(Re)Searching for a Safer Car

The Other Major Component of Keeping People Safe on the Roads

Medical College of Wisconsin
And
VA Medical Center
Milwaukee, Wisconsin
Laboratory Personnel

- 10 PhD Scientists; 1 MPH; 8 engineers; 25 technologists and Post docs/grad Students
VA Laboratories

- Mechanical testing
  - Electro-hydraulic piston actuator
  - Drop towers
  - Pendulum
- Acceleration Servo Sled testing
- Full-scale vehicle crash testing
- Basic Neuroscience & Neurobiology
  - Tissue culture and cellular imaging
  - Histology and Immunohistochemistry
  - Stem cell biology
The Biomechanics of Trauma

- Human – Machine Environment
  - Vehicle crashes
  - Military equipment
  - Occupational hazards
  - Intentional/Unintentional events
- Determine mechanisms of injury
- Define human tolerance
- Design primary interventions
- Design secondary interventions
<table>
<thead>
<tr>
<th>Year</th>
<th>Fatal Number</th>
<th>Fatal Percent</th>
<th>Injury Number</th>
<th>Injury Percent</th>
<th>Property Damage Only Number</th>
<th>Property Damage Only Percent</th>
<th>Total Number</th>
<th>Total Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>34,172</td>
<td>0.6%</td>
<td>1,630,000</td>
<td>28.1%</td>
<td>4,146,000</td>
<td>71.4%</td>
<td>5,811,000</td>
<td>100.0%</td>
</tr>
<tr>
<td>2009</td>
<td>30,862</td>
<td>0.6%</td>
<td>1,517,000</td>
<td>27.6%</td>
<td>3,957,000</td>
<td>71.9%</td>
<td>5,505,000</td>
<td>100.0%</td>
</tr>
<tr>
<td>2010</td>
<td>30,296</td>
<td>0.6%</td>
<td>1,542,000</td>
<td>28.5%</td>
<td>3,847,000</td>
<td>71.0%</td>
<td>5,419,000</td>
<td>100.0%</td>
</tr>
<tr>
<td>2011</td>
<td>29,867</td>
<td>0.6%</td>
<td>1,530,000</td>
<td>28.7%</td>
<td>3,778,000</td>
<td>70.8%</td>
<td>5,338,000</td>
<td>100.0%</td>
</tr>
<tr>
<td>2012</td>
<td>31,006</td>
<td>0.6%</td>
<td>1,634,000</td>
<td>29.1%</td>
<td>3,950,000</td>
<td>70.3%</td>
<td>5,615,000</td>
<td>100.0%</td>
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<tr>
<td>2013</td>
<td>30,202</td>
<td>0.5%</td>
<td>1,591,000</td>
<td>28.0%</td>
<td>4,066,000</td>
<td>71.5%</td>
<td>5,687,000</td>
<td>100.0%</td>
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<tr>
<td>2014</td>
<td>30,056</td>
<td>0.5%</td>
<td>1,648,000</td>
<td>27.2%</td>
<td>4,387,000</td>
<td>72.3%</td>
<td>6,064,000</td>
<td>100.0%</td>
</tr>
<tr>
<td>2015</td>
<td>32,538</td>
<td>0.5%</td>
<td>1,715,000</td>
<td>27.2%</td>
<td>4,548,000</td>
<td>72.2%</td>
<td>6,296,000</td>
<td>100.0%</td>
</tr>
<tr>
<td>2016*</td>
<td>34,748</td>
<td>0.5%</td>
<td>2,116,000</td>
<td>31.0%</td>
<td>4,670,000</td>
<td>68.5%</td>
<td>6,821,000</td>
<td>100.0%</td>
</tr>
<tr>
<td>2017*</td>
<td>34,247</td>
<td>0.5%</td>
<td>1,889,000</td>
<td>29.3%</td>
<td>4,530,000</td>
<td>70.2%</td>
<td>6,452,000</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

*A direct comparison of the 2016 and 2017 injury, and property damage-only crash estimates cannot be made with any previous year.

