(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

DEPARTMENT OF VETERANS AFFAIRS
RESEARCH SERVICE

MEDICAL COLLEGE OF WISCONSIN

Laboratory Personnel

MEDICAL COLLEGE OF WISCONSIN

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

VA Laboratories

MEDICAL COLLEGE OF WISCONSIN

- 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

MEDICAL COLLEGE OF WISCONSIN

- 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

MEDICAL COLLEGE OF WISCONSIN

Police-Reported Crashes by Crash Severity and Year, 2008–2017

Year	Crash Severity							
	Fatal		Injury		Property Damage Only		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
2008	34,172	0.6%	1,630,000	28.1%	4,146,000	71.4%	5,811,000	100.0%
2009	30,862	0.6%	1,517,000	27.6%	3,957,000	71.9%	5,505,000	100.0%
2010	30,296	0.6%	1,542,000	28.5%	3,847,000	71.0%	5,419,000	100.0%
2011	29,867	0.6%	1,530,000	28.7%	3,778,000	70.8%	5,338,000	100.0%
2012	31,006	0.6%	1,634,000	29.1%	3,950,000	70.3%	5,615,000	100.0%
2013	30,202	0.5%	1,591,000	28.0%	4,066,000	71.5%	5,687,000	100.0%
2014	30,056	0.5%	1,648,000	27.2%	4,387,000	72.3%	6,064,000	100.0%
2015	32,538	0.5%	1,715,000	27.2%	4,548,000	72.2%	6,296,000	100.0%
2016*	34,748	0.5%	2,116,000	31.0%	4,670,000	68.5%	6,821,000	100.0%
2017*	34,247	0.5%	1,889,000	29.3%	4,530,000	70.2%	6,452,000	100.0%

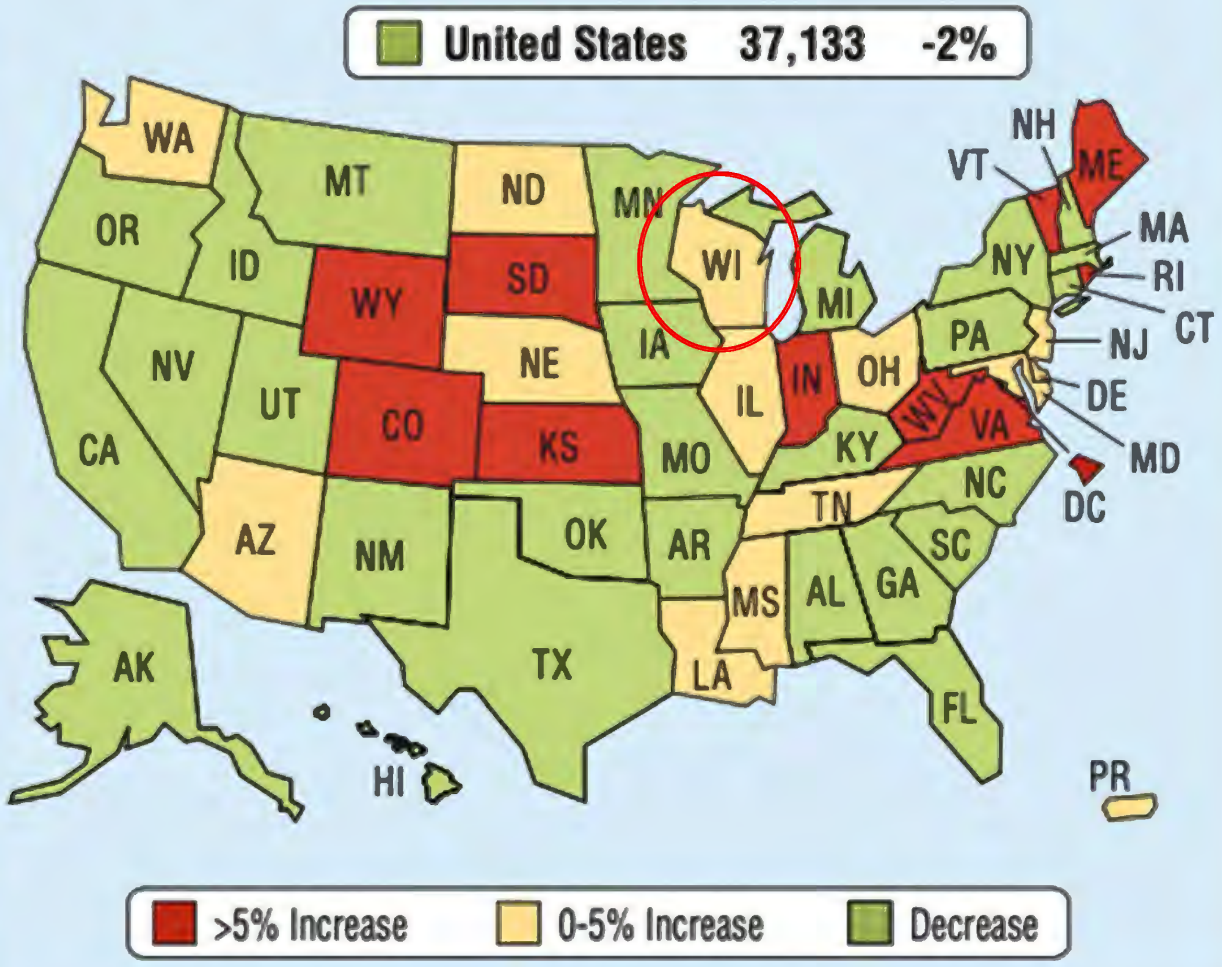
*A direct comparison of the 2016 and 2017 injury, and property-damage-only crash estimates cannot be made with any previous year.
Source: FARS 2008–2016 (Final File) and 2017 Annual Report File (ARF); NASS GES 2008–2015; CRSS 2016–2017

https://cdan.nhtsa.gov/STSI.htm
2019 Traffic Safety Report

MEDICAL COLLEGE OF WISCONSIN

2017 Traffic Fatalities by State, and Percentage Change From 2016

AL	948	-12%	MT	186	-2%
AK	79	-6%	NE	228	+5%
AZ	1,000	+5%	NV	309	-6%
AR	493	-12%	NH	102	-25%
CA	3,602	-6%	NJ	624	+4%
CO	648	+7%	NM	379	-6%
CT	278	-9%	NY	999	-4%
DE	119	0%	NC	1,412	-3%
DC	31	+15%	ND	115	+2%
FL	3,112	-2%	OH	1,179	+4%
GA	1,540	-1%	OK	655	-5%
HI	107	-11%	OR	437	-12%
ID	244	-4%	PA	1,137	-4%
IL	1,097	+2%	RI	83	+63%
IN	914	+10%	SC	988	-3%
IA	330	-18%	SD	129	+11%
KS	461	+7%	TN	1,040	+0%
KY	782	-6%	TX	3,722	-2%
LA	760	+0%	UT	273	-3%
ME	172	+8%	VT	69	+11%
MD	550	+5%	VA	839	+10%
MA	350	-10%	WA	565	+5%
MI	1,030	-3%	WV	303	+13%
MN	357	-9%	WI	613	+1%
MS	690	+0%	WY	123	+10%
MO	930	-2%	PR	290	+4%



Source: FARS 2016 Final File, 2017 Annual Report File (ARF)
NOTE: Puerto Rico is not included in the U.S. National total.

1% increase in fatalities in WI in MVAs from 2016 to 2017

https://crashstats.nhtsa.dot.gov
Data as of 2018

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States and U.S. Territories With Laws† Banning Text-Messaging While Driving

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

†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.

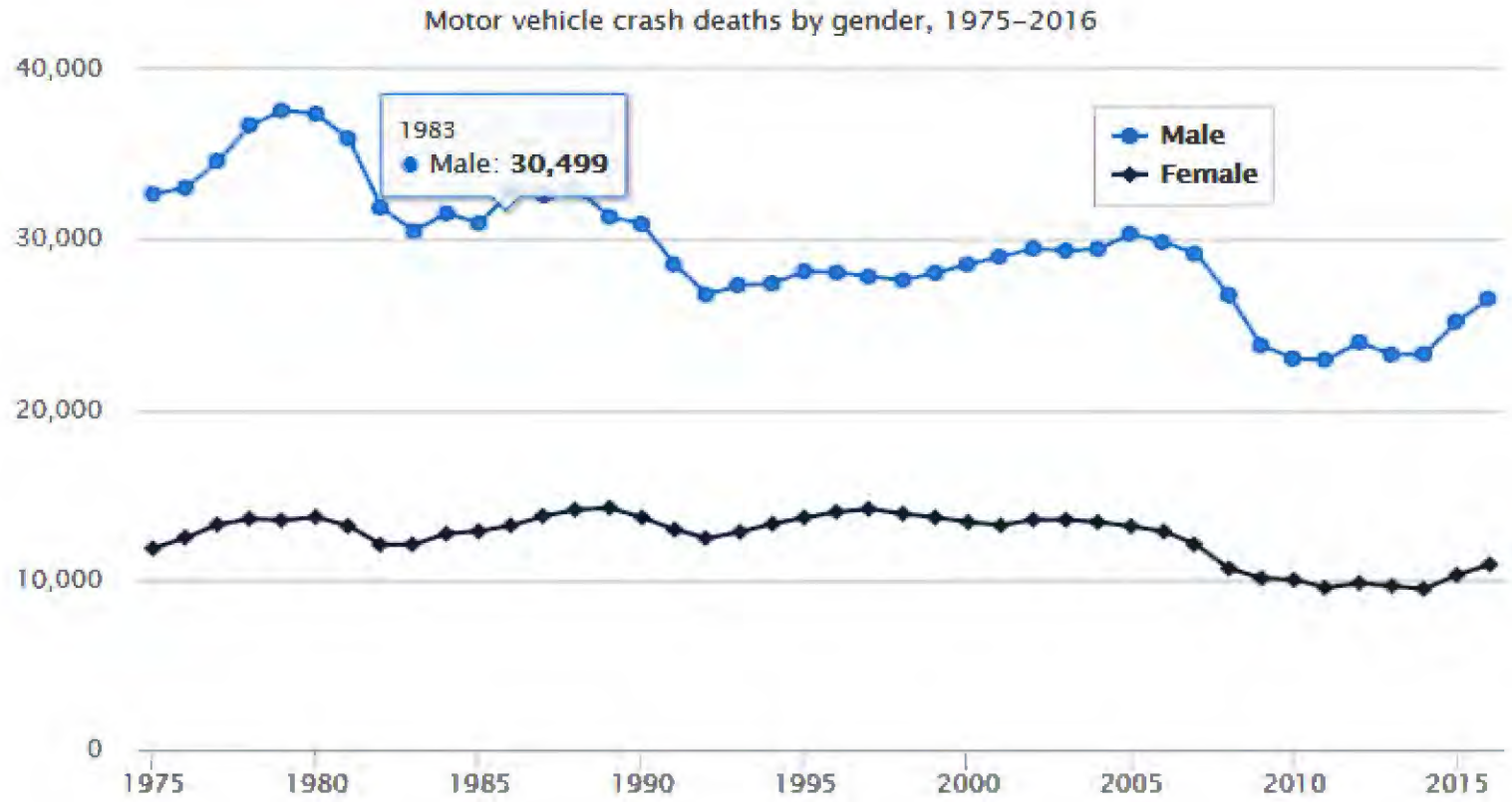
States and U.S. Territories With Laws† Banning Handheld Cellphone Use While Driving

California	Connecticut	Delaware	Hawaii	Illinois
Maryland	Nevada	New Hampshire	New Jersey	New York
Oregon	Rhode Island	Vermont	Washington	West Virginia
District of Columbia	Puerto Rico	Guam	U.S. Virgin Islands	

†States and the District of Columbia with laws in effect as of May 31, 2018

Missing Wisconsin!

https://cdan.nhtsa.gov/STSI.htm
Data as of May 2018



"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

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- Internal Factors
  - Age
  - Gender
  - Morphology (degeneration)
  - Alignment
- External Factors
  - Contact
  - Non-contact
  - Blast

The Study of Trauma

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- Human studies
  - clinical & engineering
- Physical models
- Animal models
- Tissue models
- Computational models

Models to Study Injury
Human Clinical Studies

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- 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

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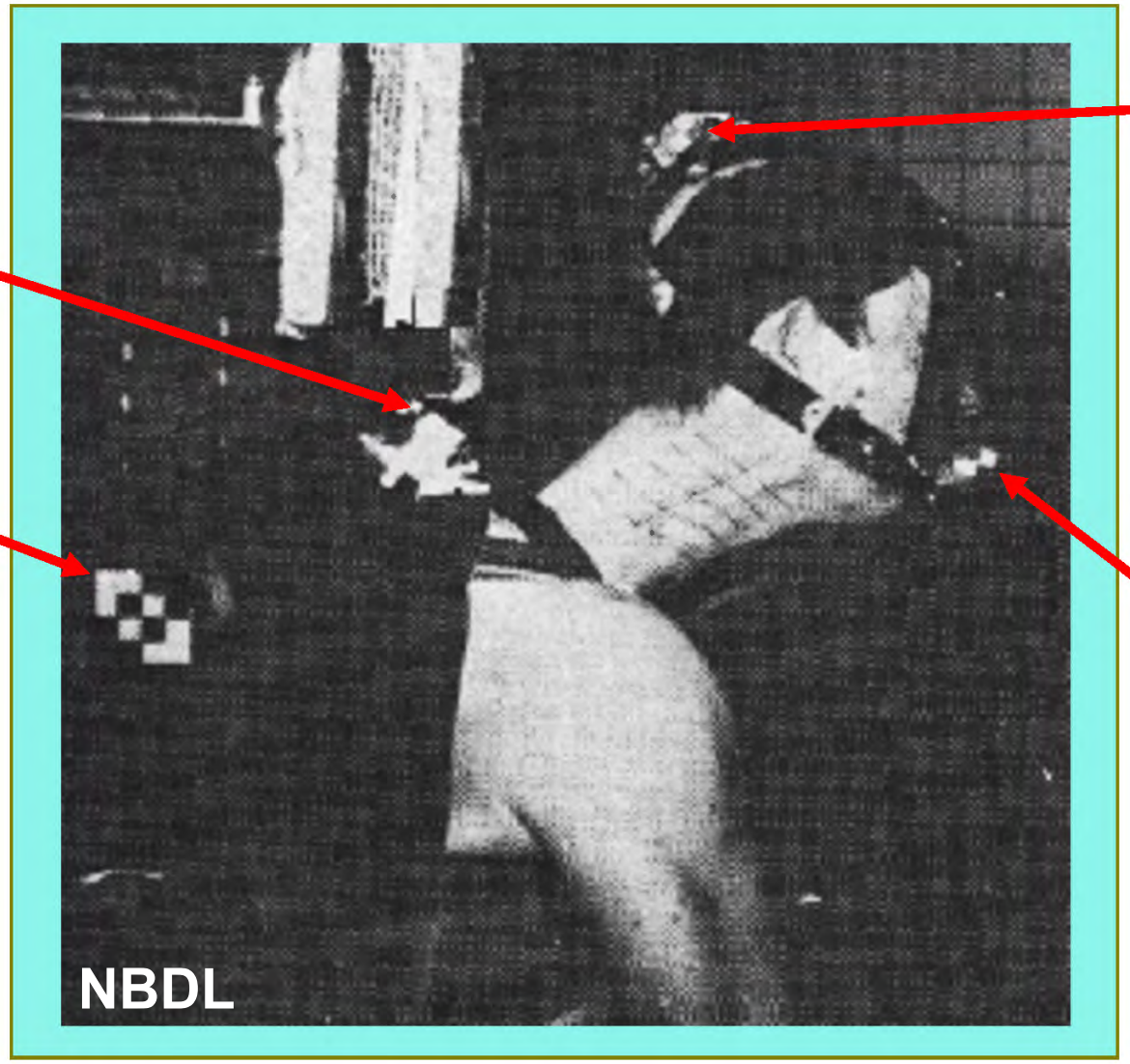

Models to Study Injury
Physical Models

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Anthropomorphic Test Devices (Dummies)

Models to Study Injury

Anthropomorphic Test Devices (Dummies)

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US DOT Consumer Information Tests

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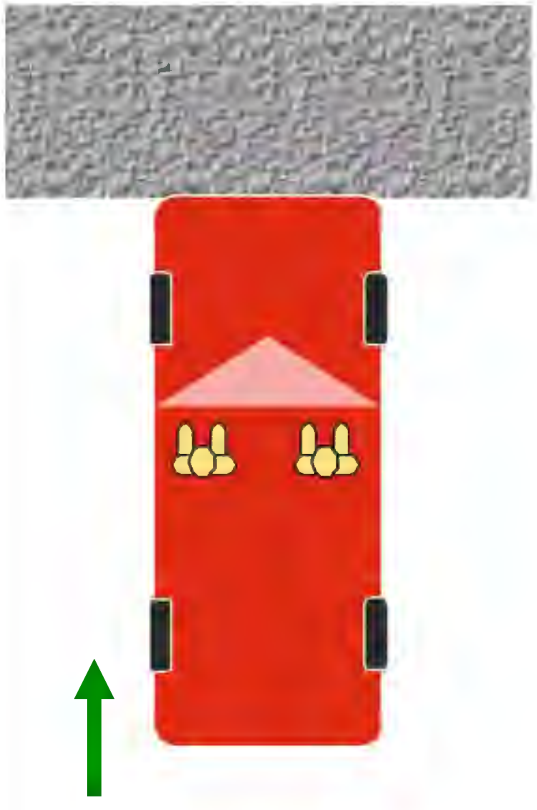
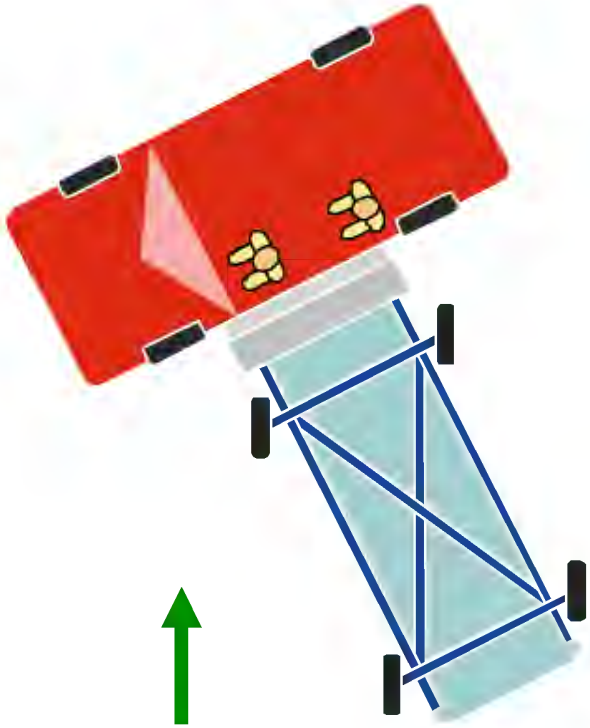
Frontal NCAP

