineering modifications may include sensor driven frontal and side airbags which are modulated with respect to occupant body weight and position, improved side door and B-pillar construction which directs the MVC impact forces away from the occupants, and universal Automatic Crash Notification technology which will allow a more effective early response that may reduce the shock driven oxygen debt injury [Siegel et al, 1990; Rixen et al, 2001] to critical associated organs so as to provide a greater margin of safety to potentially survivable AI patients who can be brought to hospital alive.

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References

Bass CR, Darvish K, Bush B, Crandall JR, et al. Material properties for modeling traumatic aortic rupture. Stapp Car Crash Journal 45: 1-18, 2001

Ben-Menachem Y. Rupture of the thoracic aorta by broadside impacts in road traffic and other collisions: further angiographic observations and preliminary autopsy findings. J Trauma 35: 363-367, 1993

Careme LM. Thoraco-abdominal impact tolerance levels in side impact accidents – collection of field data and mathematical models. Society of Automotive Engineers, Inc. SAE Report No. 890385, 1989

Crass JR, Cohen AM, Motta AO, Tomashefski JF Jr, Wiesen EJ. A proposed new mechanism of traumatic aortic rupture: the osseous pinch. Radiology 176: 645-649, 1990

Dischinger PC, Cowley RA, Shanker BS, Smialek JE. The incidence of ruptured aorta among vehicular fatalities. Proc. AAAM 32: 15-23, 1988

Eppinger RH. Prediction of thoracic injury using measurable experimental parameters. Proc 6th Internat Technical Conf on Experimental Safety Vehicles 12-15 Oct, 1978

Fabian TC, Richardson JD, Croce MA, et al. Prospective study of blunt aortic injury: multicenter trial of the American Association for the Surgery of Trauma. J Trauma 42: 374-383, 1997

Feczko JD, Lynch L, Pless JE, Clark MA, McClain J, Hawley DA. An autopsy case review of 142 nonpenetrating (blunt) injuries of the aorta. J Trauma 33: 846-849, 1992

Greendyke RM. Traumatic rupture of aorta. Special reference to automobile accidents. JAMA 195: 119-122, 1996

Hossack DW. Rupture of the aorta in road crash victims. Aust NZ J Surg 50: 136-137, 1980

Katyal D, McLellan BA, Brenneman FD, Boulanger BR, Sharkey PW, Waddell JP. Lateral impact motor vehicle collisions: significant cause of blunt traumatic rupture of the thoracic aorta. J Trauma 42: 760-772, 1997

Lasky II, Nahum AM, Siegel AW. Cardiac injuries incurred by drivers in automobile accidents. J Forensic Sci 14: 13-33, 1969

Loo GT, Siegel JH Dischinger PC, et al. Airbag protection versus compartment intrusion effect determines the pattern of injuries in multiple trauma motor vehicle crashes. J Trauma 41: 935-951, 1996

Lundevall J. The mechanism of traumatic rupture of the aorta. Acta Path Microbiol Scand 62: 34-46, 1964

Moffat RC, Roberts VL, Berkas EM. Blunt trauma to the thorax: development of pseudoaneurysms in the dog. J Trauma 6: 666-680, 1966

Nahum AM, Kroell CK, Schneider DC. The biomechanical basis of chest impact protection: I. Force-deflection characteristics of the thorax. J Trauma 11: 874-882, 1971

Nahum AM, Kroell CK, Schneideer DC. The biomechanical basis of chest impact protection. II. Effects of cardiovascular pressurization. J Trauma 13: 443-459,1973

Parmley LF, Mattingly TW, Manion WC, Jahnke EJ Jr. Nonpenetrating traumatic injury of the aorta. Circulation 17: 1086-1101, 1986

Rixen D, Raum M, Bouillon B, Lefering R, Neugebauer E. Base deficit development and its prognostic significance in posttrauma critical illness: an analysis by the trauma registry of the Deutsche Gesellschaft fur Unfallchirurgie. Shock 15: 83-89,2001

Saylam A, Melo JQ, Ahmad A, Chapman RD, Wood JA, Starr A. Early surgical repair in traumatic rupture of the thoracic aortas. Report of 9 cases and review of the current concepts. J Cardiovasc Surg 21: 295-302,1980

Sevitt S. The mechanisms of traumatic rupture of the thoracic aorta. Br J Surg 64: 166-173, 1977

Shkrum MJ, McClafferty KJ, Green RN, Nowak ES, Young JG. Mechanisms of aortic injury in fatalities occurring in motor vehicle collisions. J Forensic Sci 44: 44-56, 1999

Siegel JH, Rivkind AI, Dalal S, Goodzari S. Early physiologic predictors of injury severity in blunt multiple trauma. Arch Surg 125: 498-508, 1990.

Siegel JH, Loo GT, Dischinger PC, et al. Factors influencing the patterns of injuries and outcomes in car versus car crashes compared to sport utility, van, or pick-up-truck crashes: Crash Injury Research Engineering Network Study. J Trauma 51: 975-990, 2001

Strassman G. Traumatic rupture of the aorta. Am Heart J 33: 508-515, 1947

Sutorius DJ, Schreiber JT, Helmsworth JA. Traumatic disruption of the thoracic aorta. J Trauma 13: 583-589, 1973

Turney SZ, Attar S, Ayella R, Cowley RA, McLaughlin J. Traumatic rupture of the aorta, J Thoracic Cardiovasc Surg 72: 727-734, 1976

Viano DC, Haut RC, Golocovsky M, Absolon K. Factors influencing biomechanical response and closed chest trauma in experimental thoracic impacts. Proc 22nd AAAM Conf 10-14 July, 1978

Viano DC. Biomechanics of nonpenetrating aortic trauma: a review. Society of Automotive Engineers, Inc. SAE Report No. 831608, 1983

Viano DC, King AI, Melvin JW, Weber K. Injury biomechanics research: an essential element in the prevention of trauma. J Biomech 22: 403-417, 1989

Voigt GE, Wilfert K. Mechanisms of injuries to unrestrained drivers in head-on collisions. Society of Automotive Engineers, Inc. SAE Report No. 690811, 1969

Wilfert K, Voigt G. Mechanisms of injuries to unrestrained front seat passengers and their prevention by progressive instrument panel design. Society of Automotive Engineers, Inc. SAE Report No. 710862, 1971

Williams JS, Graff JA, Uku JM, Steinig JP. Aortic injury in vehicular trauma. Ann Thorac Surg 57: 726-730, 1994

Zehnder MA. Delayed post-traumatic rupture of the aorta in a young healthy individual after closed injury. Angiology 7: 252-267, 1956

William Lehman Injury Research Center

At the University of Miami School of Medicine

CIREN Program Report

Lifesaving through Better Recognition and Treatment of Crash Injury

This report illustrates the value of CIREN and the CIREN research process. Multi-disciplinary observational studies of serious injury crashes in CIREN generate insights into safety problems and potential solutions. Subsequent analyses can then advance scientific understanding of ways to improve the prevention and treatment of crash injuries.

Since its inception in 1991, researchers at the University of Miami's William Lehman Injury Research Center (WLIRC) have been conducting research on crashes, injuries, treatments, and outcomes. From the beginning of their work, researchers in Miami and at NHTSA recognized a need for better use of information from the crash to provide more effective emergency medical care to save lives and reduce disabilities.

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

Research Note

August 1993

Detection of Internal Injuries in Drivers Protected by Air Bags

Louis V. Lombardo
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Early results from research being conducted for the National Highway Traffic Safety Administration at Jackson Memorial Hospital in Miami by a team of medical, engineering and crash investigators suggest the emergence of changing injury patterns in motor vehicle crashes in which an air bag has deployed. Emergency medical services (EMS), both prehospital and hospital personnel, as well as the public, could benefit by becoming aware of these changing injury patterns.

Prior to air bags, drivers involved in crashes often had visible injuries such as bleeding, facial lacerations, abrasions, bruises, and broken facial bones that were obvious to rescue personnel. Now, drivers protected by air bags and safety belts often do not have visible injuries.

The research team has found that among drivers protected by air bags, in some severe crashes, serious internal injuries may be present but not be externally apparent. As is the situation with so many cases of blunt trauma (regardless of restraint system) that EMS providers encounter, internal injuries often are survivable if detected and treated in time, but can be fatal if not detected and treated appropriately and promptly.

EMS personnel conducting initial injury assessments should not be deceived by the lack of external injury signs and symptoms customarily associated with crash injuries. The driver protected by an air bag may look fine and feel fine, but not be fine. This may be important even for drivers who are fully ambulatory and apparently uninjured at the crash scene.

To address this situation and increase the chances that these crash victims receive timely and appropriate emergency care, the research team has offered suggestions for improved internal injury detection. One "tell-tale" indicator of injury is deformation of the steering wheel. In the case of a motor vehicle crash in which an air bag has deployed, rescue personnel should **lift the deployed air bag** to look for steering wheel deformation. After removal of the occupant, rescue personnel can easily lift the deflated air bag out of the way and make a visual check of the steering wheel.

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The first discovery was that while air bags protected the head and face in serious crashes, internal injuries could be missed. This happened because the previously common "tell tale" signs of bleeding from facial lacerations and broken facial bones were now not present to alert emergency medical care providers to the severity of the crash. In 1993, this discovery of a new injury pattern led NHTSA to issue a Research Note "Detection of Internal Injuries in Drivers Protected by Air Bags" to help emergency medical care providers better recognize occult internal injuries. The Research Note recommended that rescue workers "lift the deployed air bag to look for steering wheel deformation." [1] This "Lift and Look" tip to make a quick visual check was made to reduce the likelihood that potentially fatal internal injuries would be missed because motorists protected by air bags "may look fine and feel fine, but not be fine." Occult internal injuries from blunt trauma often are survivable if detected and treated appropriately in time.

In 1994, NHTSA published and widely distributed the poster "Look Beyond the Obvious" based on continued research at the Lehman Center [2]. This research found additional occult injury patterns that could be recognized using information from the crash. The "Look Beyond the Obvious" poster listed five indicators based on crash scene information to help emergency care providers detect internal injuries. These were organized into a checklist in an easy to remember mnemonic **SCENE**:

S – Steering wheel deformation? Look for a bent steering wheel.

C – Close proximity of the driver to the steering wheel?

For short and/or heavy drivers.

E – Energy of the crash? Twenty or more inches of vehicle crush.

N– Non-use of seat belts? Non-use of lap or lap/shoulder belts - look for internal injuries.

E – Eyewitness report of crash scene? Report crash severity indicators of occult injuries.

NHTSA continued efforts to use crash scene information to improve triage, transport, and treatment decision-making involving a team of researchers from several CIREN Centers. In 1996, NHTSA, under the direction of Dr. Ricardo Martinez, established a research project to improve the capability of identifying the characteristics of motor vehicle crashes that increase the risk of serious injury. The project was headed by Dr. Howard R. Champion, of the University of Maryland Medical School, and managed for NHTSA by Mr. Louis V. Lombardo [3-7].

URGENCY ACN software to Improve Triage, Transport and Treatment

This research resulted in the development of an algorithm to estimate the probability of the presence of serious injury in a car crash based on crash severity measures. In 1997, the NHTSA research team incorporated the algorithm into computer software named URGENCY 1.0 to relate crash severity measures to the probability of serious injuries. This software, URGENCY 1.0, was developed for use with Automatic Crash Notification (ACN) technologies to improve the rescue of seriously injured crash victims through faster and smarter emergency medical care decisions.

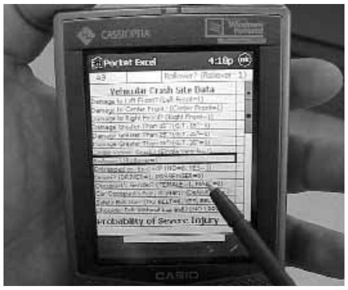
ACN with URGENCY software is designed to help the emergency medical care system distinguish, instantly and automatically, the approximately 250,000 vehicles in crashes with serious injuries that are both urgent and important from the 28 million vehicles in crashes each year that are mostly only property damage crashes.

URGENCY software uses vehicle crash sensor data in Automatic Crash Notification (ACN) systems to assist in instantly identifying crashes that are most likely to have time critical injuries. The URGENCY algorithm also provides the capability of improving injury identification, using data obtained from the scene. The prime purpose of the algorithm is to automatically provide emergency medical responders with objective information on crash severity to assist in detecting the approximately 1% of crashes with serious injuries needing the most urgent medical care. The algorithm calculates the risk of a MAIS 3+ injury being present in the crashed vehicle, instantly, and automatically at the time of the crash. The prediction can be subsequently updated as more information becomes available. The algorithm was based on multiple regression analyses using data from the National Accident Sampling System, Crashworthiness Data System, (NASS/CDS) years 1988-95.

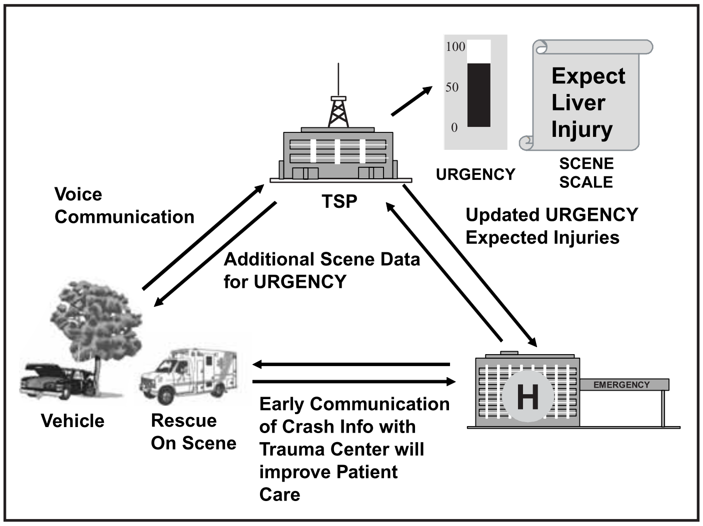
The accuracy of the URGENCY algorithm was first evaluated by applying it retrospectively to the population of injured occupants in the CIREN database at the Lehman Center [8].

URGENCY SCENE Software to Detect and Treat Occult Crash Injuries

In addition to developing improvements in URGENCY 1.0 for use with ACN, work has proceeded at the WLIRC to develop URGENCY SCENE 1.0 for use with handheld computers for use in all current crashes since most vehicle currently are not equipped with ACN systems.



The figure below illustrates how URGENCY information from the scene of a crash can be shared in the future to alert emergency medical care providers to improve treatment of crash victims using a pop-up Occult Injury Warning Flag "Expect Liver Injury".



The CIREN Centers are in a unique position to test and evaluate both the ACN and the SCENE versions of URGENCY and to demonstrate how we can do a better job of saving lives and preventing disabilities in the hopefully near future. Because the CIREN Centers have multi-disciplinary teams investigating crashes, injuries, treatments and outcomes, they are uniquely positioned to identify and promote successful technologies and techniques for improvement of the prevention and treatment of crash injuries.

Research on the continuous improvement of URGENCY software has shown that better recognition of injuries could be obtained if URGENCY 1.0 was modified to take into account the additional crash factors. Of particular interest has been the inclusion of factors to assist in predicting occult injuries.

Occult injuries comprise a very small fraction of all crash injuries, but account for large fraction of the unnecessary deaths. In many cases the deaths might have been prevented had the injuries been recognized and treated in time. Independent studies commissioned by NHTSA found a range of preventable deaths from 17% in rural Montana in a 1992 report [9], 12.9% in a rural Michigan study [10], and 7-21% in North Carolina in a 1995 report [11]. Better prediction of occult and other serious injuries could contribute to earlier recognition of time critical injuries and a reduction of deaths and disabilities from medical errors. [12-30]

Some of the factors, more recently identified by CIREN research, that lead to occult injuries are as follows:

- Certain far side crashes and offset crashes (see Case 1 Illustration)
  - These crashes may increase abdominal loading by the shoulder belt
- Crashes with rigid narrow objects (see Case 2 Illustration)
  - These crashes increase safety belt loading and delay air bag deployment
- Frontal crashes with unrestrained rear seat occupants (see Case 3 Illustration)
  - The driver and right front passenger become vulnerable to injuries from rear seat occupants thrown forward.
- Side crashes with the impact at the front wheels
  - Post crash spinning and delayed intrusion may contribute to aortic rupture
- Crashes involving multiple impacts
  - These crashes may introduce complex loading of the chest, abdomen & spine

Research at the WLIRC has proposed the above factors as additional useful indicators of the potential presence of occult injuries. These factors are being incorporated into later versions of URGENCY software as pop-up "Occult Injury Warning Flags" to supplement the serious injury probability ratings of URGENCY version 1.0. The aim of Occult Injury Warning Flags is to create a more robust information tool for point of care emergency medical alerts to prevent tragic misses of occult injuries.

Following is a case summary of a tragically missed liver injury in a far-side crash.

CASE 1 – Occult Liver Injury in Far-Side Crash

Case Vehicle 1997 Lexus

This case involved a 12 year old female who was the left rear-seat occupant in a 1997 Lexus LS 400. The occupant was wearing the available 3-point lap and shoulder restraint. The case vehicle was struck on its right side by a 1997 Toyota Tercel. The point of impact was at the rear right door opposite from the case occupant (see Figure 2.6). The lateral delta V was estimated to be 15 mph and the PDOF was 2 o'clock.

At impact, the occupant moved towards the right side of the vehicle consistent with the 2 o'clock direction of force impact. The left rear occupant contacted and loaded the lap and shoulder restraint with her chest and abdomen. The loading of the chest against the shoulder portion of the restraint resulted in bi-lateral lung contusions at the medial aspect of the lungs. These contusions were at the hilar region of the lung, below the sternum. In addition to the lung contusions, the left rear occupant sustained a heart contusion, which was most prominent over the left ventricle. Both these injuries are below the area that the shoulder restraint crosses when the restraint is used. The loading by the lower portion of the shoulder restraint against the lower right quadrant of the abdomen, resulted in a compression of the abdominal wall as well as the lower portion of the right rib cage. The compression of the lower right rib cage resulted in multiple superficial contusions to the posterior aspect of the left and right lobes of the liver.

Following the impact, the occupant was taken to a local hospital and admitted to the emergency room. She did not meet any trauma criteria based on physiologic criteria and was not triaged to a trauma center based on high suspicion of injury. Although the occupant complained of stomach pains on scene, she remained alert for three hours after the crash. After becoming dizzy in the ER, she was registered to be seen by the pediatrician, her vitals were taken, intravenous access attempted when she went into respiratory arrest. She was then transferred to the trauma room and CPR was initiated. An intra-abdominal hemorrhage was suspected. Her condition deteriorated and at 10:45pm, she was pronounced dead. This crash occurred at 07:02pm.

Occult liver bleeding was not recognized early enough in this case. Had this relatively minor liver injury been suspected earlier, additional abdominal evaluations would have lead to a discovery of her fatal injury. It should be noted that diagnosis and treatment of this injury could have been made in a non Level I trauma center if necessary. An indication that this injury was likely, based on mechanism, could have altered initial triage decisions and/or focused attention to the abdomen in the emergency room.

Case 2- Occult Liver/Head Injury in Crash with Rigid Narrow Object

Case Vehicle: 1997 Jeep Wrangler

The case vehicle was equipped with 3-point lap and shoulder restraints for all outboard seating positions. In addition the case vehicle was equipped with driver and passenger airbags both of which deployed on impact. The driver and lone occupant of the case vehicle was a restrained 40 year-old female, 64” (163-cm) tall and 135 lbs (61-kg).

The case vehicle was northbound at an estimated speed of 35-mph (56-kph). For unknown reasons (possibly due to a medical condition) the driver lost control and the case vehicle departed the intersection via the northeast corner. The front of the case vehicle impacted a metal traffic signal pole. Direct damage to the case vehicle was 12.6” (32-cm) wide and centered almost perfectly on the frontal plane. This 12 o’clock direction of force impact (CDC: 12FCEW3) crushed the frontal structure of the case vehicle to a maximum depth of 31.9” (81-cm). The crash investigator estimates the deltaV to be 30 -mph (48-kph). Upon impact the restrained driver moved towards the 12 o’clock direction of force as the airbags deployed. The driver’s torso contacted and loaded the airbag resulting in anterior and posterior fractures to the left ribs 1-3. The driver’s face contacted and loaded the airbag resulting in ecchymosis to the upper right eyelid. The anterior aspect of the driver’s left forearm contacted the airbag resulting in a contusion to the forearm. Contact with the restraint system caused a horizontal linear contusion to the driver’s lower abdomen and a contusion to the upper left quadrant of her chest. Loading from the shoulder restraint caused a contusion to the right lung and a grade III laceration to the anterior right liver. The driver’s right shin sustained abrasions form contact with the knee bolster. The driver’s left knee sustained lacerations from contact with the knee bolster. On rebound the driver moved rearward and the left side of her head contacted and loaded the rearmost vertical surface of the window frame. This contact caused swelling to the posterior parietal scalp, a small hemorrhage to the anterior cisterna and a contusion to the anterior temporal lobe.

Case 3- Occult Splenic Injury to Belted Front Passenger Loaded by Unrestrained Rear Seat Occupant

Case Vehicle -1995 Ford Mustang

The case vehicle was a 1995 Ford Mustang equipped with 3-point lap and shoulder restraints for all outboard seating positions. In addition the case vehicle was equipped with driver and passenger airbags both of which deployed. The driver was an unrestrained 22-year-old male. The right front passenger, who was the case subject, was a restrained 22 year-old female, 60” (152-cm) tall and 120 lbs (54-kg). The 2 rear seat occupants were not restrained. The case vehicle was eastbound at an estimated speed of 35-mph (56-kph). The driver lost control due to distractions in the vehicle. The case vehicle departed the roadway to the right and struck a metal light pole. The light pole fractured at its base, and the case vehicle came to rest a short distance from the point of impact. Direct damage to the case vehicle was 14.2” (36-cm) wide and was centered 7”(18-cm) right of the case vehicle’s centerline. This 12 o’clock direction of force impact crushed the frontal structure of the case vehicle to a maximum depth of 24.4” (62-cm) located at C4. The delta V for the case vehicle totaled 29.9 mph. Upon impact the restrained right front passenger (case subject) moved towards the 12 o’clock direction of force as the airbags deployed. The unrestrained rear seat occupants impacted the right front seatback, and this increased the case subjects loading of the 3-point restraint (belt). The case subject sustained an abrasion at the base of the anterior right neck as a result of contact with the shoulder restraint. Loading from the shoulder restraint also caused a contusion to the left lung and fracture to the left ribs 7-9 with pneumothorax.

Loading to the left hip from the lap restraint caused a fracture to the case subject’s left iliac wing. The case subject was the only occupant admitted to the hospital and she recalls getting out of the car on her own. The crash occurred at 03:42am. The case subject was originally taken to Jackson Memorial Hospital Emergency Room at 04:42am (note: not a trauma center). She was then transferred to Ryder Trauma Resuscitation Unit arriving at 06:22am where an occult splenic laceration was discovered. Following surgery, the occupant was taken to the SICU area at 04:08pm that day for a 9-day recovery period with follow-up rehabilitation. The outcome of this occupant was good, however, her splenic laceration was undiagnosed for nearly three hours. The delay increased the risk of fatality and may have contributed to lengthening the recovery period.

Summary of Research Findings and recommendations by WLIRC

- The large number of passenger car occupants suffering serious head injuries from side impacts by light trucks suggests that is a frequent mode of severe and fatal injury. The current deformable barrier test devices used in the US and European Side Impact Safety Standards do not induce head impacts during crash tests. Consequently, they do not adequately address this mode of injury. [25, 29]
- The test dummies currently used in the Federal Motor Vehicle Safety Standards do not distinguish the safety belt load concentrations that produce liver injuries observed in the field. The liver injuries suffered by drivers were found to be prevalent in one o'clock crashes. The computer modeled deflection of the lower rib on the dummy was found to predict the liver injuries that were observed in the 1 o'clock crashes. These higher deflections were not present at the center chest location where the chest deflection is currently measured on the Hybrid III. To control safety belt induced injuries, changes in the dummy instrumentation, the chest injury criteria and the crash test condition should be considered in future standards. [27]
- Safety improvements in far side crashes should concentrate on reducing injuries from belt loading in the lower severity crashes. In higher severity crashes the prevention or mitigation of head impact with the opposite side interior should take precedence. Crash testing to evaluate safety features to mitigate contacts with the opposite side interior should be done without a near-side dummy. [28]
- A limited sample of depowered air bag cases showed that a high level of protection continues to exist at high crash severities. However, severe internal chest/abdominal injuries persist in low and moderate speed crashes for unrestrained occupants. [(See Paper in Item 4 below)
- Crashes that involve narrow objects and crashes that involve multiple impacts were found to carry a high risk of injury. Neither of these crash modes is currently simulated by current standards. Future standards should consider safety features to reduce casualty risk in these crash modes. [8]

1. Findings for Improving FMVSS 214 — The Side Impact Safety Standard

"Injuries in Near-Side Collisions" AAAM, 1999 [25] and "Injury Patterns in Near-side Collisions", SP –1518, SAE 2000-01-0634, March 2000 [29] examine injuries and injury mechanisms in side impact crashes being addressed by the United States standard, FMVSS 214. In this side impact protection standard, a moving deformable barrier impacts the occupant compartment of a vehicle being tested. The moving barrier is crabbed at an angle of 23 degrees measured relative to the side of the struck vehicle. The standard assesses the crash protection provided in a vehicle-to-vehicle crash to an occupant seated on the struck side, in the vicinity of the maximum intrusion. The National Automobile Sampling System /Crashworthiness Database System (NASS/CDS) data indicates that 75% AIS 3+ injuries occur in vehicle-to-vehicle crashes, 66% occur to the struck side occupants and 94% occur in crashes with damage to the occupant compartment. Crash directions of 10 and 2 o'clock are the most common injury producing crashes.

The University of Miami School of Medicine -William Lehman Injury Research Center (WLIRC) data was found to be representative of the severe injury crashes in the NASS/CDS database. In the WLIRC data, the most frequent severely injured (AIS 4+) organs were the brain (21%) and the thoracic aorta (21%).

In-depth analysis of brain induced injuries showed that the most frequent injury causing contacts for head injuries were: other vehicle 37.5%; pillar, 25%, and side interior, 25%. Light trucks were most frequently the source of the injuring head strikes. Trucks were the striking vehicles in 48% of the cases, and head contact with a striking truck is the most frequent source of AIS 3+-head injury. In NASS/CDS 1988/96, the striking vehicle was a light or heavy truck in 46% of the cases with AIS 3+ injuries. In the same years of NASS/CDS, trucks constituted about 15% of vehicles in the database.

This large difference in exposure versus involvement suggests that impact from a truck is a strong injury risk factor. The high percentage of serious head injuries from impacts with light trucks in the WLIRC data suggests that is a frequent mode of severe and fatal injury. The current deformable barrier test devices do not induce head impacts during crash tests, and may not adequately address this mode of injury.

For aortic injuries, 100% of WLIRC cases were from contact with the side interior. Other factors that were observed in the WLIRC cases with aortic injuries were: older occupants, oblique angles of impact, and damage to the front fender and door of the struck vehicle. The lower severity crashes with aortic injuries all involved an initial impact in the front 1/3 of the struck vehicle, frequently beginning at the front wheels. The characteristics of these crashes need further study to assess the adequacy of current test procedures in simulating the injury producing crash environment for aortic rupture.

2. Findings for Improving Dummy Design

"Dummy Measurements of Chest Injuries Induced by Two-Point Belt Systems", *44th Annual Proceedings of the Association for the Advancement of Automotive Medicine*, October, 2000 [27]

This paper reported on an observed pattern of severe liver injuries suffered by drivers wearing shoulder belts, without the lap belt fastened. The study found that existing crash dummies were unable to measure the potential for these injuries. Further, the test procedures required by existing safety standards did not simulate the crash condition that produced these injuries.

During the period 1993-1997, 48 cases of drivers protected by shoulder belts but without the lap belt fastened were admitted to the database. Fifty percent of these drivers suffered liver lacerations. Further study showed that the majority of the crashes involved damage to the right front of the vehicle. Among the drivers in vehicles with right front damage, 92% sustained injuries to the liver and the majority were at crash severities lower than 25 mph. This observation indicated that 2-point belts were most likely to produce liver injuries in low severity frontal collisions when the crash direction is 1 to 2 o'clock.

An analysis of the National Accident Sampling System for the years 1988-95 showed that the risk of chest injury is more likely among drivers with automatic shoulder belts than drivers with manual belts. Analysis of NHTSA's crash testing showed that the test dummies required by Federal Motor Vehicle Safety Standards do not distinguish differences between belt systems with and without a lap belt. Consequently, the liver injuries observed in the field were not predicted.

Finite element computer modeling of the currently utilized Hybrid III dummy indicated that the deflection at the right lower rib location was greatly increased when the lap belt was not fastened. The computer models further showed that higher deflections were not present at the central location where the chest deflection is currently measured on the Hybrid III. These results suggested that improvements in test dummy design and instrumentation could offer significant injury assessment benefit.

3. Findings for Improving Occupant Protection in Far Side Crashes

"Injuries to Restrained Occupants in Far-Side Collision", 44th Annual Proceedings of the Association for the Advancement of Automotive Medicine, October 2000. [28]

Occupants exposed to far-side crashes are those seated on the side of the vehicle opposite the struck side. Test procedures required by present safety standards for side crashes require the crash dummies to be located on the side of the vehicle closest to the impact. Far-side occupants, those located on the side opposite the impact, are not included in any test. Studies of injuries in far-side crashes were conducted to assist in identifying safety systems and test procedures to further improve occupant safety.

This study used the NASS/CDS 1988-98 to determine distributions of AIS 3+ injuries among occupants exposed to far-side crashes and the sources of the injuries. The William Lehman Injury Research Center (WLIRC) data from 1994-98 was used to assess injury mechanisms among seriously injured crash exposed far-side occupants.

The NASS/CDS indicated that injury patterns for far-side restrained drivers were different from far-side restrained front passengers. For the driver, the head accounted for 40% of the AIS 3+ injuries in far-side collisions and the chest/abdomen accounted for 45.5%. For the right front passengers, head injuries contributed 27.2%, while chest and abdominal injuries accounted for 64.5%. The opposite-side interior was the most frequent contact associated with driver AIS 3+ injuries (30.5%). The seat belt was second, accounting for 22.6%. Among thirteen WLIRC cases of far-side belted occupants with MAIS 3+ injuries, five of the most serious injuries were attributed to the seat belt. The liver or the spleen was the most seriously injured body organ in all five cases.

The presence of an occupant on the near-side changes the injury pattern of the far-side occupant, mitigating injuries from contacts with the opposite side interior. Crash testing to evaluate safety features to mitigate contacts with the opposite side interior should be done without a near-side dummy. Safety improvements in far side crashes should concentrate on reducing injuries from belt loading in the lower severity crashes. In higher severity crashes the prevention or mitigation of head impact with the opposite side interior should take precedence.

4. Findings on the Field Performance of Depowered Air Bags

"Performance of Depowered Air Bags in Real World Crashes", SAE 2002 01-0188, March 2002.

The paper compared the crash characteristics for injured occupants in vehicles with 1st generation and depowered air bags. In the limited number of depowered cases investigated by the William Lehman Injury Research Center, the performance of depowered air bags has been very good. High speed protection in very severe crashes has been observed for both restrained and unrestrained occupants. The database of depowered air bags contains no significant injuries in very low speed crashes, and no injuries to children. However, serious internal chest injuries were observed in two cases with unrestrained drivers at low crash severities. One of these crashes produced in a fatal heart injury and the other an AIS 5 liver injury. These cases contained the only unexpected injuries among the population protected by depowered air bags.

During the period 1992 through 2000, the William Lehman Injury Research Center collected crash and injury data on 141 drivers and 41 right front passengers in frontal crashes with air bag deployment. Among these cases were twenty-eight cases with depowered air bags.

The population with 1st generation air bags contained unexpected fatalities at low delta-V's. To date, these populations are absent among the fatally injured occupants of vehicles with depowered air bags. The depowered cases include both belted and unbelted survivors at crash severities above 40 mph delta-V. The maximum injury in these severe crashes was AIS 3 with no evidence of unsatisfactory air bag performance. However, serious internal chest injuries were observed in two cases with unrestrained drivers at crash severities of 19 and 24 mph.

This limited sample of depowered air bag cases indicates that a high level of protection continues to exist at high crash severities. However, severe internal chest/abdominal injuries persist in low and moderate speed crashes for unrestrained occupants.

5. Improvements in Crash Injury Identification and Treatment

"Development and Validation of the Urgency Algorithm to Predict Compelling Injuries", Paper Number 350, ESV Conference, June 2001 [8]

The development of methods for improving the identification and treatment of crash injuries has been a major priority for WLIRC. In 1994 WLRIC proposed the SCENE Scale to assist first care providers in identifying crash victims with occult injuries. This effort has continued and expanded to the development of the URGENCY Algorithm. The URGENCY algorithm uses data from onboard crash recorders to assist in identifying crashes that are most likely to have time critical (compelling) injuries. The injury risks projected by using the NASS/CDS data are the basis for the URGENCY algorithm. [31]

This study applied the algorithm retrospectively to a population of injured occupants in the database from the University of Miami School of Medicine, William Lehman Injury Research Center (WLIRC). The population selected was adult occupants in frontal crashes that were protected by three point belts plus an air bag.

The conclusions are applicable to the URGENCY algorithm applied to all William Lehman Injury Research Center cases of frontal crashes with occupants protected by belts and air bags. This research with WLIRC cases found confirmation that URGENCY can differentiate crashes with serious injuries from non-serious injury crashes, but that improvement in the algorithm is both necessary and possible.

For the cases with greater than 50% predicted MAIS 3+ injury probability, 96% had MAIS 3+ injuries. Specific improvements introduced were risk factors associated with multiple impact crashes, pole crashes and air bag deployment injuries.

Overall, the predictive capability of the URGENCY algorithm was considered to be satisfactory for use as an aid in identifying occult injuries among occupants that do not meet physiological triage criteria at the crash scene.