1% increase in fatalities in WI in MVAs from 2016 to 2017
## States and U.S. Territories With Laws\(^\d\) Banning Text-Messaging While Driving

<table>
<thead>
<tr>
<th>Alabama</th>
<th>Alaska</th>
<th>Arkansas</th>
<th>California</th>
<th>Colorado</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecticut</td>
<td>Delaware</td>
<td>Florida(^*)</td>
<td>Georgia</td>
<td>Hawaii</td>
</tr>
<tr>
<td>Idaho</td>
<td>Illinois</td>
<td>Indiana</td>
<td>Iowa</td>
<td>Kansas</td>
</tr>
<tr>
<td>Kentucky</td>
<td>Louisiana</td>
<td>Maine</td>
<td>Maryland</td>
<td>Massachusetts</td>
</tr>
<tr>
<td>Michigan</td>
<td>Minnesota</td>
<td>Mississippi</td>
<td>Nebraska(^*)</td>
<td>Nevada</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>New Jersey</td>
<td>New Mexico</td>
<td>New York</td>
<td>North Carolina</td>
</tr>
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<td>North Dakota</td>
<td>Ohio(^*)</td>
<td>Oklahoma</td>
<td>Oregon</td>
<td>Pennsylvania</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>South Carolina</td>
<td>South Dakota(^*)</td>
<td>Tennessee</td>
<td>Texas</td>
</tr>
<tr>
<td>Utah</td>
<td>Vermont</td>
<td>Virginia</td>
<td>Washington</td>
<td>West Virginia</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Wyoming</td>
<td>District of Columbia</td>
<td>Puerto Rico</td>
<td>Guam</td>
</tr>
<tr>
<td>U.S. Virgin Islands</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{\d}\) States and the District of Columbia with laws in effect as of May 31, 2018

\(^*\) States with have secondary enforcement of texting for drivers.

## States and U.S. Territories With Laws\(^\d\) Banning Handheld Cellphone Use While Driving

<table>
<thead>
<tr>
<th>California</th>
<th>Connecticut</th>
<th>Delaware</th>
<th>Hawaii</th>
<th>Illinois</th>
</tr>
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<tbody>
<tr>
<td>Maryland</td>
<td>Nevada</td>
<td>New Hampshire</td>
<td>New Jersey</td>
<td>New York</td>
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<tr>
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<td>Rhode Island</td>
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<td>U.S. Virgin Islands</td>
<td></td>
</tr>
</tbody>
</table>

\(^{\d}\) States and the District of Columbia with laws in effect as of May 31, 2018

Note: States with have secondary enforcement of texting for drivers.

Missing Wisconsin!
“Many more men than women die each year in motor vehicle crashes. Men typically drive more miles than women and more often engage in risky driving practices including not using safety belts, driving while impaired by alcohol, and speeding. Crashes involving male drivers often are more severe than those involving female drivers. However, females are more likely than males to be killed or injured in crashes of equal severity, although gender differences in fatality risk diminish with age.”

http://www.iihs.org/iihs/topics/t/generalstatistics/fatalityfacts/gender
Mechanisms of Injury: Factors

- Internal Factors
  - Age
  - Gender
  - Morphology (degeneration)
  - Alignment

- External Factors
  - Contact
  - Non-contact
  - Blast
The Study of Trauma

- Human studies
  - clinical & engineering
- Physical models
- Animal models
- Tissue models
- Computational models
Models to Study Injury
Human Clinical Studies

- National Data base evaluations
  - National Trauma Data base
  - NHTSA FARS
  - NHTSA NASS
  - NHTSA CIREN
  - National Fire Incident Reporting System

- Local Data
  - Police Accident Reports
  - Hospital records
Models to Study Injury
Human Volunteers

- Head target
- Spine targets
- Sled target
- Mouth target

NBDL
Models to Study Injury
Physical Models

Anthropomorphic Test Devices (Dummies)
Models to Study Injury
Anthropomorphic Test Devices (Dummies)

-50 msec

Insert video of child dummy with airbag
US DOT Consumer Information Tests

Frontal NCAP

35 mph

NCAP = New Car Assessment Program

Side NCAP

38.5 mph

Five Star ★★★★★★ Rating System

20 mph
Side Impact: 5 Star-rating System

Side crash injury risk for this vehicle is much less than average
Side crash injury risk for this vehicle is less than average to average
Side crash injury risk for this vehicle is average to greater than average
Side crash injury risk for this vehicle is greater than average
Side crash injury risk for this vehicle is much greater than average
Side Pole NCAP Crash Test