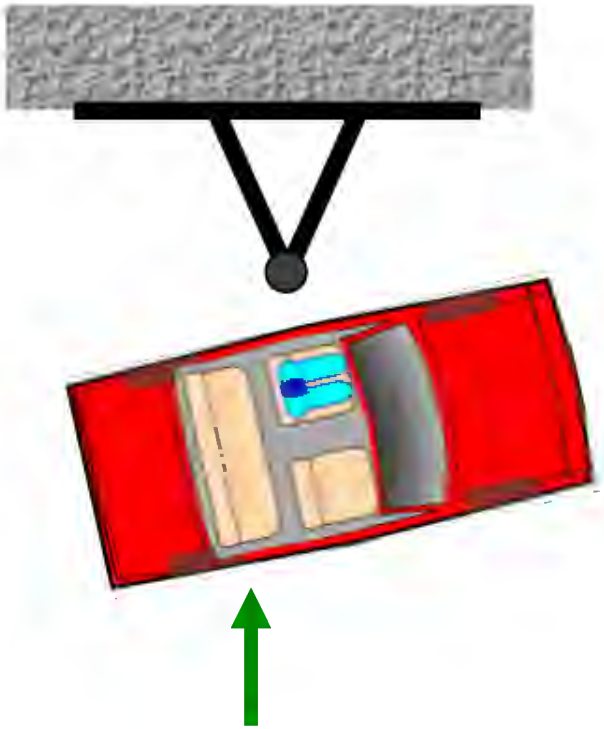


35 mph

Side NCAP



38.5 mph



20 mph

NCAP = New Car Assessment Program

Five Star ★★★★★ Rating System

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

MCW - Vehicle Crashworthiness Laboratory

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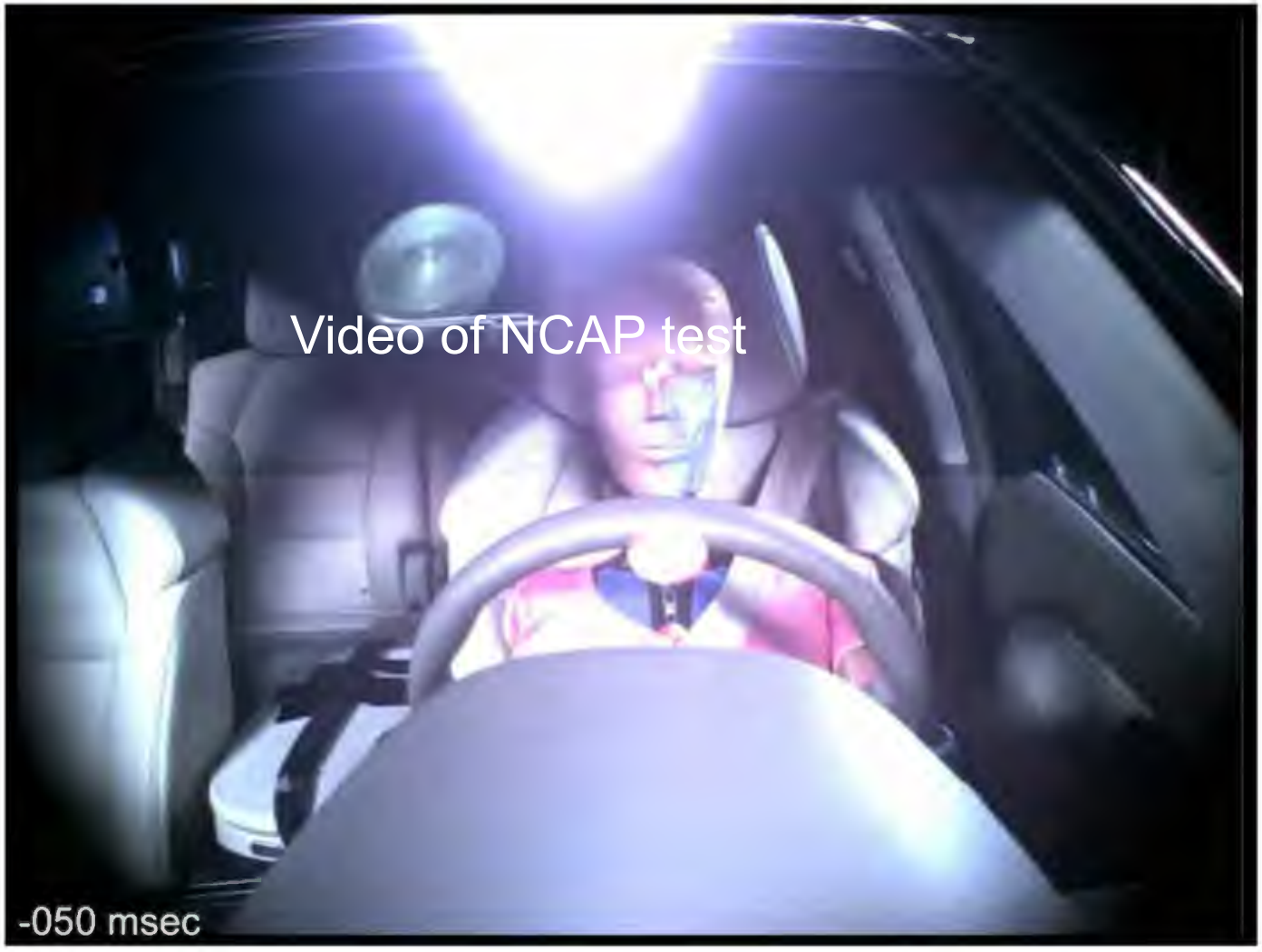
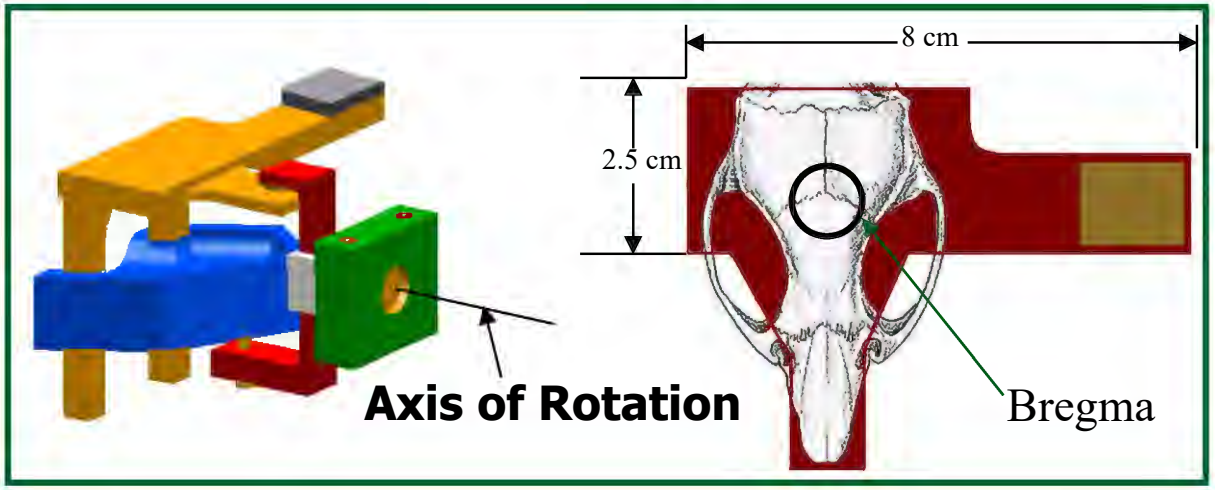
Side Pole NCAP Crash Test

Side Pole NCAP Crash Test



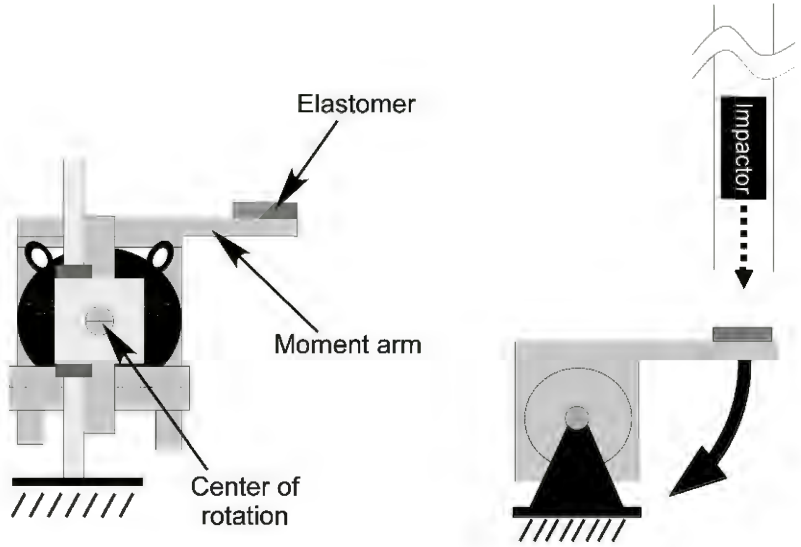
Models to Study Injury

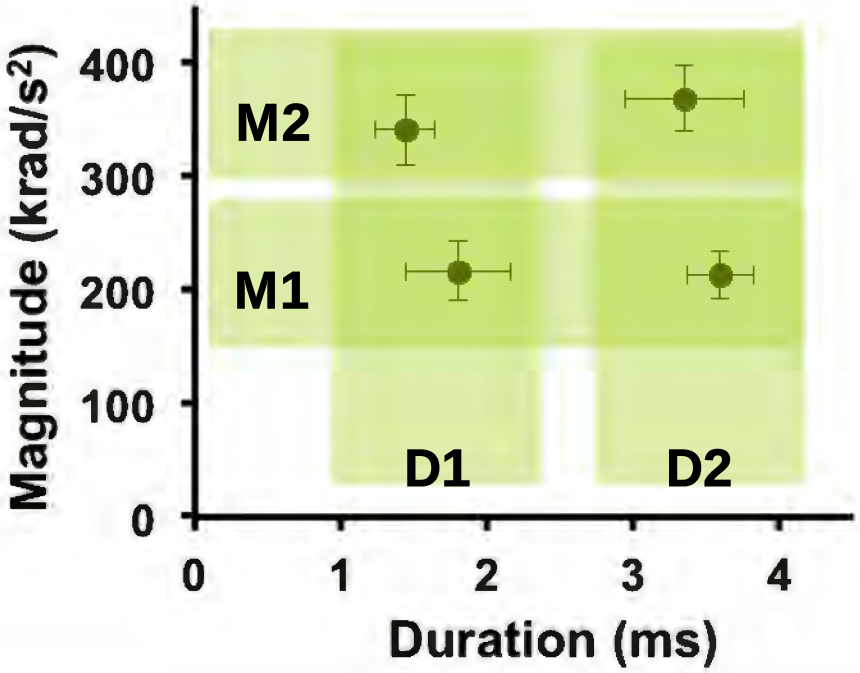
Animal Models



Rodent Helmet Fixture

In vivo rodent model of brain injury





Fijalkowski et al., J Neurotrauma 2007

Ex Vivo Diffusion Tensor Imaging

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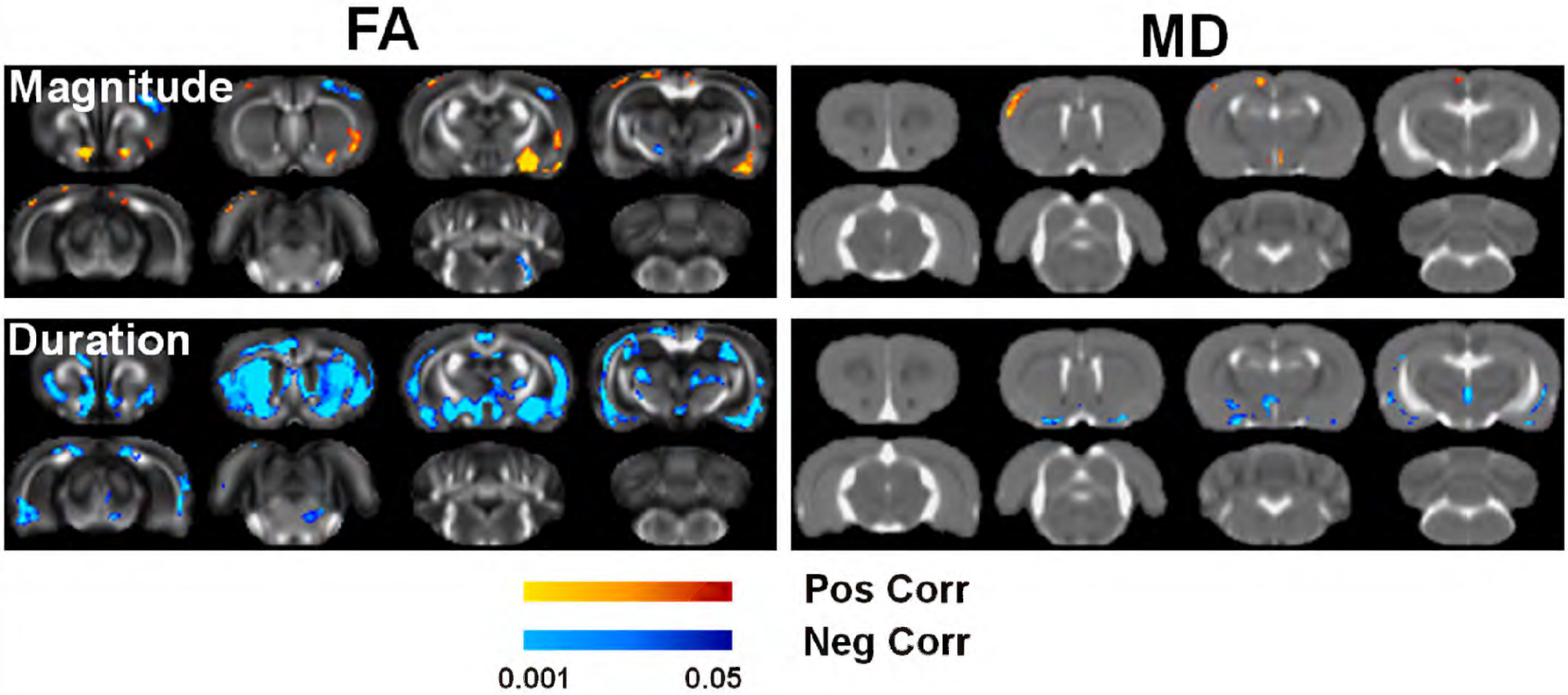
Models to Study Injury Animal Models



Mechanisms of Injury

By Body Region

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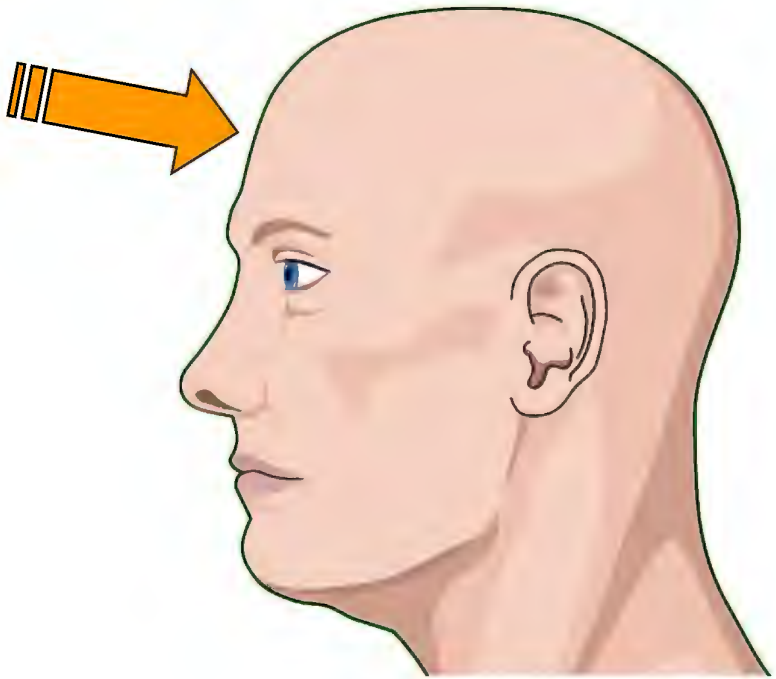
Biomechanics of Skull Fracture



Compression

Biomechanics of Brain Injuries

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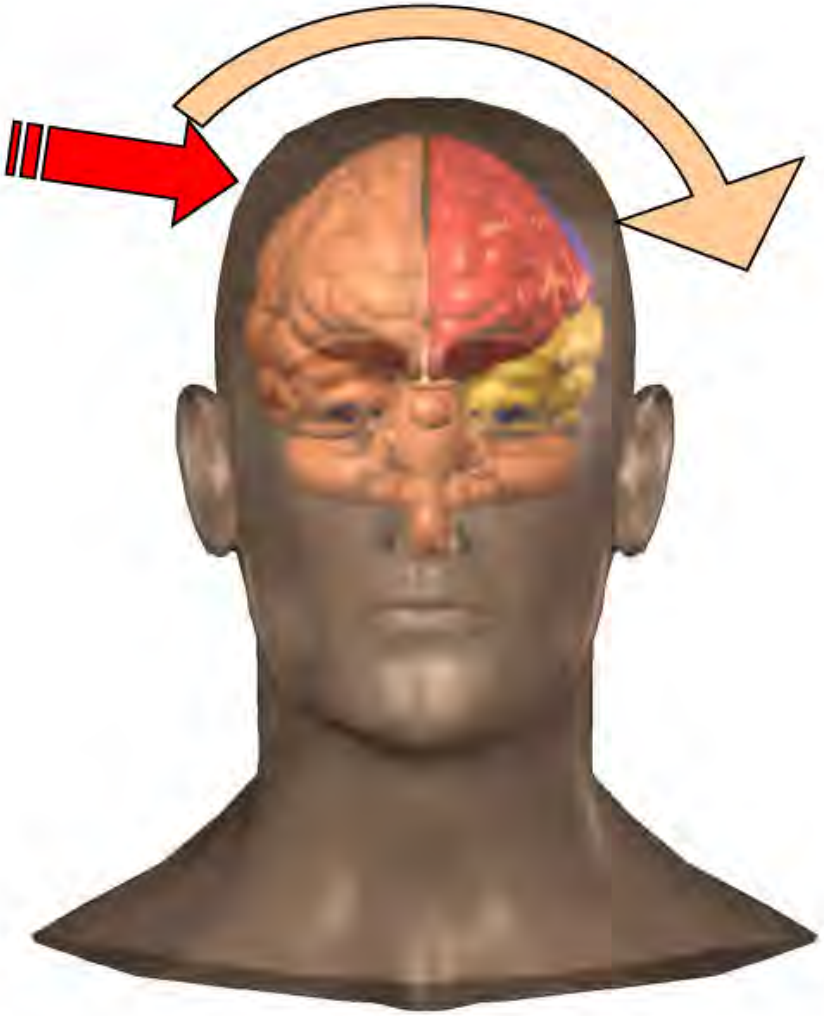
Focal