"Validation of the URGENCY Algorithm for Near Side Crashes, *46th Annual Proceedings of the Association for the Advancement of Automotive Medicine*, p. 305-314, October, 2002.

The URGENCY algorithm was validated for near-side crashes by applying it retrospectively to the population of injured occupants in NASS 1997-2000. The use of an injury probability of greater than 50% gave reasonable predictions of MAIS 3+ injuries in near-side crashes.

Knowledge of vehicle side intrusion was found to be beneficial in reducing the false negatives, but with an increase in false positives. Treating intrusion as a continuous variable reduced the number of false negatives at the expense of increases in false positives.

Overall, the URGENCY algorithm predicted about 67% of the occupants with MAIS 3+ injuries and about 94% without MAIS 3+ injuries. The use of intrusion as a continuous variable increased the percent of MAIS 3+ injuries predicted to 80.7%.

References

1. Lombardo LV, Ryan SD, "Detection of Internal Injuries in Drivers Protected by Air Bags," *NHTSA Research Note*, August 1993.
2. National Highway Traffic Safety Administration (NHTSA), "Look Beyond The Obvious" Poster, a.k.a. "The SCENE Poster" provides tips to recognize crash conditions warranting an increased index of suspicion for occult internal injuries, 1994.
3. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, Lombardo LV, *Post-Crash Injury Control*, Briefing for NHTSA Administrator, R Martinez, Washington, DC, March 27, 1997.
4. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "Automatic Crash Notification," *AirMed*, March/April 1998, p. 36.
5. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "Urgency for a Safer America," *AirMed*, March/April 1999, pp.18-23.

6. Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, “Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Crash Recorders to Emergency Medical Services Providers,” *Proceedings of the National Transportation Safety Board (NTSB) International Symposium on Transportation Recorders*, May 3-5, 1999, pp. 67- 84. Also available at www.ntsb.gov, and at www.nhtsa.dot.gov/events/symp_rec/proceedings/authors/champion.htm.
7. Malliaris AC, Digges KH, DeBlois JH, “Relationships Between Crash Casualties and Crash Attributes,” Society of Automotive Engineers SAE 970393, February 1997.
8. Augenstein JS, Digges KH, Ogata S, Perdeck E, Stratton J, “Development and Validation of the Urgency Algorithm to Predict Compelling Injuries,” *Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles*, June 4-7, 2001, Amsterdam, DOT HS 809 220, www.nhtsa.dot.gov.
9. Esposito TJ, Reynolds SA, Sanddal ND, Hansen JD, Rinker CF, Dale G, Maningas PJ, O’Reilly PJ, Bleicher J, Petrashek B, *Rural Preventable Mortality Study*, NHTSA Report DOT HS 807 973, Washington, DC, Dec. 7, 1992.
10. Maio RF, Burney RE, Gregor MA, Baranski M, Welch KB, Rothman ED, *Michigan Rural Preventable Mortality Study*, NHTSA Report DOT HS 808 341, Washington, DC, June 1995.
11. *Cunningham PRG*, *North Carolina Preventable Mortality Study with Inter-Rater Reliability Modifications*, NHTSA Report DOT HS 808 345, Washington, DC, July 31, 1995.
12. Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Quigley CV, Malliaris AC. “Airbag Protected Crash Victims – The Challenge of Identifying Occult Injuries.” The Engineering Society for Advancing Mobility Land Sea Air and Space International (SAE) 1994 Technical Paper Series reprinted from *In-Depth Accident Investigation: Trauma Team Findings in Late Model Vehicle Collisions* (SP 1042) SAE 940714, February 1994.
13. Augenstein JS, Perdeck EB, Stratton J, Digges KH, Lombardo LV, Malliaris AC. “Injuries Sustained by Air Bag Occupants in Frontal Crashes” *The 13th International Technical Conference on Enhanced Safety of Vehicles*, Paper no. 94-S4-O-18, 1994.
14. Augenstein JS, Digges KH, Malliaris AC, Perdeck EB, Lombardo LV, Stratton J, Nunez D Jr., Byers PM, Quigley CV, Young P, Andron J, Murtha M, Craythorne AK, Zych G. “Liver Injuries Associated with 2-Point Belt Restraints in Frontal Crashes”, *Accident Analysis & Prevention*, *39th Annual Proceedings of the Association for the Advancement of Automotive Medicine*, 1995.
15. Augenstein JS, Digges, KD, Malliaris AC, Lombardo L, Perdeck E, “Injuries Sustained by Air Bag Protected Drivers,” SAE 960660, in (SP-1144).
16. Augenstein JS, Digges, KD, Malliaris AC, Lombardo L, Perdeck E, Stratton J, Murtha M, sapnas K, “Heart Injuries Among Restrained Occupants in Frontal Crashes,” SAE 970392
17. Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Quigley CV, Malliaris AC. “Chest and Abdominal Injuries Suffered by Restrained Occupants.” The Engineering Society for Advancing Mobility Land Sea Air and Space International (SAE) 1995 Technical Paper Series reprinted from *Advances in Occupant Protection Technologies for the Mid-Nineties* (SP-1077) SAE 950657, February 1995.
18. Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Malliaris AC, Quigley CV, Craythorne AK, Young PE, “Occult Abdominal Injuries to Airbag Protected Crash Victims: A Challenge to Trauma Systems,” *Journal of Trauma*, Vol. 38, No. 4, 1995.
19. Augenstein JS, Digges KH, Perdeck EB, Lombardo LV, Malliaris AC, “Injuries Sustained by Air Bag Protected Drivers.” The Engineering Society for Advancing Mobility Land Sea Air and Space International. (SAE) 1996 Technical Paper Series reprinted from *Occupant Protection Technologies for Frontal Impact: Current Needs and Expectations for the 21st Century*, (SP-1144) SAE 960660, February 1996.
20. Digges KH, Haffner M, Lombardo L, Stucki L, Malliaris AC, Augenstein JS, Perdeck EB. “Challenges in Injury Measurement Technology for Testing of Driver Air Bag Systems.” *The XIV International Technical Conference on the Enhanced Safety of Vehicles*. Melbourne, Australia. Paper no. 96-S10-O-02. May 15, 1996.
21. Augenstein JS, Perdeck EB, Murtha M, Stratton J, Quigley C, Zych G, Byers PM, Nunez D, Digges KH, Lombardo LV, Malliaris AC. “Injuries Sustained by Drivers in Air Bag Crashes.” *The 15th International Technical Conference on Enhanced Safety of Vehicles*. Melbourne, Australia. Paper no. 96-S10-O-01. May 15, 1996.
22. Augenstein JS, Perdeck E, Williamson J, Stratton J, Murtha M, Sapnas K, Digges KH, Malliaris AC, Lombardo LV, “Heart Injuries Among Restrained Occupants in Frontal Crashes”, The Engineering Society for Advancing Mobility Land Sea Air and Space International (SAE) 1997 Technical Paper Series reprinted from *Occupant Protection and Injury Assessment in the Automotive Crash Environment* (SP-1231) SAE 970392, February, 1997.

23. Augenstein JS, Digges KH, Cooper G, Hoyt DB, Eastman B, Burgess A, Dischinger P, Scally J, Wang S, Schneider L., Siegel, JH, Loo G, Grossman D, Rivara F, Eichelberger M, Gotschall C, Lombardo LV, Brown L, Eppinger R. "The CIREN Experience." 98-S6-P-21, *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*, May 31-June 4, 1998, Windsor, Ontario, Canada, published by US Department of Transportation, National Highway Traffic Safety Administration, DOT HS 808 759, Vol. 2, pp. 1325-1327, October 1998.
24. Augenstein JS, Perdeck E, Williamson J, Stratton J, Horton T, Malliaris AC, Lombardo LV. "Injury Patterns Among Air Bag Equipped Vehicles." 98-S1-O-06, *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*, May 31-June 4, 1998, Windsor, Ontario, Canada, published by US Department of Transportation, National Highway Traffic Safety Administration, DOT HS 808 759, Vol. 1, pp. 213-221, October 1998.
25. Augenstein JS, Perdeck E, Bowen J, Stratton J, Singer M, Horton T, Rao A. "Injuries in Near-Side Collisions." *43rd Annual Proceedings*, *Association for the Advancement of Automotive Medicine*, Annual Meeting, September 19-22, 1999, p. 139.
26. Augenstein JS, Perdeck E, Bowen J, Stratton J, Horton T, Singer M, Rao A, Digges KH, Malliaris AC. "Injury Patterns Among Belted Drivers Protected by Air Bags in 30 to 35 mph Crashes." Society of Automotive Engineering (SAE), 1999. Windsor, Canada 199 99B-180.
27. Augenstein JS, Perdeck E, Bowen J, Stratton J., Horton T, Singer M, Digges KH, Malliaris AC, Steps J. "Dummy Measurement of Chest Injuries Induced by Two-Point Shoulder Belts." *44th Annual Proceedings*, *Association for the Advancement of Automotive Medicine*, October, 2000, p. 1.
28. Augenstein JS, Perdeck E, Bowen J, Stratton J, Horton T, Singer M, Digges KH., Steps JH. "Injuries to Restrained Occupants in Far-Side Crashes." *44th Annual Proceedings*, *Association for the Advancement of Automotive Medicine*, October 2000, p. 57.
29. Augenstein JS, Bowen J, Perdeck E, Singer M, Stratton J, Horton T, Rao A, Digges KH, Malliaris AC, Steps J. "Injury Patterns in Near-Side Collisions." Society of Automotive Engineering Technical Paper Series 2000-01-0634. Detroit, MI. March 6-9, 2000.
30. Horton TG, Cohn SM, Heid MP, Augenstein JS, Bowen JC, McKinney MG, Duncan RC. "Identification of Trauma Patients at Risk of Thoracic Aortic Tear by Mechanisms of Injury." *J Trauma*, Vol. 48, No. 6, June 2000.
31. Champion HR, Augenstein JS, Blatt AJ, Cushing B, Digges KH, Hunt RC, Lombardo LV, Siegel JH, "Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Vehicles in Crashes to EMS" *Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles*, *2003*.

HARBORVIEW INJURY PREVENTION AND RESEARCH CENTER
HARBORVIEW MEDICAL CENTER

Harborview Injury Prevention & Research Center at University of Washington

CIREN Program Report

Introduction

Motor vehicle related injuries are the main cause of death and disability among children and young adults in America. Much has been accomplished to address this problem over the past 30 years, since the National Highway Traffic Safety Administration was created. However, much remains to be done. The Seattle CIREN team believes that our work has been assisting with the development of a safer America and helping to lower the rates of death and disability from automotive crashes through three main mechanisms:

- Surveillance and vehicle design feedback;
- Basic research;
- Outreach activities.

Each of these will be considered in turn.

Surveillance and Vehicle Design Feedback

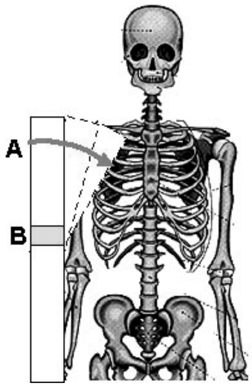
A basic mission of the entire CIREN project has been to gather information on how automotive safety improvements and related standards have been performing in the real world. Crash tests employing anthropomorphic test devices (ATDs or more commonly known as “crash test dummies”), although very useful, have significant shortcomings in being able to provide all the information necessary for automotive safety design. Hence the CIREN network was created to provide additional information. It is designed to analyze real-world crashes and to provide feedback for possible design and related motor vehicle safety standards modifications. It may also function as a surveillance system to help detect or provide additional information about unexpected field issues, such as the recently publicized problems with airbag-related injuries to children.

The Seattle CIREN team has been contributing cases to the overall CIREN database for these purposes. To date we have gathered information on 290 cases. A few brief examples will be considered. Airbags have been required in front passenger positions for protection in frontal crashes. Some late model vehicles have begun installing side airbags to improve protection in side impacts. The potential effectiveness of these side airbags has yet to be documented in real world crashes. The Seattle CIREN team has investigated several crashes in which such side airbags deployed (Figure 1, page 48). Valuable information on the performance of this new safety technology has been included in the CIREN database, for review by NHTSA and the automobile manufacturers.

In addition to individual safety technologies, CIREN provides information on performance of Federal Motor Vehicle Safety Standards (FMVSS). For example, FMVSS 214 was created to provide increased protection for occupants in side impact collisions. The standard was originally created to take into account a passenger vehicle striking the side of another passenger vehicle. This was the most common scenario in side impacts in the early 1990s. However, in recent years the American vehicle fleet has changed with an increase in the numbers of light truck vehicles (LTV), such as pick-up trucks and sport utility vehicles. As a consequence, many side impact collisions now occur between these LTVs and smaller passenger vehicles. The result is that the FMVSS 214 mandated reinforced side impact protection is often overcome by the greater vehicle mass and higher bumper frames of the LTVs. The net effect is an increase risk of serious injury to the passengers of the smaller passenger vehicles, as is demonstrated in Figures 2 and 3 (page 48).

Figure 1. Side airbag that deployed in a crash. CIREN investigations allow analysis of the effectiveness of such new safety technology

Figure 2. Side Impact Protection in a Typical Passenger Car



Point B indicates the usual height of side impact protection mandated by FMVSS 214. This height provides significant protection against side impacts by other passenger vehicles. However, the bumper frames of light truck vehicles, such as sport utility vehicles and pick up trucks, are usually located higher (Point A). In side impacts of light truck vehicles into passenger cars, the mandated side impact protection is often overcome due to such mismatch, resulting in a high risk of severe chest injuries to the occupants in the passenger vehicle.

In similar fashion, the mismatch of frame heights between LTVs and passenger vehicles leads to an increase risk of injury in frontal crashes. In these, the higher LTV bumper frames often override the frames of the passenger vehicles. The protection provided by the passenger vehicle frames are thus bypassed, with a resulting increase in the propensity for longitudinal intrusion of the instrument panel and an increase in the risk of serious injury to the passengers. This is shown in Figures 4 and 5 (page 49). Such mismatch in bumper frame heights also results in an under-ride being experienced by the LTVs. The lower bumper height of the passenger vehicle may result in intrusion of the LTV toe pan, with increased risk of foot and ankle injuries to the LTV occupants. This is shown in Figures 6 and 7 (page 50).

Figure 3. Photo of Side Impact Collision of Sport Utility Vehicle into a 1998 Passenger Vehicle

The side impact protection in the passenger vehicle door was overcome by the higher bumper frame of the sport utility vehicle. This is demonstrated by the intrusion of the upper portion of the door. Such intrusion results in a significant risk of severe chest injury.

Figure 4. External View of Passenger Car Involved in Frontal Offset Crash

Frontal offset impact showing mismatch and override of the vehicle frame of a passenger vehicle (shown here) by the higher bumper frame of a light truck vehicle. The white rectangle indicates the position of the bumper of the light truck vehicle.

Figure 5. Interior of the Vehicle Seen in Figure 4.

The bumper frame height mismatch and override resulted in significant intrusion of the instrument panel and consequent lower extremity injuries.

Research

In addition to the individual case reports which our CIREN center provides for the surveillance and vehicle design feedback noted above, we have been undertaking research on larger numbers of crashes and drawing inferences that may be useful in the overall approach to vehicle safety. Several projects are underway. We report here several that have reached publication. These include both publications that have specifically employed CIREN cases, as well as those that have employed other data sources, based on ideas generated from CIREN case reviews at our center. All of these studies provide information that helps us better understand how people get injured in crashes and hence how we can better prevent such injuries.

A. "Effectiveness of automatic shoulder belt systems in motor vehicle crashes." Frederick Rivara, Thomas Koepsell, David Grossman, Charles Mock. *Journal of the American Medical Association*, Vol 283, pg. 2826-2828, June, 2000.

The automatic shoulder harness was originally envisioned as a means by which occupants would have automatic shoulder restraints without having to remember to take the action of buckling up. However, the successfulness of the safety technology was lessened by the fact that many people regarded the shoulder harness as sufficient protection and did not take the action of buckling up their manual lap belt. Reports on the effectiveness of the shoulder harness alone had been mixed in prior research. The effectiveness of the shoulder harness alone is of significance in that approximately 10 million cars with automatic shoulder belt systems are currently in use in the United States. Anecdotal report from our own CIREN database suggested that shoulder harnesses alone were in fact of low effectiveness at preventing injuries. We set out to determine this more scientifically by analyzing over 25,000 crashes in the 1993-1996 National Highway Traffic Safety Administration Crashworthiness Data System (CDS).

We looked at the main outcome measures of death and serious injury and compared them for occupants in frontal crashes using the varying forms of restraints: lap and shoulder belts together, automatic shoulder belt without lap belt, and no restraint use.

This research showed that automatic shoulder belts with lap belts lowered the risk of death by 86% compared to use of no restraint alone. Use of automatic shoulder belts without the lap belts, however, resulted in a lesser (34%) decrease in mortality. Moreover, use of the automatic shoulder belt alone without lap belts was associated with a two fold increase in the risk of serious chest or abdominal injuries.

The study concluded with a call for increased awareness of this problem and for increased efforts to alert the public to the need to use lap belts along with automatic shoulder harnesses.

B. "The relationship between body weight and risk of death and serious injury in motor vehicle crashes." Charles Mock, David Grossman, Frederick Rivara, Robert Kaufman, Christopher Mack. *Accident Analysis and Prevention*, 34: 221-228, 2002.

Anecdotal reports from our CIREN database suggested that heavier occupants were at an increased risk of injury and

Figure 6. External View of SUV Involved in Frontal Offset Impact

Offset frontal impact in which the pictured sport utility vehicle (SUV) with a higher bumper frame collided with a passenger vehicle with a lower bumper frame. This resulted in an impact to the tire/axles below the SUV bumper frame.

death in motor vehicle crashes. There had been smaller studies in the literature suggesting that this may indeed be the case. However, these studies looked at the effect of weight on a variety of different types of mechanisms of injury but not specifically focusing on automobile crashes.

We set out to evaluate the question on a larger scale and more specifically for automobile occupants. We evaluated data on 27,263 occupants in crashes from the 1993-1996 National Highway Traffic Safety Administration Crash Worthiness Data System. We compared the likelihood death and serious injury by different categories of weight. We showed an increased risk of death with increased body weight. Compared to occupants who weighed less than 60 kg (132 lbs) occupants who weighed 60-99 kg (133-219 lbs) were 93% more likely to die. Occupants who weighed 100-119 kg (220 – 263 lbs) were 157% more likely to die and occupants who weighed over 120 kg (over 264 lbs) were 348% more likely to die. This increased risk of death may, in part, be due to increased medical problems among those who are more over-weight. However, the study also showed an increased likelihood of sustaining severe injuries with increasing weight. These findings persisted even after adjusting for differences in vehicle curb weight, seating position, restraint use, occupant age and gender. The implication of these findings is that heavier occupants' weights may need to be taken into consideration in the future in vehicle safety design.

Figure 7. Interior of the Vehicle Seen in Figure 6.

The impact with the tire/axle of the lower passenger vehicle forced the front left tire of the sport utility vehicle (shown here) into the floor and toe pan of the driver position. This resulted in severe bilateral foot fractures. The intruding front left tire of the sport utility vehicle is outlined in white.

C. "Femur Fractures in Relatively Low Speed Frontal Crashes: The possible role of muscle forces." By A Tencer, R Kaufman, K Ryan, D Grossman, B Henley, F Mann, C Mock, F Rivara, S Wang, J Augenstein, D Hoyt, B Eastman. *Accident Analysis and Prevention*, 34: 1 – 11, 2002.

The setting of motor vehicle safety standards and the determination of safety ratings of vehicles (e.g. The New Car Assessment Program) have depended on background information on injury thresholds. These thresholds represent the probable force that can be tolerated by the human body and above which injury typically occurs. For example, in frontal crashes, it has been generally accepted, based on cadaver research, that the human thigh can tolerate, on average, 8900 Newtons (2000 lbs) in compression along its axis before a femur fracture occurs. The validity of this estimate has not been well substantiated in actual crashes.

We set out to determine the actual forces required to fracture a femur from the data collected from CIREN crashes. We studied a group of relatively low speed frontal collisions (mean collision speed change of 40.7 kph or 25.4 mph) in which the only major injury suffered by the partly or fully restrained occupant was a femur fracture. However measurements from tests using crash dummies in similar vehicles at greater speed changes (mean of 56.3kph or 35.2 mph) showed that in almost all cases, the femur should not have fractured because the measured loads were below fracture threshold.

In order to explain the fractures that we observed, the loads in the femurs of the occupants in our crash sample were estimated and compared to recognized femur fracture thresholds (derived from previous cadaver research). Femur loads in the crashes we studied were estimated by inspecting the scene and measuring crush deformations in each vehicle, defining occupant points of contact and interior surface intrusion, and calculating crash change in velocity (delta V) and deceleration. Measured femoral loads in crash dummies from test data in comparable vehicles were scaled to the crashes in our sample by adjusting for differences in crash deceleration, occupant weight, and restraint use.

All the 20 occupants in our sample sustained at least a transverse midshaft fracture of the femur with comminution (multiple fragments), which is characteristic of axial compressive impact, causing bending and impaction of the femur. However, the average estimated femur compressive load was 8187N (1,840 lbs), which is below the generally accepted threshold of 8900N (2000 lbs). Moreover, based on the previous cadaver tests, the average probability for fracture in our study was only 19%. In fact, in 13 crashes the fracture probability was less than 10%.

Two factors we propose might explain the discrepancy. The occupant's femur was out of position (typically the driver's right foot was on the brake) and did not impact the knee bolster, instead hitting stiffer regions around or on the steering column. The knee bolster is the region of the dashboard designed to absorb knee impact when the occupant is sitting, as would a crash dummy, with both legs forward and both feet on the floor, not with the right leg angled and the foot on the brake. Additional compressive force on the occupant's femur probably resulted from muscle contraction due to bracing for impact. Adding the estimated internal load on the femur from muscle contraction to the estimated external load from knee to dashboard impact, increased the femur loads beyond threshold, explaining the fracture in all but one case.

Since crash tests using dummies do not simulate out of position knee to dashboard contact or muscle contraction loading, they may underestimate the total loads acting on the femur during actual impacts where the driver is avoiding and bracing for the crash. These results may have implications for altering knee bolster design to accommodate out of position knee to dashboard contact and the internal compressive loads caused by muscle forces from bracing.

D. "Are Drivers More Likely to Injure Their Right or Left Foot in a frontal Car Crash: A Crash and Biomechanical Investigation." M Assal, P Huber, A Tencer, E Rohr, C Mock, R Kaufman. In *Proceedings of the 46th Meeting of the Association for the Advancement of Automotive Medicine*, Tempe, AZ, October 2002.

Extremity injuries, although not generally life threatening, are a major source of disability after motor vehicle crashes. This is especially the case for fractures and dislocations involving the feet and ankles. Factors which contribute to these injuries and which can be manipulated to lower the risk and severity of such injuries are not well understood. In this study, we wished to determine what factors relating to foot position and use of brake pedals might contribute to foot injuries. We hypothesized that for frontal crashes, the driver was more likely to sustain foot injury than the front seat passenger. Likewise, we hypothesized that the driver's right foot was more likely to be injured than the left because that right foot was likely positioned in dorsiflexion and eversion during the crash and hence less able to tolerate crash forces. If drivers were more likely to sustain injury, it might result from the drivers' foot being pressed against the brake pedal during the crash, medial to the knee, forcing the foot into eversion combined with dorsiflexion. If this were the case, the threshold force of the foot to injury in eversion combined with dorsiflexion should be considered. Currently available data on foot threshold is based on dorsiflexed position alone. Therefore, we addressed two questions: (1) are drivers who are braking during a crash more likely to injure their right (possibly everted) foot; and (2) does the everted and dorsiflexed foot have a different force threshold than the dorsiflexed foot?

Data were utilized from several sources, including CIREN, NASS, and biomechanical laboratory tests. Seventeen Seattle CIREN frontal crashes in which there was a significant tibial shaft, ankle or foot injury were studied. The majority (16 / 17) were drivers and most (13/17) had injured their right lower extremity. The distribution of injuries were: fibula fractures (8), calcaneus fracture (3), malleolus fracture (3), and talus fracture (4). This component of the study provided preliminary evidence to support the study hypothesis.

Next, data from NASS were utilized to provide an epidemiologic perspective. A total of 26,168 occupants fit the study criteria. In total, 1.3% of occupants had a serious foot/ankle injury. Such injuries were more common among drivers (1.4%) than among front seat passengers (0.7%). The difference was almost exclusively due to a higher risk of right-sided injuries among drivers. These were 2.6 times as likely for drivers as passengers. The action of braking seemed to play a role. In cases with toe pan intrusion of 15 cm or more, drivers who were braking were twice as likely to sustain a foot/ankle injury (18%) as were drivers who were not braking (9%). Such injuries were also primarily right sided.

Finally, in the biomechanics laboratory, nine matched pairs of cadaveric feet were tested in compression with one in dorsiflexion, and the other in dorsiflexion and eversion. There was a significant decrease in load to failure between specimens forced into dorsiflexion and eversion (mean 4107 Newtons) compared with dorsiflexion alone (mean 6468 Newtons). The dorsiflexion alone data were similar to that reported in the literature, indicating that foot position, and not a different sample, accounted for the lower threshold force for dorsiflexion and eversion.

Implications of this work are that if thresholds based on data from dorsiflexion and compression loading are used to predict foot and ankle injury in frontal crashes, they may not represent that population of drivers who are braking at the time of the crash and who could suffer injuries at forces lower than current threshold values. Moreover, brake design and resulting foot position at the time of frontal crash may be a useful safety feature to evaluate further.

E. "Correlation of head injury to vehicle contact points using Crash Injury Research and Engineering Network (CIREN) data." Nirula R, Mock CN, Kaufman R, Rivara FP, Grossman D. *Accident Analysis and Prevention,* 2003 Mar;35:201–10.

Head injury is one of the most common causes of death in automotive crashes. It is also a common cause of long-term disability. Such deaths and disability occur despite optimal use of existing treatment capabilities. Hence, prevention emerges as a key element in our efforts to decrease the toll of head injury. Efforts to improve vehicle design, which minimize forces exerted to the occupant's head, may lead to a reduction in the frequency and severity of head injury. We set out to identify mechanisms producing severe head injury in motor vehicles crashes derived from the CIREN database. From the Seattle CIREN database, we compiled 15 cases with severe head injury (abbreviated injury score of 4 to 6) from 1997 to 1998. For these cases, we examined crash mechanism, energy transfer, point of head contact, vehicle intrusion, and resulting injuries.

The injuries were primarily due to side impacts (n=10) in comparison to frontal crashes (n=5). The average net change in velocity (delta V) was 15 miles per hour. In cases where the primary point of head contact could be elucidated, the B-pillar predominated (4 cases, 33%) followed by striking external objects (2 cases, 17%). The following structures each was associated with one case (8%): A-pillar, C-pillar, roof side rail, windshield header, windowsill, and airbag.

In this series, the predominant mechanism of head injury was lateral impacts, especially those in which the victims' heads struck the B-pillar. The need for improved head protection from lateral impacts is indicated. Potential engineering changes to provide such protection might include side airbags and softer, more energy absorbing materials to cover the pillars, especially the B pillar.

Outreach

The Seattle CIREN team, primarily Rob Kaufman, has conducted 80 outreach and training events from January 1999 to October 2002 (See Appendix 1). These have been attended by over 7000 participants, primarily in NHTSA X region. Evaluations have been overwhelmingly excellent. The demand for this knowledge about crash injury mechanisms has been demonstrated by requests for Seattle CIREN staff to return for repeat presentations at many of the major regional safety conferences. Most presentations were given for an hour, and some events were half-day or full-day training sessions.

The Seattle CIREN outreach and training presentations have utilized the crash and medical data from 150 Seattle CIREN cases to help illustrate various crash injury mechanism topics and themes such as: frontal and side impact injury mechanisms, intrusion equals injury, the effectiveness of seatbelts, the demographics of children and the elderly, lower extremity injuries, head injuries, abdominal and thoracic injuries, mismatch vehicle impacts, and rollovers. In addition, much of the outreach content utilizes the above peer reviewed research conducted by the Seattle CIREN center.

The Seattle CIREN tracking data showed that almost a third of the motor vehicle crash victims admitted to the trauma center were between the ages of 15-21 and nearly two-thirds were not wearing seatbelts. This unfortunate fact prompted another Seattle CIREN outreach presentation targeted at high school students and pre-drivers, called "The Force is With You". This program was created to increase knowledge of how injuries occur to occupants who do not wear their seatbelt and hence to reinforce the importance of seatbelts. An evaluation demonstrated an increase in knowledge and improved seatbelt use among nearly 1000 students who had participated in the program. The program recently received national attention after being presented at the American Driver and Traffic Safety Education conference. The response was overwhelmingly positive to the effective approach of utilizing the CIREN crash injury mechanisms data to illustrate the importance of seatbelts. Many driver educators have approached our team to develop this program for distribution nationally since no similar material currently exists.

The following is a list of the target audiences at these outreach events. The diversity of the audiences demonstrates the versatility of utilizing the CIREN data for training and outreach purposes.

Target Audience Listing:

Surgeons/ED Staff/Trauma Nurses/ Airlift nurses

Medics/EMS Fire Rescue at Local, County, State, & Regional levels

Medical Examiners/Coroners

- Engineers/Auto manufacturers
- NHTSA/Government — CIREN Public meetings
- Traffic Safety/Interest Groups
- Public Safety/Interest Groups
- State DOT and Dept. of Health
- Law Enforcement/Reconstuctionist
- Law Enforcement/Officers
- Public / High Schools
- Driver Educators

For physicians and nurses, this has involved discussions of the scientific basis of the CIREN project and how this information is useful to prevent and treat injuries. For paramedics, the emphasis has been training for recognition of exceptionally dangerous crash patterns which should increase the level of suspicion for occult injuries. For traffic police, the emphasis has been improvement in their skills in crash reconstruction with special emphasis on injury-related aspects of the analysis.

The various forms of outreach have been very popular with the target groups with more requests for subsequent sessions than we are able to handle with our staff and budget at this time. We are currently working on the design of pre-formatted teaching modes such as videos and CD-ROMs to increase the reach of these training activities. A selected few of the testimonials that have been received from participants in CIREN outreach programs are listed in Appendix B.

In addition to formal presentations, the training from the CIREN project has been applied on an on-going basis. All of the Advanced Life Support (ALS) ambulance rigs in Seattle and surrounding King County have been supplied with digital cameras to take pictures of the exterior and interior of damaged vehicles in the most severe crash situations. The photographs are brought into the emergency room on floppy disk. These are then viewed by doctors and nurses caring for the injured person. Especially dangerous crash deformation patterns, such as those with high degrees of intrusion, result in increased evaluation and monitoring for occult injuries.

Finally, Seattle CIREN cases have been utilized in nationwide presentations at public meetings for the entire CIREN network. These are detailed in Appendix 3.

Cross Cutting Issues

The above sections have demonstrated the importance of the work carried out by the Seattle CIREN team in feedback on automotive design; basic research in crash injury causation; and outreach and training. Frequently these approaches are utilized in a combined manner to address major safety concerns, as outlined next.

A. Side impacts of trucks/SUVs into passenger vehicles are increasingly overriding the impact support beams mandated by FMVSS 214, with resulting severe chest injuries.

- Seattle CIREN's use of detailed medical data on crash occupants suggests side impact standards (e.g. FMVSS 214) need to be changed, along with greater harmonization of the bumper frame heights of all vehicles.
- Outreach and training to first responders and trauma care providers has been done to identify these damage patterns, which are directly associated with thoracic injuries.

B. Side impact door panel stiffness and geometry may contribute to serious abdominal penetration and injuries

- Review of Seattle CIREN cases suggested that stiff armrests may be a source of some serious abdominal injuries. The possibility is being evaluated further by epidemiologic research using NASS data and by biomechanics laboratory data. Seattle CIREN bioengineers have also used MADYMO modeling showing the door geometry's and armrest are likely sources of abdominal and thoracic injuries. These studies are preliminarily, suggesting a need to consider the stiffness of arms rests in future research and possibly in safety standards.
- Outreach and training of trauma care providers has been done to assist identification of occult injuries from armrests in side impact collisions.

C. Offset frontal impacts of SUV/trucks into passenger cars are creating serious problems due to the bumper height mismatch.

The override into passenger cars is causing significant passenger compartment intrusion causing serious lower extremity and thoracic injuries. The passenger cars are also under-riding the SUV/truck's bumper with resulting impact into the SUV/truck's front tires. These are then forced into the toe pan, causing serious lower extremities fractures involving the feet of the SUV / truck occupants.

- Seattle CIREN cases have been presented in public forums to draw attention to the problem of bumper height mismatch and hence to show the possible need for changes in related Federal Motor Vehicle Safety Standards.

- First responders and trauma care providers have been trained to identify such bumper height mismatch as a factor associated with increased risk of serious injury.

D. Contact with the B-pillar and to some extent the A and C pillars have been identified by Seattle CIREN research as major sources of head injury, especially in side impacts.

- Individual case reviews have suggested the possible importance of side impact airbags, especially those designed to protect the head.
- The Seattle CIREN bioengineers have shown in MADYMO simulations that a padding of a few inches to the interior surfaces of the pillars might reduce the injury producing forces to the head.
- Even a moderate reduction in the rate of serious head injuries would result in significant savings to society, as each serious head injury is associated with $53,330 in medical costs.
- Outreach and training has been conducted to first responders and trauma care providers on how to identify when a potential for serious head trauma may exist.

Secondary Benefits

The involvement of our center with the CIREN project has resulted in several secondary benefits above and beyond the project itself. These have included the outreach work noted above. They have also included an expanded capacity of our center to understand automotive safety issues and to undertake related research and safety promotion work. Such increased capacity has amplified our center's promotion of the use of child booster seats both in the northwest region and nationwide. This increased capacity has also resulted in garnering of other research funds for related activities. We will conclude with a few words on each example.