Video of NCAP test

-050 msec
Side Pole NCAP Crash Test

Video of NCAP test

-050 msec
Models to Study Injury
Animal Models

In vivo rodent model of brain injury

Fijalkowski et al., J Neurotrauma 2007
Ex Vivo Diffusion Tensor Imaging

Models to Study Injury Animal Models
Mechanisms of Injury

By Body Region
Biomechanics of Skull Fracture

Compression
Biomechanics of Brain Injuries

Focal Motion

Translational Acceleration

Rotational Acceleration
CIREN Example Focal Brain Injury

Right Occipital Skull Fx
Cerebellar contusion
CIREN Example Motion Brain Injury

DAI
IVH
SAH
Right External swelling
Brain strain distribution
Using SIMon FE Model

- Translational + rotational
- Translational only
- Rotational only

9 cases
Spine Injury
Thoracic and Lumbar Spine Fractures Follow Alignment Principal

- Shoulder loading may induce upper and middle Thoracic Spine trauma
- Buttocks loading may induce lower Thoracic Spine or Lumbar spine trauma

Myklebust, Maiman, et al, Stapp, 1983
Human Neck Injury Tolerance
Dynamic Compressive Load
Effect of Loading Rate  males
Injury Severity

Minor

Moderate

Severe
Experimentally Created Burst Fracture
Models to Study Injury
Computational Models
Column Alignment and Injury are Related

McElhaney, Stapp, 1983

Compression Injury

Burst Fracture

Wedge Compression Fracture

Bilateral Facet Dislocation

Increasing Eccentricity

Burst Fracture

Wedge Fracture

Fracture dislocation

McElhaney, Stapp, 1983
Cervical Column Alignment Dictates Injury Outcome
CIREN case 2002 Volvo

58 yo Female driver
lower cervical fractures
$182,000 medical bills

Occupant excursion
with load-limiting seat belt allowing 9 cm spool-out.

Steering-column compressed and rim deformed 6 cm
T&L spine – frontal impact

- Frontal impact assessed on:
  - Head, upper neck, chest, femur
- No agreed tolerance for assessment of thoracic or lumbar spine fractures
Hypothesis: Seat Pan Loading
Database Analysis

- National Automotive Sampling System (NASS)
  - US DOT NHTSA database
  - Selective sample; Population based
  - Tow-away crashes; hospital records
  - AAAM AIS injury scoring
- 1993-2012 crash years
- Separate impact types
  - Frontal crashes vs all other crashes
- Search occupant injuries
  - Thoracic vertebral body fxs
    - AIS-codes 650430.2, 650432.2, 650434.2
  - Lumbar vertebral body fxs
    - AIS-codes 650630.2, 650632.2, 650634.2
Models to Study Injury
Computational Models
Models to Study Injury
Computational Models
Lumbar Spine Fractures

- Lumbar spine compression occurs in planar frontal impact
- “Stiff” seats in static tests did not produce max loads in dynamic tests
- Maximum belt loads generally precede maximum lumbar loads
- Peak lumbar loads not time coincident with belt or femur loads
- Peak lumbar compressive forces generally greater for frontal pole pulse than full frontal
- Computational model allows for mechanistic evaluation
Knee-Thigh-Hip Injury
Developments in Understanding Pelvic Fractures

- Knee-Thigh-Hip trauma
- Knee contact – knee bolster
- Effect of loading rate
- Effect of position

Rupp & Schneider, Orthop Clin N Am, 2004

Rupp, et al, ESV 2005
Real-World Trauma
Pelvic Fractures

Frontal impact of 1997 Lexus LX450
Acetabular Fxs induced by knee contact with knee bolster

Side impact of 2006 Toyota Corolla
Pelvis Fxs induced by hip/pelvis contact with door
Thorax and Abdomen Injury
Full Frontal Impact

unbelted occupant, airbag deployed

Injury Mechanism
Full Frontal Impact

3-pt belted occupant, airbag deployed

Injury Mechanism

Is the study of trauma in the laboratory applicable to the real world?

Yes!