Translational Acceleration

Motion



Rotational Acceleration

CIREN Example Focal Brain Injury

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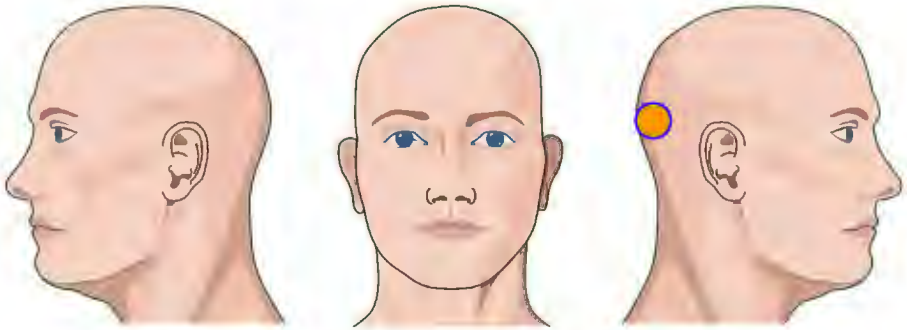
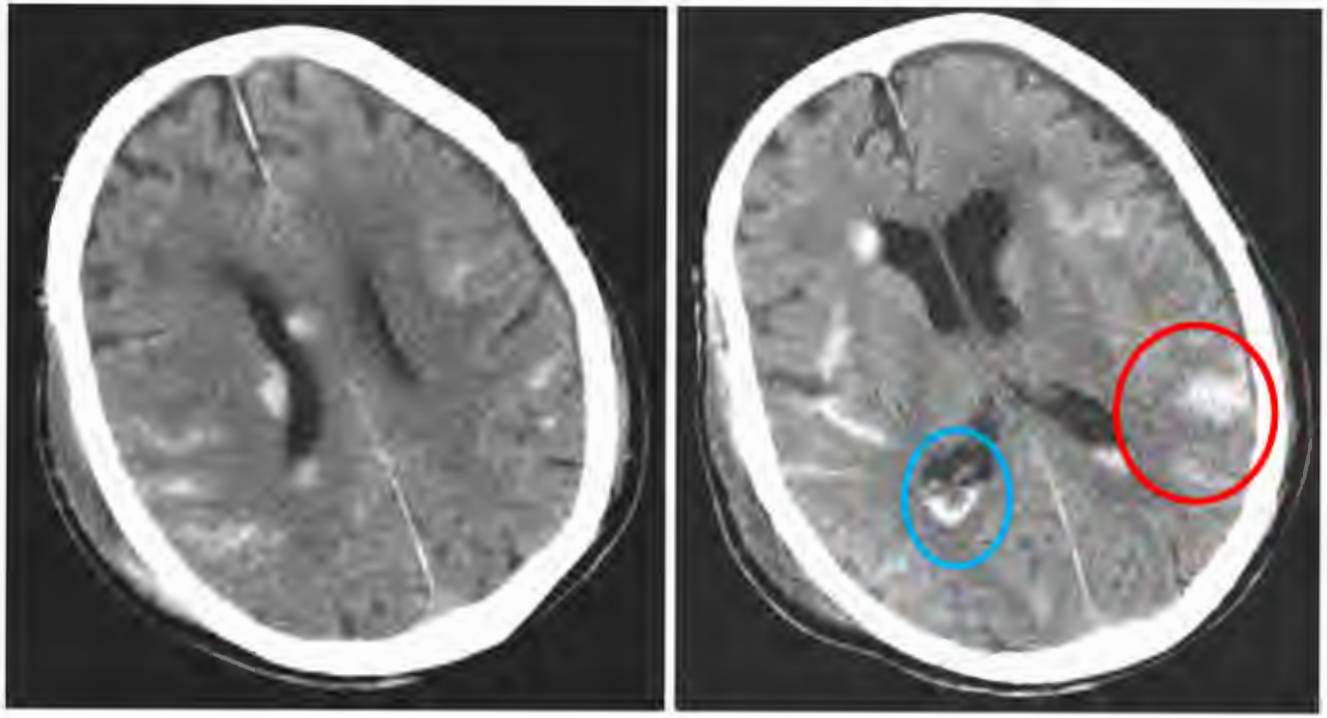
Right Occipital Skull Fx

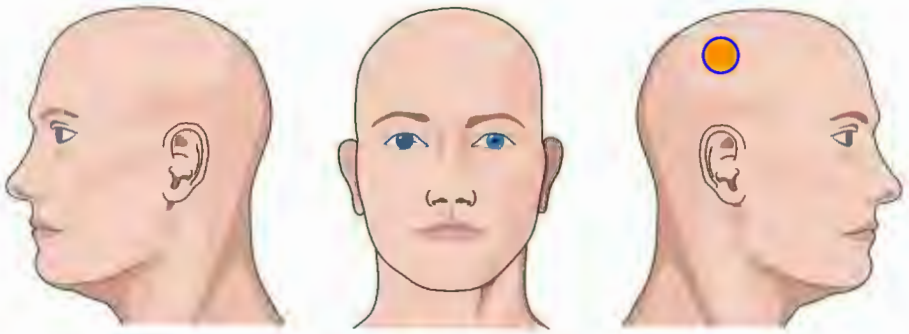
Cerebellar contusion



CIREN Example Motion Brain Injury



DAI
IVH
SAH
Right External swelling



Brain strain distribution

Using SIMon FE Model

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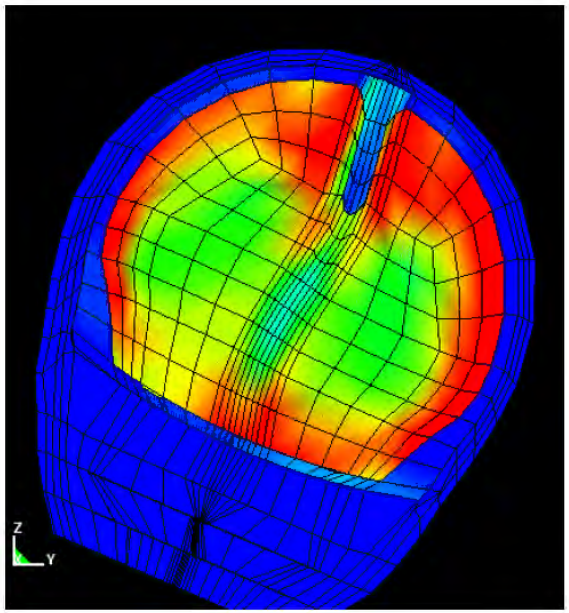
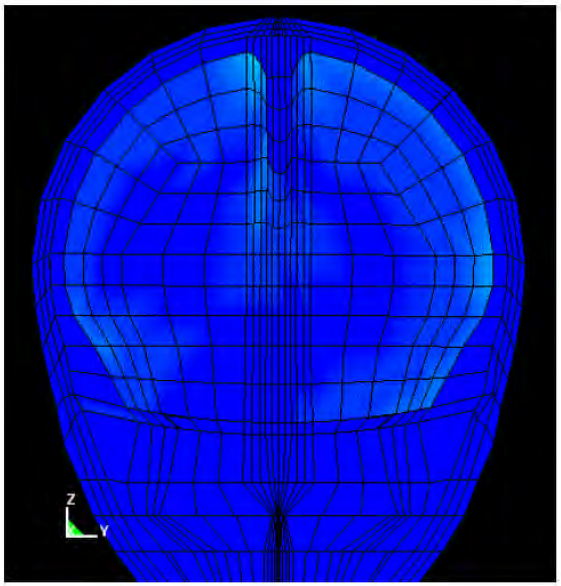
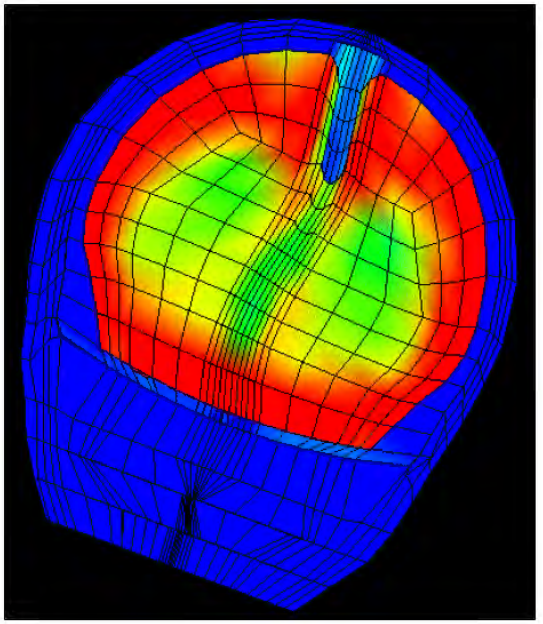


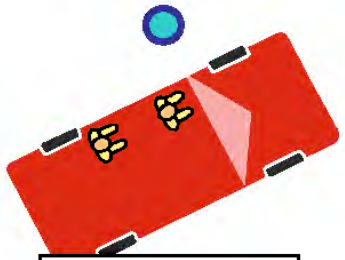
Translational + rotational



Translational only



Rotational only



Spine Injury

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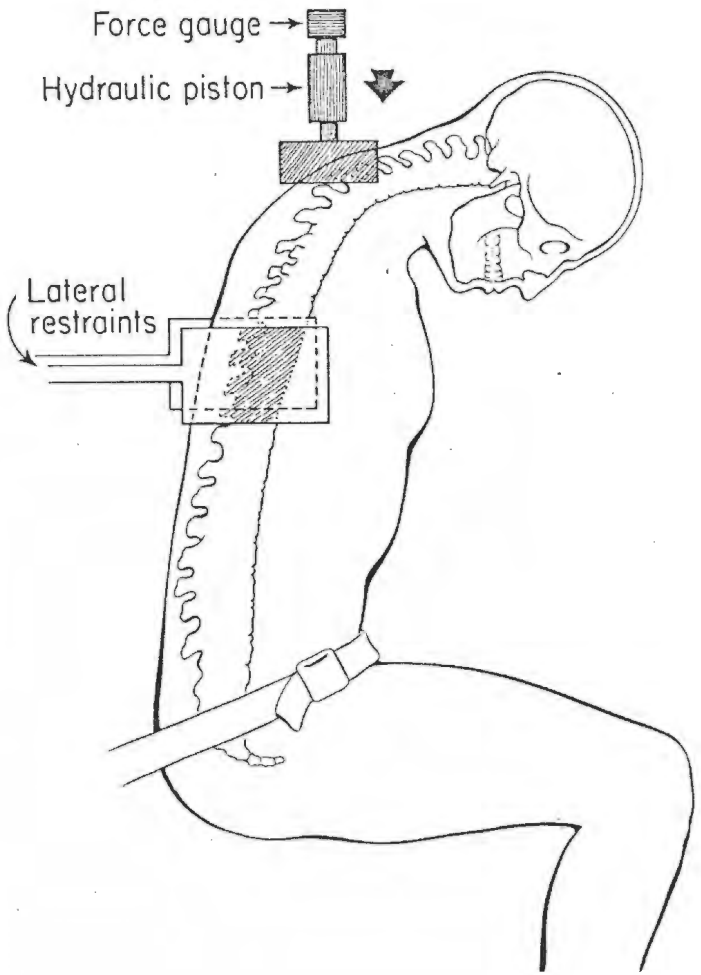
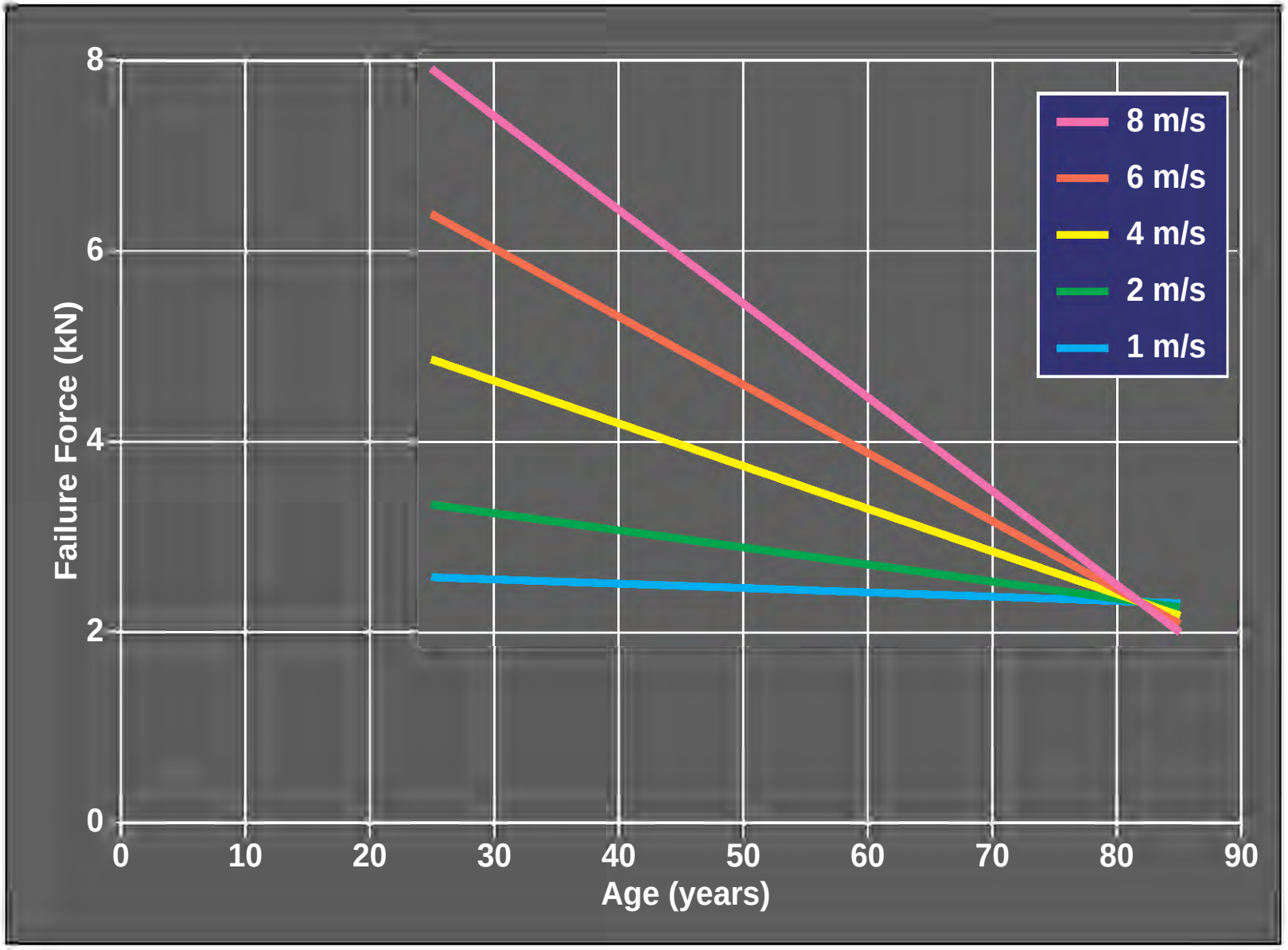
Thoracic and Lumbar Spine Fractures Follow Alignment Principal