Promotion of Child Booster Seats. By better understanding the biomechanics of children in crashes, we have been better able to demonstrate the efficacy of child booster seats. These are seats for children aged 4 – 8 years, who are too big for the usual car seats, but not yet big enough to be properly restrained by adult restraint systems. Prior lack of attention to this age group has resulted in a stagnation in automotive death rates in this age group, while rates of death have fallen for older and younger children. Promotion of booster seats is increasingly understood as a way to overcome this problem. Our center has been demonstrating the efficacy of such booster seats through CIREN case reviews and by computer simulations using MADYMO.

Related Research. CIREN case reviews at our center suggested to us a likely association of stiffer door panels and increased risk of chest and abdominal injuries as shown in

Figure 8. Armrest stiffness and protrusion may result in increased risk of abdominal injuries in side impact collisions.

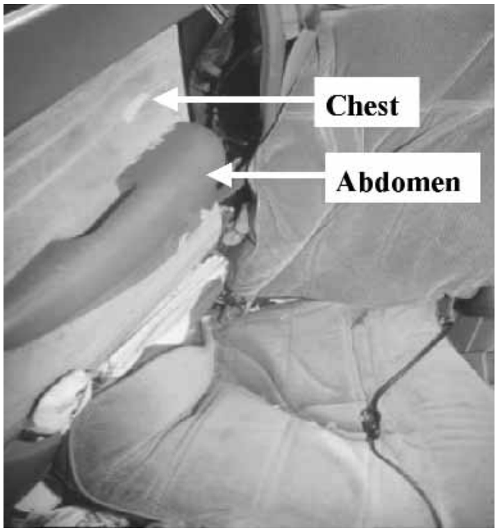


Figure 8. We have pursued this lead by using biomechanical examination of door geometry and MADYMO simulation. Based on such preliminary work, Dr. Allan Tencer of our center has recently been awarded $486,000 from the National Center for Injury Prevention and Control of the CDC for a study on the role of vehicle door interior surfaces during a side impact collision. This study will use modeling and cadaveric testing to: (1) investigate how the occupant interacts with, and document the injuries occurring from contact with the interior surface of actual doors in simulations of side impact crashes, (2) compare the injuries resulting from actual doors with features such as protruding armrests when primary occupant to door contact occurs either at the hip or abdominal regions during impact, and (3) provide additional data to assess the ability of various proposed criteria to predict injury. The results of this research project will hopefully provide insight into how persons of different stature are affected by contact with the door surface during a side impact, how thoracic injuries can result, and whether deformation based, acceleration based, or other injury criteria are the best predictors of injury.

In conclusion, the Seattle team feels that the CIREN project has significantly contributed to our pre-existing injury prevention efforts and hence to a safer America. Through a combination of feedback on the performance of safety technology; through basic research into automotive safety; and through outreach and training, we believe we have contributed to a better understanding of automotive safety and injury causation.

Report prepared by:
Charles Mock & Robert Kaufman
September 27, 2002

Appendix 1

List of Seattle CIREN Outreach Activities: 1999–2002

January 1999 – Oregon State DOT Three Flags Safety Conference

April 1999 – National Trauma Care 99 – Harborview Medical Center

May 1999 – “Coffee Talks” – Harborview Medical Center monthly staff meeting

June 1999 – NHTSA LifeSavers National Conference

July 1999 – Washington State Traffic Safety Commission / Three Flags Conference

August 1999 – Harborview Medical Center Board Meeting

September 1999 – 3rd Annual CIREN Conference, San Diego

October 1999 – Annual Oregon Transportation Safety Conference

October & November 1999 – Harborview Injury Prevention and Research Annual Training.

November 1999 Ford Motor Engineers – Video conference

November 1999 Stanford University – Stanford Medical Trauma Conference

December 1999 – Harborview Medical Center Surgery Department Seminar.

January 2000 – King County Medical Examiners Traffic Conference.

February 2000 – Trauma Care for the New Millennium, Spokane WA

February 2000 – Idaho Office of Highway Safety, Safety Seatbelt Summit.

March 2000 – King County Traffic Coalition Seminar

March 2000 – District 7 of the Washington State Patrol Reconstructionist training.

April 2000 – Harborview Medical Center staff monthly “Brown Bag staff meeting”

May 2000 – NHTSA Region X – All hands Meeting

May 2000 – High School Outreach Project Pilot – “The Force is with you”

May 2000 – Alaska Highway Safety “Buckle up” Seatbelt Summit, Anchorage, AK

April 2000 – HIPRC research seminar on Femur fractures CIREN study

May 2000 – HIPRC research seminar on Air bag technologies with live deployment in parking lot

June 2000 – WA State Law Enforcement Crash Investigator Training, Criminal Training Center.

July 2000 – Idaho Buckle up Seatbelt summit

July 2000 – CIREN public presentation – “Side impacts-Affects of door panel geometry and stiffness”

August 2000 – Annual Washington State EMS and Trauma Conferences

September 2000 – Seattle Medic Tuesday Series Meeting

October 2000 – Oregon Department of Transportation-Annual Traffic Safety Conference

September 2000 – NAME National Association of Medical Examiners conference

November 2000 – Pediatric Grand Rounds at Children’s Hospital

December 2000 – The Force is With You – High School Outreach

December 6, 2000 – Washington State Driver Impaired conference – WA Traffic Safety conference

January 2, 2001 – Harborview Medical Center Paramedic Training

January 10, 2001 – Oregon DOT – Three flags Law Enforcement conference

January18, 2001 – Bellevue EMS medic meeting

Feb 1st, 2001 – Kitsap County EMS monthly training meeting.

Feb 8th, 2001 – Child Safety Technician Regional Update Training, Portland Oregon

March 16th, 2001 – CIREN NHTSA Public quarterly meeting

March 17th, 2001 – Wenatchee EMS North Central Washington EMS conference.

April 10th, 2001 – National Harborview Medical Center Trauma Conference.

April 10th, 2001 – National Harborview Medical Center Trauma Conference Workshops

April 13, 2001 – Harborview Medical Center Thoracic Trauma and Critical Care Conference

April 27th, 2001 – Legacy Emmanuel Trauma Center, Portland Oregon

April 28th, 2001 – Mount Vernon – Northwest Washington State EMS conference

May 18th , 2001 – Alaska Buckle Statewide Seatbelt Summit

May 29, 2001 – Pierce County EMS Training Conference

June 5, 2001 – Law Enforcement Crash Investigator Training, Criminal Justice Training Center

June 11, 2001 – Trauma Surgeon Meeting

June 20, 2001 – CIREN NHTSA Public Meeting – Theme- “Getting the word out – CIREN”

July 11, 2001 – City of Eugene Oregon Medic and Fire Rescue Training

July 20, 2001 – Washington State Patrol Technician Training

August 15, 2001 – Airlift Northwest Flight Nurses training

September 6, 2001 – CIREN NHTSA Public Meeting – Theme- SUV’s

September 2001 – Idaho Buckle up Seatbelt summit

October 22, 2001 – Alaska DOT – Transportation and Technology conference, Anchorage AK

October 26, 2001 – Oregon Department of Transportation Traffic Safety Conference

November, 2001 – Alaska statewide EMS Symposium training

Dec 4-6, 2001 – NASS – National Automotive Sampling System Update Training Instructor

Jan 16, 2002 – Seattle Harborview Medical Center Paramedic Training

March 4, 2002 – Shorewood High School – Force is with you outreach

March 15, 2002 – WA Traffic Safety Educator Conference

April 13, 2002 – SADD Conference – Students Against Destructive Decisions

April 25, 2002 – CIREN NHTSA Public conference – Traumatic Brain and Head Injuries

May 8, 2002 – WATAI – Washington Association of Traffic Accident Investigators Conference

May 15,2002 – Alaska Buckle Up Conference

May 23, 2002 – Oregon Health Division Quarterly Meeting

June 5, 2002 – Trauma Nurses Talk Tough Meeting

June 6, 2002 – Legacy Emmanuel Trauma Conference – Seaside, Oregon

June 17, 2002 – Harborview Medical Center Advisory Board Meeting

June 25.2002 – Alaska Injury Prevention Course – AK Department of Health

July 19, 2002 – Mason General County Hospital/Medic/Fire Rescue training

August 5, 2002 – American Driver and Traffic Safety Education Conference- Overland, KS

August 17, 2002 – National Traffic Safety Conference - Boise, ID

August 22, 2002 – CIREN Public Outreach Meeting, Seattle,WA

August 28-29, 2002 – Three Flags Law Enforcement Conference – Buckle up Oregon

September 19, 2002 – Peace Hospital – EMS Washington Southwest Region Training conference

October 9, 2002 – Washington State Patrol and Eastern WA Technician Law Enforcement training

October 25, 2002 – Oregon Department of Transportation Traffic Safety Conference

November 14-15, 2002 – Alaska statewide EMS Symposium Training

November 15, 2002 – Providence Hospital Grand Rounds, Anchorage AK

December 3, 2002 – CDC Injury Prevention Grand Rounds

December 5, 2002 – CIREN Public Meeting, NHTSA Washington D.C.

December 14, 2002 – Oregon Health and Science Trauma Center Conference

December 14, 2002 – Forensic Accident Reconstructionists of Oregon

Appendix 2.

Comments from people through out NHTSA Region X and selections from letters of appreciation for the outreach and training conducted by Seattle CIREN center

John Moffat, Director for the Washington Traffic Safety Commission and the Governor’s Highway Safety Representative for the state of Washington stated:

“Your research has reached over 500 law enforcement officers in Washington State at over ten law enforcement training forums, and has brought an innovative and useful investigative element to reconstruction of collisions along with enhancing the ability of trained personnel to more effectively investigate collisions.”

Jo Ann Moore, Highway Safety Manager of the State of Idaho wrote the following letter after Rob Kaufman was the keynote speaker for their statewide event.

Dear Rob:

Thank you so much for taking the time to help us make Idaho's fourth Start Smart... Buckle Your Belt Summit a huge success. Your presentation was very well received and we heard many positive comments, especially about the crash investigation information.

We believe that the motivation to enforce safety restraint laws in Idaho was significantly increased as a result of the summit. The participants appreciated hearing your comments and they are more aware of the value of their efforts to focus on safety restraint usage so that more Idahoans won't suffer needless tragedies.

Attendance included 110 law enforcement officers and 57 highway safety partners from various agencies and organizations. Thanks in part to you, the evaluations were extremely positive and indicate that participants learned a great deal at the summit and are eager to make even greater efforts to get all Idahoans buckled up.

Again, Mary Hunter, who coordinated the summit, and I thank you for contributing to the success of Idaho's fourth Start Smart... Buckle Your Belt Summit. You have been an outstanding asset to Idaho, not only by presenting at our summits, but also by being of assistance when we have called on your for technical expertise. Thank you for your contribution to our efforts to increase safety restraint usage in Idaho.

Sincerely,

JO ANN MOORE
Highway Safety Manager
Idaho Office of Highway Safety

Grangeville, Idaho police officer who attended a CIREN presentation at a state wide traffic safety conference stated:

" the presentation really brought home to me why supporting this effort to get the public to use seatbelts is so important." He later added, "the review of real world crashes clearly illustrated to me that low speed crashes can be serious and even fatal without the use of seatbelts."

Alaska Injury Prevention course attendees commented on their evaluations about the CIREN presentation and many stated that the material was excellent and increased their understanding of crash injury mechanisms and the importance of the continued effort to promote child restraint and seatbelt use.

Rosemary Nye from the NHTSA region X office stated:

"the Seattle CIREN team has done numerous presentations to hundreds, even thousands, of injury control traffic safety advocates around our region. This CIREN information has enhanced the advocates' knowledge on crash injury mechanisms and the Seattle team have continually been asked to return to many of the States in our region on an annual basis over the last four years.

Dr. Jerry Jurkovich, Trauma Director at Harborview Medical Center

"The CIREN program has been instrumental in bringing an awareness of engineering safety construction to the clinical care arena. The ability to reconstruct the forces involved in a crash help define the mechanism of injury, help explain the injury patterns, and hopefully will assist in the design of safer vehicles. The cooperative effort of engineers, surgeons, emergency medical personal, and crash reconstruction specialists has been brought about by the CIREN project, and the benefits of this new joint investigation should have great future dividends for trauma care and vehicle safety."

Carla Levinski Oregon Department of Transportation Occupant Protection Program Manager stated:

"Rob Kaufman from the Seattle CIREN team has delivered occupant kinematics presentations several times annually for the past four years in Oregon. He speaks once a year to police officers who work federal safety belt overtime enforcement, and has also spoken to Oregon Department of Transportation's annual statewide safety conference, Oregon Health Division's injury prevention program staff, and Legacy Emmanuel Hospital's trauma staff. Rob's enthusiasm, thorough knowledge, exceptional presentation skills, and continually updated materials have helped me (as a state safety belt program manager) to generate much greater awareness of the importance of "proper" restraint use and the importance of buckling all occupants. Rob relates his crash investigations to current policy issues (e.g., booster seat use) and walks you through crashes so you understand it is a real process with predictable outcomes based on restraint use."

Mary Moran, Alaska Highway Safety Office stated:

"we are grateful to have Rob Kaufman from the Seattle CIREN center give his CIREN presentation recently at our Buckle Up! Alaska event. The information about seatbelts and vehicle crash investigations was wonderful and the audience made up of police officers and emergency medical personnel found the material very informative. I can already think of several future occasions where his expertise could prove very useful in our state."

Appendix 3.

Summary of CIREN Public Meeting presentations done by Seattle team

October 1997, CIREN First Annual Meeting

Title: "Cervical Spine Injuries in Motor Vehicle Crashes"

Examined the injuries to the cervical spine occurring from all directions of force.

September 1998, CIREN Second Annual Meeting

Title: "The relationship of body weight and the risk of death in motor vehicle crashes"

Demonstrated an increased risk of injury and death to higher weight occupants in crashes. Formed the basis for a subsequent peer reviewed publication (See above).

September 1999, CIREN Third Annual Meeting, San Diego

Title: "Estimating the femur loads of occupants in actual motor vehicle crashes using frontal crash test data"

Examined a series of CIREN cases where the forces calculated for mid-shaft femur fractures were below the previously utilized threshold. Most of the occupants were bracing or braking at impact with the fractured leg. The muscle forces can produce 30 percent more force on the leg. Combining the muscle forces with the external force for the cases examined then produced the force needed to fracture the leg. Other factors involved the knees missing the bolster systems and striking a more stiff area on the instrument panels. Formed the basis for a subsequent peer reviewed publication (See above)

May 5, 2000 NHTSA CIREN public meeting – Theme: lower extremity injuries

Title: "Knee bolster contacts and leg fractures"

Examined a series of crashes showing the mechanisms associated with lower extremity fractures impacting the various knee bolster systems. Longitudinal intrusion of the instrument panel was directly related to increasing the axial load of the legs. Bracing of the leg, for instance on the brake, produced additional muscles forces which combined with the external force also produced fractures. Finally, many out of position lower legs in real world crashes missed the bolster systems striking very stiff areas on the instrument panel as compared to the perfectly placed crash dummies in crash tests that would strike the narrow region. CIREN data addressed the real world situations.

July 2000, NHTSA CIREN public meeting – Theme: Side Impacts

Title: "Injury Patterns in Side Impact: The Effects of Door Panel Stiffness and Geometry"

Examined a series of CIREN crashes showing the result of side door panel intrusion is directly related to body region injuries. For a near-sided occupant the lower door panel intrusion causes pelvic fractures, and the upper door panel intrusion may cause thoracic or head injuries. To further examine the near-sided occupant position it appeared the stiff armrest and geometry of the door panel was causing abdominal and chest injuries to the occupant. Selected door panels were mapped showing the stiffness and geometry. This showed that over three inches of penetration would occur to the abdomen in a relatively low speed crash from a stiff armrest. Seattle CIREN cases illustrated actual crashes showing the result of abdominal injuries from the stiff armrest.

March 2001, NHTSA CIREN Public Meeting – Theme: Offset Frontal Impacts

Title: "Offset Frontal Impact with SUV's and Corner to Corner (FLEE) Impacts"

Examined frontal offset collisions of passenger vehicles impacting SUVs that produced extensive longitudinal intrusion of the passenger vehicle compartments resulting in lower extremity, chest and head injuries. Further examined a series of critically injured occupants in passenger vehicles that involved in a frontal impact with an SUV with less than 14 inches contact at the bumper corners of both vehicles. This mechanism produced significant longitudinal and even laterally intrusion in the passenger vehicles. Many of these corner-to-corner impacts resulted in fatalities in the passenger vehicles.

July 2001, NHTSA CIREN Public Meeting – Theme: Getting the Word Out

Title: "Seattle CIREN Outreach in the NHTSA region X"

Discussed the various presentations created utilizing CIREN crash and medical research. Listed many of the target audiences and conferences where presentations had reached thousands of attendees in the northwest region. Presented an example presentation that mapped the injury mechanisms for all body regions. This presentation had been given to trauma care providers, traffic safety groups, and law enforcement professionals.

September 2001, CIREN Public Meeting – Theme: SUVs

Title: "SUVs involving rollovers, frontal offsets, and corner impacts called FLEE's"

Looked at a series of CIREN crashes showing how the weak roof structures of SUVs produced vertical intrusion causing neck and head injuries. Examined CIREN cases involving SUV frontal offset crashes that produced significant intrusion to opposing passenger vehicles especially in the corner to corner offsets.

December 2001, CIREN Public Meeting – Theme: Age-related Injuries

Title: "Children and Crashes"

Examined a series of children injured in motor vehicle crashes addressing suboptimal use of car seats as a potential safety item needing improvement. Through the use of MADYMO modeling, simulations were produced to show the forces acting on a 6-year-old child with and without the use of booster seats. The forces on the neck, abdomen and lumbar spine were greatly reduced when a booster seat was in place. Success stories were examined to show the effectiveness of utilizing child restraints correctly. Special attention was directed towards booster seats.

April 2002 CIREN Public Meeting – Theme: Head and Traumatic Brain Injuries

Title: "Head Injury Mechanisms and Preventive Measures"

Using the CIREN crash research, this presentation mapped critical head injury sources in motor vehicle crashes. Near-side impacts produced the most severe head injuries. Developed MADYMO model to examine HIC and G forces acting on the head when contacting a very stiff interior surface versus a possible padded interior surface. The reduction in HIC occurred dramatically with just minimal padding.

August 2002, CIREN Public Meeting – Seattle CIREN Center

Title: "Crash Injury Mechanisms in Vehicle Mismatch Collisions"

Examined three types of collisions involving the greater height of bumper frames on light truck vehicles (LTV) impacting the side and front of passenger vehicles. In side impact collisions, the LTV bumper height produced upper door panel intrusion causing injuries to an adult's thorax and a child's head. For frontal impacts, the override/underride of the bumper frames produce extensive crush to the grill and hood of the passenger vehicles. In most cases this produced longitudinal intrusion of the instrument panel causing injuries to the lower extremities, chest and even the head to the occupants in the passenger vehicle. Also, in the mismatch of bumper frame heights in the frontal impact the passenger frame makes contact to the tires and front axle of the LTV forcing these components rearward creating toe pan intrusion in the LTV. This produced serious foot and ankles injuries to the LTV front seat passengers. Biomechanical testing of cadaver feet showed that intrusion of the toe pan is directly related to foot and ankle injuries. All of these findings suggest the need for engineering changes in vehicles to provide greater side impact protection in passenger vehicles and to achieve greater harmonization between the bumper frame heights of all vehicles.

San Diego County Trauma System

CIREN Center

CIREN Program Report


San Diego County Administration Center


Children's Hospital & Health Center


Scripps Mercy Hospital


Palomar Medical Center


Scripps Memorial – La Jolla


Sharp Memorial Hospital


UCSD Medical Center

Commitment

The San Diego CIREN center is committed to saving lives, and mitigating and preventing serious injuries. CIREN is in a unique position to accomplish these goals through multidisciplinary review of motor vehicle crashes. It is able to identify how injuries occur and how they may be prevented either by changes in engineering design or occupant safety education. These primary prevention actions will decrease the occurrence of injuries and reduce their severity. Additionally, CIREN findings can be utilized to limit injury sequelae by improving triage, transport and treatment of motor vehicle crash (MVC) occupants. CIREN identification of injury patterns stratified by crash configuration, is provided to prehospital providers and nurses and physicians responsible for making triage and transport decisions for victims of MVCs. The CIREN research can then be used to assist in the early medical treatment of these patients.

Introduction

The San Diego region is rich in diversity. San Diego County, the fifth largest county in the United States, is home to 2.8 million residents and approximately 1.8 million licensed drivers. Covering 2.7 million acres, San Diego County has over 7,700 miles of roadways, 600 miles of which is made up of state highways. San Diego County is bordered by the Pacific Ocean to the west, Camp Pendleton to the north, the Anza-Borrego desert to the east, and the U.S.-Mexico border to the south. These boundaries insulate San Diego from adjacent regions thereby becoming a natural laboratory for research. In fact, because San Diego has highly urbanized areas as well as rural areas the CIREN team is exposed to a wide range of crash configurations, from T-bone crashes in red light running cases to potential delayed notification for crashes occurring in the less densely populated areas.

Trauma System Participation

The San Diego CIREN Center is a collaborative effort between the six regional Trauma Centers and the County of San Diego, Health & Human Services Agency, Division of Emergency Medical Services. The unique configuration of the San Diego CIREN program, incorporating six hospitals rather than one, presents logistical challenges for its participants but also offers research outcomes rich in rewards.

The CIREN Program was established in 1996 through the General Motors Corporation settlement agreement and is currently underwritten through a Cooperative Agreement with the NHTSA. The Principal Investigators for the project are:

- Gail F. Cooper, Administrator, County of San Diego Office of Public Health
- A. Brent Eastman, M.D., Chief Medical Officer of Scripps Health and the N. Paul Whittier Chair of Trauma at Scripps Memorial Hospital – La Jolla
- David B. Hoyt, M.D., Chief, Division of Trauma and the Monroe E. Trout Professor of Surgery at the University of California San Diego (UCSD) Medical Center

Other key personnel include:

- Sharon E. Pacyna, RN, BSN, MPH, Project Manager
- Steven M. Erwin, Crash Investigator
- Teresa M. Vaughan, RN, BSN Assistant Project Manager

The Principal Investigators and program coordinators are supported by the Trauma Medical Directors and nurse administrators, researchers and case managers at the county's trauma centers. The participating Trauma Centers are:

- Children's Hospital and Health Center, San Diego (Pediatric Center)
- Palomar Medical Center
- Scripps Mercy Hospital
- Scripps Memorial Hospital – La Jolla
- Sharp Memorial Hospital
- University of California San Diego (UCSD) Medical Center

The San Diego CIREN program benefits from the seventeen-year working relationship of the San Diego Trauma System. The trauma system partners include the six Trauma Centers, the Division of Emergency Medical Services (EMS) and the Office of the Medical Examiner. Established in 1984, San Diego's trauma system is nationally recognized for its pioneering efforts, not only in patient care, but for its integration between EMS and Public Health and its strides in quality improvement activities. Personnel from the County of San Diego, Emergency Medical Services provide administrative and managerial oversight to the CIREN project. The trauma system participants have engaged in collaborative efforts to improve the triage, transport and treatment of injured patients, including motor vehicle crash occupants.

Quality Assurance Network (QA Net)

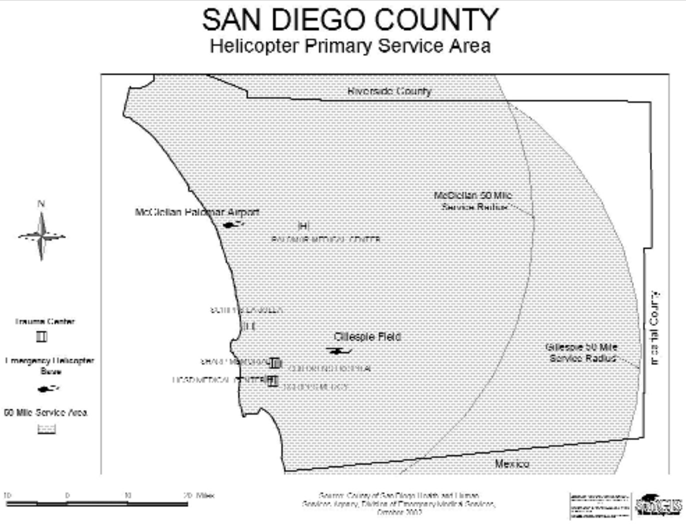
In addition to their participation in the Trauma System, EMS has on-line access to all prehospital provider data. Housed in the office of EMS is a wide area network computer system, linking prehospital providers with Emergency Departments in a real time prehospital patient information system identified as the QA Net.

The San Diego CIREN system uses the QA Net to assist personnel in identifying potential candidates. The QA Net is queried daily to track all MVC patients transported to one of the six trauma centers. This data is forwarded to the nurse managers at each trauma center and they use it as a guide to screen patients.

Information is maintained in a database and evaluated for exclusion criteria and since 1999 the San Diego CIREN Center has screened over 17,000 MVC transports. Not all exclusion reasons are tracked for every patient. Once it has been discovered the occupant does not meet criteria, the reason is entered into the database. For example, if the patient is transported to the Emergency Department (ED) and discharged, it is apparent the severity of injury is not adequate for study entry. This is reflected in Table 1 in the Minor Injury category which includes discharges from the ED as well as patients who do not have Abbreviated Injury Scores (AIS) of three or greater.

Table 1. San Diego CIREN Motor Vehicle Crash Victims, 1996–2001

Year	Screened victims	Inclusions	Exclusions	Reasons for Exclusion	
1996	(not available)	2			
1997	(not available)	40			
1998	(not available)	54			
1999	5522	46	5476	Minor injury (ED D/C 72%, AIS< 3 28%)	73%
				Crash Type	9%
				Vehicle exclusions	4%
				Consent issues	0.4%
2000	6037	48	5989	Minor injury (ED D/C 71%, AIS< 3 29%)	79%
				Crash type	6%
				Vehicle exclusion	3%
				Consent issues	0.7%
2001	6106	42	6067	Minor injury (ED D/C 71%, AIS< 3 29%)	81%
				Crash Type	6%
				Vehicle exclusions	3%
				Consent issues	1.2%
Total	**17665+**	**232**	**17532+**		

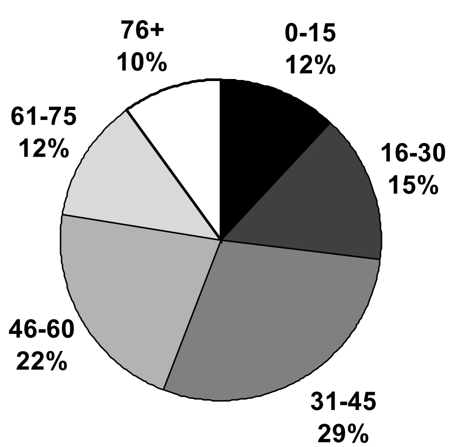


The majority of on-scene helicopter responses are within a 30 mile radius. However Mercy Air covers the entire County of San Diego.

Prehospital Transport

The County of San Diego Division of Emergency Medical Services (EMS) is the primary regulatory agency for the local integrated emergency medical services (EMS) system. EMS coordinates activities of prehospital and trauma care services for San Diego County residents and visitors. County ambulance service providers respond to more than 250,000 calls annually. There are more than 6,000 emergency medical technicians (EMT-Is), defibrillation personnel (EMT-Ds), paramedics (EMT-Ps), and mobile intensive care nurses (MICNs) in San Diego County. The EMT's are employed by advanced life support (ALS) ambulance providers (17), including air medical providers and basic life support (BLS) ambulance providers (15). Prehospital transports are directed to one of 24 emergency receiving hospitals including trauma centers (6) and base hospitals (8).

Age Frequencies and Percents of San Diego CIREN Motor Vehicle Occupants



Helicopter transfer is an important means of transport in San Diego County for victims of motor vehicle crashes. Crashes in rural areas, involving seriously injured patients or patients with a high risk for occult injuries often utilize the county's Mercy Air helicopter service to expedite transport to a trauma center. The County of San Diego protocol requires a first responder to evaluate the occupants and crash dynamics before a helicopter can be dispatched. In San Diego the first responders are well trained and arrive at a decision quickly. The problem arises if there is a delay between the time of the crash and the time of crash discovery. These situations would benefit enormously from the Automatic Crash Notification (ACN). Additionally, in some rural areas in the United States, where first responders may be volunteers, the level of education regarding crash configurations and risk of occult injury may not be equal to full-time professionals.

In these instances the URGENCY Algorithm system would be an important asset in determining whether the victims can be transported by land, or whether a helicopter should be dispatched. In San Diego County helicopters are also frequently used in urban and suburban areas during rush hour traffic when highway congestion would delay land transport times. In calendar year 2001 Mercy Air transported approximately 490 motor vehicle crash occupants to area hospitals.

Detection and Analysis of Emerging Injury Patterns

To date, the San Diego CIREN Program has enrolled 260 motor vehicle occupants in the research project. Of these 139 (53%) were males, 121 (47%) were females; 227 (87%) survived the crash, 22 were dead on scene and an additional 11 occupants died in the hospital. The ages of the occupants ranged from 11 months to 87 years with an average age of 39 years. Vehicle drivers totaled 180 (69%) of the enrolled occupants, right front seat passengers numbered 57 (22%), and 23 (9%) were backseat passengers. Recent passenger safety education has stressed placing children in the backseat of the vehicle. Of our case occupants ages 11 months to 11 years 60% were seated in the backseat. Fortunately only two of the front seat children had serious injuries.

The San Diego CIREN team has conducted in-depth analysis for an array of injury patterns. A few of the most significant areas of research include mediastinal injuries, diaphragm injuries, and side impact injury patterns, with and without airbags

Our research pursuits in these specific injury realms stem from our interest in areas where the edge of current safety standards may be exceeded by distinct crash configurations and patterns. By determining these patterns CIREN can make a contribution to the body of knowledge of crash dynamics.

In addition to incorporating all of the National Automotive Sampling System (NASS) data elements, the national CIREN database houses detailed descriptions and images of occupant injuries. CT scans, x-rays, operative pictures and anatomic injury classification permit all CIREN participants to evaluate injury details and analyze them for trends and patterns. No other database integrates crash data with this degree of detailed injury description. Large integrated databases are essential in determining injury biomechanics, injury sources and finally determining methods to prevent or mitigate injury occurrence.

Outreach Efforts for the Prehospital and Medical Community

In keeping with the NHTSA and CIREN goals of reducing the incidence of mortality and morbidity from motor vehicle crashes, San Diego has stepped-up its efforts to bring CIREN findings to the professionals who take care of MVC victims. Making triage decisions regarding appropriate transport destination is key to saving lives and ensuring that medical treatment will result in the best possible outcome.

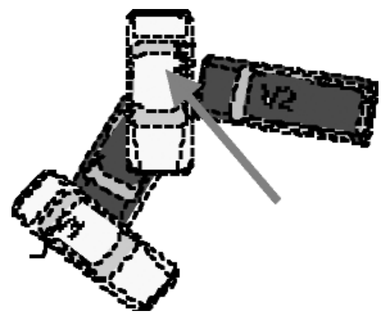
X-ray of Fractured Left Ankle

Initially, CIREN impacted transport guidelines by providing input to a county-wide task force responsible for determining triage guidelines for all prehospital providers and Emergency Department personnel. The CIREN crash investigator provided education to task force members resulting in the adoption of a triage algorithm incorporating intrusion and deformation parameters. The triage guidelines assist personnel in determining whether the MVC occupants require the resources of a trauma center.

To reinforce the new triage guidelines, CIREN personnel conducted outreach reviewing the specifics of the new policy. Included in the presentations were digital images of vehicles depicting intrusion and deformation matching the countywide criteria as well as the injuries associated with the specific vehicle damage. Prehospital providers vocalized their interest in the presentation topics because they related to their everyday work and helped explain the source of injury patterns they observed in their professional practice.

CIREN also used these forums to provide information about specific crash configurations and the corresponding occupant kinematics. Research findings were presented including occult liver/spleen injuries associated with shoulder belt-only crashes, examples of occult aortic injuries, and side airbag protection systems.

Graphic representation of vehicle impact depicting a principal direction of force of 320 degrees and vehicle point of rest.



Other areas of emphasis include occult injuries often encountered in offset frontal crashes with shoulder belt only use. This knowledge can assist providers in choosing the correct transport destination and assist treating physicians with quickly diagnosing the injuries.

Education regarding “double impacts” has met with a favorable response. Prehospital personnel, assessing the scene of a crash, may be lulled into believing an occupant’s injuries are less severe because they identify that an airbag has deployed. However, if the first impact was of sufficient magnitude to deploy the airbag and a second impact was encountered during the crash, the occupant may have had less protection (if a seatbelt was used) or no protection (if a seatbelt was not used) at the time of the second impact.

Prehospital personnel are also reminded that unbelted backseat occupants can easily load front seat occupants in frontal crashes potentially increasing the injury severity.

San Diego CIREN has also incorporated information regarding the proper use of child restraint systems. A CIREN participant has worked on a statewide committee to incorporate child seat information on the California EMS Authority web page, encouraging prehospital providers to become involved in injury prevention activities for pediatric motor vehicle occupants.

Costs Related to Motor Vehicle Occupants

Table 2 uses a NHTSA formula to project motor vehicle crash costs for 1996 - 2001 San Diego CIREN patients. The NHTSA cost figures are based on a report entitled “The Economic Impact of Motor Vehicle Crashes, 2000”. Unit costs are sorted by the occupant’s highest Abbreviated Injury Score (AIS), which is an indicator of patient injury severity. Please note the NHTSA 2000 figures are national averages and do not reflect the actual costs in San Diego. The NHTSA economic cost components include productivity losses, property damage, medical costs, rehabilitation costs, travel delay, legal and court costs, emergency service costs, insurance administration costs, premature funeral costs and costs to employers. Although these costs do not include estimated values for pain and suffering experienced by patients and their families, they do provide an indication of the strictly economic impact of motor vehicle crashes.