But CIREN & similar projects are the verification
Crash Injury Research and Engineering Network (CIREN) Center

The Medical College of Wisconsin (MCW), The Department of Neurosurgery, and Froedtert Memorial Lutheran Hospital

in association with The VA Medical Center, Milwaukee, Wisconsin
Six CIREN Centers Nationally

- Harborview Injury Prevention & Research Center, Seattle, WA
- Medical College of Wisconsin, Milwaukee, WI
- University of Virginia / Inova-Fairfax Hospital, Falls Church, VA
- University of Maryland, Baltimore, MD
- University of Alabama at Birmingham, Birmingham, AL
- Wake Forest University, Winston Salem, NC / Virginia Tech, Blacksburg, VA
Aim of the CIREN Program

Understand how injuries occur to real people
CIREN Program

- Study emerging trends in Vehicle-related Injuries
- Evaluate existing concepts of Injury Mechanisms
- Verification of Laboratory concepts
- Improve vehicle design by identifying new injury sources
- Improve clinical treatment methods by evaluating patient outcome
CIREN Database

- **Medical Data**
  - EMS treatment
  - Surgical decisions
  - Recovery process
  - Follow-up
  - 250 entries

- **Engineering Data**
  - Crash reconstruction
  - Physics of occupants
  - Mechanics of injury
  - Vehicle causation
  - 600 entries
Objectives of Real-world Crash Investigation

- Understand crash and injury causation
- Improve treatment for crash trauma patients
- Provide data to industry, regulatory, and public agencies
- Develop strategies to reduce fatalities and injuries
- Disseminate safety messages to the public
- Develop training for EMS and health care providers
- Evaluate the role of changing vehicle structure and role of crash avoidance technology
Example Video of Scene
Occupant Contact Zones – Far-side Kinematics
07-491 DRIVER

B-pillar above beltline; bilateral sublux (50%) on R, FX of L facet

12 G W/S header to top plane of IP
12 IP top plane of IP to floor pan
12 C Center consoles floor/first row

13 G W/S header to top plane of IP
13 IP top plane of IP to floor pan
13 S Seat back/headrest/Other Occupant

13 A Roof/side rail to beltline
13 PA Pillar above beltline and rearward
13 D kick-panel, door beltline to rocker
13 PE Pillar below beltline and rearward
Haddon Matrix

Pre-Crash

Human

Vehicle

Environment

Crash

Post-Crash
Occupant Protection System

- **Airbags**
  - Tethers – control airbag shape
  - Location
    - Driver – trending to more recessed into steering wheel
    - Passenger – trending away from top mounted to mid-mounted airbags
  - Frontal Impact AB Volume
    - Driver avg. 56 liters;
    - Passenger pre-1998 165 liters; post-1998 120 liter
  - Inflation Time
    - Driver – Average time 33 ms
    - Passenger – Average time 50 ms

100 kpa = 14.7 psi = 1 atmosphere
Critical Factors Related to Airbags

- Crash severity
- Occupant restraint use
- Weight, size, age, and gender
- Proximity to the airbag
- Timing
- Inflator mass flow
- Airbag response - fold pattern, deployment path, venting, and tethers
Additional Factors Related to Airbags

- Pediatrics population:
  - Not appropriate size of belts
  - Not appropriately used
  - Not appropriately explained (to parents/children)
  - Tend to be out of position
  - Bodies not developed enough to be able to handle such high speed crashes.
Airbag-Induced Skin Abrasions
Occupant Protection System

- Occupant related crash sensors
  - Buckle sensors to observe belt use – varies AB inflation level
  - Seat position sensors
  - Weight/pattern recognition sensors

- Seat belts
  - Pre-tensioners – usually pyrotechnic
    - Load limiters – allows seat belt webbing to yield to limit forces impart to occupant by belt system
      - Web Clamps – Restrict the amount of webbing that spools out of the belt retractor
Seat Belt Technology Testing
Pre-tensioners and Load-limiters
Training

● Occupant... Occupant... Occupant!