- 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

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Minor

Moderate

Severe

Experimentally Created Burst Fracture

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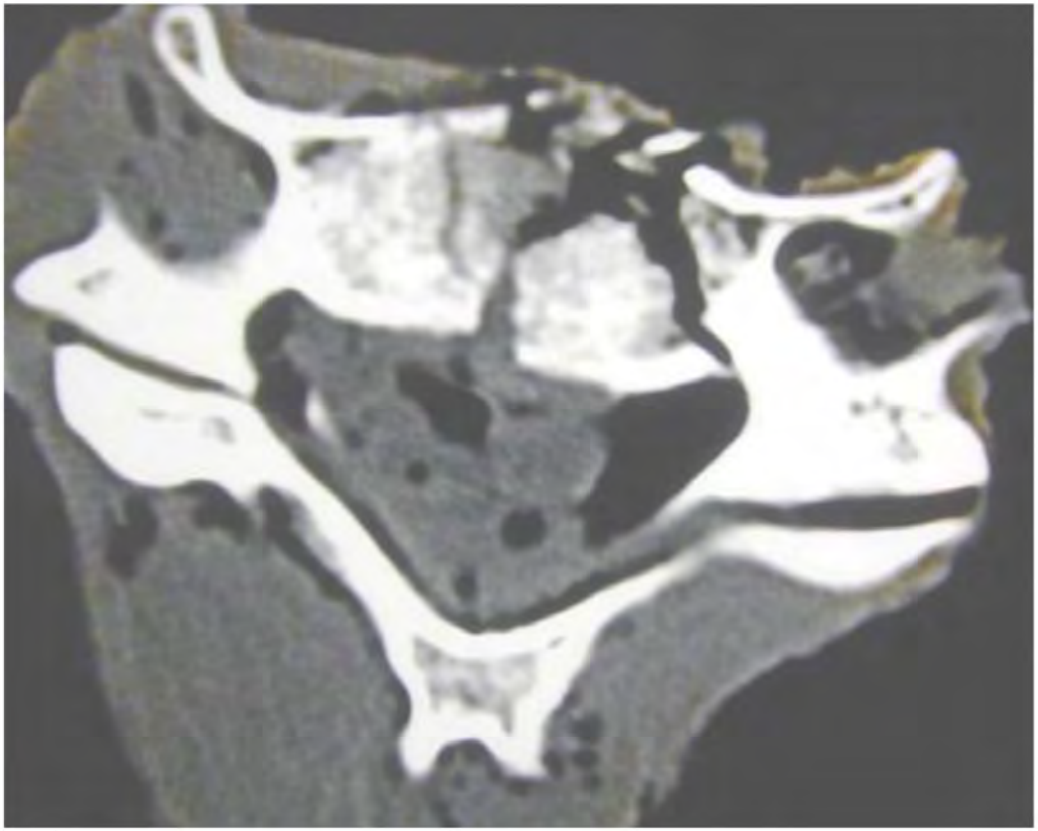
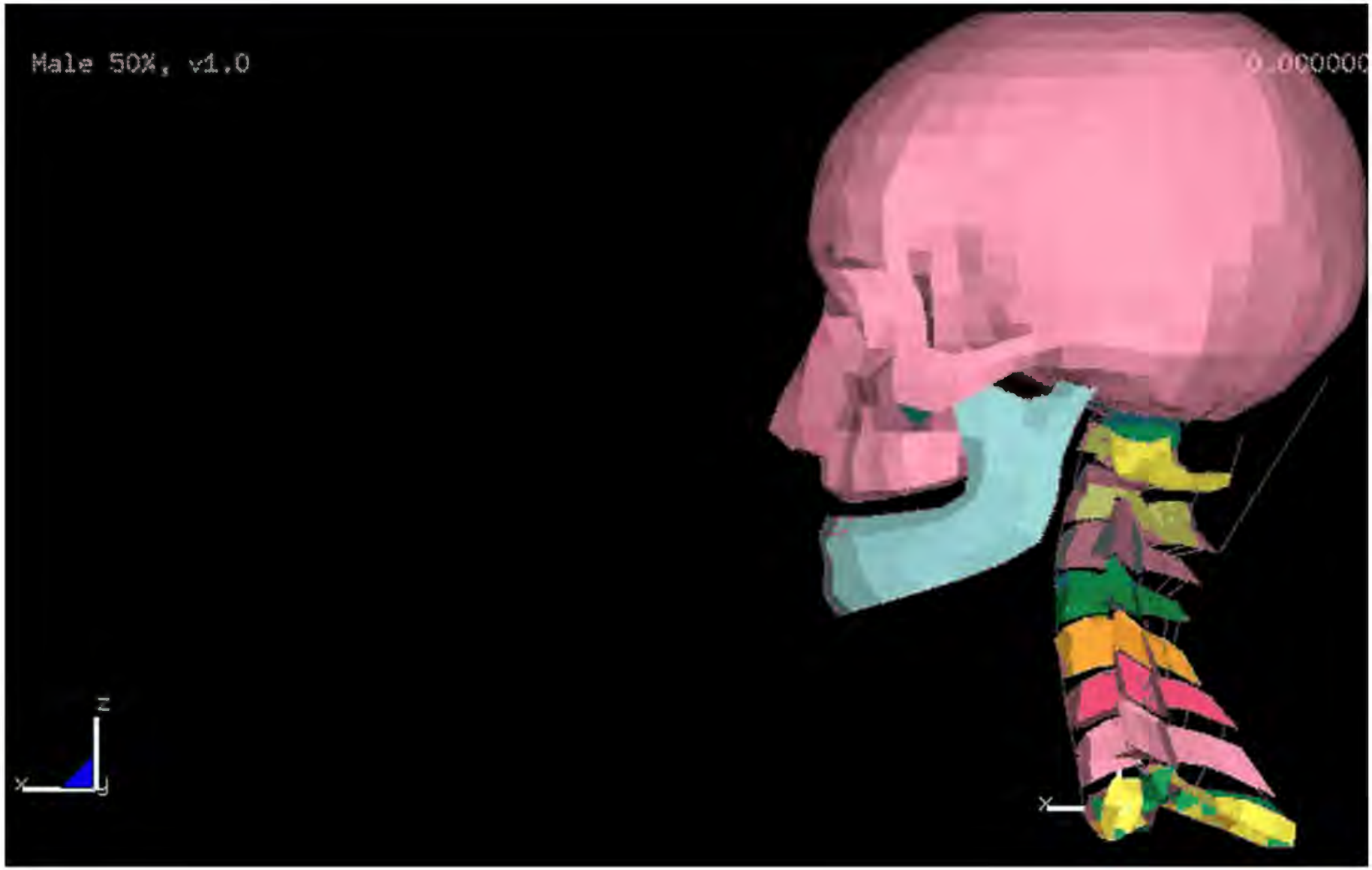
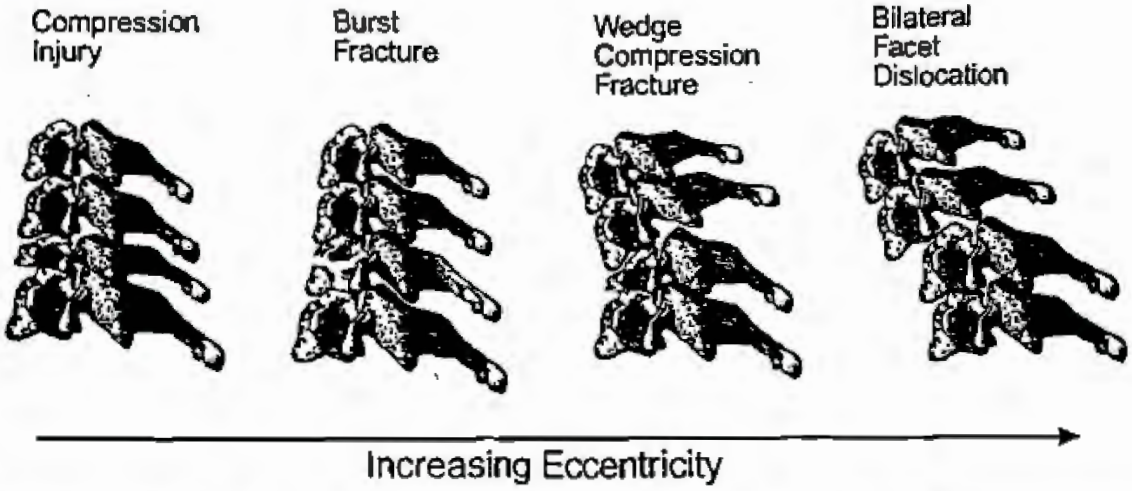


Models to Study Injury
Computational Models

MEDICAL COLLEGE OF WISCONSIN



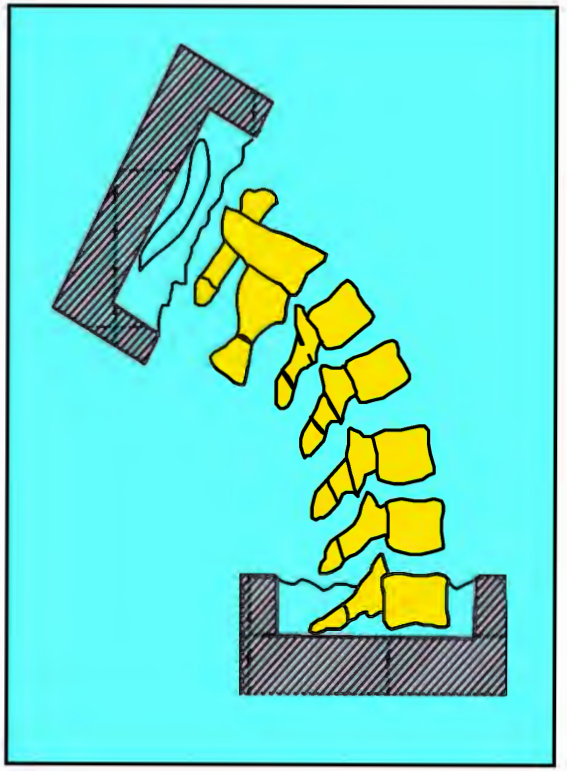
Column Alignment and Injury are Related



Burst Fracture

Wedge Fracture

Fracture dislocation



McElhaney , Stapp, 1983

Cervical Column Alignment Dictates Injury Outcome

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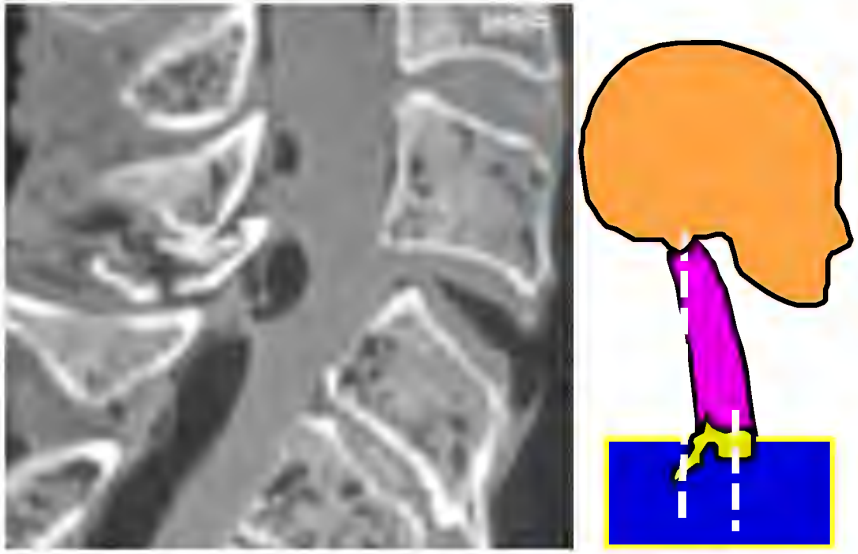
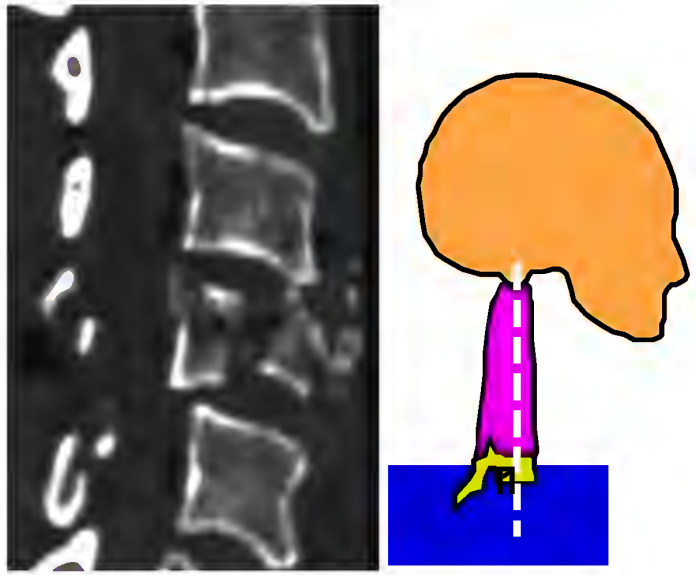
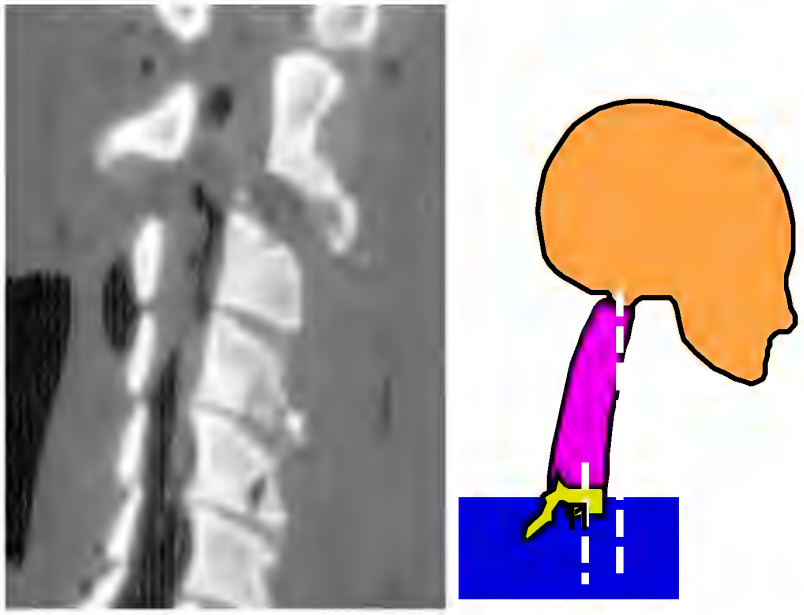
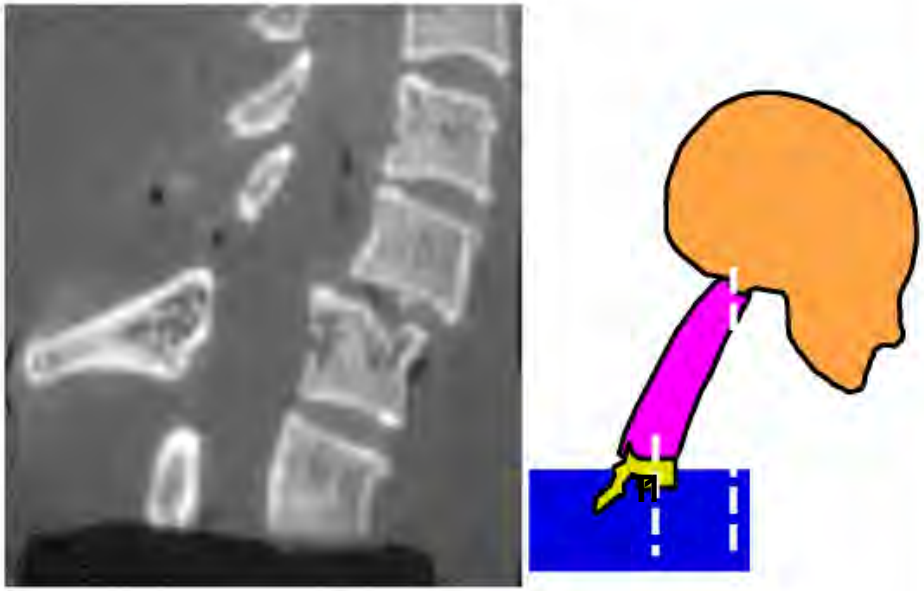








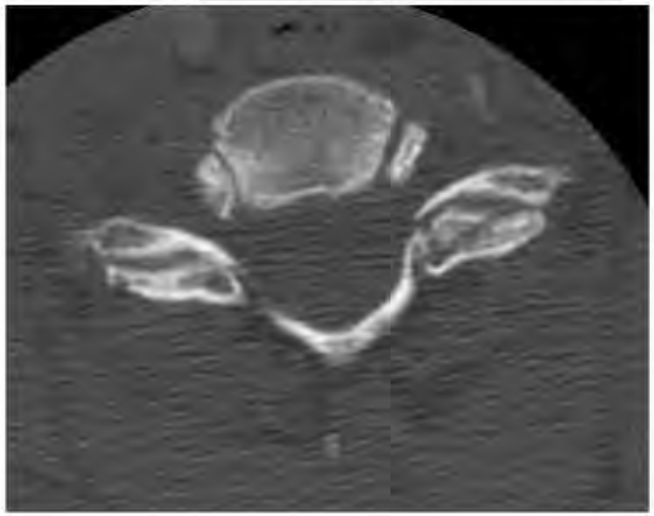
CIREN case 2002 Volvo

58 yo Female driver
lower cervical fractures

$182,000 medical bills

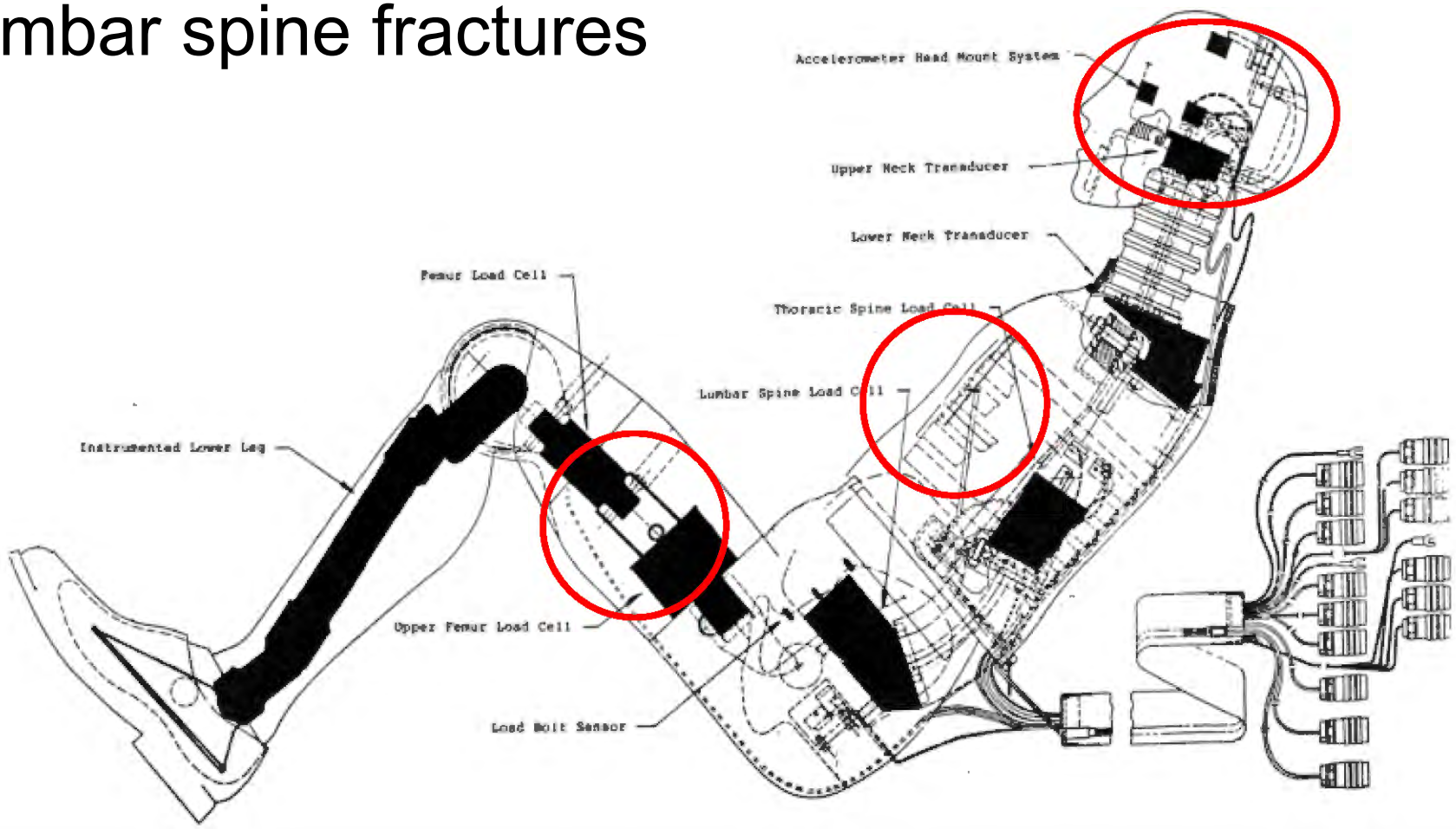
Occupant excursion with load-limiting seat belt allowing 9 cm spool-out.