Table 2

Severity per AIS	CIREN Patients by MAIS	NHTSA Cost Formula per AIS	Estimated Costs for San Diego CIREN Patients
		2000	
1	3	$5,941	$17,823.00
2	8	$62,020	$496,160.00
3	26	$178,358	$4,637,308.00
4	5	$337,301	$1,686,505.00
5	4	$1,077,567	$4,310,268.00
6	2	$957,787	$1,915,574.00
		TOTAL	**$13,063,638.00**
		2001	
1	0	$5,941	$0.00
2	2	$62,020	$124,040.00
3	29	$178,358	$5,172,382.00
4	7	$337,301	$2,361,107.00
5	2	$1,077,567	$2,155,134.00
6	2	$957,787	$1,915,574.00
		TOTAL	**$11,728,237.00**
		1996–2001	
1	14	$5,941	$83,174.00
2	20	$62,020	$1,240,400.00
3	129	$178,358	$23,008,182.00
4	36	$337,301	$12,142,836.00
5	29	$1,077,567	$31,249,443.00
6	11	$957,787	$10,535,657.00
		TOTAL	**$78,259,692.00**

San Diego CIREN Presentation Roster 2001–2002

National Presentations/Posters

August 22, 2002, Airbags in lateral crashes and the Boeing Survival Award

Audience: CIREN Quarterly Meeting, Seattle, WA. MD's, RN's, Prehospital Providers, Engineers, Automotive Manufacturing Executives and Researchers

Speakers: David B. Hoyt, MD and Steven M. Erwin

April 25, 2002, Brain Injury; the Role of Directionality

Audience: CIREN Quarterly Meeting, Washington D.C. MD's, RN's, Engineers, Automotive Manufacturing Executives and Researchers

Speakers: A. Brent Eastman, MD, Thomas A. Gennarelli, MD, and Steven M. Erwin

December 6, 2001, Injuries in the Elderly

Audience: CIREN Quarterly Meeting, Washington D.C. MD's, RN's, Engineers, Automotive Manufacturing Executives and Researchers

Speakers: Sharon E. Pacyna RN, MPH and Steve Erwin, Crash Investigator and Mary Kracun, BSN, PhD.

San Diego CIREN's presentation focused on San Diego CIREN crashes involving elderly occupants. Compared culpability of elderly versus non-elderly drivers and compared similar crashes involving young and old subjects.

Oct. 18-20, 2001, Orthopedic Trauma Association 17th Annual Meeting San Diego – Poster Session

Audience: Over 600 orthopedic surgeons, nurse practitioners, and nurses attended the conference.

Presenters: Sharon E. Pacyna, BSN, MPH, Steven M. Erwin, Crash Investigator, Teresa M. Vaughan, RN, BSN, Mary Kracun, BSN, PhD

Presentation included a Poster Session with an overview of the national CIREN Program and a continuously playing PowerPoint presentation which depicted occupant kinematics, vehicle reconstruction, crash video clips and case presentations. Additionally, a crashed vehicle was displayed with contour gage and calibrated rods sticks demonstrating crush and deformation.

June 21, 2001, Emergency Department Personnel – Piecing it Together

Audience: CIREN Quarterly Meeting, Washington D.C. MD's, RN's, Engineers, Automotive Manufacturing Executives and Researchers

Speakers: Sharon E. Pacyna RN, MPH and Steve Erwin, Crash Investigator

San Diego CIREN's presentation developed for Emergency Department personnel includes CIREN overview, basic crash dynamics, and patient inclusion criteria. It emphasized the importance of injury documentation and crash details. Crash dynamics associated with injury patterns was discussed.

Mar. 16, 2001, Real Life Injuries in Offset Frontal Crashes

Audience: CIREN Quarterly Meeting, Washington D.C. MD's, RN's, Engineers, Automotive Manufacturing Executives and Researchers.

Speakers: A. Brent Eastman, MD and Steve Erwin, Crash Investigator

Review of San Diego CIREN incidence of FY offset frontal crashes including patient outcome. Presentation of two offset frontal crashes with vehicle and occupant simulations.

Regional/Local

Jul. 25, 2002, UCSD Critical Care Conference

June 15, 2002, Outreach Presentation for American Medical Response

June 22, 2002, Outreach Presentation for American Medical Response

May 7, 2002, Outreach Presentation for Poway Fire Department

Apr. 18, 2002, Outreach Presentation for Poway Fire Department

Apr. 19, 2002, Outreach Presentation for Poway Fire Department

Mar. 4, 2002, Outreach Presentation for Carlsbad Fire Department

Mar. 1, 2002, Outreach Presentation for Carlsbad Fire Department

Jan. 31, 2002, Outreach Presentation for Tri-City Field Care Audit

Jan. 30, 2002, Outreach Presentation for Tri-City Field Care Audit

Jan. 29, 2002, Outreach Presentation for Tri-City Field Care Audit

Dec. 21, 2001, Outreach Presentation for Rancho Santa Fe Fire Dept

Oct. 22, 2001, Vehicle Intrusion And Crush As Indicators For Trauma Triage

Sep. 3, 2001, CIREN Update: Side Impact Case Presentations

Jun. 15, 2001, The Case of the Human Crash Dummies

Mar. 6, 2001, What Really Happens to You When You're in a Crash!

Feb. 13, 2001, Vehicle Intrusion and Crush as Indicators for Trauma Triage

University of Michigan at Ann Arbor CIREN Center

CIREN Program Report

University of Michigan Program for Injury Research and Education

The University of Michigan CIREN team is an integral part of the University of Michigan Program for Injury Research and Education (UMPIRE). UMPIRE's primary purpose is to improve public safety. Research and Education are the backbone of everything we do in pursuit of this objective.

Research

Detection and Analysis of Emerging Injury Patterns

Head Injuries

It is well known that head injuries are among the most complicated and expensive injuries sustained by individuals involved in motor vehicle crashes (MVCs). The UMPIRE team has been working with UM neurosurgeons to try to understand the mechanisms of these injuries as well as how they have changed with the new safety systems in modern vehicles. We have also been working with automotive engineers in the field of head protection to improve vehicle countermeasures that may mitigate head injuries in the future.

University of Michigan Transportation Research Institute

Occupant restraint systems are designed and tuned to control head kinematics and cushion head impacts. In addition, FMVSS 201 and 208 contain head injury potential requirements. Data on how different vehicle, occupant, and crash characteristics affect head injuries in real-world crashes was analyzed to provide insight into current field performance and where the greatest potential is for further enhancing safety.

For both side and frontal impacts, head injury risk was greater for older case occupants and lower for heavier case occupants. Serious head injuries were found to be more common in side impacts than in frontal impact cases, and the pattern of head injury is different for frontal versus side impact cases. Neither the presence of intrusion in the head region nor near side occupant position in offset frontal and side crash cases was observed to be associated with increased head injury risk in our data sample. Among all injury sources, the most common head injury severity was AIS 3. Of interest, airbag contact severities were shifted to either side of AIS 3.

University of Michigan Health System

For frontal impact cases, there were fewer head injuries for airbag only restrained occupants than for seat belt only restrained occupants. Occupants restrained by an airbag and seat belt experienced the smallest number of head injuries. The data also suggests that de-powered airbags offered slightly better head injury protection than full-powered airbags. No comparison of head injury potential to occupants that were not restrained by either a seat belt or airbag could be made because they were not included in the data sampling.

Since most of the crash cases studied pre-date new regulations that required improved head impact protection, none of the vehicles in our analysis had head countermeasures in place. As new vehicles with these head impact countermeasures are incorporated into the fleet, it will be important to determine if and how these new countermeasures are affecting head injuries.

Knee, Thigh, and Hip Injuries

Late model passenger cars and light trucks incorporate occupant protection systems with airbags and knee restraints. Knee Restraints are designed principally to meet the unbelted portions of Federal Motor Vehicle Safety Standard 208 that requires femur load limits be met in barrier crashes up to 30 mph, +/- 30 degrees. In addition, knee restraints provide additional lower torso restraint for belted occupants in higher severity crashes.

Knee, thigh, and hip (KTH) injuries to occupants of vehicles involved in frontal crashes were analyzed to determine the influence of vehicle, crash and occupant parameters. The data sample consists of driver and right front passengers involved in frontal crashes who sustain significant injuries (AIS > 3 or two or more AIS > 2) to any body region.

Significant KTH injuries are still occurring; and the observed percentage of significantly injured, belted occupants sustaining KTH injuries has not been reduced by newer vehicles. Obviously, reductions in the number of significantly injured occupants from other safety improvements influence this percentage, but KTH injuries remain a problem. Most KTH injuries are occurring within a delta V range no greater than that used for current Federal regulation and consumer information testing. A higher percentage of drivers sustain KTH injuries than right front passengers. KTH injuries still occur with little or no toe pan or instrument panel motion relative to the vehicle.

The data show a higher percentage of belted occupants with air bags and knee restraints sustained hip injuries than belted occupants in non-airbag/knee restraint vehicles. Comparison of the percentage of unbelted occupants sustaining hip injuries in pre- and post air bag/knee restraint vehicles could not be made because the CIREN data base does not contain sufficient numbers of unbelted occupants in vehicles without airbags.

Hip injuries occurring in frontal crashes are predominately acetabular fractures. Hip injuries are generally far more disabling and costly in the long term than thigh and knee injuries. Unexpectedly, these injuries are more frequent among tall male drivers between 150 and 200 pounds of all ages. The rate of hip fracture occurrence increases somewhat with age, but KTH injuries occur in all adult age groups. Hip injuries were more frequent for unbelted occupants, but many belt-restrained occupants also sustained hip fractures. Interestingly, the hip injury tends to occur on the side of the body towards the damaged area of the vehicle and/or principal direction of force.

The results of this study suggest that the current limit on femur loads alone may not be sufficient to address hip injury risk in real-world frontal crashes. They also suggest there is a need for a better understanding of the biomechanics of hip injuries, injury criteria, and related ATD instrumentation.

Increasing Anatomic Injury Detail

In an effort to improve our understanding of injury mechanisms, we feel it is important to record and analyze injuries in as great anatomic detail as possible. The University of Michigan Medical System utilizes the most advanced imaging technologies available today for the care of its trauma patients. As a result, we have three-dimensional records of each study subject's injuries. This 3D radiological imaging system allows us to focus on each injury and follow the path of the forces acting on the body to cause that injury. For instance, in cases where we see a kidney injury, we are able to first look at the kidney itself and slowly add layers of the body back to the image until we have seen the exact location of other associated injuries within the surrounding soft tissues. In this way, we can see from which direction the force came. If we can determine which parts of the occupant's body were struck and where, we can better place the occupant within the vehicle at the time of the crash. We can better determine how the occupant moved in relation to the principal direction of force as well as the mechanisms of injury.

The imaging analysis software also allows us to take measurements in previously unavailable detail. We are able to examine a patient's CT to calculate the breadth of his chest, the thickness of his ribs, and the volume of his lungs. The UMPIRE team has the radiological image data of its CIREN patients. More importantly, UMPIRE also has access to the radiological data of thousands of other patients who may or may not have been traumatically injured. We are in the process of analyzing the body composition data contained in these radiological files to determine the effect of body composition differences on injury tolerance.

We also believe that the 3D radiological imaging system will help engineers in the future. With our access to the uninjured patients, we will be able to compile a database that will better characterize the constantly changing population with respect to height, weight, and body habitus. Since the crash dummies currently used in vehicle testing are based on cadaveric studies done several decades ago, they do not optimally represent the current population as a whole. With the advent of computers and computer simulated crashes, our data will also be invaluable for the development of virtual dummies useful for computer models of motor vehicle crashes and injury causation.

Human Factors in Injury Tolerance

Another of our areas of interest is the elderly population. With our 3D imaging software, we are aware of a number of areas in which the elderly body differs from the young. As people age, it is widely known that bone density decreases. We have also noticed that chest breadth increases.

We have also seen an increase in intra-abdominal fat. Whereas an obese young person has fat located mostly around the outside of the abdominal muscle tissue; the elderly person's fat has migrated inward creating a sort of "packing material" effect.

It is unclear the effect these changes may have on injury causation and treatment. Along with our in depth study on body composition across the population, we are looking closely at the elderly to determine if these changes increase the severity of injuries sustained and how best to prevent these injuries.

Education

Automotive Safety Engineers

It is our belief at UMPIRE that the information collected for CIREN should be disseminated as quickly as possible to the people who will use it. Currently in its second year, our UMPIRE fellowship program has been instrumental in providing automotive engineers with an in depth medical perspective. Our fellows continue to participate on a day-to-day basis with the collection of information for our database. At the same time, they are acquiring the additional expertise needed to augment their understanding of the influence car design has on injury mechanism and prevention. The initial fellows are now back at their sponsoring organizations full-time and are able to instruct other engineers on current trends in MVC injury and the potential influence that this work holds.

What the fellows have brought to the UMPIRE team is no less important. Their knowledge of automotive design allows our medical personnel to gain insights into vehicle interiors and automotive structure that in turn help when treating patients involved in MVCs. The fellows' assistance at our case reviews is invaluable. In many instances, they possess first-hand knowledge of the components within a vehicle interior – what materials they are made from, and the process by which they are created. They are able to tell us why a certain component reacted the way it did to the forces of the crash; they can also tell us if something didn't work the way it was designed to.

Child Booster Seat Education Program

UMPIRE has struck a partnership with the Society of Plastics Engineers (SPE) to develop a Booster Seat Program for elementary schools. The plan is to provide teaching professionals with a kit that includes a curriculum and interactive activities to show children how important it is for them to be buckled up properly. Studies have shown that so few parents and caregivers are aware of the importance of booster seats, we felt it appropriate to educate the parents as well as the children. We have prepared informational sheets to go home to the parents after their children have participated in our program. There are many booster seat programs currently in existence, but we feel what has been missing is the "human element." It is our desire to actively recruit and train people to deliver our booster seat message in as many classrooms as possible within the state of Michigan. In the future, we would like to expand this program to include pediatricians' offices, home daycare workers' licensing bureaus, and county health facilities.

The Mercedes-Benz CIREN Center at the University of Alabama at Birmingham

2002 Progress Report

The Mercedes-Benz CIREN Center is located at the University of Alabama at Birmingham. The University of Alabama at Birmingham (UAB) Health System is one of the largest and most diverse providers of health care, research, and education in the Southeast. With 908 beds, the UAB Hospital is the largest tertiary care institution in Alabama. UAB trains most of Alabama's physicians, nurses, dentists, optometrists, and allied health professionals. The Center is directed by Loring W. Rue, M.D. The Team is comprised of other trauma care clinicians and researchers, emergency care providers, epidemiologists, crash investigators, and engineers. Key participants of the Mercedes-Benz CIREN Center include Drs. Jorge Alonso, Stephan Moran, Donald Reiff, Gerald McGwin, Alan Eberhardt, Gregory Davis, Jim Davidson, Mr. Daniel Selke, Ms. Marilyn Doss, Ms. Holly Waller, and Ms. Kassi Webster.

Progress and Accomplishments

As of September 2002, the Mercedes-Benz CIREN Center team has screened 1564 patients for enrollment since investigating its first case in November 1999. So far, 127 cases have been enrolled. Between January and September 2002, the Center screened 515 patients and accepted 33 cases. Case review meetings involving trauma specialists, orthopaedic specialists, EMS providers, biomedical engineers, automotive safety engineers, etc. were held each month and the Team entered approximately 50 cases into the CIREN database.

The team has presented their work at many conferences and meetings. Past year conference and outreach presentations include:

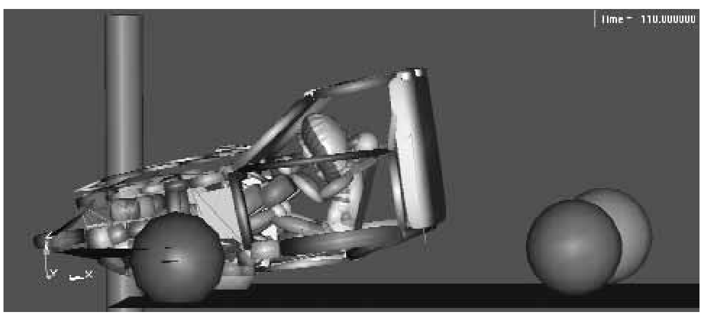
- "The Other CIREN — The Crash Injury Research and Engineering Network," presented by Holly Waller, RN, BSN at Emergency Nurses' Association Leadership Challenge, March 2, 2002—Charlotte, NC.
- "CIREN: Improving Motor Vehicle Safety" presented by Holly Waller, RN, BSN, May 16, 2002, UAB Trauma Burn Clinical Update, Birmingham, AL.
- "CIREN – Closing the Crashworthiness Loop" by Moran SG., presented at the Department of Surgery Grand Rounds, University of Alabama at Birmingham School of Medicine. Birmingham, AL. June 27, 2002.
- "CIREN – Closing the Crashworthiness Loop" Moran SG., Presented to the Western Automotive Journalists. San Francisco, CA. November 17, 2002.
- "The relationship between age and lower extremity fractures in motor vehicle collisions." Moran SG, Metzger J, McGwin G, Alonso JE, Rue LW. Poster presentation at 62nd Annual Meeting of the Association for the Surgery of Trauma.

CIREN was also highlighted at the Annual Southeast Trauma Conference for Orthopedic and Trauma Surgeons, held in Destin, FL, April 4-7, 2002. CIREN-focused presentations included "CIREN and Skeletal Trauma" by Dr. Andrew Burgess of the University of Maryland and the Johns Hopkins University and "Restraint use and Lower Extremity Fracture in Frontal Motor Vehicle Collisions" by Dr. Lance Estrada, orthopedic resident at UAB.

Researchers associated with the Mercedes-Benz CIREN Center have been very prolific over the past year, publishing several articles in nationally and internationally recognized trauma care and injury analysis journals and presenting works at national and regional conferences. A list of recent publications and presentations, along with abstracts is presented under "Research Results".

Student Involvement

As part of the UAB Center for Injury Sciences (CIS), the Mercedes-Benz CIREN Center has had the opportunity to involve medical students and residents in its activities. Residents in general surgery participate in the collection and interpretation of data collected as part of a CIREN investigation and review. This past year, the Center's involvement with medical students expanded. Students were responsible for investigating hypotheses about injury patterns in motor vehicle collisions that are generated from individual CIREN cases. Working with CIS staff, these students addressed hypotheses using databases including NASS, FARS and GES.



Students have also participated in CIREN-related activities within the School of Engineering. Both graduate and undergraduate engineering students have been involved in the biomechanical lower extremity research being conducted by Drs. Eberhardt and Alonso. Several theses and publications have resulted. Also, through funding from the National Science Foundation, National Highway Traffic Safety Administration, and the University Transportation Center for Alabama, engineering students have explored, for example, causes and mechanisms of motor vehicle crash induced head injury, causes and mechanisms of injury in children, and technology needed for an integrated system for the remote determination of injuries incurred during motor vehicle crashes.

Partnerships

During the past year, the involvement of two important partnerships was expanded. As part of the partnership was with the Jefferson County Coroner/Medical Examiner Office (JCCMEO), 22 motor vehicle collision related fatalities were accepted as CIREN cases and reviewed. A partnership with The Children's Hospital of Alabama (TCHA) was also formed. Dr. William Hardin, Associate Professor of Surgery, and Carden Johnston, Professor of Pediatrics, participated in cases reviews over the past year and will lead the CIREN effort at TCHA.

Research Results

Differences in the Incidence and Etiology of Blunt Thoracic Aortic Injury in Motor Vehicle Collisions by Age

McGwin G, Reiff DA, Rue LW. Differences in the incidence and etiology of blunt thoracic aortic injury in motor vehicle collisions by age. *J Trauma*. 2002;52:859-65.

Introduction – Motor vehicle collision (MVC) related blunt thoracic aorta injury (BAI) is rare and highly lethal. Vascular disease as related to advancing age potentially subjects older adults to increased risk of BAI; the mechanisms associated with such injuries may be different as compared to younger adults. The goal of the present study is to test this hypothesis using population-based data. **Methods** – The 1995-1999 National Automotive Sampling System (NASS) data files were utilized. NASS is a national probability sample of passenger vehicles involved in police-reported tow-away crashes. BAI was defined according to the Abbreviated Injury Scale codes. Among those with BAI, information on occupant (age, seating position, restraint use), collision (collision type, delta-V, vehicle intrusion) and outcome characteristics were obtained and compared according to age. **Results** – The overall incidence of BAI was 6.8 per 10,000 occupants and a steady increase in the BAI rate for advancing decades of life. The proportion of occupants with BAI who die at the scene of the collision is relatively consistent across all age groups (~85%). Among those who survive to receive medical care, ultimate survival is lowest among those aged 60 and older. Near-side collisions were responsible for more BAI among older adults than other age groups (50% vs. 20.6%, $p < .05$). Older adults sustained BAI in collisions with lower delta-V values compared with younger persons ($p < .05$). **Conclusions** – Older adults have the highest rate of MVC related BAI and their injuries tend to occur in less severe collisions. Age associated atherosclerosis and calcification of the great vessels, which diminish vessel elasticity and compliance, may explain this difference. A high level of suspicion for BAI among older adults should not be reserved for high-energy collisions only.

Restraint Use and Injury Patterns Among Children Involved in Motor Vehicle Collisions

Valent F, McGwin G, Hardin W, Johnston C, Rue LW. Restraint use and injury patterns among children involved in motor vehicle collisions. *Journal of Trauma*. 2002;52(4):745-51.

Introduction – Motor vehicle collisions (MVC) are the leading cause of death among children over 1 year of age (YOA). Use of appropriate restraint systems is associated with reductions in morbidity and mortality in this age group. No studies have evaluated the association between specific injury patterns and restraint use among children. The purpose of this study was to evaluate differences in rates of specific injuries according to restraint use among children 0-11 YOA. **Methods** – The 1995-1999 National Automotive Sampling System (NASS) data files were utilized. NASS is a national probability sample of passenger vehicles involved in police-reported tow-away crashes. Information on occupant (seating position, restraint use), collision (change in velocity, vehicle intrusion) and outcome characteristics was evaluated. Rates for specific injuries (Abbreviated Injury Scale [AIS] ≥ 2) were calculated and compared according to restraint use. **Results** – Between 1995 and 1999 there were approximately 1.5 million children 0-11 YOA involved in police-reported tow-away MVCs; 36,640 experienced an injury of AIS≥2 (2.4/100). Proper restraint use varied by YOA subgroups; 0-3 (53.9%), 4-7 (60.5%), 8-11 (74.7%). Injury rates were lower among properly restrained than among unrestrained children. Additionally, improperly restrained occupants had higher rates than those properly restrained, and rates of face, upper extremity, and lower extremity injury were significantly higher among improperly restrained children than among those properly restrained. **Conclusion** – Proper restraint use among children is associated with lower rates of injury. Educational initiatives should focus not only on encouraging restraint use but also ensuring that parents know the appropriate age dependent restraint method.

The Relationship Between Age and Lower Extremity Fractures in Motor Vehicle Collisions

Moran SG, Metzger JS, McGwin G, Alonso JE, Rue LW. The relationship between age and lower extremity fractures in motor vehicle collisions. Poster presentation at 62nd Annual Meeting of the Association for the Surgery of Trauma. *Journal of Trauma*. In press.

Background – Older adults (age > 65 years) represent the single fastest growing segment of the United States population and will comprise one in five Americans during the third decade of this century. As this population segment rapidly expands, lower extremity fractures (LE Fx) and their associated disability will become a greater public health concern. The purpose of this study was to quantify the risk for LE Fx from motor vehicle collisions (MVC) according to age. **Methods** – The 1995-2000 National Automotive Sampling System data files were utilized. Study entry was limited to front seated occupants involved in frontal MVCs. Risk ratios for LE Fx and age were adjusted for gender, driver vs. passenger, seatbelt use, airbag deployment, delta-V, intrusion and vehicle type. **Results** – Beginning in the fourth decade, there was a trend of higher relative risk for LE Fx with age that reached statistical significance in the seventh decade of life. **Conclusion** – This study documented an increased risk of LE Fx in older MVC occupants. Efforts to prevent these disabling injuries and to better protect occupants' lower extremities in MVCs should include improved vehicle design and reevaluation of the existing Federal Motor Vehicle Safety Standards.

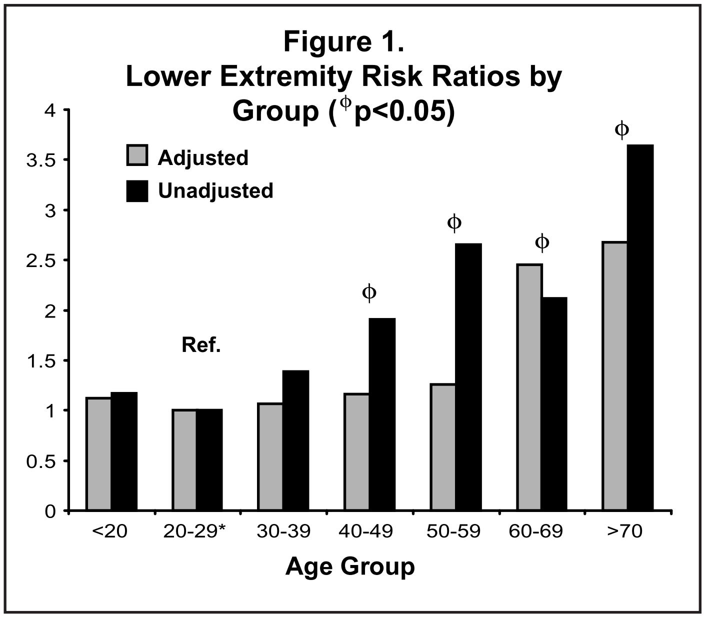


Figure 1.
Lower Extremity Risk Ratios by Group ($^{\phi}$p<0.05)

Splenic Injury in Side Impact Motor Vehicle Collisions – The Effect of Occupant Restraints

Reiff DA, McGwin G, Rue LW. Splenic injury in side impact motor vehicle collisions – The effect of occupant restraints. *J Trauma*. 2001; 51:340-5.

Introduction – Side impact motor vehicle collisions (MVCs) are associated with higher morbidity and mortality compared to other types of MVCs. The stiffness of the lateral aspect of the vehicle and restraint use may play a role. The purpose of this study was to evaluate the role of restraint use, vehicle size and compartment intrusion on the incidence of splenic injury in side impact MVCs. **Methods** – The National Automotive Sampling System (NASS) was used to identify drivers involved in side impact collisions for the years 1996-1998. The incidence of splenic injury in these collisions was compared according to restraint use, vehicle size and magnitude of vehicle crush. Information on the perceived etiology of splenic injuries sustained in the MVC was also obtained from

NASS investigator records. **Results** – Overall, among drivers involved in side impact MVCs, restraint use was associated with a significantly reduced rate of mortality (odds ratio [OR]= 0.40, p<0.0001) and splenic injury (OR=0.76, p<0.0001). Restrained drivers of small vehicles (<2,500 lbs.), however, had a higher incidence of splenic injury in both minimal (lateral intrusion < 30 cm.) (OR=60.1, p<0.0001) and severe (lateral intrusion > 30 cm.) (OR=4.0, p<0.0001) magnitudes of vehicle crush on the driver's side of the vehicle. For both mid-sized (2,500 – 3,000 lbs.) and large (>3,000 lbs.) vehicles, restraint use was associated with a lower risk of splenic injury regardless of the magnitude of crush. In nearly all cases of splenic injury, the left vehicle interior was the source of injury. **Conclusio**n – Overall, restraint use is associated with lower rates of splenic injury and mortality in side impacts. Despite this fact, restrained drivers of small vehicles have a higher risk of splenic injury following lateral impact MVCs when compared with unrestrained drivers. Evaluation of the combined role of restraint use, crash and injury patterns may provide novel insight regarding vehicle safety design features.

Injury Rates among Restrained Drivers in Motor Vehicle Collisions: The Role of Body Habitus

Moran SG, McGwin G Jr, Metzger JS, Windham ST, Reiff DA, Rue LW. Injury rates among restrained drivers in motor vehicle collisions: the role of body habitus. *J Trauma*. 2002;52:1116-20.

Background – Previous studies have examined the independent effects of occupant height, obesity, and body mass index in motor vehicle collisions and identified related injury patterns. The hypothesis of this study was that as the driver's body habitus diverges from the 50% percentile male Hybrid III Crash Dummy (H3CD), the frequency of injury changes. **Methods** – The 1995 to 1999 National Automotive Sampling System Crashworthiness Data System was used. Study entry was limited to restrained drivers who were then subdivided into height and weight categories. Incidence rates were calculated for injuries to selected body regions as defined by the Abbreviated Injury Scale for overall, frontal, and driver's side collisions. **Results** – When grouped according to height and weight as descriptors of body habitus, injury rates for restrained drivers were increased as well as decreased in several subgroups. This association was seen in overall, frontal, and driver's side collisions. **Conclusion** – The H3CD plays a major role in vehicular cabin interior design and crash testing. For drivers with a body habitus different from that of the H3CD, the vehicle cabin/body fit changes and the safety features may perform differently, which could account for these observations.

The Association between Body Mass Index, Restraint Use, and Fatality in Motor Vehicle Collisions

Moran SG, McGwin G, Reiff DA, Rue LW. The association between body mass index, restraint use, and fatality in motor vehicle collisions. *Proceedings of the Association for the Advancement of Automotive Medicine*. 2001;45:107-123.

Background – The purpose of this study was to characterize the association between BMI, body habitus (height and weight) and risk of death for restrained drivers involved in MVCs. In characterizing any association, the authors sought to identify patterns of the rare occurrence of fatality in MVCs. **Methods** – The 1995-1999 National Automotive Sampling System Crashworthiness Data System was utilized. Fatality rates were calculated and compared between BMI and body habitus categories. The data was further stratified according to general area of damage; fatality rates were then compared. To quantify the magnitude of these associations, fatality relative odds ratios (ORs) and 95 percent confidence intervals (CIs) were calculated with the 50th percentile Hybrid III male crash dummy as the reference point, p-values of £0.05 were considered statistically significant. SUDAAN" 7.52 was used for all statistical analyses. **Results** – Body mass index as a descriptor of body habitus was not associated with fatality rates. When grouped according to height and weight as descriptors of body habitus, fatality rates for restrained drivers were significantly different in several subgroups. In MVCs overall, fatality rates were decreased in three of the lighter subgroups. The fatality rate was increased in the subgroup shorter than the Hybrid III in driver's side collisions and the lighter subgroup in frontal collisions. The 5th percentile female subgroup did not have fatality rates and ORs significantly different from the H3CD. **Conclusions** – The 50th percentile male Hybrid III Crash Dummy plays a major role in vehicular cabin interior design and crash testing. For drivers with a dissimilar body habitus, the vehicle cabin/body fit changes and the safety features perform differently which may account for these observations.

Identifying Injuries and Motor Vehicle Collision Characteristics That Together Are Suggestive of Diaphramatic Rupture

Reiff DA, McGwin G, Metzger J, Doss M, Rue LW. Identifying injuries and motor vehicle collision characteristics that together are suggestive of diaphramatic rupture. *Journal of Trauma*. In press.

Introduction – Diaphragmatic rupture (DR) remains a diagnostic challenge due to the lack of an accurate test demonstrating the injury. As non-operative management of solid organ injury is more frequently employed, early recognition of DR has become more complicated. Our purpose was to identify motor vehicle collision (MVC) characteristics and patient injuries, which collectively could indicate DR. **Methods** – The National Automotive Sampling System was used to identify front seat occupants involved in MVCs from 1995-99 who sustained abdominal (Abbreviated Injury Scale (AIS ≥ 2) and/or thoracic injuries (AIS ≥ 3). The frequency of specific injuries and MVC characteristics, alone and in combination, were compared among patients with and without a DR. Odds ratios (OR) and 95% confidence intervals (CI) were calculated to quantify the association between patient injuries, vehicle collision characteristics and DR. Sensitivity and specificity were also calculated to determine the ability of organ injury and MVC characteristics to correctly classify patients with and without DR. **Results** – Overall, among drivers and front seat passengers involved in MVCs, patients with DR had a significantly higher delta-v (DV) (50.3 kph vs. 36.4 kph, $p < 0.0001$) and a greater degree of occupant compartment intrusion (70.6 cm vs. 52.3 cm, $p < 0.0001$). Specific abdominal and thoracic organ injuries were associated with DR including thoracic aortic tears (OR, 4.2; 95% CI 1.8-10.1), splenic injury (OR, 5.4; 95% CI 2.5-11.8), pelvic fractures (OR, 4.0; 95% CI 2.4-6.7) and hepatic injuries (OR, 2.3; 95% CI 0.9-5.7). Combining frontal or near-side lateral occupant compartment intrusion ≥ 30 cm or (DV) ≥ 40 kph with specific organ injuries generated a sensitivity for detecting diaphragm injury ranging from 85-88%. Patients with any of the following characteristics; splenic injury, pelvic fracture, DV ≥ 40 kph or occupant compartment intrusion from any direction ≥ 30 cm had a sensitivity for detecting DR of 91%. **Conclusion** – We have identified specific MVC characteristics combined with patient injuries, which together are highly suggestive of DR. For this subpopulation, additional invasive procedures including exploratory laporotomy, laparoscopy or thoracoscopy may be warranted to exclude DR.

Common Bile Duct Transection in Blunt Abdominal Trauma: Case Report Emphasizing Mechanism of Injury and Therapeutic Management

Melton SM, McGwin G, Cross JM, Davidson J, Waller H, Doss MW, Vickers S, Rue LW. Common bile duct transection in blunt abdominal trauma: Case report emphasizing mechanism of injury and therapeutic management. *Journal of Trauma*. In press.

Extrahepatic biliary tract injuries occur in three to five percent of all abdominal trauma victims with 85% resulting from penetrating wounds. Of the remaining 15%, the vast majority, 85%, involve the gallbladder alone. Consequently, common bile duct injuries from blunt abdominal trauma are exceeding rare, especially those resulting in complete transection of the duct. A patient sustaining complete transection to the CBD following blunt force motor vehicular trauma will be presented. A review of diagnostic techniques and therapeutic management is summarized. The details of the mechanism of injury in this motor vehicle crash are closely examined using data obtained from an in-depth crash investigation and analysis.

