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 on-

going 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.

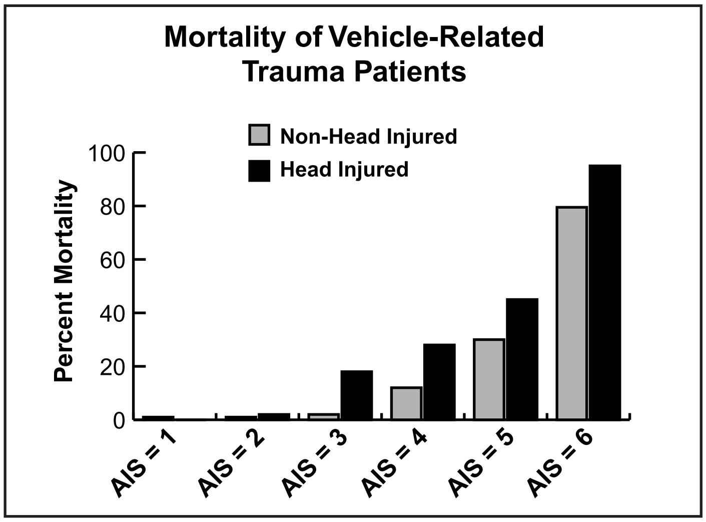
The impact to the manufacturer of the data obtained cannot be minimized. The prevention of injury should be a primary incentive for all of them. In addition, the ability to separate user failure, i.e., human factors (versus vehicular factors) in spine trauma are of extraordinary importance.

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.

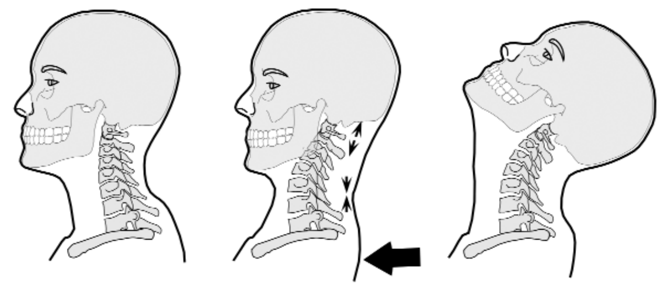
of space and employ 18 full- or part-time research technologists, engineers, and administrative assistants. Post-doctoral fellows and graduate students from the engineering school at Marquette University and from the Medical College of Wisconsin basic science departments are being trained on an ongoing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



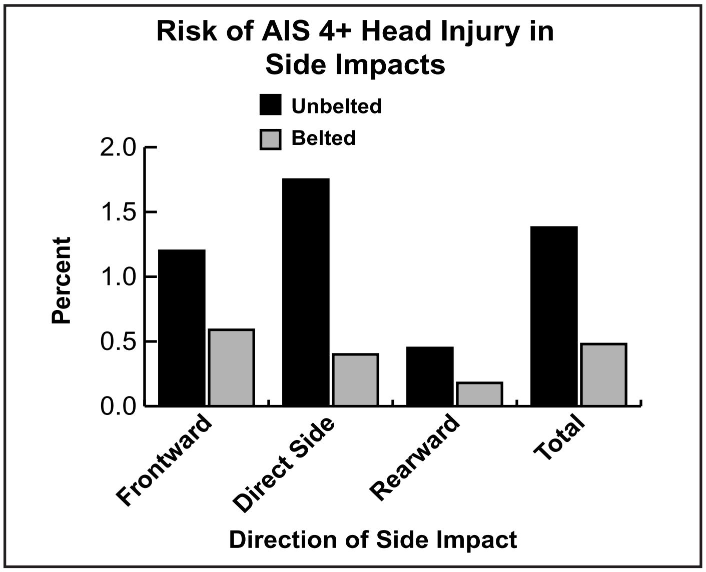
The spine experiences a transient S-shaped curvature during the first 50-100 msec of the event. At this time, the lower cervical facet joints are compressed together and the upper cervical segments undergo local tension posteriorly.