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

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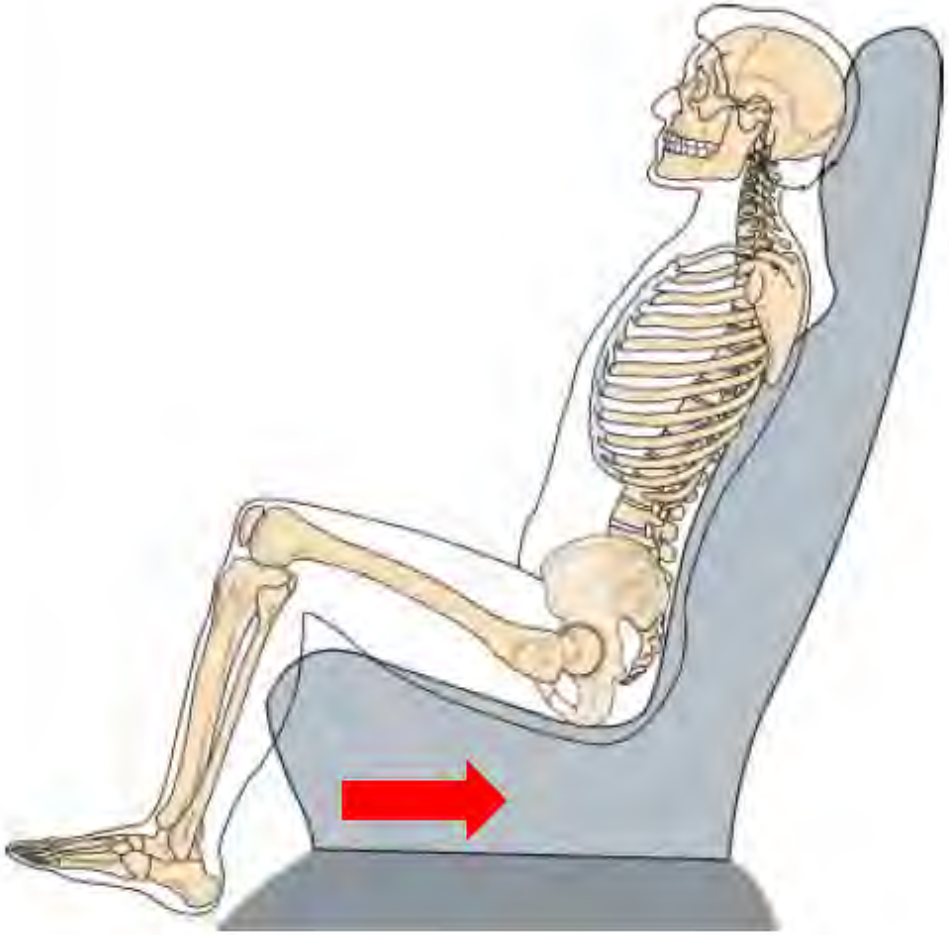

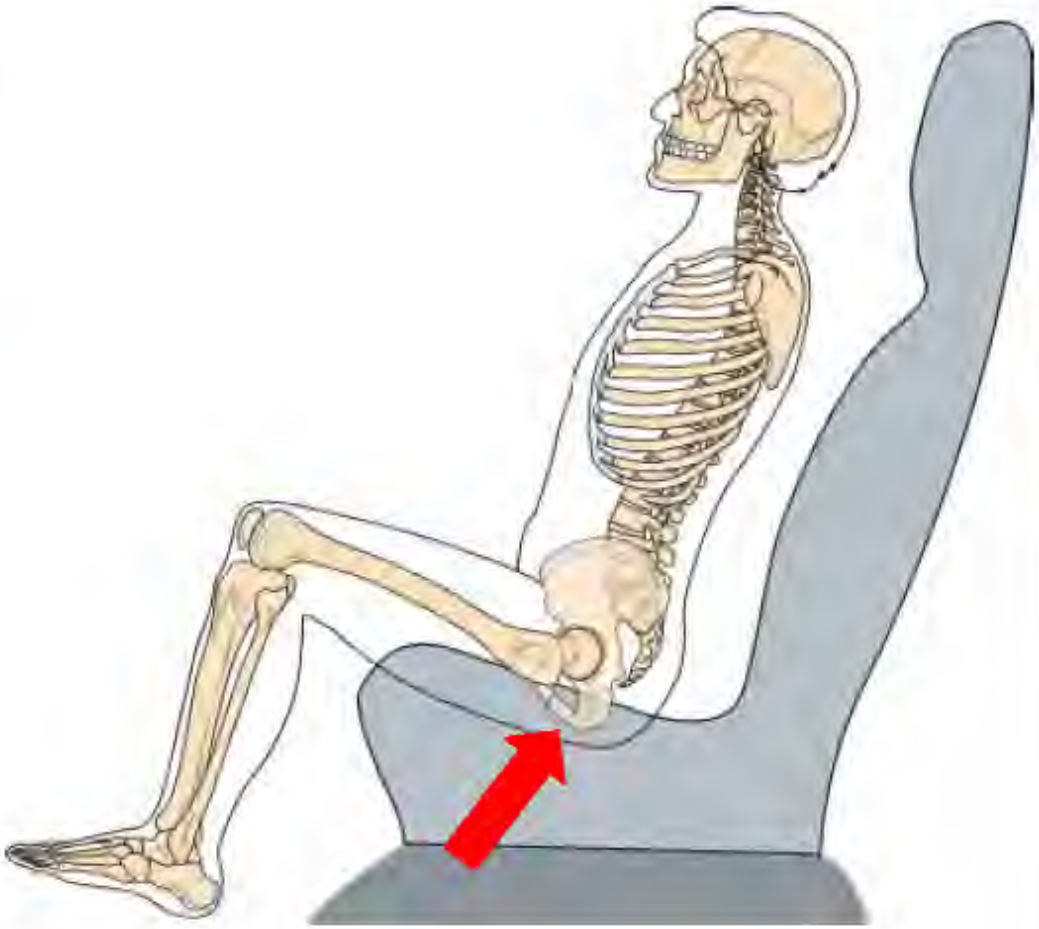

Database Analysis

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- 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

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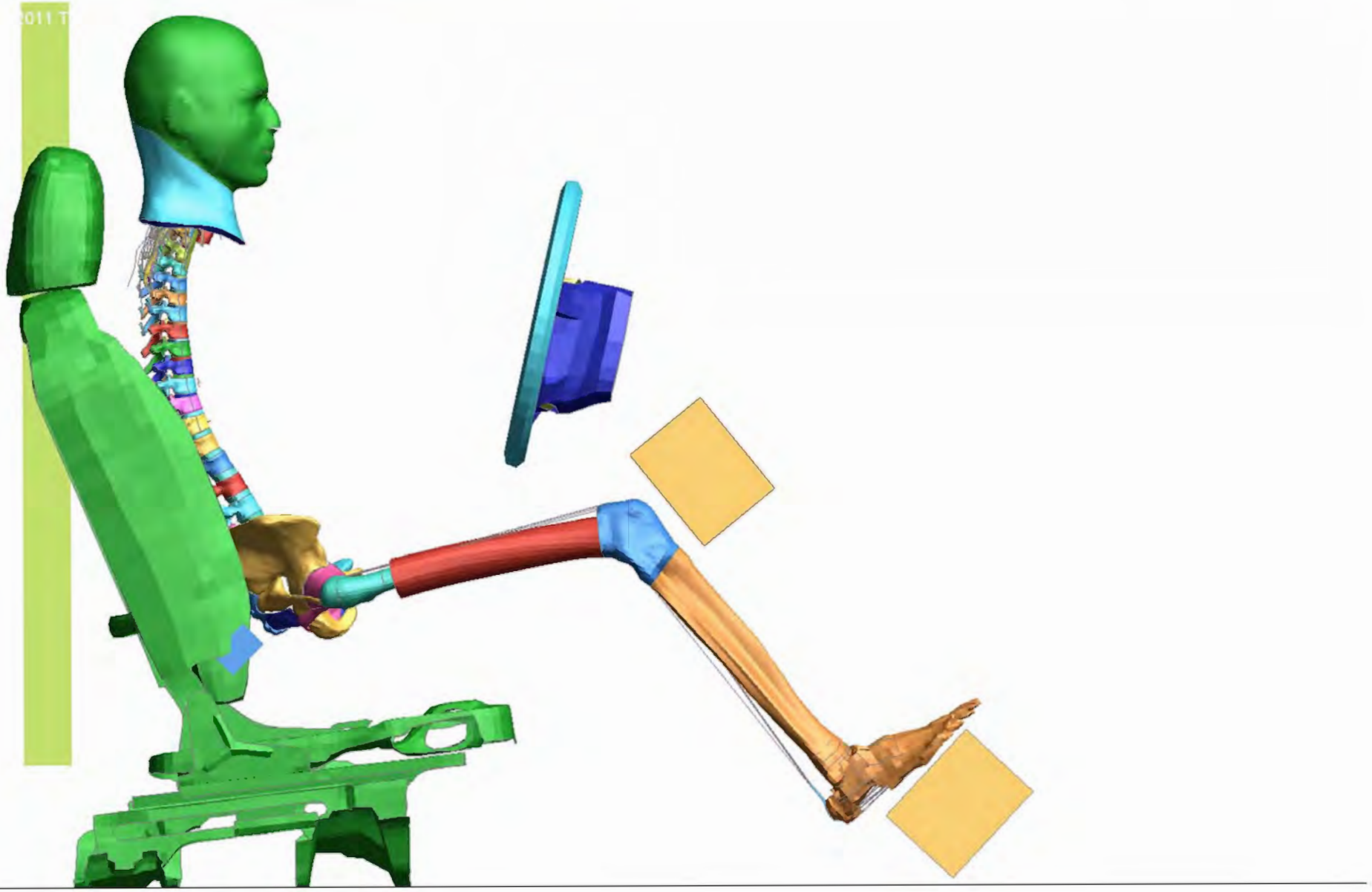
Models to Study Injury

Computational Models

MEDICAL COLLEGE OF WISCONSIN



Lumbar Spine Fractures

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- 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

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Developments in Understanding
Pelvic Fractures

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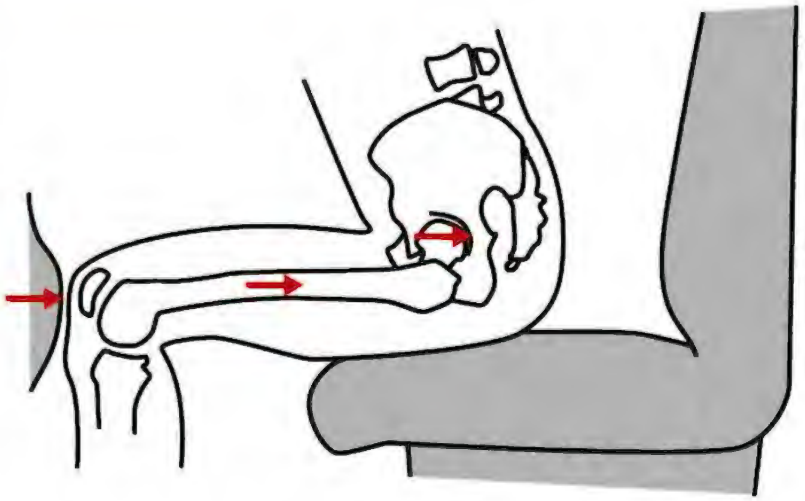
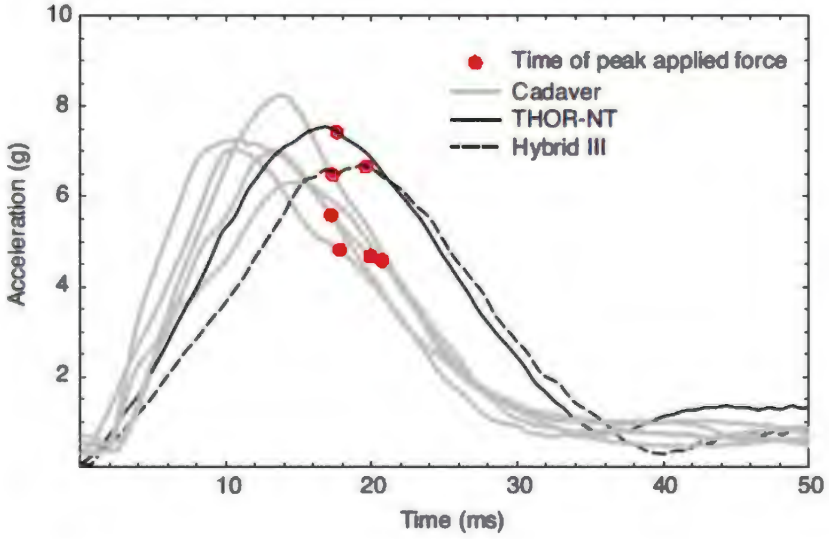
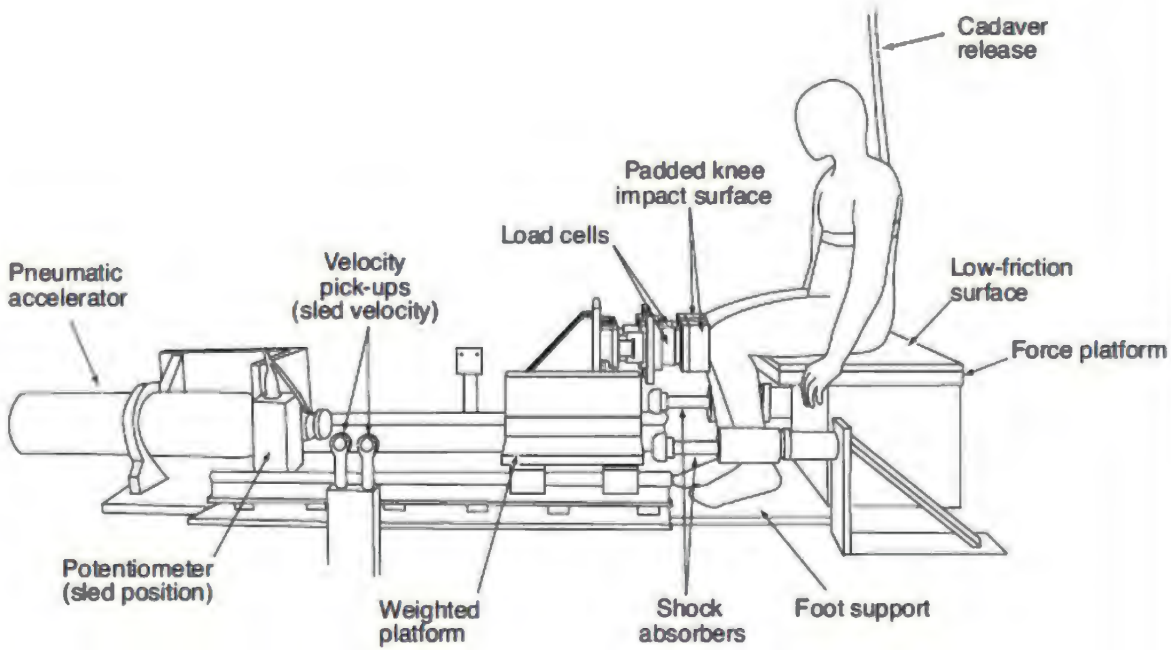


- Knee-Thigh-Hip trauma
- Knee contact – knee bolster
- Effect of loading rate
- Effect of position

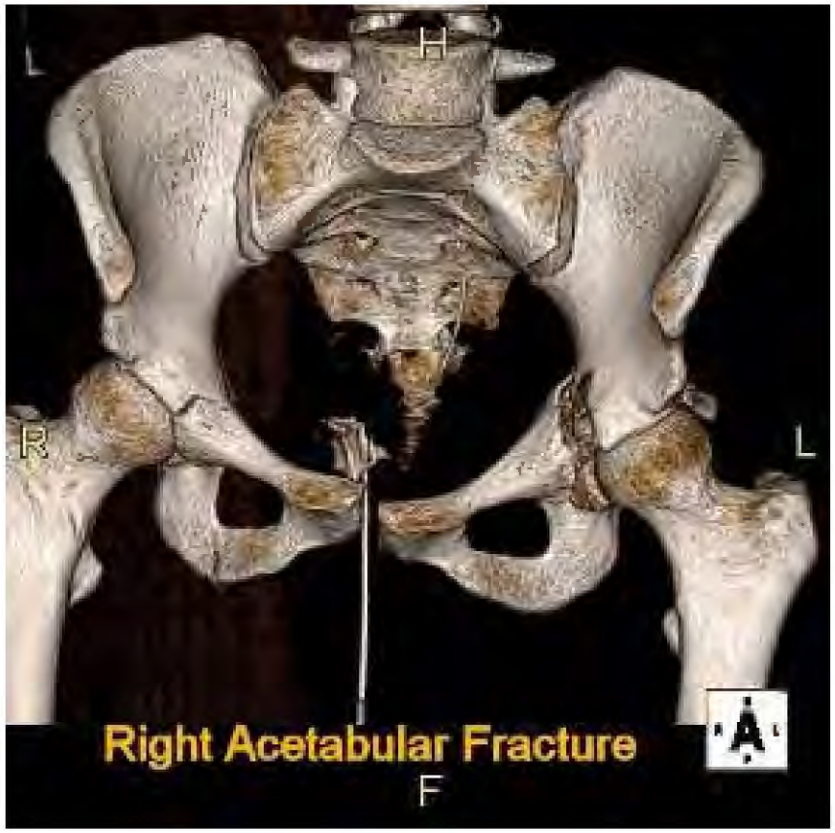
Rupp & Schneider, Orthop Clin N Am, 2004