The Association Between Restraint Systems and Frontal Motor Vehicle Collision-Related Morbidity and Mortality

McGwin G, Metzger J, Alonso JE, Rue LW. The association between restraint systems and frontal motor vehicle collision-related morbidity and mortality. *Journal of Trauma*. In press.

Background – An evaluation of seat belt use and air bag deployment, either alone or in combination, on risk of injury to specific body regions has yet to be completed. **Methods** – A retrospective cohort study of front seat occupants involved in police-reported, tow-away frontal MVCs using data from the 1995 through 2000 National Automotive Sampling System was conducted. Only vehicles with a change in velocity (ΔV) of ≥15 kmph were included. Risk of injury (Abbreviated Injury Scale [AIS], ≥2) to specific body regions was compared according to seat belt use and air bag deployment. **Results** – Compared to completely unrestrained occupants, those using a seat belt alone or in combination with an air bag had a reduced overall risk of injury (relative risk [RR] 0.42 and 0.71, respectively); no association was observed for those restrained with an air bag only (RR 0.98). This pattern of results was similar for specific body regions with the exception of the lower extremity wherein a significantly increased risk was observed for air bay deployment alone. **Conclusion** – Air bag deployment does not appear to significantly reduce the risk of injury either alone or in combination with seat belts. Air bag deployment without associated seat belt use may increase the risk of lower extremity injury.

Gender Differences in the Incidence of Below Knee Fractures following Offset Frontal Motor Vehicle Collisions

McGwin G, Reiff D, George R, Davidson J, Rue LW. Gender differences in below knee fractures following offset frontal collisions. *Journal of Trauma*. Submitted.

Introduction – Motor vehicle collisions (MVCs) are the leading cause of injury-related deaths in the United States. While the fatality rate associated with MVCs has dramatically fallen as personal restraint use has increased, the rate of lower extremity (LE) injuries has not been significantly affected by their use. Lower extremity injuries are costly and the cause of permanent disability and impairment following MVCs. Previous authors have found females to be at particular risk of LE fractures and attributed this gender dimorphism to their shorter stature. **Methods** – The National Automotive Sampling System was used to identify drivers involved in frontal MVCs from 1995-99. The rate of below knee fractures was compared between males and females both overall and stratified by occupant and crash characteristics. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated to quantify the association between gender and below knee LE fractures. **Results** – Below knee fractures following offset frontal MVCs occur less frequently among males compared with females (OR 0.61, 95% CI 0.43-0.85). Neither age nor DV, the change in velocity at the time of collision, was able to explain this observed difference. Among occupants who sat with the seat in the middle or back position, males had a lower incidence of below knee fractures (OR 0.67, 95% CI 0.46-0.97); this pattern was also present among those seated in the forward position (OR 0.26, 95% CI 0.07-0.93). **Conclusion** – Females are at greater risk of below knee fracture regardless of height, seat position and DV following offset-frontal MVCs. Possible explanations of these findings include footwear, driving habits and/or bone density. These findings warrant further investigation by automobile and federal agencies in an effort to reduce these lifelong disabling injuries.

Injury Patterns Among Older Adults Involved in Motor Vehicle Collisions – The Role of Near Side Collisions

McGwin G, McRae WE, Taylor AJ, Davidson JS, Rue LW. Injury patterns among older adults involved in motor vehicle collisions – The role of near side collisions. *Journal of Orthopaedic Trauma*. Submitted.

Background – Automobile collisions are more likely to result in injury and result in poorer outcomes for older adults. Of particular concern are side-impact collisions which have been shown to result in elevated morbidity and mortality for older adults. The objective of this study is to compare injury patterns in near-side (NS) versus non-NS collisions among patients 60 years of age and older treated at a Level I trauma center. **Methods** – The study population was 201 patients aged 60 years and older admitted to a Level I trauma center for injuries sustained in motor vehicle collisions. Injury patterns were compared between patients involved in NS versus non-NS collisions. **Results** – Differences in injury patterns between NS and non-NS patients were a function of seatbelt use and vehicle speed. Among restrained patients and those involved in high-speed collisions, NS patients were more likely to sustain head injuries and pelvic fractures. Among unrestrained patients, tibia/fibula fractures were more common among NS compared with non-NS patients (NS: 42.9% vs. non-NS: 11.4%; p=0.07). **Conclusion** – Injury patterns among older adults involved in motor vehicle collisions differ according to characteristics of the collision. Future research should determine whether these injury patterns are independent of age.

Occupant and Collision Related Risk Factors for Blunt Thoracic Aorta Injury

McGwin G, Metzger J, Moran SG, Rue LW. Occupant and collision related risk factors for blunt thoracic aorta injury. *Journal of Trauma*. Submitted.

Introduction – Blunt thoracic aortic injury (BAI) is a rare and highly lethal injury. We sought to identify occupant and collision characteristics associated with motor vehicle collision (MVC) related BAI. **Methods** – The 1995-2000 National Automotive Sampling System (NASS) data files were utilized. NASS is a national probability sample of passenger vehicles involved in police-reported tow-away MVCs. The risk of BAI was calculated according to specific occupant (e.g., age, seat belt use) and collision (e.g., ΔV, vehicular intrusion) characteristics. The association between BAI and these characteristics was calculated using risk ratios (RRs) and associated 95% confidence intervals (CIs). **Results** – Specific occupant and collision characteristics demonstrated independent association with BAI. Occupant characteristics included age ≥60 (RR 3.61, 95% CI 2.53-5.15), seat belt use (RR 0.33, 95% CI 0.21-0.53), and being a front-seated occupant (RR 3.11, 95% CI 1.51-6.34). Frontal and near-side collision were associated an increased (RR 3.10, 95% CI 1.88-5.11 and RR 4.30, 95% CI 2.58-7.18, respectively) relative to other collision types. Collisions with a ΔV ≥ 40 km/h (RR 3.80, 95% CI 2.59-5.57) or that produce extensive vehicle crush (≥40 cm.) (RR 4.11, 95% CI 2.70-6.27) or intrusion (≥15 cm.) (RR 5.03, 95% CI 3.47-7.30) also increase the risk of BAI. **Conclusion** – The risk factors for BAI identified in this study support generally accepted etiologic mechanisms for this injury.

Is Seat Belt Use Associated with Fewer Days of Lost Work Following Motor Vehicle Collisions?

Metzger J, McGwin G, Rue LW. Is seat belt use associated with fewer days of lost work following motor vehicle collisions? *Journal of Trauma*. Submitted.

Introduction – Seat belt use has consistently been shown to reduce motor vehicle collision (MVC) related morbidity and mortality. The goal of this study is to determine whether seat belt use is associated with fewer lost workdays among occupants involved in MVCs. **Methods** – The 1995-2000 National Automotive Sampling System (NASS) data files were utilized. NASS is a national probability sample of passenger vehicles involved in police-reported tow-away MVCs. Occupants' lost workdays, which are routinely collected as part of a NASS investigation, were compared according seat belt use. **Results** – During 1995-2000 in the United States, surviving occupants involved in MVCs lost a total of 36.8 million workdays (~6.1 million lost workdays per year; 2.1 lost workdays per person). The overall difference in lost workdays between the belted and unbelted occupants was 1.38 days (1.75 days vs. 3.13 days, respectively; p=0.002). After adjusting for potentially confounding factors, belted occupants had 1.29 fewer lost workdays compared with unbelted occupants (p=0.002). This translates to an estimated 6.2 million lost workdays and an associated $480 million in lost wages and $910 million in workplace costs attributable to lack of seat belt use in the United States during 1995-2000. **Conclusion** – Lost workdays attributable to MVCs in the United States have sizable financial implications. Furthermore, seat belt use significantly reduces lost time at work and is associated with a significant cost savings. The national impact of unbelted driving on work productivity is dramatic and further efforts to promote appropriate seat belt use should continue as part of the national safety agenda.

The Association Between Side Air Bags and Risk of Injury in Near-Side Impact Motor Vehicle Collisions

McGwin G, Metzger J, Porterfield JR, Moran SG, Rue LW. The Association Between Side Air Bags and Risk of Injury in Near-Side Impact Motor Vehicle Collisions. Presentation at the 2003 EAST Meeting.

Context – Side air bags (SABs) have been introduced in an attempt to reduce the risk of injury in near-side impact motor vehicle collisions (MVCs). The impact of SABs on MVC-related mortality and morbidity has yet to be evaluated with a large population-based study. **Objective** – To assess the effectiveness of SABs in reducing the risk of injury or death in near-side impact MVCs. Design, Setting, **Subjects** – A retrospective study of outboard front-seated occupants involved in police-reported, near-side impact MVCs using data from the General Estimates System (1997-2000). **Main Outcomes Measures** – MVC-related non-fatal and fatal injury. **Results** – Front seated occupants in vehicles with SABs had a similar risk of injury as those occupants in vehicles without SABs (relative risk [RR] 0.96, 95% confidence interval [CI] 0.79 -1.15). Adjustment for the potentially confounding effects of age, gender, seat belt use, seating position, damage severity and location and vehicle body type did not meaningfully affect the association (RR 0.90, 95% CI 0.76-1.08). **Conclusion** – There is no association between the availability of SABs and overall injury risk in near-side impact MVCs. Future research will be necessary to determine the effectiveness of SABs in preventing those injuries for which they were specifically designed.

Risk of Injury and Death for Occupants of Motor Vehicle Collisions from Unbelted Occupants

MacLennan P, McGwin G, Metzger J, Rue LW, Moran SG. Risk of Injury and Death for Occupants of Motor Vehicle Collisions from Unbelted Occupants. Presentation at the 2003 EAST Meeting.

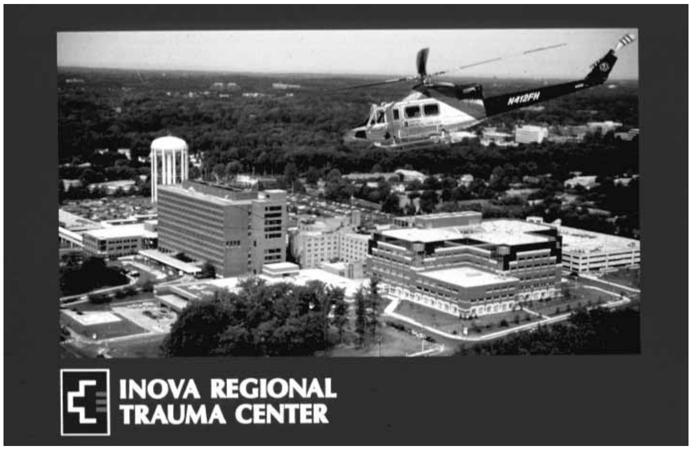
Context – In a motor vehicle collision (MVC), unbelted occupants may increase the risk of injury and death for other occupants by becoming projectiles within the vehicle. Few studies have investigated this issue. **Objective** – The purpose of the study was to evaluate the association between occupant restraint use and the risk of injury and death to other vehicle occupants. **Design** – A population based case-control study. **Setting** – The 1991-1999 General Estimates System (GES), a probability sample of all police reported MVCs annually in the United States. **Patients** – At-risk subjects were defined as MVC occupants seated with a belted or unbelted occupant contiguous to them and in the line of the principal direction of force (PDOF). **Main Outcome Measure** – Cases were occupants with a known, non-incapacitating, incapacitating, fatal or severity unknown injury, while controls were occupants that were not injured. The primary exposure of interest was seat belt usage of the occupant contiguous to the at-risk occupant. **Results** – For all at-risk occupants, exposure to unbelted occupants was associated with a 2.4 fold increased risk of injury or death (OR=2.4, 95% CI 2.2-2.6) when adjusted for age, seating position, vehicle type and crash severity. This association was modified by the seat belt use of the at risk occupant. When at risk occupants were belted, they were at increased risk (OR=1.7, 95% CI 1.5-1.8), though less than if they were unbelted (OR=3.2, 95% CI 2.9-3.6). For belted at-risk occupants, there was a 70% increased risk of injury or death associated with exposure, but among unbelted at-risk occupants, the association was absent (OR=1.0, 95% CI 0.8-1.1). **Conclusions** – Belted occupants seated with an unbelted occupant contiguous to them and in the line of the PDOF are at an increased risk of injury and death in the event of a MVC.

Inova Fairfax Hospital CIREN Center

CIREN Program Report

About the Inova Regional Trauma Center

The Inova Regional Trauma Center (IRTC) is one of the busiest trauma centers in the Washington, DC, metropolitan area. In 2001 the trauma center treated more than 2,600 severely injured patients with the majority of patients injured in motor vehicle crashes (61 percent), which represents a significant increase (12 percent) from the previous year. The IRTC is committed to decreasing trauma-related death and disability through education, outreach, prevention, and research to improve the quality of life for everyone in the community. Sixty-nine percent of the patients treated at the IRTC are from Fairfax County, which is an affluent community with a high percentage of new vehicles in the population resulting in a higher probability of encountering new vehicle safety technology.



This report is for the period of time primarily funded by Ford Motor Company until September 2002. Subsequently, Ford funding was replaced by American Honda Motor Company.

The CIREN Center at the IRTC has the unique opportunity to capture crash events and information because of our long standing integration with the Fairfax County Fire and Rescue Department and the on-scene real-time availability of the Fairfax County Police Accident Reconstruction Unit for most of our cases. The Fairfax County Fire and Rescue Department provide all-professional staffing for vehicle crash victims backed up by the Inova Fairfax Hospital Helicopter service (Inova Medical AirCare). The Fairfax County Fire and Rescue Department have an average response time to crashes of 4–6 minutes. The helicopters are less than 10 minutes from any point in the county. The Fairfax County Police Department has a specialized Accident Reconstruction Unit (ARU) available on call 24 hours per day, 7 days a week in response to fatal and other severe crashes (including potential CIREN cases). This provides real time, accurate reconstruction of crashes and more reliable data.

What is New at the Inova Regional Trauma Center

In May 2001 the Inova Regional Trauma Center joined forces with trauma centers across the state and the Medical Society of Virginia to hold the first annual Blue Ribbon Campaign, Trauma Awareness Month. Staff from the trauma center and the Ford Inova Fairfax Hospital CIREN Center checked motorists driving into the parking areas on the Inova Fairfax Hospital campus for seat belt usage and gave them a blue ribbon if they were buckled up. Unbelted drivers received educational brochures regarding the dangers of unbelted driving.

In August 2001, the Inova Regional Trauma Center hosted two groups of Northern Virginia legislators for the presentation "Trauma in your Community: The Reality". The goals of the of these presentations were: to increase awareness of Northern Virginia's highway injury problems; provide an overview of the variety of ways the trauma center is working to address these problems; present injury prevention and safety measures for consideration; and highlight the resources available when trauma/injury issues arise.

In 2001, the Inova Regional Trauma Center received a grant for $87,200 from the Centers for Disease Control to support and facilitate the recovery of trauma patients and caregivers from the effect of trauma.

As part of the continued research on aggressive driving in the Washington, DC, metropolitan area: presented "Results of Research on Aggressive Driving Behavior" at the Second Annual Symposium on Aggressive Driving, "Strategies and Solutions for Aggressive Driving, held at the University of Maryland; received a $120,000 grant from the motor vehicle administration of Maryland, Virginia and the District of Columbia to support this research for the coming year; support a joint effort with the Washington Redskins to survey fans at local games regarding aggressive driving behaviors and the Smooth Operator Program.

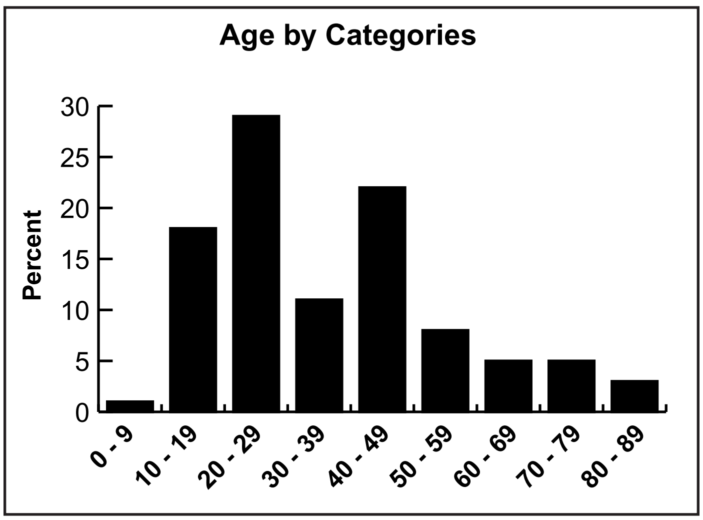
In 2001, REBUILD, a support group for victims of trauma, expanded its services to address the special needs of traumatic brain injury (TBI) and spinal cord injury (SCI) victims and their families.

James D. Bean has joined the Ford Inova Fairfax Hospital CIREN Center, as a crash reconstructionist. Mr. Bean has retired after 26 years as a police officer and has 17 years experience in crash reconstruction for the Fairfax County Police Department.

Ford Inova Fairfax Hospital CIREN Center Statistics

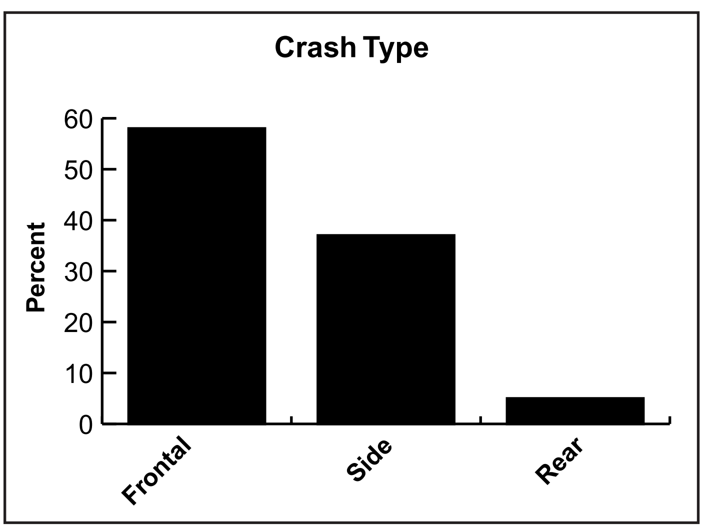
Since joining the CIREN network in May 2000, the Ford Inova Fairfax Hospital CIREN Center has enrolled eighty-eight (88) subjects into this study.

Age Distribution



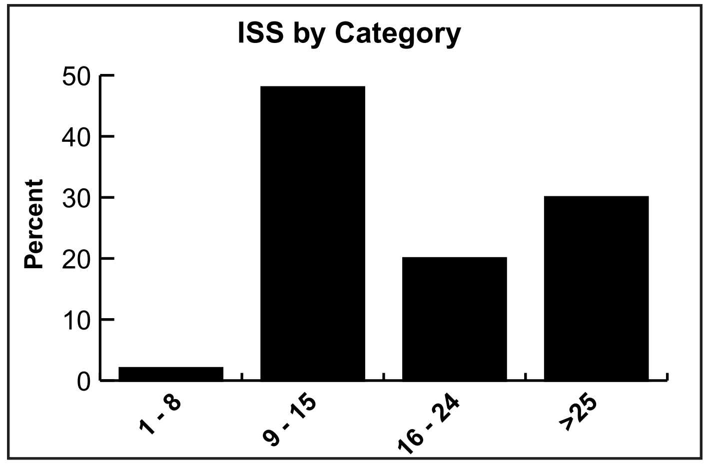
Crash Types

55% cases in frontal crash; 39% cases in side crash; 6% cases in rear crash



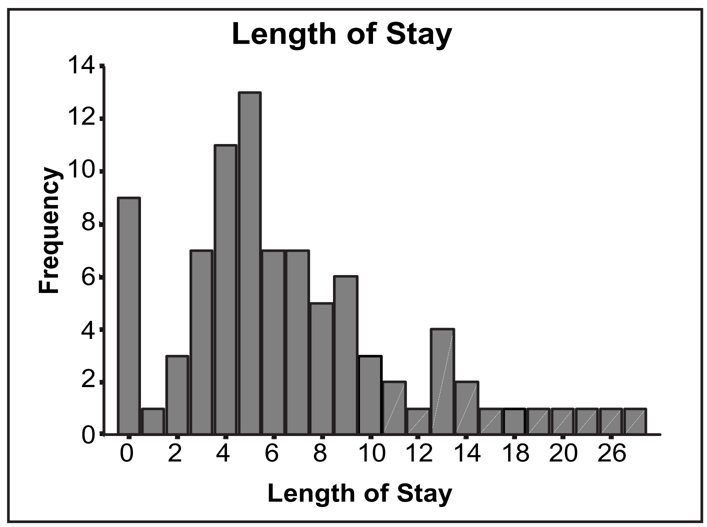
Injury Severity Scores (ISS)

ISS 1-8	3%	ISS 9-15	45%
ISS 16-24	21%	ISS > 25	31%

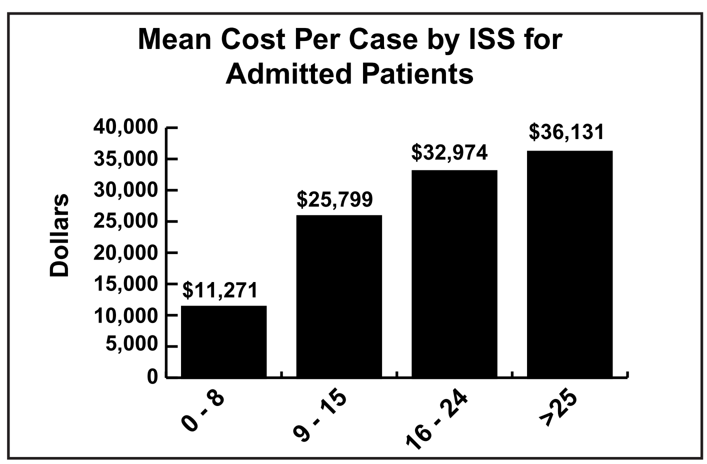


Crosstabulation analysis determined that 50% of frontal crash ISS scores were 16 or greater and 44% of side crash ISS scores were > 25.

Average length of hospital stay was 7 days. 10% of patients were fatalities accounting for 0 hospital days.



Mean Cost Per Case by ISS for admitted patients



Testimonial

> "Since the beginning of the involvement of the Fairfax County Police Department's Accident Reconstruction Section with the Crash Injury Research and Engineering Network (CIREN) Program, we have noticed a change in our investigations. The Accident Reconstruction Section has the responsibility of investigating all fatal and life threatening motor vehicle crashes.
>
> During the investigation of the crashes, a determination is made as to occupant positioning within vehicles. Our involvement with CIREN has improved our evidence gathering, occupant kinematics and documentation of the vehicle, thusly making a determination as to positioning.
>
> The relationship with INOVA Fairfax Hospital that has developed through CIREN participation has been used to provide a flow of information. This information is used to assist the Fairfax County Police Department in its mission to save lives. As this relationship continues, I am sure we will continue to save more lives within the realm of transportation."
>
> James J. Banachoski, Detective
> Fairfax County Police Department
> Accident Reconstruction Section

What We Have Learned

Pre-Hospital Providers

Fairfax County Fire and Rescue representatives are invited to all CIREN Case Reviews since only a few can attend at any one time, results from the CIREN Case Reviews are forwarded to the individual stations that transported the study subject to allow them insight into the crash. Based on this information paramedics are now triaging and transporting with more emphasis on side impacts and the differences in injury patterns and severity seen in side impacts.

Trauma Surgery

Through participating in CIREN Case Reviews, trauma surgeons have learned to more completely understand mechanisms of injury, which has led them to consider the seriousness of side impacts vs frontal impacts. Trauma surgeons are now paying more attention to the pre-hospital providers reporting on mechanism of injury, pictures taken at the scene and appreciate the relationship of crash description to the patient's risk of injury. Residents and medical students are educated in considering mechanism of injury when evaluating a motor vehicle crash victim.

CIREN information has led to tying the seriousness of side impact into the Aggressive Driving Study that is funded by the Department of Motor Vehicles of the States of Virginia, Maryland and the District of Columbia. Traffic signal violation statistics have found disturbing evidence that the disregard for traffic signals and stop signs have reached dangerous highs (Aggressive Driving: A Preliminary Analysis of a Serious Threat to Motorists in a Large Metropolitan Area, Journal of Trauma, 2001, Volume 52). The knowledge gained from CIREN will help educate the public on the danger of side impact crashes and is planning to be a part of the public education campaign. The Ford Inova Fairfax Hospital CIREN Center has also utilized CIREN data to educate student drivers that participate in the Reality Check Program on the dangers of driving under the influence of drugs and/or alcohol as well as distractions by other vehicle occupants and other sources. In the future, Reality Check will also include crash modeling from the University of Virginia to convince young drivers to utilize seatbelts and become more safety conscious.

New Injury Patterns

Being operational for only a short period of time, the Ford Inova Fairfax Hospital CIREN Center has not enrolled a large enough patient base to show any patterns in injury.

Education and Outreach

Over the past two years, the CIREN team has held numerous educational presentations to pre-hospital providers educating approximately 500 pre-hospital providers on advanced occupant protections systems, vehicle dynamics and occupant kinematics. The following is a selection of outreach and educational sessions offered by the Ford Inova Fairfax Hospital CIREN Team.

Anatomy of a Crash

A representative from the Discovery Channel contacted Dorraine D. Watts, PhD, PI, CIREN in March 2002 indicating interest in developing a Discovery Channel documentary on the "Anatomy of a Crash". A CIREN study participant agreed to have her crash highlighted in this educational TV program. The Discovery crew filmed the scene, the vehicle inspection, which included an interview with Detective James Banachoski, Fairfax County Police Department, as well as interviews with Dr. Dorraine D. Watts and the patient. The show aired in September and October 2002.

Trauma Externship Program

The Trauma Externship is a bi-annual intensive three-week program that offers preprofessional students interested in a career in the trauma care a comprehensive introduction to the world of trauma. As part of the curriculum, the students receive a lecture on CIREN. The following is a testimonial from one of the students that attended the program in July 2002.

> "My name is Heather McGraw, and I am a 24-year-old nursing student who recently participated in the trauma externship program at Inova Fairfax Hospital. One of my favorite parts of the externship was learning

about CIREN. I had never heard of anything quite like CIREN before, and I was absolutely fascinated by it. After having spent a great deal of time this summer observing the devastating effects of motor vehicle crashes – not just the victims themselves, but also on families, friends and even on the community as a whole – I am more convinced then ever that injury prevention needs to be a major focus in our society. That is why I think the CIREN program is so tremendously important. By collecting data from real-life crashes and integrating it with the expert knowledge of professionals from multiple disciplines, CIREN produces a unique, highly-detailed body of research which can help automotive engineers design safer cars. I think CIREN is cool, and I am hoping to get involved with it personally once I graduate."

Heather McGraw
Trauma Extern Participant

EMS Night

Trauma Services and Inova AirCare sponsors a bi-annual EMS Night at the hospital. This provides an opportunity for pre-hospital personnel to attend an educational session and participate in related discussion. Invitations are sent to all Fire and Rescue stations, EMS agencies, and emergency departments in Inova Regional Trauma Center's catchment area. In an effort to educate pre-hospital providers in outlying areas the Ford Inova Fairfax Hospital CIREN Center presented **"Advanced Occupant Protection Systems, Vehicle Dynamics and occupant Kinematics: Implications for Pre-hospital Providers" at the May 2002 EMS Night. Approximately 100 pre-hospital providers attended the program.**

EMS Week

As part of EMS week that took place June 3-8, 2002, the Ford Inova Fairfax Hospital CIREN Center sponsored an advanced course on vehicle extrication considerations for cars equipped with Advanced Occupant Protection Systems for the Fairfax County Fire and Rescue Department. The course covered rescuer and patient issues as well as new equipment available. Dorraine Watts, PhD, PI, CIREN also spoke on "Vehicle Dynamics and Occupant Kinematics: Reconstructing the Crash".

Other Education

June 28, 2002 – International Pre-Hospital Education Course for Firefighter and Paramedics, Plymouth, Massachusetts – "Vehicle Dynamics and Occupant Kinematics: Predicting Patient Injury", presented by Dorraine D. Watts, PhD

May 13, 2002 – EMS Case Review – "Case Studies of 2 Frontal and 2 Side Impact Crashes and their Associated Injuries", presented by Christopher Michetti, M.D. and James D. Bean, Accident Reconstructionist

April 25, 2002 – Quarterly CIREN Meeting – Washington, D.C. – "Unbelted Occupant Kinematics and Head Injury in Frontal Crashes", presented by Detective James D. Bean and Christopher Sherwood, UVA

January 22, 2002 – Fairfax County Fire and Rescue – Alexandria "A Case Review in Rear and Frontal Impact" presented by Kevin Dwyer, M.D., Associate Chief, Trauma Services

October 8, 2001 – The Association of Operating Room Nurses (AORN) Meeting – Inova Fairfax Hospital – VA "Motor Vehicles Crash Injuries: Implications for Clinical Practice" presented by Dorraine Watts, PhD, RN, Trauma Research Manager

October 2001 – American College of Emergency Physicians Meeting – Chicago "Airbags and Eye Injuries", presented by Dorraine Watts, PhD, RN, Trauma Research Manager and Bill Hauda, MD from the Department of Emergency Medicine. This research was sponsored by Ford Motor Company as part of the CIREN program. The results also are published in Annals of Emergency Medicine.

September 6, 2001 – CIREN Quarterly Meeting – Ann Arbor, MI – "Case Studies in SUV Performance in Gross Mismatch Crashes" presented by Samir M. Fakhry, M.D. and Dorraine D. Watts, PhD.

June 21, 2001 – CIREN Quarterly Meeting – Washington, DC – "Fire and Rescue Personnel: Education is a Two-Way Street", presented by D. Watts, PhD and K. Watts, FXC Fire & Rescue

May 4, 2001 – Fairfax County Fire and Rescue – Merrifield, VA – "Biomechanics of Motor Vehicle Crashes with Shoulder Belt Only Use and Liver Injuries", presented by D. Watts, PhD

March 16, 2001 – CIREN Quarterly Meeting – Washington, DC – "A Case Study in Offset Frontal Collision", presented by D. Watts, PhD

Publications

Watts, D., Fakhry, S., Pasquale, M., Kurek, S., Malhotra, A., Fabian, T., & Boulanger, B. (2002). Motor Vehicle Crash (MVC) And Abdominal Seatbelt Mark As Risk Factors For Perforating Small Bowel Injury (SBI): Results From A Large Multi-Institutional Study. *Proceedings of the Eastern Association for the Surgery of Trauma Fifteenth Scientific Assembly*, January 2002, Orlando, FL.

Watts, D., Hauda, W., & Anderson, J. (2001). The Role of Airbags in Eye Injures: Protective or Injury Producing? *Proceedings of the American College of Emergency Physicians 2001 Research Forum*, October 2001, Chicago, IL.

Watts, D. (2001). Management of Patients with Neurologic Trauma. S. Smeltzer, & B. Bare (editors), *Medical Surgical Nursing* (10th ed., Vol. (in press) Chapter 58). Philadelphia: Lippincott.

Rivera, L., Peitzman, A. B., …, Fakhry, S., & et.al. (2001). Contributions of Age and Gender to Outcomes of Blunt Splenic Injury in Adults: Multicenter Study of the Eastern Association for the Surgery of Trauma. in *Proceedings of the Fourteenth Annual Scientific Assembly of the Eastern Association for the Surgery of Trauma* (p. page 46).

Peitzman, A. B., Harbrecht, B. G., …, Fakhry, S., & et.al. (2001). EAST Study of Failure of Observation of Blunt Splenic Injury in Adults. *Journal of Trauma*.

Hanfling, D., Watts, D., Mayer, T., Trask, A., & Fakhry, S. (2001). Forming the Initial Link: Educating Providers in the Guidelines for Pre-hospital Management of Traumatic Brain Injury. *Proceedings of the American College of Emergency Physicians 2001 Research Forum*, October 2001, Chicago, IL.

Fakhry, S., & Salaita, K. (2001). Aggressive Driving: Preliminary Analysis of a Serious Threat to Motorists in a Large Metropolitan Area. in *Proceedings of the Fourteenth Annual Scientific Assembly of the Eastern Association for the Surgery of Trauma* (page 122).

Froedtert Hospital–Medical College of Wisconsin CIREN Center

CIREN Program Report

Introduction

The Froedtert Hospital-Medical College of Wisconsin CIREN center is based in the Department of Neurosurgery. The department directs a comprehensive head and spinal cord injury care center with long-term follow-up care. Both the Froedtert Hospital (adult) and the Children's Hospital of Wisconsin are located on one campus. This unique combination of academic affiliation with both trauma centers and a long history of injury research are most conducive for CIREN activities. The CIREN Center at MCW derives its uniqueness and strength from (a) internationally renowned surgeons and researchers at the Trauma Center, (b) world-class biomechanics and engineering investigators, and (c) unparalleled impact testing facilities. The close collaboration between these groups, housed on a single campus, provides an ideal environment to achieve the objectives of the CIREN Center and the aims of the CIREN Program. This CIREN Center focuses its activities on brain and spinal cord injuries in motor vehicle crashes, concentrating on injuries to the very young and the elderly. Special attention will also be given to assuring quality improvement measures for injury scaling and crash investigation.

Background: Spinal Injury

Spinal cord injury represents an epidemic problem in the United States. Of the 10,000 to 12,000 new injuries per year and the well over 125,000 potentially paralyzed from spine fractures, the majority are related to motor vehicle crashes.

Certainly, mortality rates resulting from car crashes have decreased. However, morbidity continues to be a significant problem. It is estimated that spinal cord injury alone may cost as much as $100 million per year, in terms of ongoing disability and medical care costs. Identification of preventative measures for these catastrophic injuries is a priority of the CIREN network.