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]

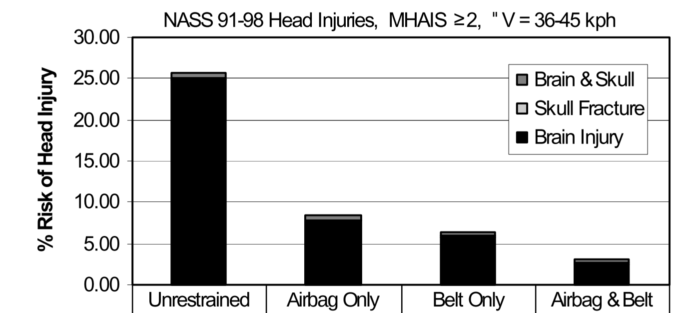
The objective of this study was to conduct an analysis from the 1993-2000 NASS database and determine the occurrence of head injuries (HI) as a function of restraint use to



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

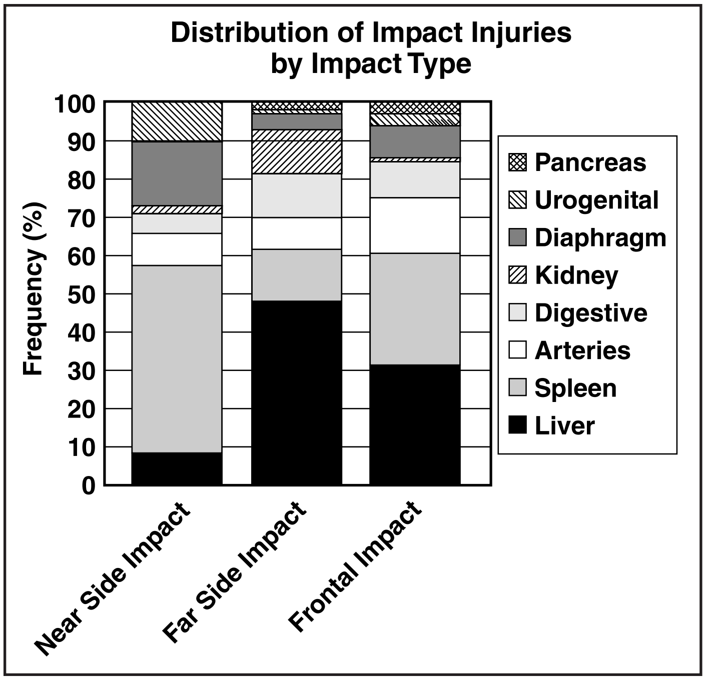


	Unrestrained	Airbag Only	Belt Only	Airbag & Belt
Brain & Skull	0.64	0.59	0.39	0.45
Skull Fracture	0.21	0.00	0.14	0.12
Brain Injury	24.85	7.81	5.76	2.52

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].

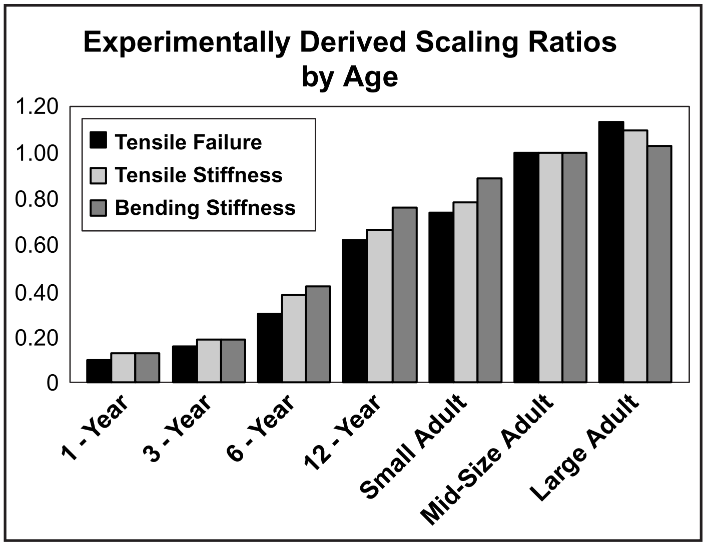
Public awareness of safety and vehicle improvements has contributed to significant reduction in injuries secondary to motor vehicle crashes. The spectrum of trauma has shifted from one region of the body to another with varying consequences. For example, airbags have minimized head and neck injuries 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.