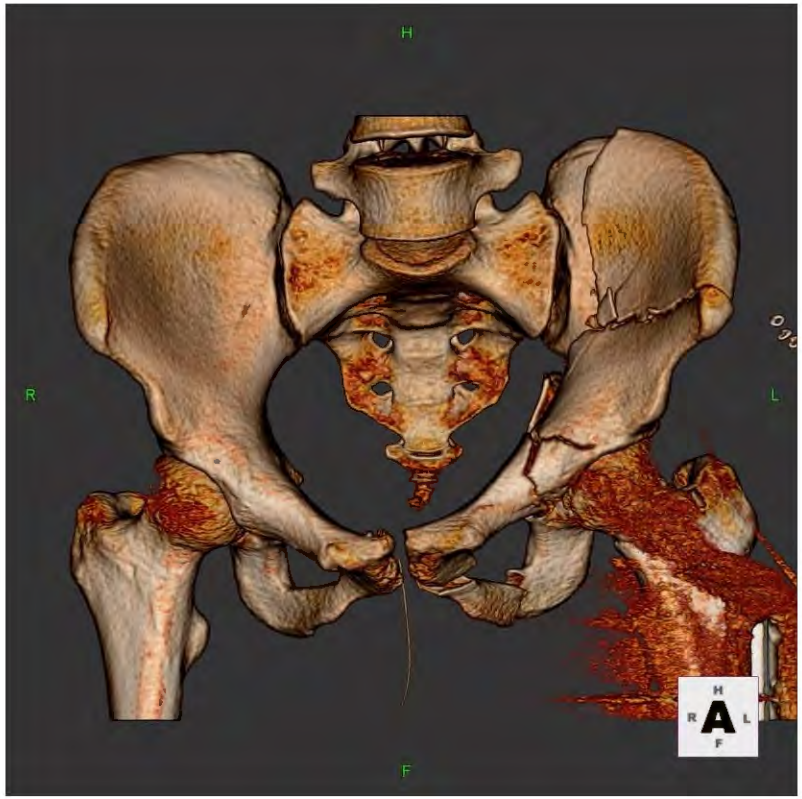
Rupp, et al, ESV 2005



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

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Full Frontal Impact

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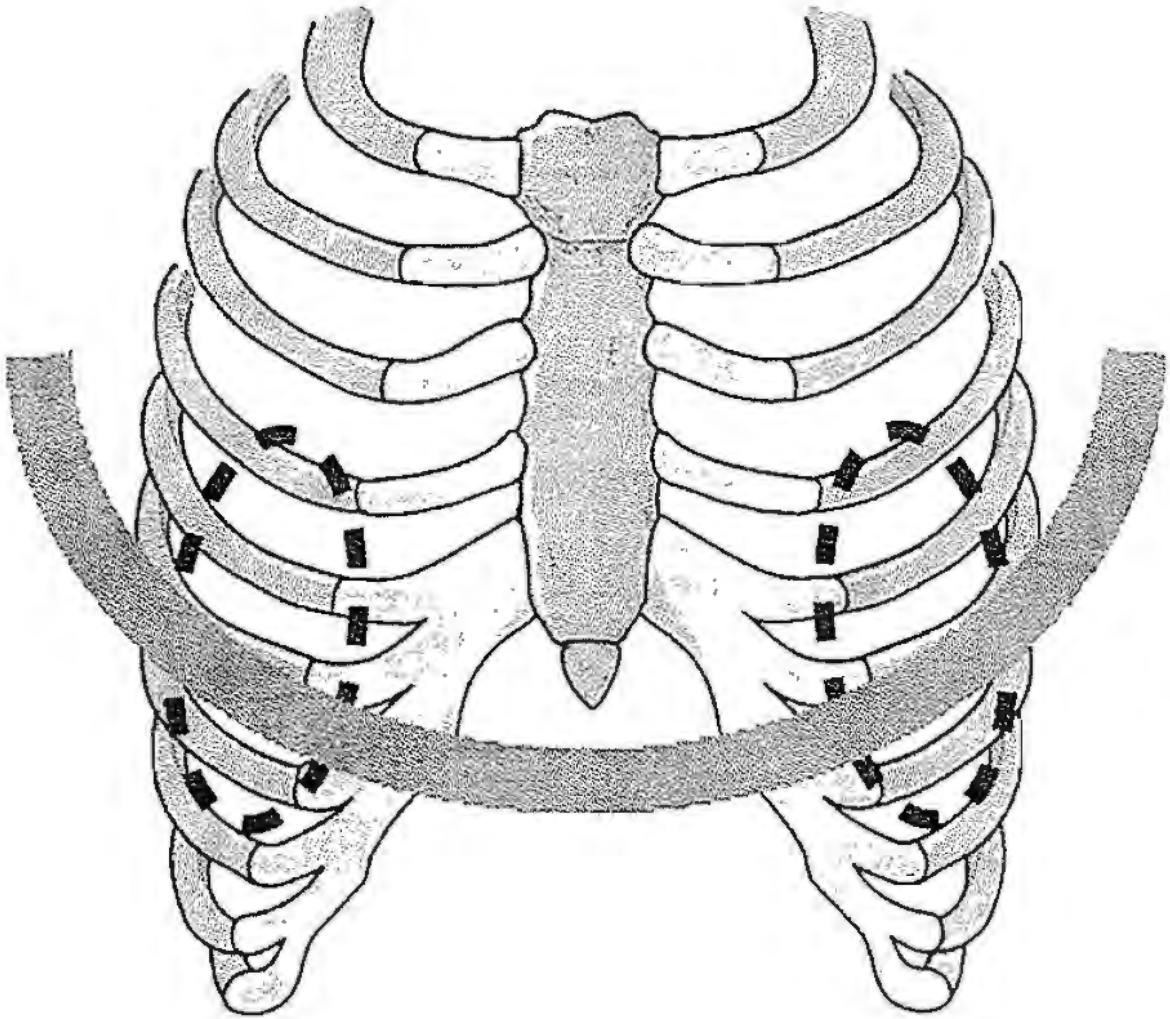
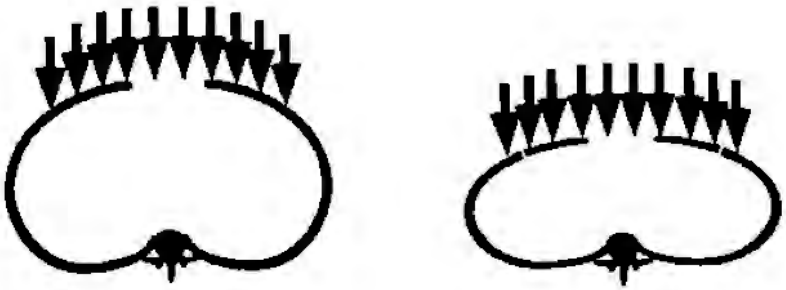
unbelted occupant, airbag deployed



Injury Mechanism



Full Frontal Impact

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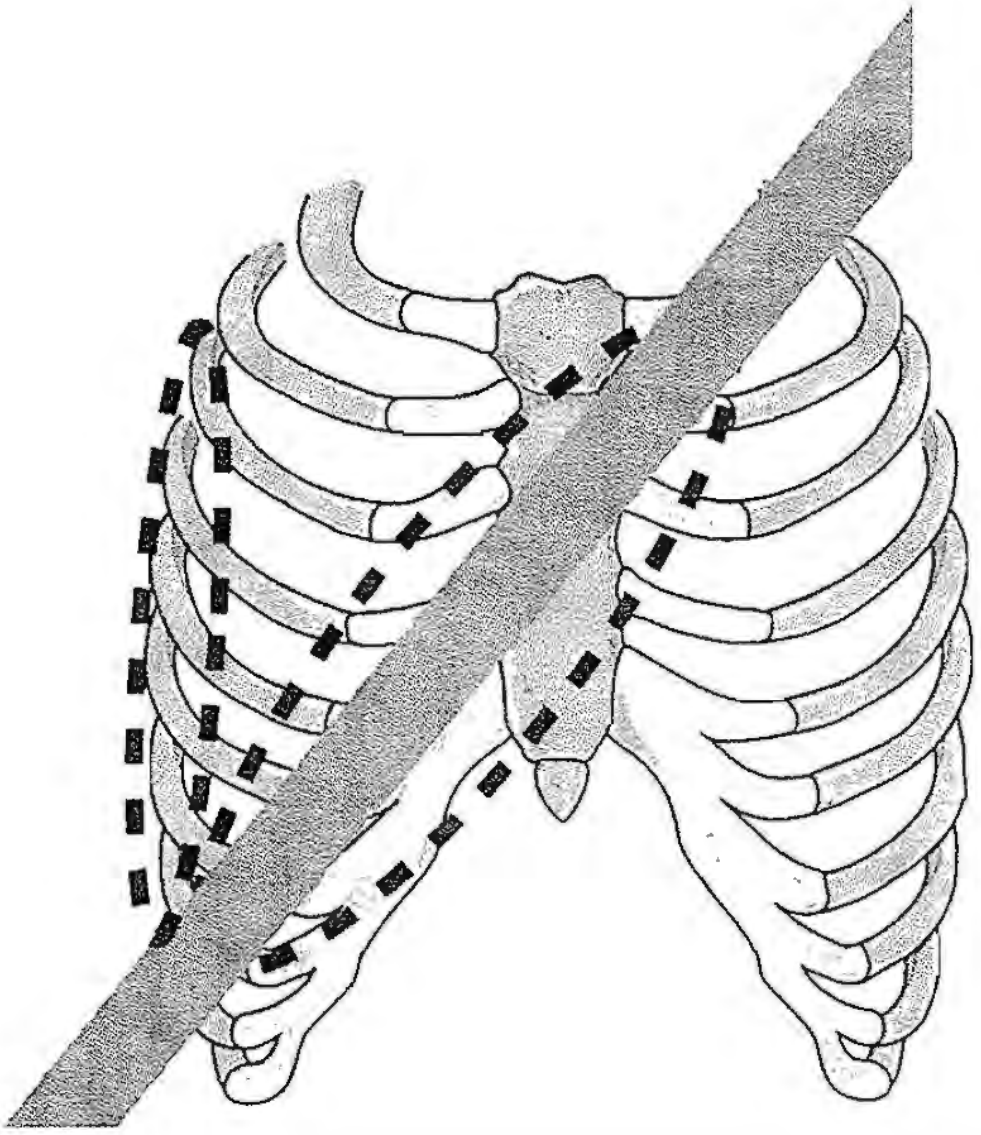
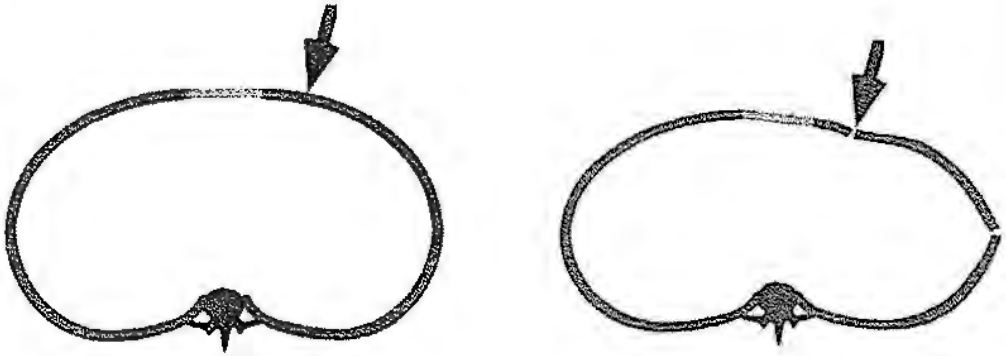
3-pt belted occupant, airbag deployed



Injury Mechanism



Yoganandan et al. 1991, 1994, 1996

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

Yes!

But CIREN & similar projects are the verification

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The National Highway Traffic Safety Administration

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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

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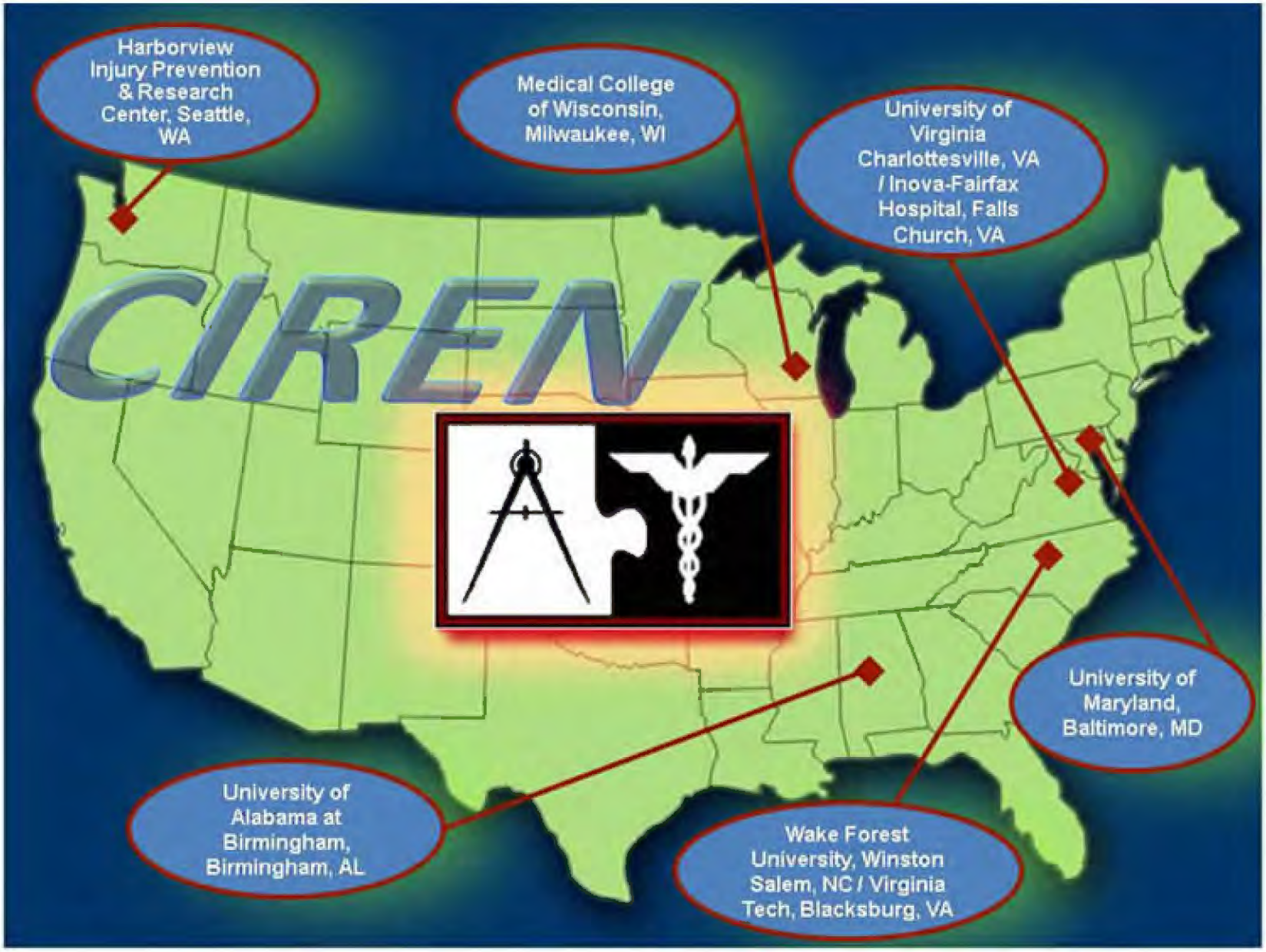
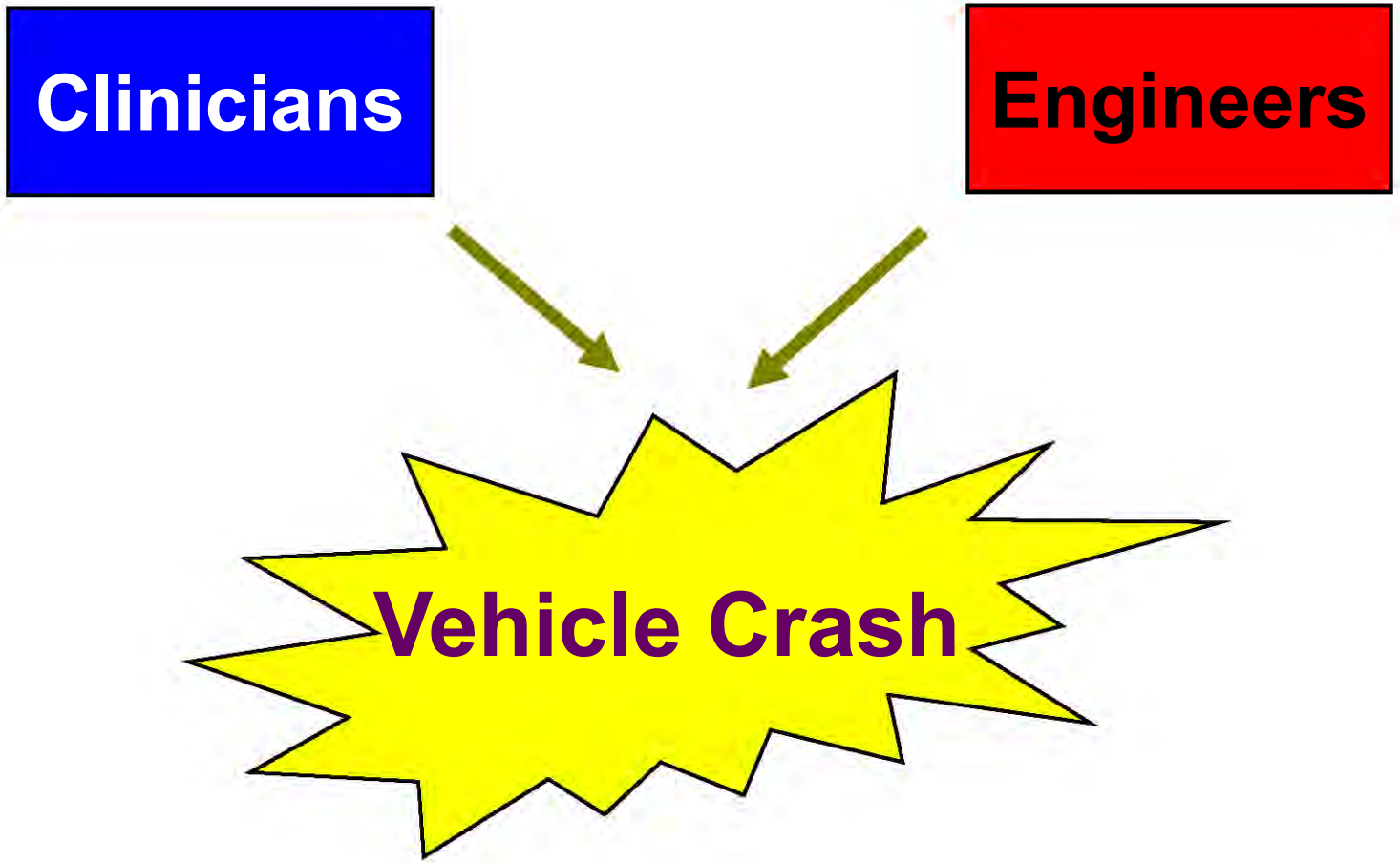


Aim of the CIREN Program



Understand how injuries occur to real people

CIREN Program

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- 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

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- **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

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- 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