Safety systems on motor vehicles resulting from prior intervention efforts (i.e., airbags, stiffened compartments, active restraints, etc.) have gone a long way to reduce the number of spinal injuries. However, there is still a great deal of work to be done, considering the severity of the problem. It is likely that further alterations of motor vehicles will further decrease the incidence of spine trauma.

In addition, there are less catastrophic spine injuries, such as fractures, whiplash injuries, and degenerative conditions of the spine, that are produced by motor vehicle crashes. While less severe, these also create significant rates of disability and costs in our health care system.

Information obtained from careful vehicle crash analysis can be of dramatic importance, particularly in injuries of the spine, for prevention, understanding pathophysiology, and predicting treatment. Issues in treatment of spine fractures prominently reflect areas of stability, including bony fracture and ligamentous injury. Determination of the nature and direction of the forces during trauma helps us understand tolerance of these structures well beyond what we see in the laboratory. Thus, CIREN efforts are directly applicable to treatment of patients with spinal trauma.

In terms of early evaluation and treatment, we have improved significantly from where we were twenty years ago. Twenty years ago, organized paramedic networks were uncommon and many patients were treated in archaic ways. There is no question that patients suffered increased neurological deficit as a result of improper handling. CIREN has the ability to discover information that will definitely lead to improvement in field and early hospital management. To wit, the ability to predict certain types of fractures for certain types of crashes and understand what kinds of events have the highest potential to lead to neurological dysfunction are of extraordinary potential benefit to individuals requiring hospital care. In addition, as we move to electronic systems that contact emergency services, the data we collect will become the basis for the choices emergency medical personnel are required to make.

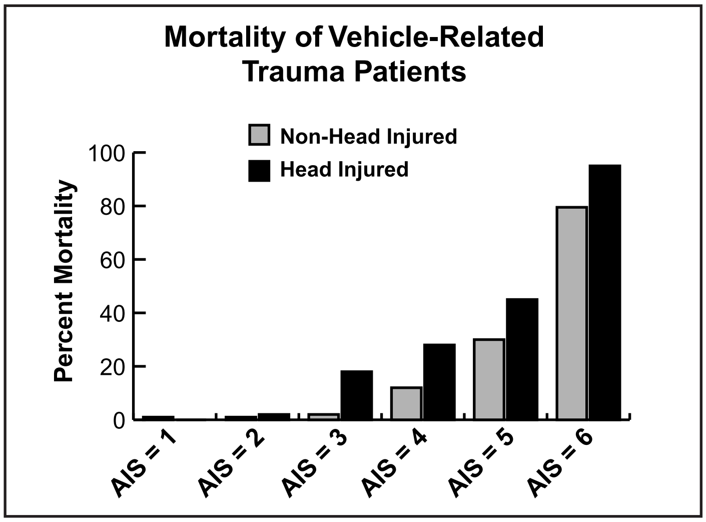
The impact to the manufacturer of the data obtained cannot be minimized. The prevention of injury should be a primary incentive for all of them. In addition, the ability to separate user failure, i.e., human factors (versus vehicular factors) in spine trauma are of extraordinary importance.

Background: Head Injury

Head injuries can be clinically classified into three primary categories: skull fractures, focal injuries, and diffuse brain injuries. Skull fracture may occur with or without concomitant damage to the brain, and a skull fracture is usually not a direct cause of neurologic disability. Focal brain injuries, however, are found in approximately one-half of all patients with severe head injuries and are responsible for nearly two-thirds of deaths associated with head injury. Focal injuries are defined as macroscopically visible damage to the brain tissue and are generally limited to a well-defined area. Examples of focal head injuries include cortical contusions and subdural, epidural, and intracerebral hematomas.

Diffuse brain injuries are fundamentally different from focal injuries in that they are associated with widespread brain dysfunction, often without macroscopic structural damage. Observed in approximately 40% of patients with severe head injuries, diffuse brain injuries account for one-third of deaths due to head injury. Diffuse brain injuries are also the most prevalent cause of persisting neurologic disability in survivors. In the more severe cases of diffuse brain injury such as prolonged coma without mass lesions, damage involves some degree of structural derangement. The widespread damage to axons in cases of prolonged coma without mass lesion have led to the clinical term "diffuse axonal injury" (DAI).

Of the total head injuries treated at major trauma centers, approximately two-thirds are related to vehicle crashes. Occupants involved in vehicle crashes incur more than three times the number of head injuries compared to the next most frequent cause and almost equal the number of head injuries produced by all other causes combined. Although the absolute number of head injuries compared with injuries to other body regions might be considered small, the mortality rate for head-injured patients is much higher than for any other injured body region. Indeed, the overall mortality rate with a head injury can be three times higher than if no head injury occurred.



Examining head-injured patients by the AIS severity of their injury, the head-injured occupant of a vehicle crash will always have a higher mortality rate compared to the non-head-injured patient. For example, an AIS 3-injured vehicle crash patient has approximately a 3% mortality rate, whereas the head-injured vehicle crash patient has a mortality rate six times that for the same AIS level [5]. Thus, despite advances in vehicular safety and design and hospital delivery and care, head injuries remain a very prominent cause of death and disability. For vehicle crash patients who initially survive their injury and arrive at the hospital alive, presence or absence of head injury is an important factor in their ultimate survival and in their ultimate outcome.

Research

The Froedtert Hospital-Medical College of Wisconsin CIREN center has many ongoing research projects related to trauma occurring in the vehicle crash environment. The Department of Neurosurgery is home to world-class research facilities in impact biomechanics and basic science research including a crash occupant simulation sled laboratory, component and materials test laboratory, neurobiology/tissue-culture laboratory, and a full-scale vehicle crash laboratory. These facilities occupy over 25,000 square feet

Vehicle Crashworthiness Laboratory at the Medical College of Wisconsin – VA Medical Center Facilities

US DOT NHTSA Side NCAP tests are conducted at this facility.

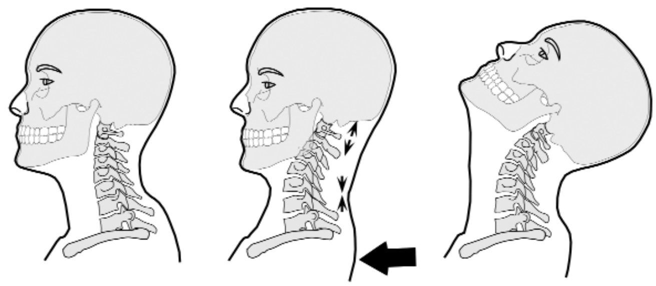
of space and employ 18 full- or part-time research technologists, engineers, and administrative assistants. Post-doctoral fellows and graduate students from the engineering school at Marquette University and from the Medical College of Wisconsin basic science departments are being trained on an ongoing basis. Some of the vehicle-related trauma projects are outlined below.

Whiplash-Related Projects

Although whiplash-associated disorders were first recognized in 1928 by Crowe to result from automotive rear-end impact, a concerted effort into the investigation of biomechanics leading to injury has not been undertaken until recently. Interest in whiplash biomechanics in the 1990s was spurred by the development of technology necessary to provide a comprehensive understanding of the event; in particular, high-resolution imaging techniques to record rear impact events and document soft tissue injuries. This interest was also fueled with a number of clinical and epidemiological studies documenting the frequency of whiplash injuries in automotive rear impacts and costs associated with the treatment and litigation of these injuries. It is well known in clinical literature that increased motion leads to increased spinal instability, and spinal fixation devices are used to stabilize the spine, which decreases physiologic symptoms such as pain. Our studies on whiplash-associated disorders center around the analysis of motion changes occurring in the spine on a level-by-level basis as well as localized facet joint motions.

Although catastrophic tissue failure is not always detected after rear-end impact injury, fundamental spinal motions may be altered enough to lead to subcatastrophic tissue failures. Subcatastophic failure can occur without discernible changes in physical structure. Peripheral sensitization is a possible result of subcatastrophic failure, leading to allodynia in nociceptive nerve endings (lowered mechanical thresholds). Lower thresholds, in turn, can result in nociceptive firing with decreased mechanical stimuli. Innervated structures of the cervical spine that can experience peripheral sensitization are intervertebral ligaments, intervertebral discs, and facet joints. Facet joint injury is of particular interest due to clinical results published by others and because of the high concentration of pain facilitating neuropeptides such as Substance P and Calcitonin Gene Related Peptide (CGRP). Neuropeptides play a role in the inflammation of injured tissue.

Mechanism of Whiplash Trauma During Rear Impact Crashes



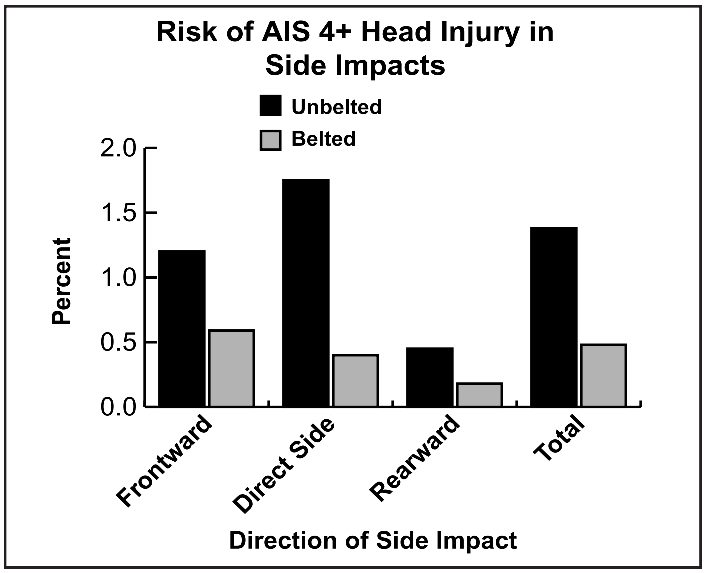
The spine experiences a transient S-shaped curvature during the first 50-100 msec of the event. At this time, the lower cervical facet joints are compressed together and the upper cervical segments undergo local tension posteriorly.

Structures such as the facet joint have been clearly shown in clinical and experimental biomechanical studies to be involved in chronic pain, and the kinematics of this joint are such that it undergoes characteristic motions during the early stages of rear impact acceleration. The presence of the transient non-physiologic reverse curve, i.e., upper head-neck flexion is attributed to the headaches, and the concomitant existence of the lower cervical spine extension during the early stages of rear impact acceleration are attributed to the mechanism of neck pain in whiplash. The principal components involved in defining the mechanisms of injury must include the identification of tissues sustaining the stresses/strains that result in damage, determination of local mechanical variables associated with the damage, documentation of the temporal sequence of the events, and establishment of injury criteria. Many mechanisms have been proposed; in some cases, injury criteria have been derived based on postulates. Because the actual injury/damage sustained by the structural components was not identified, the validity of the mechanism and/or the applicability of the injury criteria is questionable. This inconclusive output is chiefly responsible for the confusion that exists in the biomechanical assessment of whiplash-associated disorders. In fact, dummies have been designed and validated based on other dummies for rear impact-induced injury without actually possessing injury-related biomechanical data. Identification of the structural components that may sustain injury is a critical step in understanding the disorder. The two critical factors in the determination of whiplash injury mechanisms are, therefore, the application of single-event acceleration and documentation of injury to the soft tissues structures secondary to the load. These studies are ongoing. See publications [1, 2, 13, 15, 19, 20].

Database Analysis Projects

Head injuries to nearside occupants in lateral impacts: epidemiological and full-scale crash test analyses [4]

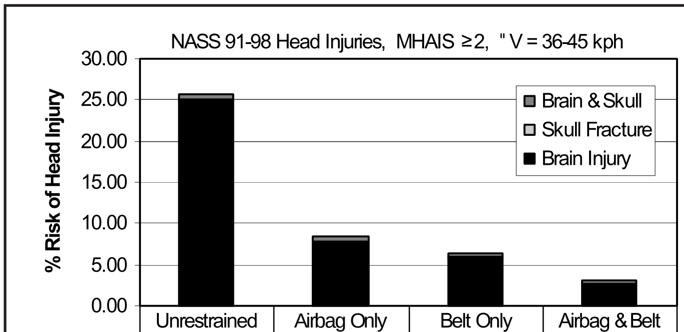
The objective of this study was to conduct an analysis from the 1993-2000 NASS database and determine the occurrence of head injuries (HI) as a function of restraint use to



nearside occupants in lateral impacts. Data from NCAP crash tests conducted in our vehicle crashworthiness laboratory and elsewhere were used to determine the potential for HI. The NASS analysis indicated that the risk of sustaining HI of any severity was higher without than with belt use. The risk increased by four-fold in direct side impacts (3 and 9 o'clock). Although the overall risk of sustaining a very severe HI (AIS 4-6) was low (<5%), the significant morbidity (30%) associated with these injuries necessitates further research. While the thoracic trauma index was the same between drivers and passengers (66 versus 65), the head injury criteria varied by a factor of approximately two (635 vs 374) between the two occupants in NCAP tests. Passenger head contact with interior components (roof-rail-C-pillar) was responsible for HI. A primary area of focus for side impact injury assessment and mitigation should be the struck side rear seat passenger. It may also be of value to better quantify HI metrics (e.g., rotational acceleration) by using a more biofidelic head-neck system in NCAP tests to advance injury mitigation strategies.

Airbag Effectiveness on Brain Trauma in Frontal Crashes [10]

The purpose of this study was to evaluate the effectiveness of frontal restraint systems in reducing the potential for head injuries, specifically brain injuries and skull fractures. The US DOT NASS database files from 1991-1998 were evaluated for drivers and right front seat occupants in frontal 10 o'clock to 2 o'clock crashes. Of the total driver

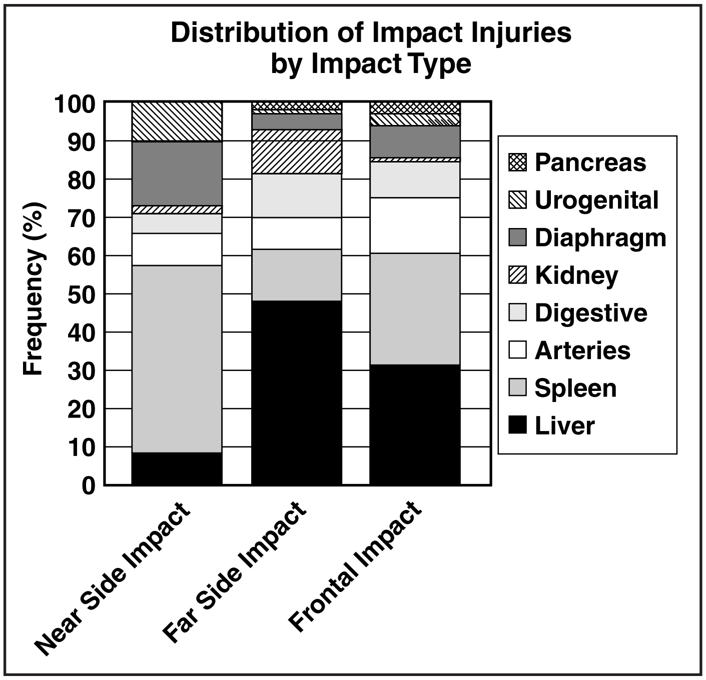


	Unrestrained	Airbag Only	Belt Only	Airbag & Belt
Brain & Skull	0.64	0.59	0.39	0.45
Skull Fracture	0.21	0.00	0.14	0.12
Brain Injury	24.85	7.81	5.76	2.52

and right front seat occupants in this data set, 3.83% sustained a brain injury without skull fracture, 0.05% sustained a skull fracture without a brain injury, and 0.16% sustained both brain injury and skull fracture. The incidence of head injury was lowest among occupants who were restrained by belt alone (2.76%) and by both airbag and belt systems (3.51%). The unrestrained population had a 10.39% incidence of at least one type of head injury. In general, for maximum AIS≥2 head injuries, airbag effectiveness was greatest between 16-45 kph crash ΔV. For the more severe maximum AIS≥3 head injuries, the airbag restraint had its greatest effect up to 35 kph. It can be concluded that brain injury in frontal crashes is substantially reduced with the presence of a restraint system and the use of both airbag and belt restraint offers the greatest protection across all ΔV categories. Restraint system effectiveness for the non-head-injured occupant varies but, generally, the belted occupant sustained the lowest percentage of injuries. Skull fractures in frontal impact were relatively rare, and the incidence appeared to be unaffected by the presence of a restraint system.

Patterns of Abdominal Injuries on Frontal and Side Impacts [14].

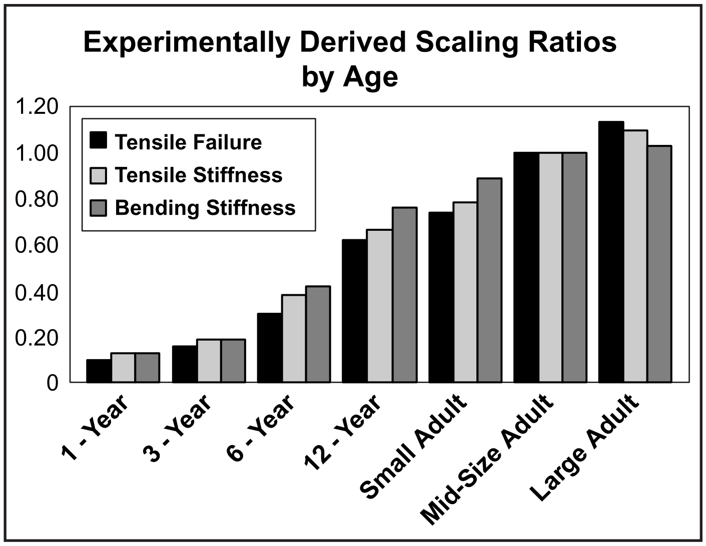
Public awareness of safety and vehicle improvements has contributed to significant reduction in injuries secondary to motor vehicle crashes. The spectrum of trauma has shifted from one region of the body to another with varying consequences. For example, airbags have minimized head and neck injuries for adults while emphasizing the lower regions of the human body. Studies have concentrated on the



changing patterns of these injuries in frontal impacts. However, there is almost a paucity of data with regard to the characterization of abdominal injuries. Consequently, this study was conducted to determine the patterns of abdominal injuries in frontal and side impacts with an emphasis on more recent crashes. In particular, the frequency and severity of trauma were investigated with a focus on the various abdominal organs (e.g., spleen and liver). Results indicate that side crashes contribute to a large percentage of injuries to the abdomen. The liver and spleen organs are most vulnerable; therefore, it may be beneficial to apply concerted efforts to focus on injury biomechanics research and prioritization activities in these areas. These data may be of benefit to develop anthropomorphic dummies with improved biofidelity.

Child Occupant Injury

The purpose of these studies was to determine neck injury tolerance scale factors for children in relation to small, mid-size and large adults using an animal cadaver model. In the first study, scaling relationships were developed to define cervical spine tolerance values of children using caprine specimens. In that study, tolerances were normalized with respect to an average adult. Because airbag-related injuries are associated with out-of-position children and small adult females, additional experimental data are needed to better estimate human tolerance. In the follow-up study, cervical spine radiographs from the 5th, 50th, and 95th percentile human adults were used to determine vertebral body heights for small, mid-size and large anthropometries. Mean human vertebral body heights were computed for each anthropometry and were normalized with respect to mid-size anthropometry. Similar measurements were calculated from caprine cervical spine radiographs and each



caprine specimen was grouped into one of the three categories based upon vertebral body size. Seventy-two motion segments (OC-C2, C3-C4, C5-C6 and C7-T1) from 18 adult caprine cadavers were subjected to pure moment and distraction loads. Pure moment testing resulted in bending stiffness, and distraction testing resulted in failure force and linear stiffness. Data were normalized with respect to the mid-size anthropometry category. For the small, mid-size, and large adult categories, tensile failure force yielded scaling ratios of 0.74, 1.00, and 1.13, linear stiffness yielded ratios of 0.78, 1.00, and 1.10; and bending stiffness resulted in ratios of 0.89, 1.00, and 1.03. For the one-year-old, three-year-old, six-year-old and 12-year-old, scaling ratios were 0.10, 0.16, 0.30, and 0.62 for the tension force; 0.13, 0.18, 0.38, and 0.66 for the linear stiffness; and 0.13, 0.19, 0.42, and 0.76 for the bending stiffness. See publications [6, 9].

Biomechanics of Side Impact

There are several ongoing projects defining occupant injury tolerance and response under side impact loading. Most recently, we collaborated on a study with the NHTSA biomechanics group to create a new set of side impact dummy biofidelity corridors. Thirty-six lateral sled tests were performed at 6.7 or 8.9 m/s, under rigid or padded loading conditions and with a variety of impact surface geometries. Forces between the simulated vehicle environment and the thorax, abdomen, and pelvis as well as torso deflections and various accelerations were measured and scaled to the average male. Mean ± one standard deviation corridors were calculated. Response corridors for force, torso deflection and acceleration were developed. The offset test condition, partnered with the flat wall condition, forms the basis of a robust battery of tests that can be used to evaluate how an Anthropomorphic Test Device (ATD) interacts with its environment, and how body regions within the ATD interact with each other [8].

We also recently collaborated with an Australian team of researchers to evaluate occupant kinematics in a far-side impact crash. This study set out to compare the suitability of five current side impact test dummies to simulate that of a 50th percentile human occupant in a far-side impact crash configuration. A number of comparative crash tests were undertaken, involving a 50th percentile human surrogate and four current side impact crash test dummies (BioSID, a BioSID with a lumbar spine modification, EuroSID, and WorldSID) using the ECE95 test procedure at 65km/h. Crash test data were collected from full-scale crash tests conducted using a Holden Commodore fitted with a 50th percentile human surrogate and a BioSID and WorldSID test dummy in the driver seat. Additional crash test data were obtained using a similar full-scale validated sled test setup. The results demonstrate that the current WorldSID prototype and a BioSID dummy with a modified lumbar spine unit can provide reasonable simulations of occupant kinematics and injuries to help advance vehicle countermeasures. Further work is required to test the robustness and generality of these findings for improved far-side impact protection [3].

Education and Training

Federal regulations and public demand have driven manufacturers to make changes and improvements in vehicle safety and design. Each year the percentage of vehicles on the road that are equipped with airbags increases rapidly. By 2008, over 90% of vehicles will have airbags. This improved safety technology is at least partially responsible for the reduction in injuries and deaths per vehicle mile driven in the last five years. While these improvements have helped a large segment of the population, there is one group that has been adversely affected by the changes. Emergency rescue personnel that extricate trapped victims from vehicles involved in crashes have not updated their methods to account for safety improvements. Each model year, as vehicle technology advances, the methods used to extricate victims have not changed. Rescue personnel have had to struggle with the limited resources available to them when extricating victims. For example, in a crashed vehicle that has an undeployed airbag, rescue personnel are at significant personal danger when extricating a trapped victim. As airbags become common place in vehicle areas such as headers and A-pillars, the method of extrication must be modified to account for these safety devices. The frame of the vehicle is now integrated into the protection of the occupant compartment, and if extrication teams are not aware of how this integration may affect their rescue efforts, additional injury risk could be imparted to the victim if procedures violate certain protecting stiffeners.

The current National Standard Curriculum for EMTs does not include extrication training. On the local level, the Wisconsin Administrative Code requires that all firefighters be trained to meet the minimum standard called "Firefighter I." At the Firefighter I level, the subject of extrication is never addressed. Firefighters must take the optional "Firefighter II" training in which only two lessons totaling six hours is devoted to extrication procedures. Thus, firefighters in Wisconsin are allowed by law to perform all duties without formal extrication training.

Extrication of a Dummy Occupant After a Controlled Laboratory Crash Test

The dummy neck loads are monitored to give firefighter rescuers feedback on techniques.

A non-profit organization in Wisconsin called Safe And Fast Extrication (SAFE) has been established to organize, provide and monitor extrication training being offered to rescue personnel. This organization consists of individuals who have provided education and training to Midwest area rescue personnel for over fifteen years. SAFE has designed extrication curriculums, and has continued to provide instructor training and certification. It is composed of nationally and internationally recognized experts in the field of extrication and is known in the Midwest as the most knowledgeable and experienced organization providing these services.

The SAFE organization and the Medical College of Wisconsin Neuroscience Research Laboratories have begun a collaborative effort to develop and study new and existing extrication procedures. Our primary purpose is to identify, test, and research conventional extrication techniques as well as develop countermeasure state-of-the-art extrication techniques that would increase the safety and efficiency of vehicle extrication. Because of the technical vehicle rescue challenges of today, vehicle extrication research and development provides the scientific strength needed to support the emergency extrication services. To develop good extrication countermeasures in today's rapidly changing vehicle design, it is essential to identify and analyze the current extrication issues, problems, and implement solutions. Ongoing research and development will be the key to this process.

After a full-scale vehicle crash test, ATDs are used so that sensors in the head, neck, chest, and legs are monitored throughout the crash event and post-crash in the extrication procedure. The emergency extrication rescue team proceeds to conduct a full-scale rescue operation of the occupants in the vehicle. The occupant dummy sensors are monitored and recorded throughout these procedures. The dummy occupant sensors provide quantitative data that indicates the exact time and type of procedure that had the highest potential to exacerbate victim trauma. These data will be used to design alternate or time-saving measures to improve the extrication and rescue procedures.

These tests also serve as an educational tool for emergency medical personnel. By viewing these tests, emergency medical personnel in our institution will have a hands-on experience in the management of victims involved in vehicle crashes. Regular Grand Rounds are planned to provide educational and training input to the various groups including EMTs, ER nurses, Trauma Surgery residents and fellows, Neurosurgery residents and fellows, and Department of Emergency Medicine residents. These tests may be open to viewing by other visitors who may benefit directly from "seeing it happen." Arrangements will be pursued with local law enforcement agencies, educational institutions, and community relations organizations. It is anticipated that the benefits resulting from these activities will be far reaching.

Recent Publications

1. Cusick JF, Pintar FA, Yoganandan N: Whiplash syndrome: kinematic factors influencing pain patterns. *Spine* 26:1252-1258, 2001.
2. DeRosia J, Yoganandan N, Pintar FA: Small female and large male responses in rear impact. Association for the Advancement of Automotive Medicine Conference, Sept-Oct 2002, Tempe AZ, pp 65-77.
3. Fildes BN, Sparke LJ, Bostrom O, Pintar FA, Yoganandan N, Morris AP: Suitability of current side impact test dummies in far-side impacts. International IRCOBI Conference, Sept 2002, Munich, Germany.
4. Gennarelli FA, Pintar FA, Yoganandan N, Beuse N, Morgan R: Head injuries to nearside occupants in lateral impacts: epidemiological and full-scale crash test analyses. International IRCOBI Conference, Sept 2002, Munich, Germany.
5. Gennarelli TA, Champion HR, Sacco WJ: Comparison of mortality, morbidity and severity of 59,713 head-injured patients with 114,447 patients with extracranial injuries. *Journal of Trauma* 37(67):962-968, 1994.
6. Hilker CE, Yoganandan N, Pintar FA: Experimental determination of adult and pediatric neck scale factors. *Stapp Car Crash Journal* 46:417-429, 2002.
7. Maiman DJ, Yoganandan N, Pintar FA: Pre-injury cervical alignment affecting spinal trauma. *Journal of Neurosurgery, Spine* 97(1):57-62, 2002.
8. Maltese MR, Eppinger RH, Rhule HH, Donnelly BR, Pintar FA, Yoganandan N: Response corridors of human surrogates in lateral impacts. *Stapp Car Crash Journal* 46:321-351, 2002.
9. Pintar FA, Mayer RG, Yoganandan N, Sun EA: Child neck strength characteristics using an animal model. *Stapp Car Crash Journal* 44:77-83, 2000.
10. Pintar FA, Yoganandan N, Gennarelli TA: Airbag effectiveness on brain trauma in frontal crashes. 44th Association for the Advancement of Automotive Medicine Conference, Oct 2000, Chicago IL, pp 149-169.
11. Pintar FA, Yoganandan N: Dynamic bending tolerance of the human forearm. *Traffic Injury Prevention* 3(2):43-48, 2002.
12. Seipel RC, Pintar FA, Yoganandan N, Boynton MD: Biomechanics of calcaneal fractures: a model for the motor vehicle. *Clinical Orthopaedics & Related Research* 388:218-224, 2001.
13. Yoganandan N, Pintar FA, Cusick JF: Biomechanical analyses of whiplash injuries using experimental model. *Accident Analysis & Prevention* 34:663-671, 2002.
14. Yoganandan N, Pintar FA, Gennarelli TA, Maltese MR: Patterns of abdominal injuries in frontal and side impacts. 44th Association for the Advancement of

Automotive Med Conference, Oct 2000, Chicago IL, pp 17-36.

15. Yoganandan N, Pintar FA, Gennarelli TA: Biomechanical mechanisms of whiplash injury. *Traffic Injury Prevention* 3:98-104, 2002.

16. Yoganandan N, Pintar FA, Gennarelli TA: Mechanisms and factors involved in hip injuries during frontal crashes. *Stapp Car Crash Journal* 45:437-448, 2001.

17. Yoganandan N, Pintar FA, Maltese MR, Eppinger RH, Rhule H, Donnelly B: Biofidelity evaluation of recent side impact dummies. International IRCOBI Conference, Sept 2002, Munich, Germany.

18. Yoganandan N, Pintar FA, Maltese MR: Biomechanics of abdominal injuries. *Critical Reviews in Biomedical Engineering* 29(2):173-246, 2001.

19. Yoganandan N, Pintar FA, Stemper BD, Cusick JF, Rao RD, Gennarelli TA: Single rear impact produces lower cervical spine soft tissue injuries. International IRCOBI Conference on Biomechanics of Impact, Oct 2001, Isle of Man, United Kingdom, pp 201-211.

20. Yoganandan N, Pintar FA, Stemper BD, Schlick MB, Philippens M, Wismans J: Biomechanics of human occupants in simulated rear crashes: documentation of neck injuries and comparison of injury criteria. *Stapp Car Crash Journal* 44:189-204, 2000.

Recent Presentations

Pintar FA: Child neck injury in vehicle crashes. Injury & Epidemiology Graduate Seminar Series, Medical College of Wisconsin, Milwaukee WI, Mar 2001.

Maiman DJ: Why does this patient need a fusion? Spine Care in the New Millennium Symposium, Medical College of Wisconsin, Milwaukee WI, Oct 2001.

Pintar FA: Neck research briefing. Department of Transportation, Washington DC, July 2001.

Pintar FA: Biomechanical parameters of the neck. Biomechanics of Impact – Understanding the Limits of Human Tolerance Workshop, Richmond VA, Oct 2001.

Gennarelli TA: Brain injury in the elderly. Association for the Advancement of Automotive Medicine, Dearborn MI, 2001.

Pintar FA: Human head-neck biomechanics in low-speed rear crashes. CDC Work-In-Progress Monitoring Workshop, Atlanta GA, Nov 2001.

Gennarelli TA: Relationship of pathophysiology of brain injury to the principles of treatment. 6th EMN Congress, Moscow, 2001.

Yoganandan N: Mechanisms and factors involved in hip injuries during frontal crashes. Stapp Car Crash Conference, San Antonio TX, Nov 2001.

Pintar FA: Mechanisms and factors involved in hip injuries during frontal crashes. Stapp Car Crash Conference, San Antonio TX, Nov 2001.

Pintar FA and Yoganandan N: Neck injury biomechanics. Department of Defense, Patuxent River MD, Jan 2002.

Yoganandan N: Material properties and modeling of neck injuries. University of Eindhoven, Eindhoven, The Netherlands, Apr 2002.

Yoganandan N: Biomechanics research at the Medical College of Wisconsin. TNO-FTSS Inc., Delft, The Netherlands, Apr 2002.

Yoganandan N: Biomechanics of neck injuries. SAE TOPTEC, Phoenix AZ, Apr 2002.

Pintar FA, Maiman DJ, Holloway D: Overview of CIREN. Traffic Safety Commission, Milwaukee WI, Aug 2002.

Pintar FA: CIREN: what's it all about? Forensic Science Seminar, Milwaukee County Medical Examiner's Office, Milwaukee WI, Oct 2002.

Gennarelli TA: Future of the Abbreviated Injury Scale. Trauma 2002, Stavanger, Norway, 2002.

Yoganandan N: Biomechanical properties of the human cervical spine. Department of Defense, Patuxent River MD, Oct 2002.

Gennarelli TA: Civilian concepts of penetrating brain injury. First Military Symposium on Neurotrauma, Bethesda MD, 2002.

Pintar FA: Anatomic study of the morphology of human cervical facet joint. Cervical Spine Research Society, Miami Beach FL, Dec 2002.

Indiana University
CIREN QUALITY CONTROL CONTRACTOR
Transportation Research Center

The Transportation Research Center (TRC) resides within the School of Public and Environmental Affairs (SPEA). It is part of Indiana University's rich tradition of research, training, and technical assistance in public sector planning, programs, operations, and evaluation. Staff at the Transportation Research Center have been involved in transportation-related research and technical assistance since 1970 when TRC's predecessor, the Institute for Research in Public Safety, was created. TRC staff members have distinguished themselves in a variety of research and technical assistance projects for federal, state, and local governments, concentrating on vehicle crash investigations, traffic safety technologies, injury control, and database management and quality control.

The TRC has conducted a broad range of projects for the U. S. Department of Transportation, the vast majority of which were sponsored by the National Highway Traffic Safety Administration (NHTSA) and involved motor vehicle crash investigations, data collection, reporting, and quality control. TRC staff members are proud of the over thirty-year organizational history of contractual involvement in highway traffic safety data collection and the development of data collection programs for the NHTSA. In addition to thousands of on-site, in-depth, and "Special Crash" motor vehicle collision investigations, TRC staff have quality controlled tens of thousands of crash cases generated within the National Crash Severity Study (NCSS), the National Automotive Sampling System (NASS), and the Crash Injury Research and Engineering Network (CIREN) systems.