● Training is one the most important step in saving time and ultimately saving lives, when seconds count:
  − Online training
  − In-person active training
Training -

Organized by MCW research, providing time, space, crashed car and dummies, and first responder training provided by besafeinc.org in WI.
Crashworthiness improvements

Full engagement (rigid)  40% overlap (deformable)

Longitudinal members

NHTSA  www.nhtsa.gov

safercar.gov

EURO NCAP  www.euroncap.com

ANCAP  Crash testing for safety

INSURANCE INSTITUTE FOR HIGHWAY SAFETY
• Continued frontal impact fatalities
  - NHTSA (2009) n = 122

Planath et al., 1993
Lindquist et al., 2004
Logan et al., 2007
Pintar et al., 2008
Sherwood et al., 2009
Small Overlap: One Longitudinal Member

Most common load paths in SOI

Lindquist 2004
Fatal Low DV Crash: Crush/Energy Management vs. Deformation Extent
What do we know from Crash Tests?
SOI Crash – Midsize Car
SOI Crash – Midsize Car
SOI Crash – Midsize Car

0170 msec
Occupant Kinematics – SOI Crash
Occupant Kinematics – SOI Crash
PDOF from Small Overlap Crash

Dynamic Principle Direction of Force

![Graph showing dynamic principle direction of force over time.](image)
Small Overlap: Structural Changes

Non Ace body

Ace body
Increasing Use of Electronic Technology
Intersection & Forward Collision Avoidance

1) Radar detects slower vehicle ahead
2) System provides audible and visual warnings
3) The vehicle automatically initiates braking to avoid or reduce the speed of a collision
Roadway Departure Avoidance

- **Prevent the straying**
  - Assist to keep the vehicle in the lane

- **Forecast the straying**
  - Vibrations on the steering wheel
  - Lane keeping assist

- **Stray too far off**
  - Lane keeping assist
  - Warning and reducing the speed
Lane Change/Merge Collision Avoidance
The Future of EDR’s Shift to FlexRay

Example of a Backbone Architecture with FlexRay
Future EDR Images Questions

Will crash avoidance activation and/or radar data be reported?

Will video images be stored?
Crash Avoidance Devices: Built-in & Aftermarket

-50 msec
Crash Avoidance Devices: Built-in & Aftermarket
Future Technology...The Driver
Visual and Ocular Measures of Driver Impairment

- **Drowsiness**
  - PERCLOS (percent of eye closure) measured using cameras aimed at face

- **Driver Distraction**
  - Machine vision analysis of glance directions shows tunnel vision of search and scan patterns or glances inside vehicle instead of on the roadway

- **Alcohol Impairment**
  - Horizontal Gaze Nystagmus
  - Pupil response to light
  - ???
Tesla autopilot caused car to accelerate before fatal crash, investigators find

Preliminary report on California collision says car steered towards barrier seconds before impact

Tom Barnes | @thomas_barnes | 3 days ago | 4 comments

The Guardian

Self-driving Uber kills Arizona woman in first fatal crash involving pedestrian

Mon, 19 Mar 2018 18.48 EDT

Tempe police said car was in autonomous mode at the time of the crash and that the vehicle hit a woman who later died at a hospital

USA TODAY

Driver killed in Tesla self-driving car crash ignored warnings, NTSB reports

Nathan Borney, USA TODAY | Published 10:25 a.m. ET June 20, 2017 | Updated 7:24 p.m. ET June 20, 2017
UPDATE 1-Uber test vehicles involved in 37 crashes before fatal self-driving incident

PUBLISHED TUE, NOV 5 2019·3:53 PM EST

REUTERS David Shepardson

GIZMODO We come from the future

LATEST REVIEWS SCIENCE IO9 FIELD GUIDE EARTHER DESIGN PALEOFUTURE

TRANSPORTATION

NTSB Finds Uber Self-Driving Car in Fatal Crash Saw Victim, But Wasn't Programmed to Handle Jaywalkers
Summary

- Study of trauma requires multiple disciplines
- Use of various models
- Define mechanisms of Injury
- Understand human tolerance
- Evaluation of changes to vehicle structure
- Sentinel watching emerging technology
- CIREN is real-world laboratory
INSURANCE INSTITUTE
FOR HIGHWAY SAFETY

Car-to-car crash test
1959 Chevrolet Bel Air
2009 Chevrolet Malibu
80 mi/h closing speed
50 percent overlap

CF09012
September 9, 2009
Acknowledgment

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US Dept. of Transportation NHTSA,
Dept. of Veterans Affairs Medical Research