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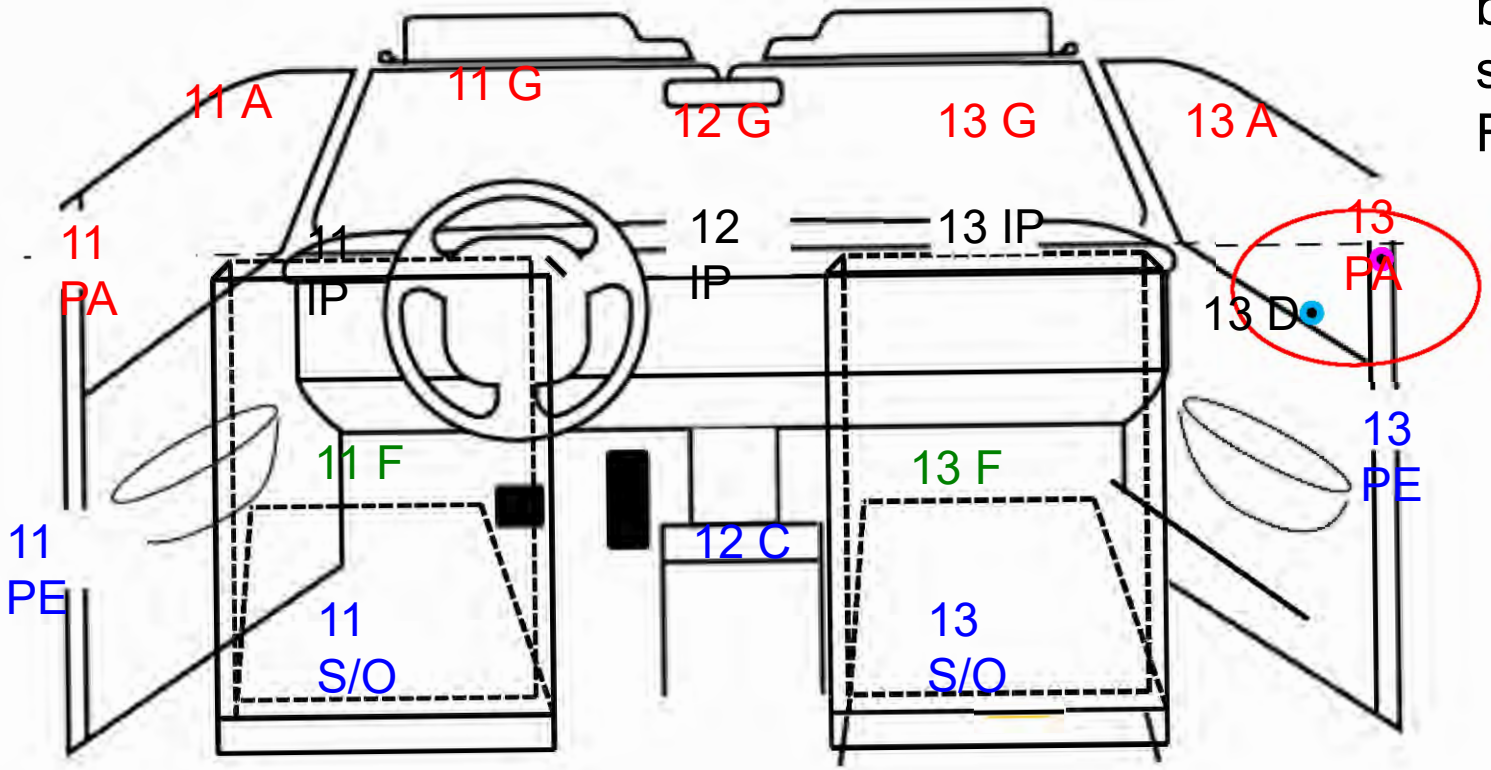
Occupant Contact Zones – Far-side Kinematics

07-491 DRIVER

Belt



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

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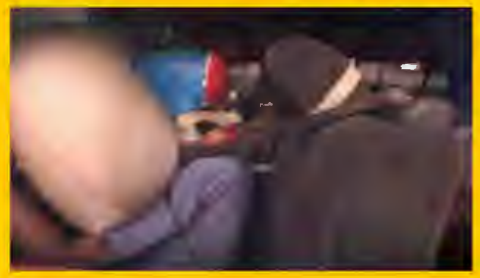
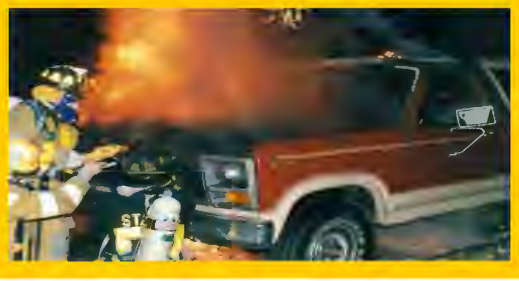
	Human	Vehicle	Environment
Pre-Crash			 
Crash			
Post-Crash			

Occupant Protection System

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- **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

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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

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Occupant Protection System

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- **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

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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

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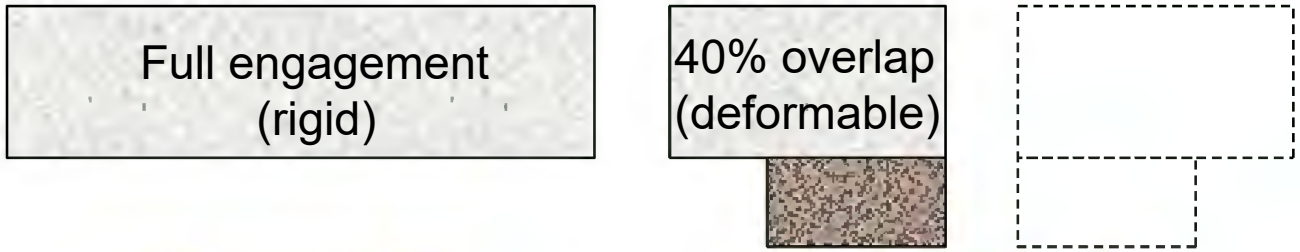
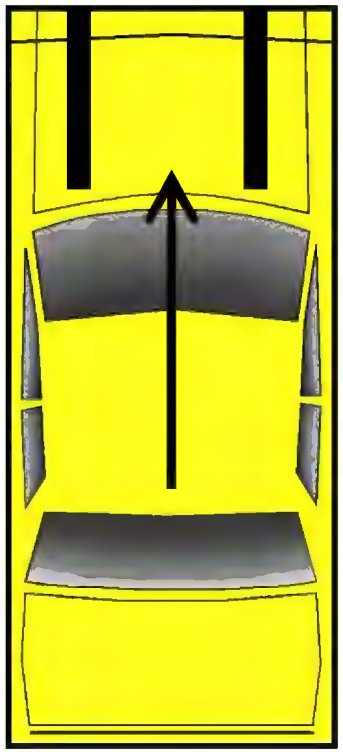
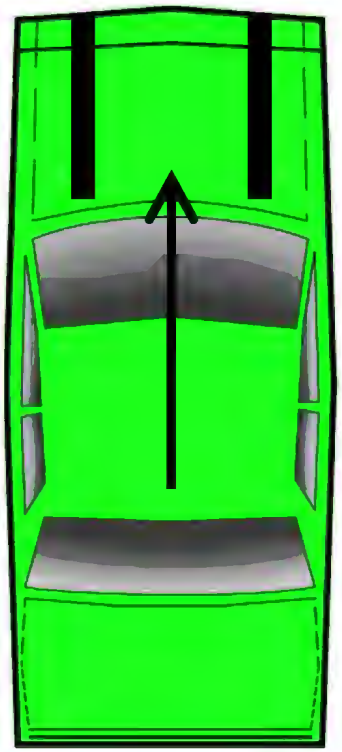


Longitudinal members





NHTSA
www.nhtsa.gov

safercar.gov
U.S. Department of Transportation

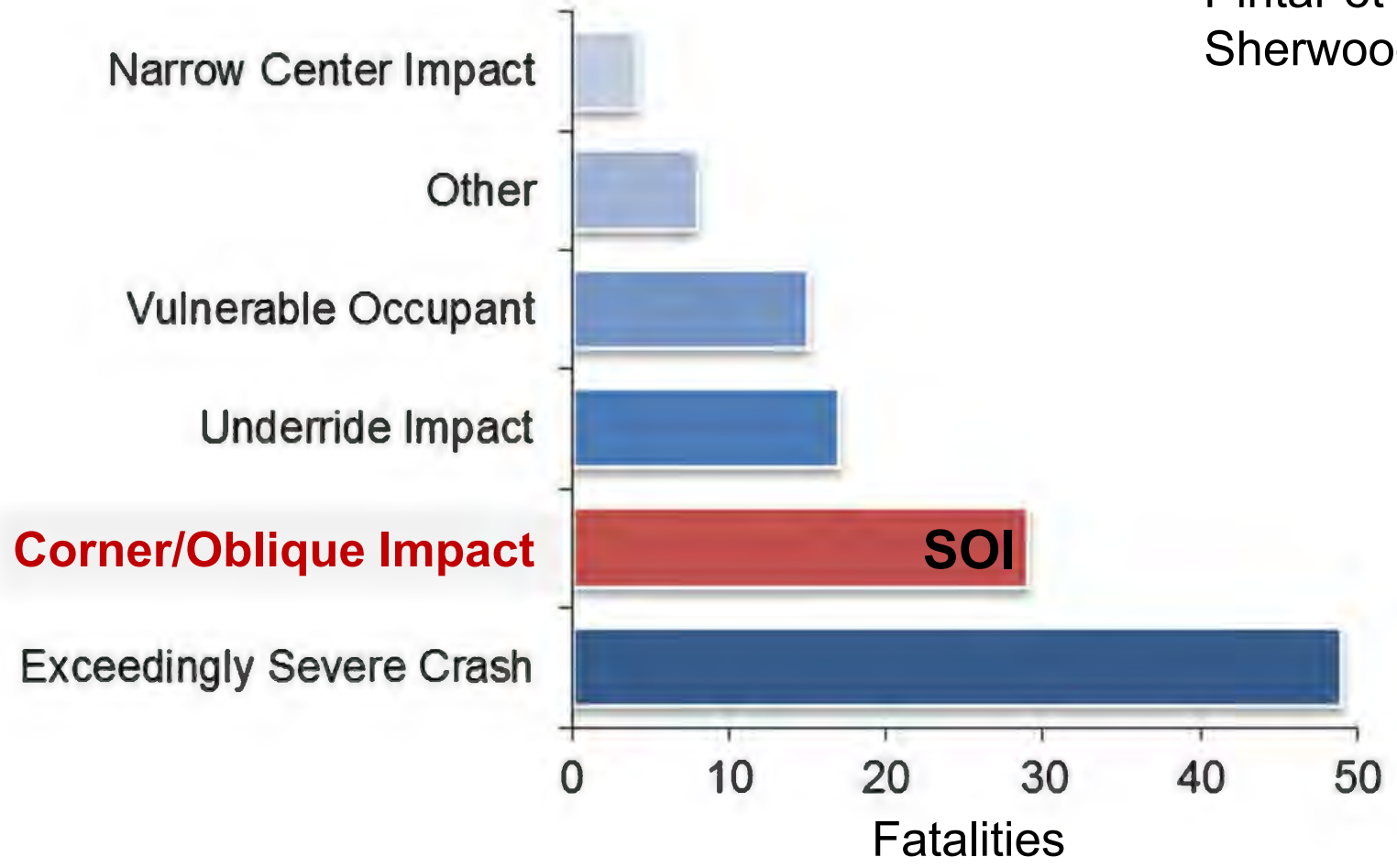
FOR SAFER CARS
EURO NCAP
www.euroncap.com

ANCAP
Crash testing for safety

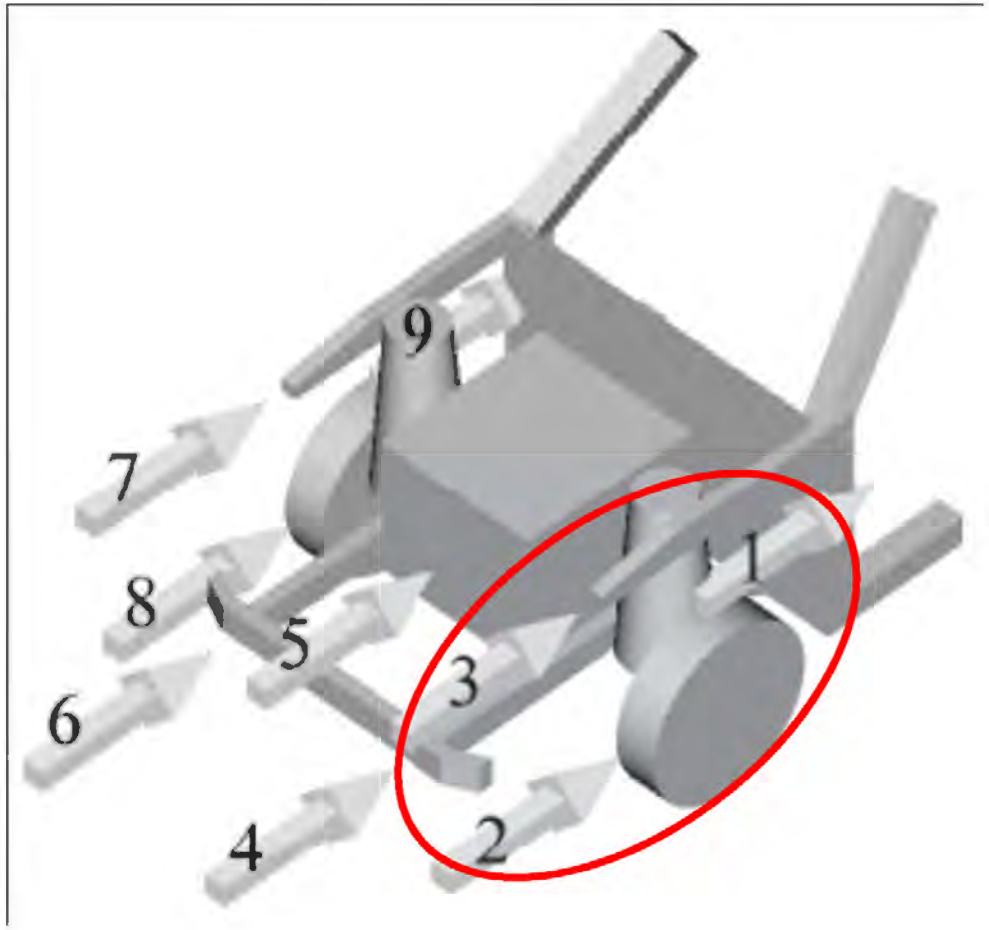
INSURANCE INSTITUTE
FOR HIGHWAY SAFETY

- 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



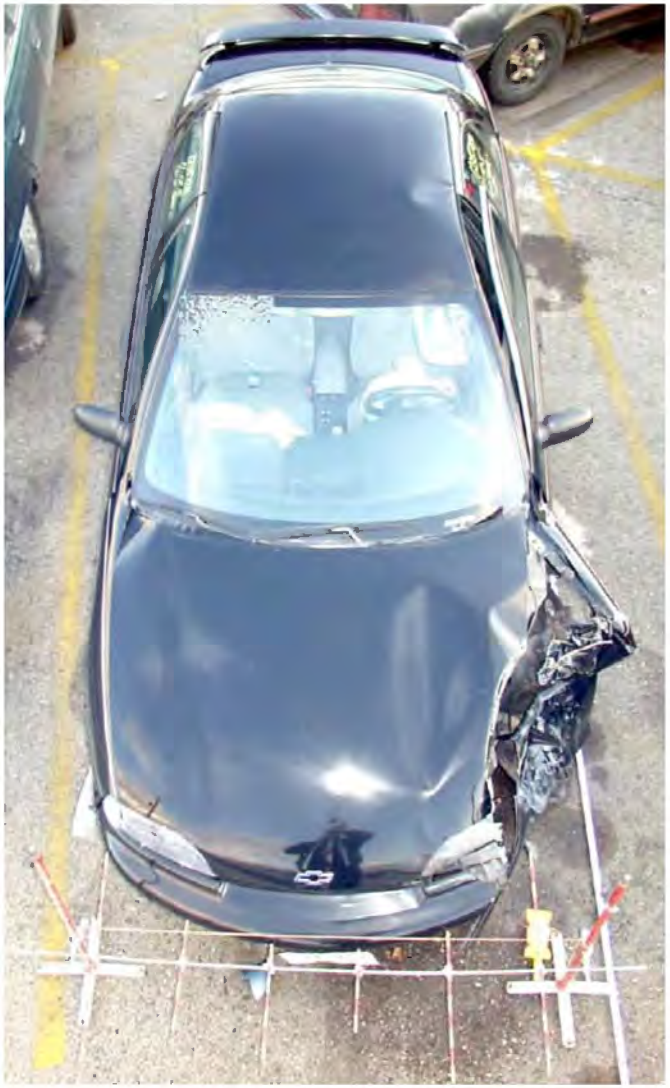
Small Overlap: One Longitudinal Member



Most common load paths in SOI

Lindquist 2004

Fatal Low DV Crash: Crush/Energy Management vs. Deformation Extent



Crush

Extent

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What do we know from Crash Tests?