Expertise

Motor vehicle crash data collection and investigatory skills were developed over more than three decades of conducting federally-sponsored research studies: *Multidisciplinary Highway Crash Investigation Team* (Federal Highway Administration,1970), *A Study to Determine the Relationship Between Vehicle Defects and Vehicle Crashes* (National Highway Safety Board, 1972), *Tri-Level Study of the Causes of Traffic Accidents* (National Highway Traffic Safety Administration, 1973, hailed as "the definitive study of the causes of traffic accidents" by *FORTUNE* magazine), *National Crash Severity Study* (National Highway Traffic Safety Administration, 1976), *Establishment of Zone Centers for the National Accident Sampling System* (National Highway Traffic Safety Administration, 1977), *Operations of Zone Center A for the National Accident Sampling System* (National Highway Traffic Safety Administration, 1979), and *Special Crash Investigations, Central Region* (National Highway Traffic Safety Administration, on-going). As well, TRC staff skill development included vehicle exterior damage assessment, vehicle interior intrusions and occupant contact points identification, crash scene permanent and transitory data collection and diagram preparation, scene and vehicle photography, occupant interview techniques, collection and coding of occupant injury information from medical sources, crash dynamics and occupant kinematics analyses, and speed estimates.

Not only was motor vehicle crash case quality control experience developed during the *Operations of Zone Center A for the National Accident Sampling System* project, but TRC staff members were intimately involved in the creation of the substance and style of the process itself. Moreover, TRC staff contributed significantly to the development and refinement of the *National Accident Sampling System's Crashworthiness Data System Data Collection, Coding, and Editing Manual and the NASS Injury Coding Manual.*

CIREN

Since 1996, the Crash Injury Research and Engineering Network (CIREN) has provided the National Highway Traffic Safety Administration (NHTSA) with a substantial number of cases that, on a crash-by-crash basis, present more highly detailed injury data on crash-involved occupants than have previous motor vehicle crash research studies that targeted detailed injury data on a relatively small number of crashes. This detailed injury information includes hospital discharge summaries, radiological images and results narratives, operation notes, autopsy reports, and photographs of injuries. As the NHTSA mission since 1966 has been to reduce traffic crashes and their consequences as much as possible (that is, save lives, prevent injuries, and reduce traffic-related health care and other economic costs), the CIREN system is a logical progression of previous highway traffic safety research that acknowledges the realities of motor vehicle crash occurrences with the desire to reduce injuries and their severities.

In August 2000, TRC staff began development of a CIREN quality control process by reviewing 50 completed cases. The process was, and remains, an electronic review of completed CIREN cases submitted by the 10 current Centers and, through TRC comments and suggested changes reported in the "Review Notes" tab that is part of the Electronic Data Collection System (EDCS) software, then returning those comments and suggested changes to the Center of record. Centers have the option of accepting or rejecting the offered TRC comments and suggestions.

The ultimate quality control review goal is to achieve, in a timely manner, the highest degree possible of data completeness, data accuracy, and internal case consistency among and between CIREN cases, specifically, and with other NHTSA-sponsored motor vehicle crash research programs, generally, through following established National Automotive Sampling System (NASS) case review protocols within the precepts of CIREN. The TRC staff strives to continually refine the quality control review process to ensure the accuracy, validity, and internal consistency of submitted cases.

CIREN Quality Control (QC) Review

Performing the Quality Control (QC) review on a CIREN case is a multi-stage operation. A CIREN case is divided into two components. Each part must contain the same Center reference; specifically, to identify one of the ten Centers as the Center of record. One component contains collected data from the crash scene, involved vehicles, and vehicle occupants (for ease of differentiation, this part of the case will be referred to as the "NASS" component). The other component contains medical information on occupants injured in motor vehicle crashes who sustained injuries of interest to participating CIREN Centers; for example, injury information collected from autopsy reports, discharge summaries, radiological narratives, operation notes, injury photographs, and other ancillary medical sources (this part of the case will be referred to as the "CIREN" component).

CIREN Quality Control (QC) Process

The TRC is a node in the nationwide Electronic Data Collection System (EDCS) network that is managed through the Volpe Center in Cambridge, Massachusetts. CIREN Centers are other nodes on the same network. When a CIREN Center judges that a case is complete, that case is marked "QC Ready" and the case automatically migrates to the TRC, usually overnight. CIREN cases that are forwarded to the TRC are electronic copies that cannot be altered except by the addition of TRC review notes. The TRC completes the required quality control review and the review notes migrate back, electronically, to the originating CIREN Center as "QC Complete" (if justified, a case can be returned to the submitting Center as "QC Incomplete"). An e-mail message is sent to both the Center of record and the NHTSA's Contracting Officer's Technical Representative (COTR) documenting that the QC process has been completed. The Center of record then has the opportunity to peruse and analyze the QC comments and suggestions and, if needed, discuss those comments and suggestions with the TRC staff (TRC does not have the ability to make any changes to a case, itself). Once the TRC releases a case as "QC Complete," that specific case can no longer be accessed by TRC staff after a period of time has passed. A case will ultimately migrate to the CIREN Web site as "Published," and will be available to qualified analysts through the CIREN archive. During this quality control review process, there are two paramount principles that guide TRC staff in the performance of tasks associated with CIREN case reviews: (1) ensure case data conform as closely as possible to agreed upon investigative, coding, and quality control procedures, and (2), ensure case data are internally consistent.

As has been previously stated, each CIREN case exists as two separate but linked components, the "NASS" component that is accessed via the NASSMAIN application and the "CIREN" component that is accessed via the CIREN application.

"NASS" Case Components

The "NASS" component records the motor vehicle crash with a Case form, General Vehicle form(s), Exterior Vehicle form(s), Interior Vehicle form(s), Safety Systems form(s), Occupant form(s), and Pictures/Thumbnails (photographs). These forms are to be coded with crash data collected through agreed upon investigatory protocols. To do so, Center crash investigators must be well-versed in agreed upon variable coding requirements contained within the current electronic version of the crash reconstruction software. The electronic *NASS 2000 CDS Data Collection, Coding, and Editing Manual* and its updates contain sections to match each form mentioned above. Additionally, Center investigators must be familiar with the current versions of *WinSMASH*, *NASS Vehicle Measurement Techniques*, *NASS Photography Guidelines*, and *Collision Deformation Classification – SAE J224 Mar 80*. Each tab in the NASSMAIN layout is opened by a member of the TRC staff and each entry reviewed.

"CIREN" Case Components

The CIREN application is similar to the NASSMAIN application in that the data encoding process is accomplished through a succession of forms with tabs and subtabs. There are two principal features of the "CIREN" component: (1) the occupant's/patient's demographic, anthropometric, diagnostic, and treatment data (i.e., the tabs and subtabs on the various CIREN/Medical components) and, (2) the specific injury data that are coded according to the

NASS adaptation of AIS90 and NASS injury mechanism coding protocols.

As with the review of the “NASS” component, each “CIREN” tab must be opened and each entry scrutinized. QC review of the “CIREN” component ascertains whether those data elements that are coded have been coded in an internally consistent manner. Additionally, QC reviews include ensuring all medical narrative entries contain no proper names, internal reference numbers, or exact dates.

The “CIREN” component provides an overview of case injuries by supplying data from hospital discharge summaries, radiology images and narratives, operation notes, and EMS activities. Perhaps the most critical tab in the “CIREN” component is the Injury Analysis tab. This section not only identifies the “case occupant,” but details that occupant’s seating position, seat posture, restraint use, air bag deployment (if any), crash dynamics, occupant kinematics, possible vehicle/occupant contact points, and resultant injuries and their severities. Also, an injury list is generated that identifies the case occupant’s injuries, each injury’s aspect (location), and vehicle component “causing” that injury. Also, an injury may be linked to an intrusion to the vehicle’s interior, an interior contact point that may have been struck by one of the occupant’s body regions, radiological images and explanations, notes on any operation procedures performed, presence of linked injury photographs, and clarifying ancillary notes. These aforementioned injury data are to be coded from medical information collected through agreed upon investigatory protocols.

Summary

As previously noted, the Crash Injury Research and Engineering Network is a logical progression of previous highway traffic safety research. The unique characteristic of CIREN is providing motor vehicle crash reconstruction data as an adjunct to the presentation of occupants’ resultant injuries. Being a hospital-based research system, the ten CIREN centers collect and report injury information in exquisite detail for virtually every submitted case.

The Indiana University Transportation Research Center looks forward to continuing its working partnership with the U.S. Department of Transportation, the National Highway Traffic Safety Administration, the current CIREN Centers, and the Volpe Center.

Bibliography of CIREN Publications and Presentations as of June 2003

2003

Fakhry SM, Watts DD, Luchette FA. Current Diagnostic Approaches Lack Sensitivity in the Diagnosis of Perforated Blunt Small Bowel Injury: Analysis from 275,557 Trauma Admissions from the EAST Multi-Institutional HVI Trial. *Journal of Trauma*, 2003; 54: 295-305.

Melton SM, McGwin G, Abernathy JH, MacLennan P, Cross JM, Rue LW. Motor Vehicle Crash-Related Mortality Is Associated with Prehospital and Hospital-Based Resource Availability. *Journal of Trauma*, 2003; 54: 273-279.

Moran SG, Metzger JS, McGwin G, Alonso JE, Rue LW. Relationship between age and lower extremity fractures in motor vehicle collisions. *Journal of Trauma*, 2003; 54: 261-265.

Nirula R, Mock CN, Kaufman R, Rivara FP, Grossman D. Correlation of Head Injury to Vehicle Contact Points Using Crash Injury Research and Engineering Network (CIREN) Data. *Accident Analysis & Prevention*, 2003 Mar; 35:201-10.

Orzechowski KM, Edgerton EA, Bulas DB, McLaughlin PM, Eichelberger MR. Patterns of Injury to Restrained Children in Side Impact Motor Vehicle Crashes: Side Impact Syndrome. *Journal of Trauma*. 2003; 54:1094-1101.

Rivara FP, Cummings P, Mock C. Injuries and Death of Children in Rollover Motor Vehicle Crashes in the United States. *Injury Prevention*, 2003; 9(1):76-80.

Watts DD, Fakhry SM. Incidence of Hollow Viscous Injury in Blunt Trauma: An Analysis from 275,557 Trauma Admissions from the EAST Multi-Institutional Trial. *Journal of Trauma*, 2003; 54:289-294.

2002

Assal M, Huber P, Tencer A, Rohr E, Mock C, Kaufman R. Are drivers morelikely to injure their right or left foot in a frontal care crash: a crash and biomechanical investigation. *Proceedings of the 46th Annual Meeting of the Association for the Advancement of Automotive Medicine*, September 30 - October 3, 2002, pp. 273-288.

Augenstein J, Perdeck E, Stratton J, Digges K, Steps J. Performance of Depowered Airbags in Real World Crashes. Society of Automotive Engineering, 2002-01-0186. Detroit, MI March 4-7, 2002.

Augenstein JS, Horton T, et al. Neck Injury: The Use of X-Rays, CTs, and MRIs to Study Crash-Related Injury Mechanisms. SAE Textbook. Jeffrey Pike, Ed. October 2002

Dischinger PC, Kerns TJ, Ho SM, Kufera JA, Burgess AR. Patterns of injury associated with airbag use. *Proceedings of the 6th World Conference on Injury Prevention and Control*. Montreal, Canada, May 12-15, 2002.

Dischinger PC, Ho SM, Kufera JA, Kerns TJ, Burch CA. Older drivers: Crashes, injuries, outcomes. *Proceedings of the 6th World Conference on Injury Prevention and Control*. Montreal, Canada, May 12-15, 2002.

Gennarelli FA, Pintar FA, Yoganandan N, Beuse N, Morgan R. Head injuries to nearside occupants in lateral impacts: epidemiological and full-scale crash test analyses. International IRCOBI Conference, Sept 2002, Munich, Germany.

McGwin G, Reiff DA, Rue LW. Differences in the incidence and etiology of blunt thoracic aortic injury in motor vehicle collisions by age. *Journal of Trauma*, 2002; 52: 859-66.

Mock C, Grossman D, Rivara F, Kaufman RP, Mack CD, Rivara FP. The relationship between body weight and risk of death and serious injury in motor vehicle crashes. *Accident Analysis and Prevention*, 34: 221-228, 2002.

Moran SG, McGwin G, Metzger J, Windham ST, Reiff DA, Rue LW. Injury rates among restrained drivers in motor vehicle collisions – The role of body habitus. *Journal of Trauma*, 2002; 52: 1116-20.

Read KM, Kufera JA, Dischinger PC, Kerns TJ, Burgess AR, Ho SM, Burch CA. Crash Outcomes and Psychosocial Effects (COPE). *Proceedings of the 4th International Conference on Measuring the Burden of Injury*. Montreal, Canada, May 16-17, 2002.

Read KM, Burgess AR, Dischinger PC, Kufera JA, Kerns TJ, Ho SM, Burch CA. Psychosocial and physical factors associated with lower extremity injuries. Presented at the 46th annual meeting of the Association for the Advancement of Automotive Medicine. Tempe, Arizona, September 2002, pp. 289-303.

Siegel JH, Smith JA, Tenenbaum N, McCammon L, Siddiqi S, Presswalla F, Pierre-Louis P, Williams W, Zaretsky L, Hutchins K, Perez L, Shaikh J, Natarajan G. Deceleration Energy and Change in Velocity on Impact: Key Factors in Fatal vs. Potentially Survivable Motor Vehicle Crash (MVC). Aortic Injuries (AI): The Role of Associated Injuries as Determinants of Outcome. *46th AAAM Conference Proceedings*, Oct. 2002, pp. 315-338.

Tencer A, Kaufman R, Ryan K, Grossman D, Henley B, Mann F, Mock C, Rivara F, Wang S, Augenstein J, Hoyt D, Eastman B. Femur Fractures in Relatively Low Speed Frontal Crashes: The possible role of muscle forces. *Accident Analysis and Prevention*, 34 (2002) pp 1-11.

Tencer A, Mirza S, Bensel K. Internal Loads in the Cervical Spine During Motor Vehicle Rear-End Impacts. *Spine*, Vol. 27, No. 1, pp 32-42, 2002.

Valent F, McGwin G, Hardin W, Johnson C, Rue LW. Restraint use and injury patterns among children involved in motor vehicle collisions. *Journal of Trauma*, 2002, 52(4): 745-51.

Watts D, Fakhry S, Pasquale M, Kurek S, Malhotra A, Fabian T, Boulanger B. (2002). Motor Vehicle Crash (MVC) And Abdominal Seatbelt Mark As Risk Factors For Perforating Small Bowel Injury (SBI): Results From A Large Multi-Institutional Study. *Proceedings of the Eastern Association for the Surgery of Trauma Fifteenth Scientific Assembly*, January 2002, Orlando, FL

In Press

Augenstein JS, Gaetano C, Figueredo J, Sfakianakis G, Miller J, Burke G. Ex-Vivo Repair and Renal Autotransplantation Following Penetrating Trauma. Is there an Upper Limit of Ischemic/Traumatic Injury Beyond Which a Kidney is Unsalvageable? *Journal of Trauma*, 2002. Accepted for Publication.

Ebel B, Tencer A, Grossman D, Mock C, Rivara FP. Computer Modeling of Mechanisms of Injury to Restrained Children in Frontal Motor Vehicle Crashes: The Role of the Booster Seat, Submitted to *Injury Prevention*.

McGwin G, McRae WE, Taylor AJ, Davidson JS, Rue LW. Injury patterns among older adults involved in motor vehicle collisions – The role of near side collisions. Submitted to *Journal of Orthopaedic Trauma*.

McGwin G, Metzger J, Alonso JE, Rue LW. The association between restraint systems and frontal motor vehicle collision-related morbidity and mortality. *Journal of Trauma*.

McGwin G, Metzger J, Moran SG, Rue LW. Occupant and collision related risk factors for blunt thoracic aorta injury. *Journal of Trauma*.

Melton SM, McGwin G, Reiff DA, Waller H, Davidson JS, Vickers S, Rue LW. Common bile duct transection in blunt abdominal trauma: case report emphasizing mechanism of injury and therapeutic management. Submitted, *Journal of Trauma*.

Metzger J, McGwin G, Rue LW. Is seat belt use associated with fewer days of lost work following motor vehicle collisions? *Journal of Trauma*.

Patel NN, Wang SC, Marentette L. A complex and unusual penetrating injury of the cheek requiring skull base exploration. *Journal of Trauma*.

Patel NN, Wang SC. Arterial dissection injury following motor vehicle collision. *Journal of Trauma*.

Pintar FA, Olshanski J, Yoganandan N. Vehicle Incompatibility Affects Occupant Extrication after Motor Vehicle Crashes. 18th Annual ESV Conference, Nagoya, Japan, May 19-22, 2003, In Press.

Reiff DA, McGwin G, Rue LW. Risk factors for diaphragm rupture in motor vehicle collisions. Accepted for presentation at the 2002 EAST meeting.

Reiff DA, McGwin G, Alonso JE, Rue LW. Gender differences in the incidence of below knee fractures following offset frontal motor vehicle collisions. *Journal of Trauma*.

Reiff DA, McGwin G, Metzger J, Doss M, Rue LW. Identifying injuries and motor vehicle collision characteristics that together are suggestive of diaphragmatic rupture. *Journal of Trauma*.

Sherwood CP, Shaw VR, Kent RW, Gupta PK, Crandel JR, Orzechowski KM, Eichelberger MR, Kallieris D. Prediction of Cervical Spine Injury Risk for the 6-Year-Old Child in Frontal Crashes. Association for the Advancement of Automotive Medicine. 2002 In Press.

Wang SC, Schneider LW, Alarcon WH, Knight KM, Kohoyda-Inglis CJ, Macwilliams, JB, Pucci PS, Augenstein JS, Burgess A, Cooper G, Dischinger P, Eastman AB, Grossman D, Hoyt DB, Loo G, Rivara F, Siegel JH, Elliot D, MuCullough C, Brown L. High incidence and morbidity of rib fractures in elderly motor vehicle crash occupants. *Journal of Trauma*.

2002 CIREN Quarterly Meeting – Presentations

Orzechowski KM, Edgerton EA, Bulas DI, McLaughlin PM, Eichleberger MR. Lateral versus Frontal Motor Vehicle Crash Injuries to Restrained Children in Motor Vehicle Crashes: An Updated Experience from the Crash Injury Research & Engineering Network (CIREN). American Association for the Surgery of Trauma Annual Conference, Orlando, FL, September 2002.

Orzechowski KM, Edgerton EA, Eichelberger MR. Injury Trends Among Children Restrained in Shield Booster Seats. Pediatric Academic Societies' Meeting. Baltimore, MD, May 2002

Orzechowski KM, Edgerton EA, McLauglin PM, Eichelberger MR. Pediatric Motor Vehicle Crash Injuries Associated with Restraint Misuse. Third National Congress on Childhood Emergencies. Dallas, TX, April 2002

Orzechowski KM, Edgerton EA, McLauglin PM, Eichelberger MR. CIREN: A Multidisciplinary Approach to the Prevention of Motor Vehicle Crash Injuries. Third National Congress on Childhood Emergencies. Dallas, TX, April 2002

Sherwood CP, Shaw VR, Kent RW, Gupta PK, Crandel JR, Orzechowski KM, Eichelberger MR, Kallieris D. Prediction of Cervical Spine Injury Risk for the 6-Year-Old Child in Frontal Crashes. 46th Association for the Advancement of Automotive Medicine Annual Conference, Tempe Arizona, October 2002.

2001

Augenstein JS, Digges KH, Ogata S, Perdeck E, Stratton J. Development and Validation of the Urgency Algorithm To Predict Compelling Injuries. paper # 352, *17th International Technical Conference on the Enhanced Safety of Vehicles, Proceedings*, June 5th 2001

Brown LJ, McCullough CA. A Characterization of CIREN. 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, Amsterdam, June 2001.

Fakhry S, Salaita K. (2001). Aggressive Driving: Preliminary Analysis of a Serious Threat to Motorists in a Large Metropolitan Area. *Proceedings of the Fourteenth Annual Scientific Assembly of the Eastern Association for the Surgery of Trauma* (page 122).

Fakhry S, Salaita K. (2001). Aggressive Driving: A Preliminary Analysis of a Serious Threat to Motorists in a Large Metropolitan Area. *Journal of Trauma*.

Funk JR, Rudd RW, King RJ, Srinivasan SCM, Crandall JR. Talar Neck Fractures and Other Injuries Caused by Brake Pedal Loading of the Midfoot and Forefoot. Final Report, University of Virginia, Automobile Safety Laboratory, August 2001

Gotschall CS, Eichelberger MR. Injuries to restrained children in motor vehicle crashes. *Recovery* 2001.

Hanfling D, Watts D, Mayer T, Trask A, Fakhry S. (2001). Forming the Initial Link: Educating Providers in the Guidelines for Pre-hospital Management of Traumatic Brain Injury. *Proceedings of the American College of Emergency Physicians 2001 Research Forum*, October 2001, Chicago, IL.

Moran SG, McGwin G, Reiff DA, Rue LW. The association between body mass index, restraint use, and fatality in motor vehicle collisions. *45th Annual Proceedings of the Association for the Advancement of Automotive Medicine*, 2001, pp 107-123.

Orzechowski KM, Lee JH, Eichelberger MR, Wang SC. Pediatric injuries associated with specific types of restraint misuse. *Proceedings of the International Child Passenger Safety Conference*. 2001.

Peitzman AB, Harbrecht BG, Fakhr, S, et.al. (2001). EAST Study of Failure of Observation of Blunt Splenic Injury in Adults. *Journal of Trauma*.

Read KM. On the road again…Psychosocial factors and injury outcomes of motor vehicle occupants over age sixty. *Proceedings of the Aging and Driving Conference sponsored by the Association for the Advancement of Automotive Medicine*. Southfield, Michigan, February 2001

Rivera L, Peitzman AB, …, Fakhry S, et.al. (2001). Contributions of Age and Gender to Outcomes of Blunt Splenic Injury in Adults: Multicenter Study of the Eastern Association for the Surgery of Trauma. *Proceedings of the Fourteenth Annual Scientific Assembly of the Eastern Association for the Surgery of Trauma* (p. page 46).

Siegel JH, Loo G, Dischinger PC, Burgess AR, Wang SC, Schneider LW, Grossman D, Rivera F, Mock C, Natarajan GA, Hutchins KD, Bents FD, McCammon L, Leibovich E, Tenenbaum N. Factors influencing the patterns of injuries and outcomes in car versus car crashes compared to sport utility, van, or pick-up truck versus car crashes: Crash Injury Research Engineering Network Study. *Journal of Trauma*, 51: 975-990, 2001.

Watts D, Hauda W, Anderson J. The Role of Airbags in Eye Injures: Protective or Injury Producing? *Annals of Emergency Medicine*. 2001;38(4): 58.

Watts D, Hauda W, Anderson J. (2001) The Role of Airbags in Eye Injures: Protective or Injury Producing? American College of Emergency Physicians 2001 Research Forum, October 2001, Chicago, IL

Abstracts & Presentations

Siegel JH, Smith JA, Tenenbaum N, Siddiqi S, Presswalla B, Pierre-Louis P, Williams A, Zaretsky LL, Hutchins KD, Perez L, Shaikh J, Natarajan G. Quantifying Motor Vehicle crash (MVS) Dynamics in Fatal and Survivable Aortic Injuries (AI). Trauma 2001 Conference, Sydney, Australia, ABSTRACT, 2001.

2001 CIREN Quarterly Meeting – Presentations

Orzechowski KM, Edgerton EA, Eichelberger MR. Injury Trends Among Improperly Restrained Booster Seat Age Children Involved in Motor Vehicle Crashes. American Academy of Pediatrics 2001 National Conference and Exhibition, San Francisco, CA, October 2001

2000

Augenstein JS, Perdeck E, Bowen J, Stratton J., Horton T, Singer M, Digges KH, Malliaris AC, Steps J. Dummy Measurement of Chest Injuries Induced by Two-Point Shoulder Belts. *Association for the Advancement of Automotive Medicine*, October, 2000.

Augenstein JS, Perdeck E, Bowen J, Stratton J, Horton T, Singer M, Digges KH., Steps JH. Injuries to Restrained Occupants in Far-Side Crashes. Association for the Advancement of Automotive Medicine, October 2000.

Augenstein JS. Beyond the ER – Epitome of Care. *Recovery*, Summer 2000, Vol. 11, No. 2, pp. 24-26, June, 2000.

Augenstein JS, Bowen J, Perdeck E, Singer M, Stratton J, Horton T, Rao A, Digges KH, Malliaris AC, Steps J. Injury Patterns in Near-Side Collisions. Society of Automotive Engineering Technical Paper Series 2000-01-0634. Detroit, MI. March 6-9, 2000.

Horton TG, Cohn SM, Heid MP, Augenstein JS, Bowen JC, McKinney MG, Duncan RC. Identification of Trauma Patients at Risk of Thoracic Aortic Tear by Mechanisms of Injury. *Journal of Trauma*, Vol. 48, No. 6, June 2000.

Lavery RF, Livingston DH, Tortella BJ, Sambol JT, Slomovitz BM, Siegel JH. The utility of venous lactate to triage injured patients in the trauma center. *J. Am. Coll. Surg.* 190: 656-664, 2000.

Pintar FA, Yoganandan N, Gennarelli TA. Airbag effectiveness on brain trauma in frontal crashes. 44th Association for the Advancement of Automotive Medicine Conference, Oct 2000, Chicago IL, pp 149-169.

Rivara F, Koepsell T, Grossman D, Mock C. Effectiveness of automatic shoulder belt systems in motor vehicle crashes. *Journal of the American Medical Association*, Vol 283, pg. 2826-2828, June, 2000.

Abstracts & Presentations

Loo GT, Siegel JH, Dischinger PC, Wang SC, Grossman D, McCammon L, Tenenbaum N, Natarajan GA, Hutchins KD, Bents FD. The influence of age and gender on the incidence, injury pattern and likelihood of lower extremity fractures sustained by frontal occupants in motor vehicle crashes. CIREN, U.S. Dept. of Transportation, National Highway Traffic Safety Administration, Washington, D.C., ABSTRACT, May 2000.

Loo GT, Siegel JH, Dischinger PC, Wang SC, Grossman D, McCammon L, Tenenbaum N, Natarajan GA, Hutchins KD, Bents FD. Side impact crashes: effect on occupant injury patterns. CIREN, U.S. Dept. of Transportation - National Highway Traffic Safety Administration, Washington, D.C., ABSTRACT, July 2000.

2000 CIREN Quarterly Meeting – Presentations

1999

Augenstein JS, Perdeck E, Bowen J, Stratton J, Singer M, Horton T, Rao A. Injuries in Near-Side Collisions. Association for the Advancement of Automotive Medicine, Annual Meeting, September 19-22, 1999.

Augenstein JS, Perdeck E, Bowen J, Stratton J, Horton T, Singer M, Rao A, Digges KH, Malliaris AC. Injury Patterns Among Belted Drivers Protected by Air Bags in 30 to 35 mph Crashes. Society of Automotive Engineering (SAE), 1999. Windsor, Canada 199 99B-180.

Brookes C, Wang SC, MacWilliams J. Maxillofacial injuries in North American vehicle crashes. *Proceedings of the British Trauma Society Annual Meeting*, 1999.

Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH. Urgency for a Safer America. *AirMed*, March/April, pp. 18-23, 1999.

Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH. Reducing highway deaths and disabilities with automatic wireless transmission of serious injury probability ratings from crash recorders to emergency medical services providers. *Proceedings of the National Transportation Safety Board (NTSB) International Symposium on Transportation Recorders*, May 3-5, 1999.

Cohn S, Dolich M, Matsuura K, Namias N, Kirton O, Shatz D, McKenney M, Sleeman D, Ginzburg E, Byers P, Augenstein J. Digital Imaging Technology in Trauma Education: A Quantum Leap Forward. *Journal of Trauma*. (Submitted April 2, 1999)

Dischinger PC, Ho SM, Kufera JA. The epidemiology of traumatic brain injury: A statewide study of hospitalized Maryland drivers. *43rd Proceedings of the Association for the Advancement of Automotive Medicine*, pp. 71-88, 1999.

Gotschall CS, Marchant M, Dougherty DJ, Eichelberger MR. Accuracy of police crash reports in determining child restraint usage and injury severity in the United States. *43rd Annual Proceedings*, *Association for the Advancement of Automotive Medicine*, 1999

Gotschall CS, Luchter S, Wing JS. Head injuries to motor vehicle occupants aged 0-5 years. *43rd Annual Proceedings*, *Association for the Advancement of Automotive Medicine*, 1999.

Hoyt D, Augenstein, J. Aortic Injuries in Near-Side Collisions. Powerpoint presentation from the Third Annual CIREN Conference in San Diego, CA. 1999

Scally JT, McCullough CA, Brown LJ, Eppinger R. Computers in Clinical Care. *International Journal of Trauma Nursing*, Volume 5, Number 4, October-December 1999

Watts D, Kokiko J. Airbags and Eye Injuries: Initial Assessment and Treatment in the Emergency Department. *Journal of Emergency Nursing*. 1999;25(12):572-574.

Abstracts & Presentations

Wang SC, Siegel JH, Dischinger PC, Loo GT, Tenenbaum N, Burgess AR, Schneider LW, Bents FD. The interactive effects of age and sex on injury patterns and outcomes in elderly motor vehicle crash occupants. 3rd Annual CIREN Conference, CA, ABSTRACT, 1999.

3rd Annual CIREN Conference – October 1999 – Presentations

1998

Alarcon WH, Klein RD, MacWilliams J, Pucci P, Taheri P, Dries D, Schneider L, Wang SC. Comparison of Outcomes of Passenger-Sedan Occupants from Near-Side Impacts by Sport Utility Vehicles and Pickup Trucks. *Proceedings, 58th Annual Meeting of the American Association for the Surgery of Trauma*, 1998, 180.

Augenstein JS, Digges KH, Cooper G, Hoyt DB, Eastman B, Burgess A, Dischinger P, Scally J, Wang S, Schneider L., Siegel, JH, Loo G, Grossman D, Rivara F, Eichelberger M, Gotschall C, Lombardo LV, Brown L, Eppinger R. The CIREN Experience. 98-S6-P-21, *Proceedings, 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*, May 31-June 4, 1998, Windsor, Ontario, Canada, published by US Department of Transportation, National Highway Traffic Safety Administration, DOT HS 808 759, Vol. 2, pp. 1325-1327, October 1998.

Augenstein JS, Perdeck E, Williamson J, Stratton J, Horton T, Malliaris AC, Lombardo LV. Injury Patterns Among Air Bag Equipped Vehicles. 98-S1-O-06, *Proceedings, 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*, May 31-June 4, 1998, Windsor, Ontario, Canada, published by US Department of Transportation, National Highway Traffic Safety Administration, DOT HS 808 759, Vol. 1, pp. 213-221, October 1998.

Augenstein JS, Maull, Kimball. Computers in Health Care. *Trauma*

Informatics: Today's Vision, Tomorrow's Concepts. Textbook on Trauma Informatics, 1998, Springer Verlag, New York, Inc., Editor.

Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH. Automatic Crash Notification. *AirMed*, March/April, pp. 36-39, 1998.

Copeland CE, Mitchell KA, Brumback RJ, Gens DR, Burgess AR. Mortality in Patients With Bilateral Femoral Fractures. *Journal of Orthopaedic Trauma*, Vol 12, No. 5, pp 315-319, 1998.

Crandall JR, Martin PG, Sieveka EM, Pilkey WD, Dischinger PC, Burgess AF, O'Quinn TD, Schmidhauser CB. Lower limb response and injury in frontal crashes. *Accident Analysis & Prevention* 30(5): 667-677, September 1998.

Dischinger PC, Siegel JH, Ho SM, Kufera JA. Effect of change in velocity on the development of medical complications in patients with multisystem trauma sustained in vehicular crashes. *Accident Analysis & Prevention* 30(6): 831-837, 1998.

Gotschall CS, Better SI, Bulas D, Eichelberger MR, Bents F, Warner M. Injuries to children restrained in 2- and 3-point belts. *42nd Annual Proceedings, Association for the Advancement of Automotive Medicine*, 42:29-44, 1998.

Gotschall CS, Dougherty DJ, Eichelberger MR, Bents FD. Traffic-related injuries to children: Lessons from real world crashes. *42nd Annual Proceedings, Association for the Advancement of Automotive Medicine*, 42:165-178, 1998.

Slomovitz BM, Lavery RF, Tortella BJ, Siegel JH, Bachi BL, Ciccone A. Validation of a hand held lactate device in determination of blood lactate in critically injured patients. *Crit. Care Med.*, 26: 1523-1528, 1998.

Abstracts & Presentations

2nd Annual CIREN Conference – September1998 – Presentations

Gotschall CS, Better M, Bents F, Eichelberger MR. Biomechanics of air bag injuries to children. *J Trauma* (abstract) 1998; 45:192.

Gotschall CS, Better AI, Eichelberger MR. Differences in injury severity and costs associated with child restraint misuse. Book of Abstracts, Volume I, and p. 363. 4th World Conference on Injury Prevention and Control, World Health Organization, May 1998.

Luchter S, Gotschall CS, Walz MC. Injury patterns experienced by infants and children surviving motor vehicle crashes. Book of Abstracts, Volume 1, p. 427. 4th World Conference on Injury Prevention and Control, World Health Organization, May 1998.

1997

Augenstein JS, Perdeck E, Williamson J, Stratton J, Murtha M, Sapnas K, Digges KH, Malliaris AC, Lombardo LV. Heart Injuries Among Restrained Occupants in Frontal Crashes, The Engineering Society for Advancing Mobility Land Sea Air and Space International (SAE) 1997 Technical Paper Series reprinted from *Occupant Protection and Injury Assessment in the Automotive Crash Environment* (SP-1231) SAE 970392, February, 1997.

Gotschall CS, Eichelberger MR, Morrissey JR, Better AL, Reardon J, Bents F. Nonfatal air bag deployments involving child passengers. *Child Occupant Protection 2nd Symposium Proceedings*, Society of Automotive Engineers, Warrendale, PA, 1997; 1724.

Gotschall CS, Eichelberger MR, Morrissey JR, Better AL, Reardon J, Bents F. Injury patterns associated with child restraint misuse. *2nd Child Occupant Protection Symposium Proceedings*, Society of Automotive Engineers, Warrendale, PA, 1997; 187194

Malliaris AC, Digges KH, DeBlois JH. Relationships Between Crash Casualties and Crash Attributes. Society of Automotive Engineers SAE 970393, February 1997. The development of the **URGENCY** triage algorithm reported in this paper was part of a multidisciplinary team's effort and was presented to the NHTSA Administrator in a briefing March 27, 1997. The multidisciplinary team was led by Champion HR, and included Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Lombardo LV, Malliaris AC, Sacco WJ, and Siegel JH.

Paparo PH, Snyder HM, Gotschall CS, Johnson DL, Eichelberger MR. The relationship of two measures of injury severity to children's psychological outcome 3 years after acute head injury. *J Head Trauma Rehab* 1997; 12(3):5167

Abstracts & Presentations

1st Annual CIREN Conference – October 1997 – Presentations

1996

Augenstein JS, Digges KH, Perdeck EB, Lombardo LV, Malliaris AC. Injuries Sustained by Air Bag Protected Drivers. The Engineering Society for Advancing Mobility Land Sea Air and Space International. (SAE) 1996 Technical Paper Series reprinted from *Occupant Protection Technologies for Frontal Impact: Current Needs and Expectations for the 21st Century*, (SP-1144) SAE 960660, February, 1996.

Augenstein JS, Perdeck EB, Murtha M, Stratton J, Quigley C, Zych G, Byers PM, Nunez D, Digges KH, Lombardo LV, Malliaris AC. Injuries Sustained by Drivers in Air Bag Crashes. The XIV International Technical Conference on Enhanced Safety of Vehicles. Melbourne, Australia. Paper no. 96-S10-O-01. May 15, 1996.

Crandall JR, Martin PG, Bass CR, Pilkey WD, Dischinger PC, Burgess AR, O'Quinn TD, Schmidhauser CB. Foot and ankle injury: The roles of driver anthropometry, footwear and pedal control. *40th Proceedings of the Association for the Advancement of Automotive Medicine*, pp 1-18, 1996

Digges KH, Haffner M, Lombardo L, Stucki L, Malliaris AC, Augenstein JS, Perdeck EB. Challenges in Injury Measurement Technology for Testing of Driver Air Bag Systems. The XIV International Technical Conference on the Enhanced Safety of Vehicles. Melbourne, Australia. Paper no. 96-S10-O-02. May 15, 1996.

Dischinger PC, Ho SM, Kerns TJ. Patterns of injury in frontal collisions with and without airbags. *Proceedings of the International Research Council on the Biomechanics of Impact*, pp 311-319, 1996.

Loo GT, Siegel JH, Dischinger PC, Rixen D, Addis MD, O'Quinn T, McCammon L, Schmidhauser CB, Marsh P, Hodge PA, Burgess AR, Bents F. Airbag protection versus compartment intrusion effect determines the pattern of injuries in multiple trauma motor vehicle crashes. *J Trauma* 41(6): 935-951, December 1996.

National Highway Traffic Safety Administration (NHTSA), "NHTSA Crash Injury Research and Engineering Network," *Annals of Emergency Medicine*, October, 1996; 28:450-451.

Siegel, JH. Patterns of associated injuries in lower extremity and pelvic MVC trauma: the effect of safety restraints. *PROCEEDINGS NHTSA Conference on Lower Extremity Injuries*, 1996

1995

Augenstein JS. Accident Reconstruction in the Air Bag Era. *Miami Medicine*, The Official Publication of the Dade County Medical Association, May 1995.

Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Quigley CV, Malliaris AC. Chest and Abdominal Injuries Suffered by Restrained Occupants. The Engineering Society for Advancing Mobility Land Sea Air and Space International (SAE) 1995 Technical Paper Series reprinted from *Advances in Occupant Protection Technologies for the Mid-Nineties* (SP-1077) SAE 950657, February 1995.

Augentein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Malliaris AC. Occult Abdominal Injury of Air Bag and Automatic Lap-Shoulder Belt Protected Crash Victims: A Challenge to Trauma Systems. *Journal of Trauma*, April 1995.

Augenstein JS, Digges KH, Malliaris AC, Perdeck EB, Lombardo LV, Stratton J, Nunez D Jr., Byers PM, Quigley CV, Young P, Andron J, Murtha M, Craythorne AK, Zych G. Liver Injuries Associated with 2-Point Belt Restraints in Frontal Crashes. *Accident Analysis & Prevention, 39th Annual Proceedings of Association for the Advancement of Automotive Medicine*, 1995.

Burgess AR, Dischinger PC, O'Quinn TD, Schmidhauser CB. Lower extremity injuries in drivers of airbag-equipped automobiles: Clinical and crash reconstruction correlations. *J Trauma* 38(4): 509-516, 1995.

Crandall JR, Martin PG, Sieveka EM, Klopp GS, Kuhlmann TP, Pilkey WD, Dischinger PC, Burgess AR, O'Quinn TD, Schmidhauser CB. The influence of footwell intrusion on lower extremity response and injury in frontal crashes. *39th Proceedings of the Association for the Advancement of Automotive Medicine*, pp. 269-286, 1995.

Dischinger PC, Kerns TJ, Kufera JA. Lower extremity fractures in motor vehicle collisions: The role of driver gender and height. *Accid Anal Prev* 27(4): 601-606, 1995.

Dischinger PC. The epidemiology of pelvic and lower extremity fractures among hospitalized drivers. *The Proceedings of the Conference on Pelvic and Lower Extremity Injuries*. National Highway Traffic Safety Administration (NHTSA), Washington, DC, December 4-6, 1995.

Dischinger, P.C., Siegel, J.H., Ho, S.M., Kufera, J. The effect of impact velocity (Delta V) on development of injury complications in multiple trauma motor vehicle crash patients. *PROCEEDINGS of the 39th Association for Advancement of Automotive Medicine* pp. 367-379, 1995.

Dischinger PC. Injury Surveillance: The Role of Data Linkage. *Proceedings of the International Collaborative Effort on Injury Statistics*, Vol. 1, CDC DHHS Publication No. (PHS) 95-1252

Sturm PF, Glass RBJ, Sivit CJ, Eichelberger MR. Lumbar Compression fractures secondary to lap belt use in children. *J Pediatric Orthopaedics*, 1995; 15:521-523.

Siegel JH. The Effect of Associated Injuries, Blood Loss, and Oxygen Debt on Death and Disability in Blunt Traumatic Brain Injury: The Need for Early Physiologic Predictors of Severity. *Journal of Neurotrauma*, Vol 12, No. 4, 1995.

1994

Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Quigley CV, Malliaris AC. Airbag Protected Crash Victims – The Challenge of Identifying Occult Injuries. The Engineering Society for Advancing Mobility Land Sea Air and Space International (SAE) 1994 Technical Paper Series reprinted from *In-Depth Accident Investigation: Trauma Team Findings in Late Model Vehicle Collisions* (SP 1042) SAE 940714, February 1994.

Augenstein JS, Perdeck EB, Stratton J, Digges KH, Lombardo LV, Malliaris AC. Injuries Sustained by Air Bag Occupants in Frontal Crashes. The XIII International Technical Conference on Enhanced Safety of Vehicles, Paper no. 94-S4-O-18, 1994.

Bents FD, Dischinger PC, Siegel JH. Trauma center based crash investigation research: Methodologies and applications. *In-Depth Accident Investigation: Trauma Team Findings in Late Model Vehicle Collisions*, Warrendale, Society of Automotive Engineers, Inc, 1994, pp 1-10.

Dischinger PC, Burgess AR, Cushing BM, O'Quinn TD, Schmidhauser CB, Ho SM, Juliano PJ, Bents FD. Lower extremity trauma in vehicular front-seat occupants: Patients admitted to a Level 1 trauma center. *In-Depth Accident Investigation: Trauma Team Findings in Late Model Vehicle Collisions*, Warrendale, Society of Automotive Engineers, Inc, 1994, SAE 940710, pp 11-18.

Dischinger PC, Burgess AR, Cushing BM, Pilkey WD, Crandall JR, Sieveka EM, Klopp GS. Lower extremity trauma in vehicular front-seat occupants. Shieh SJ (ed), *Proceedings of the Injury Prevention through Biomechanics Symposium*, Michigan, Centers for Disease Control, Wayne State University, 1994, pp 29-42.

Gokcen EC, Burgess AR, Siegel JH, Mason-Gonzalez S, Dischinger P, Ho SM. Pelvic fracture mechanism of injury in vehicular trauma patients. *J Trauma* 36(6): 789-796, 1994.

Gotschall C, Morrissey R, Moront M, Eichelberger, M. Restraint-related injury to children in motor vehicle crashes. In: Vossoughi J, ed. *Biomedical Engineering Recent Developments*. Washington, DC: Engineering Research Center, University of the District of Columbia, 1994; 598-601.

Moront ML, Gotschall CS, Eichelberger MR, Morrissey JR, Manktelo A. Analysis of injuries to restrained children in frontal vs. non-frontal motor vehicle crashes. *Journal of Trauma* 1994; 37:1017.

Siegel JH, Shafi S, Goodarzi S, Dischinger PC. A quantitative method for cost reimbursement and length of stay quality assurance in multiple trauma patients. *J Trauma* 37(6): 928-937, 1994.

1993

Bulas DI, Fitz CR, Johnson DL. Traumatic Atlanto-Occipital Dislocation in Children. *Radiology*, 1993;188:155-158.

Dischinger PC, Siegel JH, Read KM, Mason-Gonzalez S. The role of medical conditions in high-speed car crashes. *37th Proceedings Association of Advancement of Automotive Medicine* 423-424, 1993.

Dischinger PC, Cushing BM, Kerns TJ. Injury patterns associated with direction of impact: Drivers admitted to trauma centers. *J Trauma* 35(3): 454-459, 1993.

Gotschall CS, Bents FD, Khaewpong N, Sturm PF, Sivit CJ, Eichelberger MR. The performance of lap/shoulder belts in restraining children in motor vehicle crashes. *Child Occupant Protection* (SP-986). Warrendale, Pennsylvania: Society of Automotive Engineers 1993.

Gotschall CS, Khaewpong N, Bents FD, Sivit CJ, Sturm P, Morrissey JR, Eichelberger MR. Crash-related injuries to restrained children aged 3 to 6 years. In: Abstracts: American Public Health Association. Washington DC: American Public Health Association 1993; 391.

Gotschall CS, Eichelberger MR, Sivit CJ, Sturm PF. Child booster seats: What works, what doesn't. In: Abstracts: Workshops, Oral Presentations, Poster Sessions, The Second World Conference on Injury Control. Atlanta, Georgia: Centers for Disease Control and Prevention 1993; 265-266

Lombardo LV, Ryan SD. Detection of Internal Injuries in Drivers Protected by Air Bags. *NHTSA Research Note*, August 1993.

Powell DM, Gotschall CS, Khaewpong N, Morrissey JR, Eichelberger MR. Biomechanics of crash-related injury to restrained children. *Journal of Trauma* 1993; 35:168.

Siegel JH, Mason-Gonzalez S, Dischinger PC, Read KM, Cushing BM, Badellino MC, Goodarzi S, Smialek JE, Heatfield BM, Robinson RM, Parkison K, Hill WJ, Jackson JW, Livingston DJ, Bents FD, Clark CC. Causes and costs of injuries in multiple trauma patients requiring extrication from motor vehicle crashes. *J Trauma* 35(6): 920-931, 1993.

Siegel JH, Mason-Gonzales S, Dischinger P, Cushing B, Read K, Robinson R, Smialek J, Heatfield B, Hill W, Bents F, Jackson J, Livingston D, Clark C. Safety Belt Restraints and Compartment Intrusions in Frontal and Lateral Motor Vehicle Crashes: Mechanisms of Injuries, Complications, and Acute Care Costs. *Journal of Trauma*, Vol. 5, No. 34, 1993.

1992

Dischinger P, Cushing B, Kerns T. Lower extremity fractures in motor vehicle collisions: Influence of direction of impact and seatbelt use. *36th Proceedings of the Association for the Advancement of Automotive Medicine*, pp. 319-325, 1992.

Shalaby-Rana E, Eichelberger MR, Kerzner B, Kapur S. Intestinal stricture due to lapbelt injury. A report of two cases. *Amer J Radiology*, 1992; 158, 63-64.

Siegel JH, Dischinger P. *The Medical Consequences of Car Crashes: An Automobile Crash Trauma Study*, Vols. I, II, III, IV, NHTSA Reports DOT HS 808 156, 808 157, 808 158, and 808 159, July 1992.

1991

Bond SJ, Gotschall CS, Eichelberger MR. Predictors of Abdominal Injury in children with pelvic fracture. *J Trauma* 1991; 31: 1169-1173

Newman K, Bowman LM, Eichelberger MR, Taylor GA, Johnson D, Loe W, Gotschall CS. The lap belt complex: intestinal and lumbar spine injury in children. *J The Institute for Injury Reduction*, 1991; 1:54-61.

Simpson D, Cushing B, Birschbach J, Siegel JH, Dischinger P, Burgess A, Jackson J, Livingston D, Bents F, et al. Direction of collision forces: Concordance of police accident reports and crash investigation findings. *Proceedings 35th Conf. of the Association for the Advancement of Automotive Medicine*, pp. 261-267, 1991.

Siegel JH, Gens DR, Mamantov T, Geisler FH, Goodarzi S, MacKenzie EJ. Effect of associated injuries and blood volume replacement on death, rehabilitation needs and disability in blunt traumatic brain injury. *Crit. Care Med.*, 19(10):1252-1265, 1991.

Sivit CJ, Taylor GA, Newman KD, Bulas DI, Gotschall CS, Wright CJ, Eichelberger MR. Safety belt injuries in children with lap-belt ecchymosis: CT findings of 61 patients. *Amer J Radiology*, 1991; 57: 111-114.acts & Presentations

1990

Newman K, Eichelberger MR, Bowman LM, Taylor GA, Loe W, Gotschall CS. The lap belt complex: Intestinal and lumbar spine injury in children. *Journal of Trauma* 1990; 30: 1133-1140.

Siegel JH, Mason-Gonzalez S, Cushing BM, Dischinger PC, Cornwell EC, Smialek JE, Heatfield BM, Soderstrom CA, Read KM, Robinson RM, Parkinson K, Dailey JT, Hill WJ, Jackson JW, Livingston DJ, Bents FD, Shankar BS. A prospective study of injury patterns, outcomes, and costs of high speed frontal versus lateral motor vehicle crashes. *Proceedings, 34th Conference, Association for the Advancement of Automotive Medicine*, pp. 289-314, 1990.

Siegel JH, Dalal SA, Burgess AR, Young JWR. Pattern of organ injuries in pelvic fracture: Impact force implications for survival and death in motor vehicle injuries. *Acid. Anal. & Prev.*, 22(5):457-466, 1990.

Early Studies

Ommaya AK, Digges KH. A Study of Head and Neck Injury Mechanisms by Reconstruction of Automobile Accidents. *Proceedings of IRCOBI Conference*, Goteborg, Sweden, 1985.

Champion HR, Copes WS, Craig M, Morelli S, Keast S, Bain L. *A Preliminary Study of Head and Neck Trauma of Automobile Crashes, and their Consequences*, NHTSA Report DOT HS 807 052, Washington, DC, June 1986.

Ommaya AK. Mechanisms and Preventive Management of Head Injuries: A Paradigm for Injury Control. *32nd Annual Proceedings, Association for the Advancement of Automotive Medicine*, September 12-14, 1988.

MacKenzie, E.J., Siegel, J.H., Shapiro, S., Moody, M., and Smith, R.T. Functional recovery and medical costs of trauma: An analysis by type and severity of injury. *J. Trauma*, 28(3): 281-297, 1988.

MacKenzie, E.J., Shapiro, S., and Siegel, J.H. The economic impact of traumatic injuries: One year treatment related expenditures. *JAMA*, 260(22): 3290-3296, 1988.

Jones IS, Champion HR. Trauma Triage: Vehicle Damage as an Estimate of Injury Severity. *Journal of Trauma*, Vol. 29, No. 5, May 1989, p. 646.

Dalal SA, Burgess AR, Siegel JH, Young JW, Brumback RJ, Poka A, Dunham CM, Gens D, Bathon GH. Pelvic fracture in multiple trauma: Classification by mechanism is key to pattern of organ injury, resuscitative requirements and outcome. *J. Trauma*, 29(7): 981-1002, 1989.

Garcia VF, Gotschall CS, Eichelberger MR, Bowman LM. Rib fractures in children: A marker of severe trauma. *Journal of Trauma* 1989; 29:1726.

Rivkind AI, Siegel JH, Dunham M. Patterns of organ injury in blunt hepatic trauma and their significance for management and outcome. *J. Trauma*, 29(10): 1398-1415, 1989.

Siegel JH, Dalal SA, Burgess AR, Young JWR. Pattern of organ injuries in pelvic fracture: Impact force implications for survival and death in motor vehicle injuries. *PROCEEDINGS: 33rd Conf. of Assoc. for Advancement of Automotive Medicine* (pp. 353-366), 1989

References

Hoover, H, *First National Conference on Street and Highway Safety, Department of Commerce*, Washington, DC, Dec 15-16, 1924. Available at http://www1.librarydigital.com/scripts/ws.dll?login&site=dot_highways

Haddon, W, *Accident Research – Methods and Approaches*, Harper & Row, New York, 1964

National Committee on Trauma and Committee on Shock, *Accidental Death and Disability: The Neglected Disease of Modern Society*, National Academy of Sciences, Washington, DC, September, 1966.

Robertson JS, McLean AJ, Ryan GA, *Traffic Accidents in Adelaide, South Australia*, Australian Road Research Board, Special Report No. 1, 1966.

Perrine MW, Waller JA, Harris LS, "Alcohol and Highway Safety; Behavioral and Medical Aspects," Final Report to Department of Transportation, NHTSA, DOT HS 800 599, 1971.

Ryan GA, "The emergency care of traffic injury: care before hospital. *Med. J. Aus. 1: 1173, 1972.*

Clark PD, Ryan GA, "The emergency care of traffic injury: time delays during casualty care," *Med. J. Aus. 1: 1217, 1973.*

Ryan GA, "Casualty Care in Car Crashes," *International Journal of Epidemiology*, Vol. 3, No. 1, Oxford University Press, 1974.

HUK-Verband, "Interior Safety of Automobiles – Road Traffic Accidents and their Consequences," A Study by German Motor Traffic Insurers on 28,936 Car Crashes with Passenger Injury, Hamburg Germany, 1975

Foley RW, Harris LS, Pilcher DB, "Abdominal Injuries in automobile accidents: review of care of fatally injured patients", *Journal of Trauma*, 1977, August, 17(8): 611-5.

Kaufman G, Bilge B, *Effects of Automobile Accidents Upon American Families*, 1982, DOT HS 806-315, PB 83 156 539.

Rubin LR, *Children in Automobile Accidents: The Effects on the Family*, 1982, DOT HS 806 316, PB 83 161 877.

Trunkey DD, "Trauma", *Scientific American*, Aug. 1983, Vol. 249, No. 2, pp.28-35.

Committee for the Study of Health Consequences of the Stress of Bereavement, National Academy of Sciences, *Bereavement – Reactions, Consequences, and Care*, Washington, D.C., 1984.

Committee on Trauma Research, *Injury in America*, Institute of Medicine, National Academy of Sciences, Washington, DC 1985.

Ommaya AK, Digges KH, "A Study of Head and Neck Injury Mechanisms by Reconstruction of Automobile Accidents," *Proceedings of IRCOBI Conference*, Goteborg, Sweden, 1985.

Champion HR, Copes WS, Craig M, Morelli S, Keast S, Bain L, *A Preliminary Study of Head and Neck Trauma of Automobile Crashes, and their Consequences*, NHTSA Report DOT HS 807 052, Washington, DC, June 1986.

Ommaya AK, "Mechanisms and Preventive Management of Head Injuries: A Paradigm for Injury Control," *32nd Annual Proceedings*, Association for the Advancement of Automotive Medicine, September 12-14, 1988.

Trinca G, Johnston I, Campbell B, Haight F, Knight P, Mackay M, McLean J, Petrucelli E, *Reducing Traffic Injury – A Global Challenge*, Royal Australasian College of Surgeons, 1988.

Jones IS, Champion HR, "Trauma Triage: Vehicle Damage as an Estimate of Injury Severity," *Journal of Trauma*, Vol. 29, No. 5, May 1989, p. 646.

Finelli FC, Jonsson J, Champion HR, Morelli S, Fouty WJ, "A case control study for major trauma in geriatric patients", *Journal of Trauma*, Vol. 29, No.5, May 1989, p. 541.

Rice DP, MacKenzie EJ, *Cost of Injury in the United States – A Report to Congress*, National Highway Traffic Safety Administration, U.S. Department of Transportation and Centers for Disease Control, U.S. Department of Health and Human Services, 1989

Siegel JH, Mason-Gonzales S, Dischinger P, Cushing B, Read K, Robinson R, Smialek J, Heatfield B, Hill W, Bents F, Jackson J, Livingston D, Clark C, "Safety Belt Restraints and Compartment Intrusions in Frontal and Lateral Motor Vehicle Crashes: Mechanisms of Injuries, Complications, and Acute Care Costs," *Journal of Trauma*, Vol. 5, No. 34, 1993. See also Siegel JH, Dischinger P, *The Medical Consequences of Car Crashes: An Automobile Crash Trauma Study*, Vols. I, II, III, IV, NHTSA Reports DOT HS 808 156, 808 157, 808 158, and 808 159, July 1992.

Esposito TJ, Reynolds SA, Sanddal ND, Hansen JD, Rinker CF, Dale G, Maningas PJ, O'Reilly PJ, Bleicher J, Petrashek B, *Rural Preventable Mortality Study*, NHTSA Report DOT HS 807 973, Washington, DC, Dec. 7, 1992.

Lombardo LV, Ryan SD, "Detection of Internal Injuries in Drivers Protected by Air Bags," *NHTSA Research Note*, August 1993.

Hunt RC, Brown RL, Cline KA, Krohmer JR, McCabe JB, Whitley TW, "Comparison of Motor Vehicle Damage Documentation in Emergency Medical Services Run Reports Compared with Photographic Documentation," *Annals of Emergency Medicine*, 1993, 22:651-656.

National Highway Traffic Safety Administration (NHTSA), "New Car Assessment Program – Response to the NCAP FY 1992 Congressional Requirements", Report to the Congress, December 1993, NHTSA Docket 79-17-GR-088.

Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Malliaris AC, "Injuries Sustained by Air bag Occupants in Frontal Crashes", Proceedings of The XIII International Technical Conference on Enhanced Safety of Vehicles, Paper No. 94-S4-O-18, 1994.

Augenstein JS, Digges KH, Lombardo LV, Perdeck EB, Stratton JE, Malliaris AC, Quigley CV, Craythorne AK, Young PE, "Occult Abdominal Injuries to Airbag Protected Crash Victims: A Challenge to Trauma Systems," *Journal of Trauma*, Vol. 38, No. 4, 1995. See also Augenstein JS, et al, "Heart Injuries Among Restrained Occupants in Frontal Crashes," SAE 970392.

Maio RF, Burney RE, Gregor MA, Baranski M, Welch KB, Rothman ED, *Michigan Rural Preventable Mortality Study*, NHTSA Report DOT HS 808 341, Washington, DC, June 1995.

Cunningham PRG, *North Carolina Preventable Mortality Study with Inter-Rater Reliability Modifications*, NHTSA Report DOT HS 808 345, Washington, DC, July 31, 1995.

Blincoe LJ, *The Economic Cost of Motor Vehicle Crashes*, 1994, National Highway Traffic Safety Administration, 1996, DOT HS 808 425.

National Highway Traffic Safety Administration (NHTSA), "NHTSA Crash Injury Research and Engineering Network," Annals of Emergency Medicine, October, 1996; 28:450-451. See http://www-nrd.nhtsa.dot.gov/include/bio_and_trauma/ciren_final.htm

Greene DL, Jones DW, Delucchi MA, *The Full Costs and Benefits of Transportation – Contributions to Theory*, Method and Measurement, Springer, 1997.

Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, Lombardo LV, *Post-Crash Injury Control*, Briefing for NHTSA Administrator, R Martinez, Washington, DC, March 27, 1997.

Malliaris AC, Digges KH, DeBlois JH, "Relationships Between Crash Casualties and Crash Attributes," Society of Automotive Engineers SAE 970393, February 1997. The development of the *URGENCY* triage algorithm reported in this paper was part of a multidisciplinary team's effort and was presented to the NHTSA Administrator in a briefing March 27, 1997. The multidisciplinary team was led by Champion HR, and included Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Lombardo LV, Malliaris AC, Sacco WJ, and Siegel JH.

Testimony of Mortimer L. Downey, Deputy Secretary, U.S. Department of Transportation, before the U.S. Senate Committee on Environment and Public Works, Subcommittee on Transportation and Infrastructure, Feb. 13, 1997, p. 11. Also see NHTSA, *NHTSA 2020 Report*, DOT HS 808 665, Washington, DC, September 1997, p. 2.

Sampalis JS, Denis R, Frechette P, Brown R, Fleiszer D, Mulder D, "Direct Transport to Tertiary Trauma Centers versus Transfer from Lower level Facilities: Impact on Mortality and Morbidity among Patients with Major Trauma," *Journal of Trauma*, Vol. 43, No. 2, August 1997, p. 288.

Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "Automatic Crash Notification," *AirMed*, March/April 1998, p. 36.

NHTSA, 1998 Strategic Plan of the NHTSA, *Promoting Safe Passage into the 21st Century*, September 1998, DOT HS 808 785, p. 30.

Falcone RE, Herron H, Werman H, Bonta M, "Air Medical Transport of the Injured Patient: Scene versus Referring Hospital," *Air Medical Journal*, Vol. 17, No. 4, October-December 1998, p 161.

Berkowitz M, O'Leary PK, Kruse DL, Harvey C, *Spinal Cord Injury: An Analysis of Medical and Social Costs*, Demos Medical Publishing, 1998.

Luchter S, *Measuring Injury Outcomes: Proceedings of a National Conference*, NHTSA Technical Report, 1998, DOT HS 808 782.

Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "Urgency for a Safer America," *AirMed*, March/April 1999, pp.18-23.

Champion HR, Augenstein JS, Cushing B, Digges KH, Hunt RC, Larkin R, Malliaris AC, Sacco WJ, Siegel JH, "Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Crash Recorders to Emergency Medical Services Providers," *Proceedings of the National Transportation Safety Board (NTSB) International Symposium on Transportation Recorders*, May 3-5, 1999, pp. 67- 84. Also available at http://www.ntsb.gov, and at http://www.nhtsa.dot.gov/events/symp_rec/proceedings/authors/champion.htm.

Committee on Injury Prevention and Control, Institute of Medicine, National Academy of Sciences, *Reducing the Burden of Injury, Advancing Prevention and Treatment*, Washington, DC, 1999, pp. 1-17, 32.

Committee on Quality of Health Care, Institute of Medicine, National Academy of Sciences, *To Err is Human: Building a Safer Health System*, Washington, DC, 1999, pp. 4, 153.

106th Congress, Congress of th*e United States, Public Law 106-81, October 26, 1999, Wireless Communications and Public Safety Act of 1999*, 113 STAT. 1286, 47 USC 609.

World Health Organization, Geneva, *Injury – A Leading Cause of the Global Burden of Disease*, 1999, WHO/HSC/PVI/99.11, Available at www.who.int/violence_injury_prevention/index.html

Scally JT, McCullough CA, Brown LJ, Eppinger R, "Development of the Crash Injury Research and Engineering Network" *International Journal of Trauma Nursing*, Vol. 5, Number 4, October-December 1999.

NHTSA, *Traffic Safety Facts 1998*, DOT HS 808 983, October 1999, pp. 48, 170-173.

American College of Surgeons, Committee on Trauma, *Resources for Optimal Care of the Injured Patient, 1999*, p.14.

Lerner EB, Billittier AJ, Adolph JE, "Ambulance, Fire, and Police Dispatch Time Compared with the Atomic Clock," *Prehospital Emergency Care*, Jan./March, 2000, Vol.4/No.1, pp. 28-30.

Kanianthra J, Carter A, Preziotti G, "Field Operational Test Results of an Automated Collision Notification System," 2000-01-C041, SAE Proceedings, Convergence 2000, Detroit, Oct. 1, 2000.

Prasad P, "Role of Electronics in Automotive Safety," 2000-01-C086, SAE Proceedings, Convergence 2000, Detroit, Oct. 1, 2000.

Funke D, Bellis E, Donnelly B, Blatt A, McClellan R, Wilson G, "Automated Collision Notification (ACN) Field Operational Test Final Report," National Highway Traffic Safety Administration, US DOT HS 809 303, October 31, 2000.

Oppe S, De Charro FT, "The effect of medical care by a helicopter trauma team on the probability of survival and the quality of life of hospitalized victims," *Accident Analysis and Prevention*, 33 (2001) pp. 129-138.

Bachman LR, Preziotti GR, "Automated Collision Notification (ACN) Field Operational Test (FOT) Evaluation Report," National Highway Traffic Safety Administration, US DOT HS 809 304, February 2001.

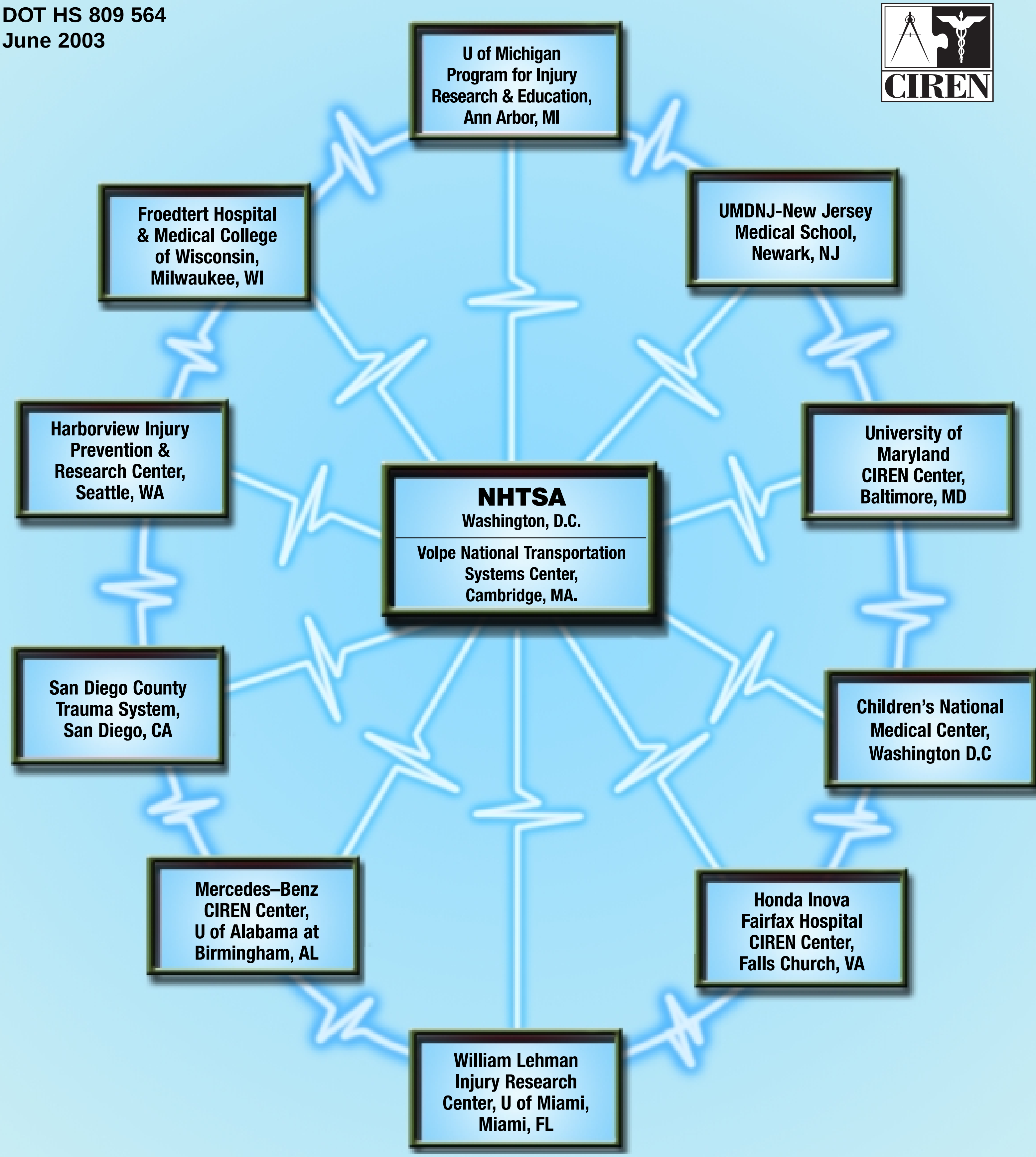
Committee on Quality of Health Care, Institute of Medicine, National Academy of Sciences, *Crossing the Quality Chasm: New Rules to Redesign and Improve Care*, Washington, DC, 2001.

Augenstein JS, Digges KH, Ogata S, Perdeck E, Stratton J, "Development and Validation of the Urgency Algorithm to Predict Compelling Injuries" *Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles, June 4-7, 2001*, Amsterdam, DOT HS 809 220, http://www.nhtsa.dot.gov

Blincoe L, Seay A, Zaloshnja E, Miller T, Romano E, Luchter S, Spicer R, "The Economic Impact of Motor Vehicle Crashes, 2000," NHTSA, DOT HS 809 446.

Champion HR, Augenstein JS, Blatt AJ, Cushing B, Digges KH, Hunt RC, Lombardo LV, Siegel JH, "Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Vehicles in Crashes to EMS" *Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, 2003*.

DOT HS 809 564
June 2003



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