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SOI Crash – Midsize Car

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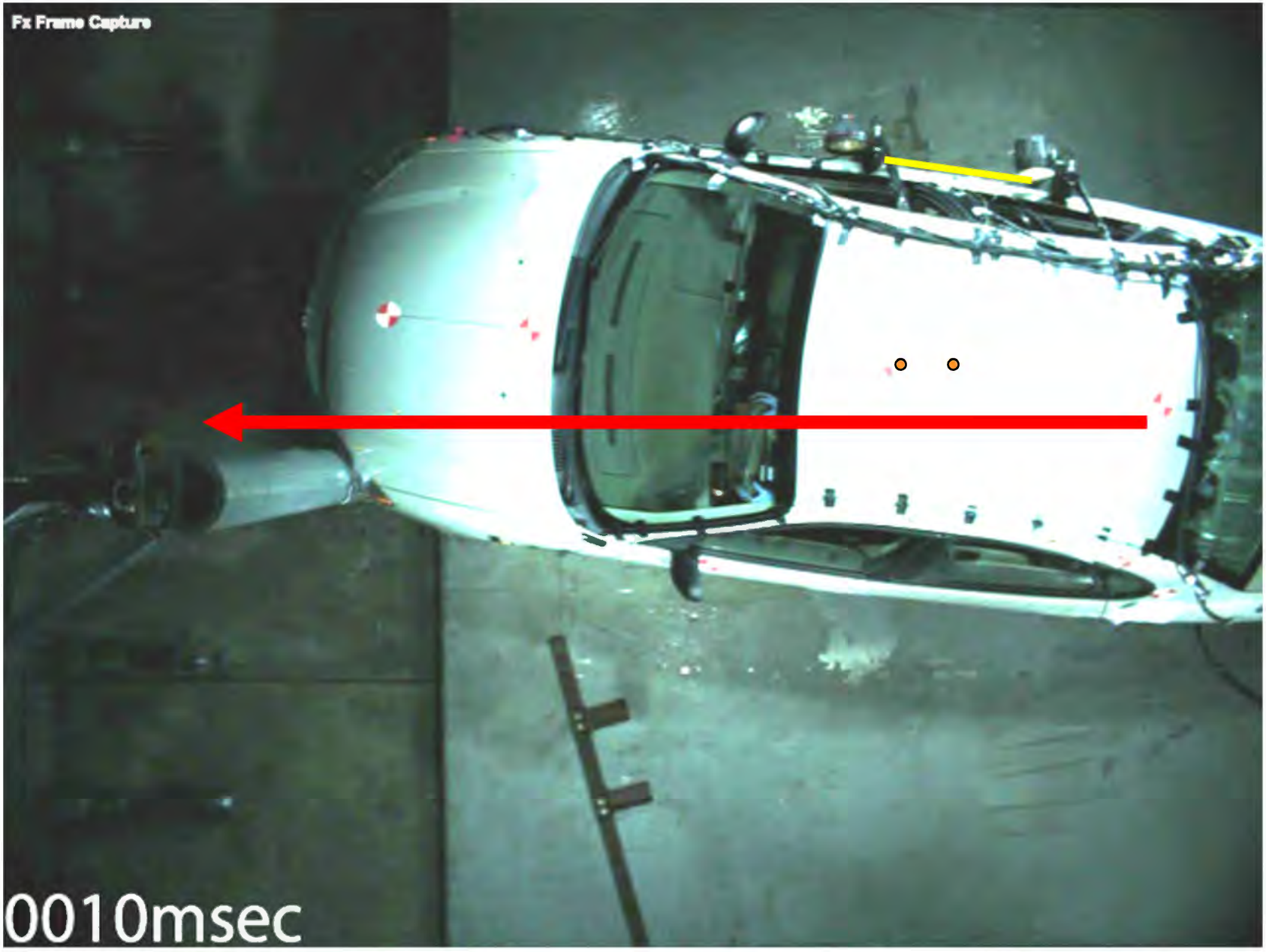
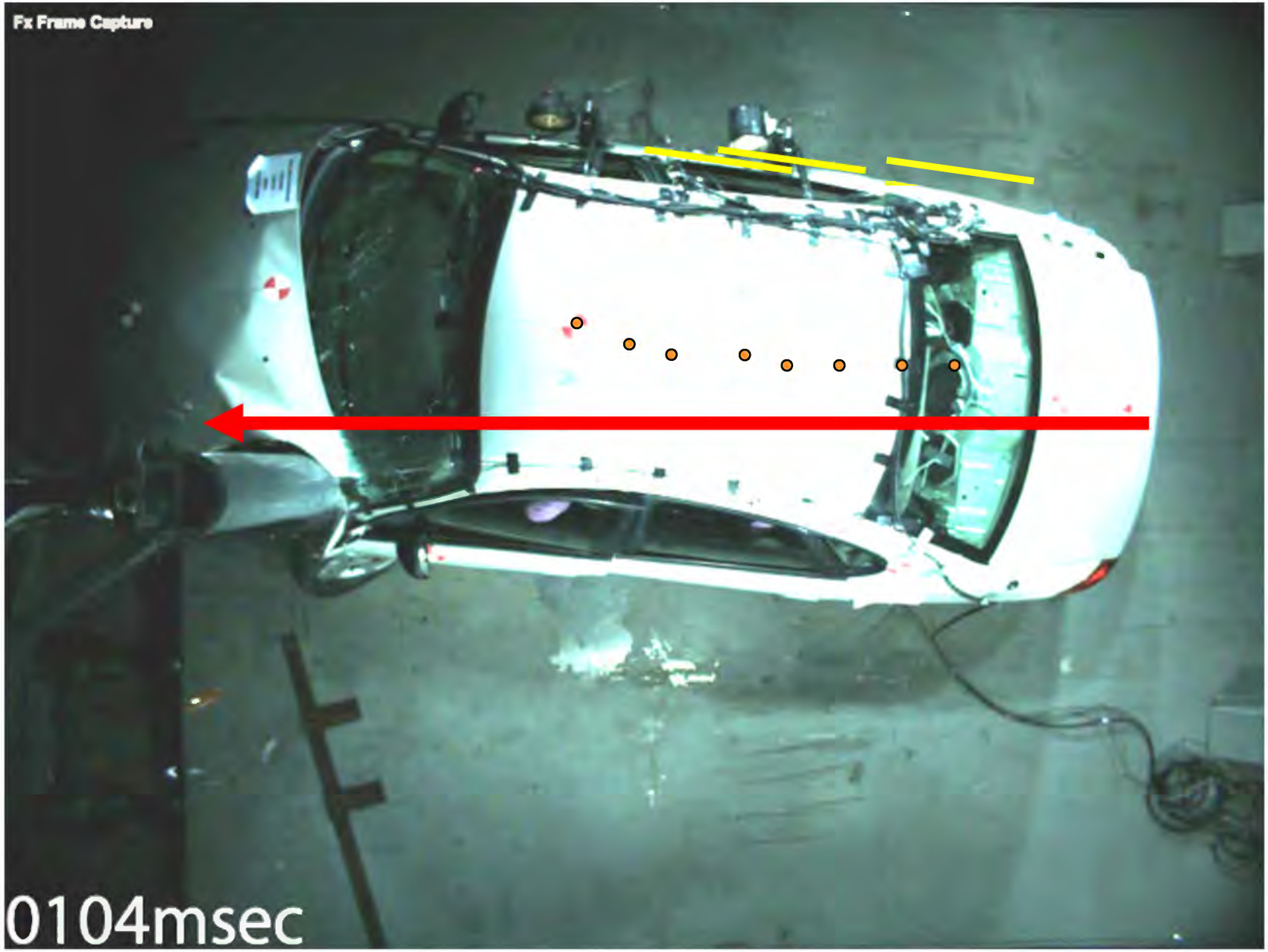


SOI Crash – Midsize Car



SOI Crash – Midsize Car

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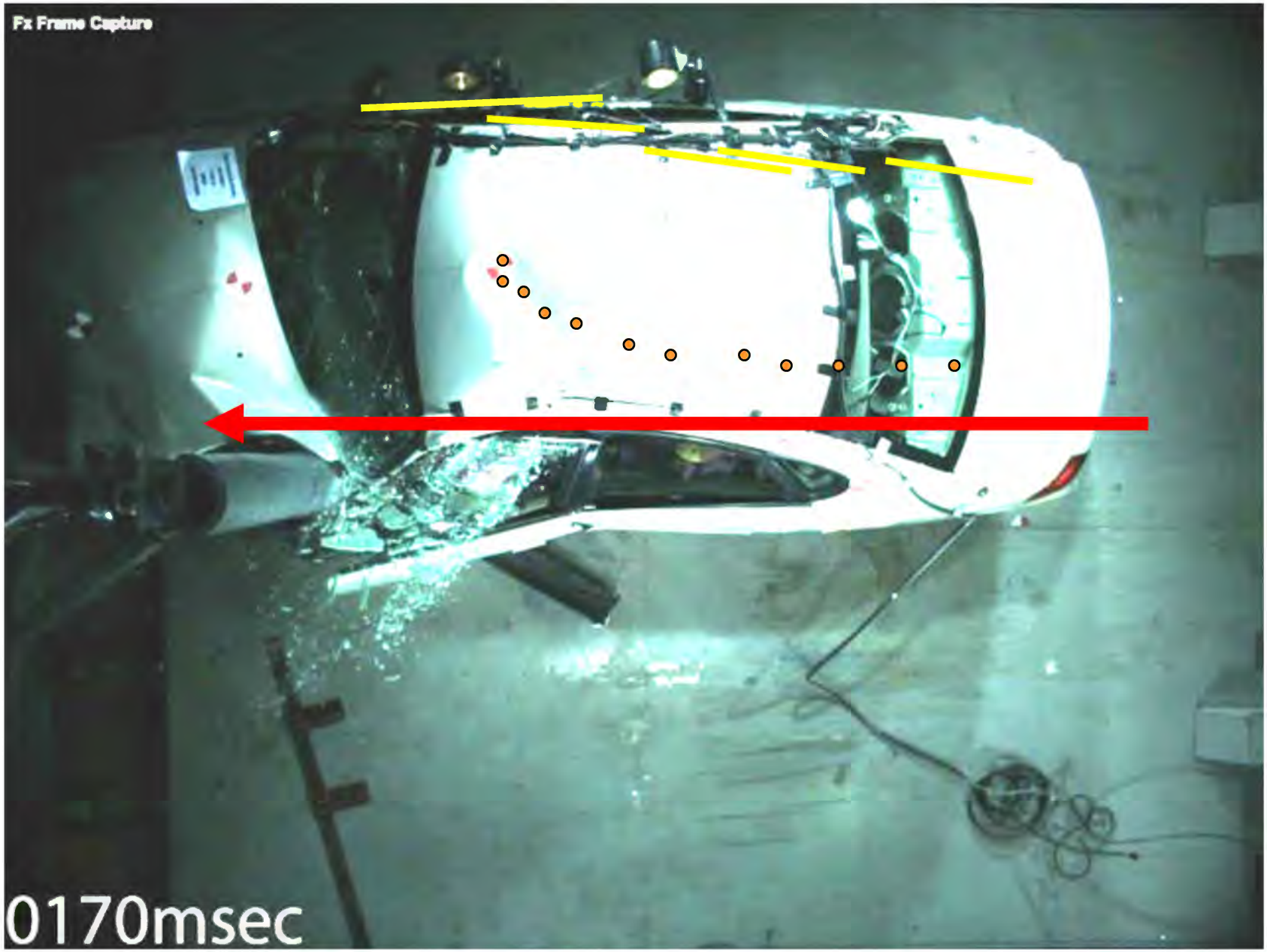

Occupant Kinematics – SOI Crash

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Occupant Kinematics – SOI Crash

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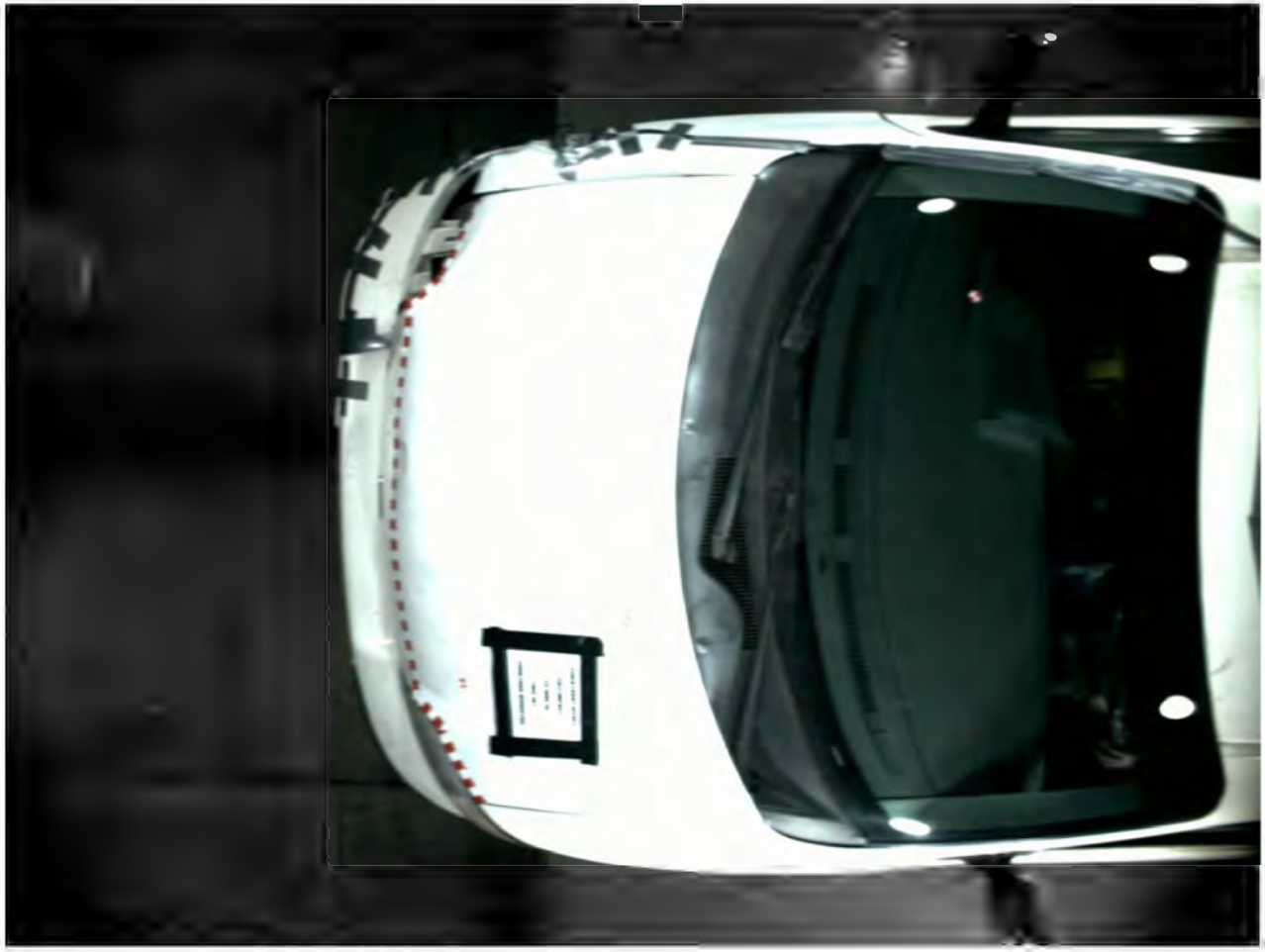

Occupant Kinematics – SOI Crash

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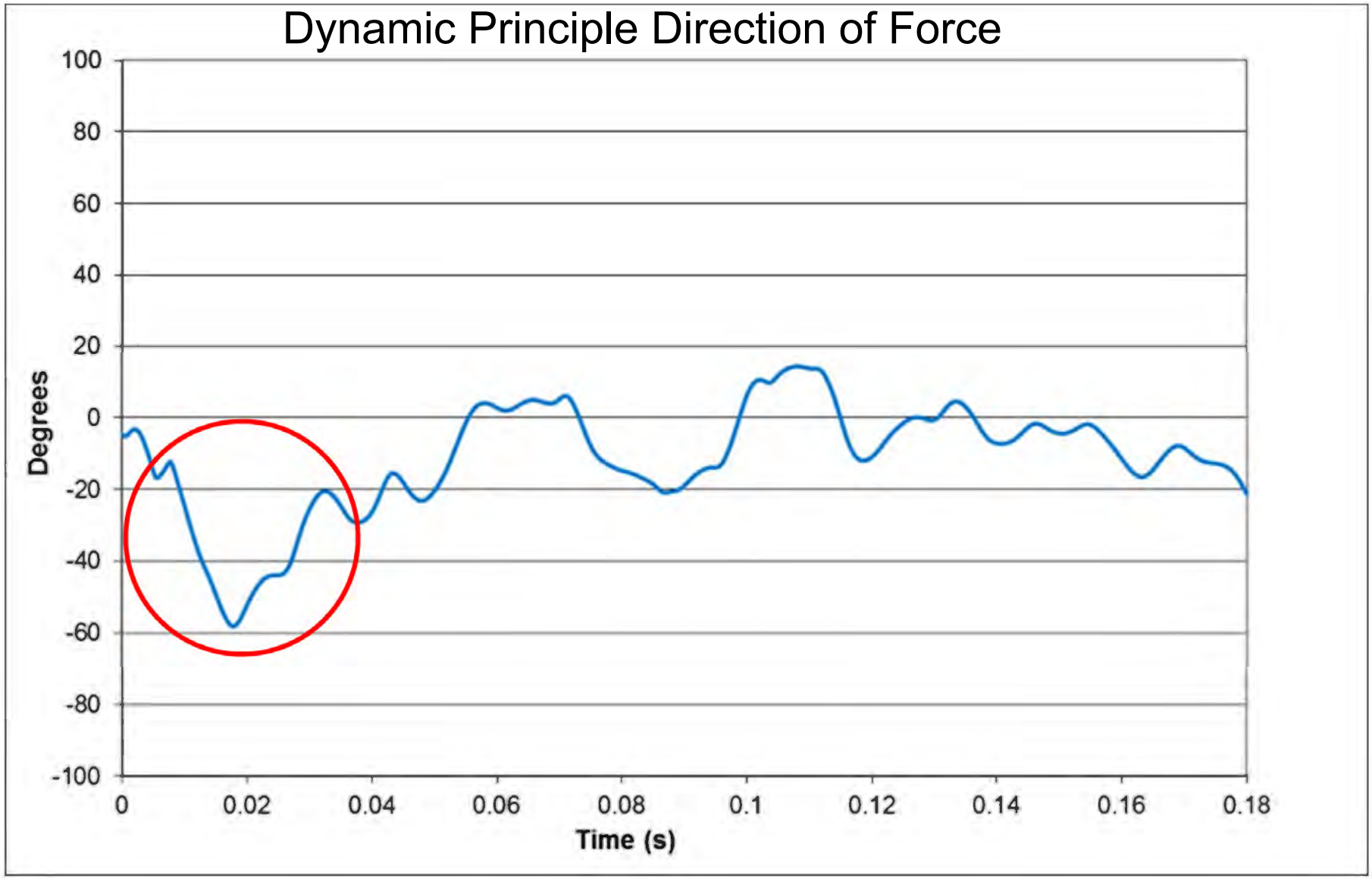
PDOF from Small Overlap Crash



Small Overlap: Structural Changes

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Non Ace body

Ace body

Increasing Use of Electronic Technology

Intersection & Forward Collision Avoidance

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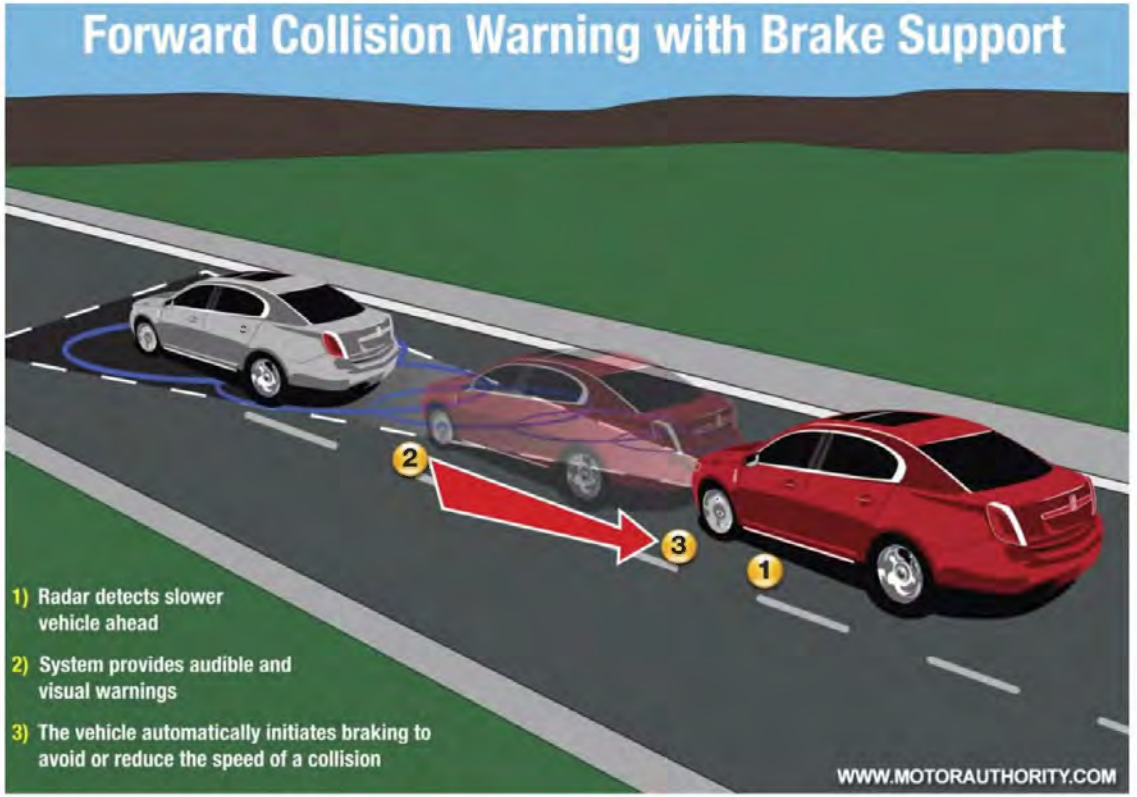
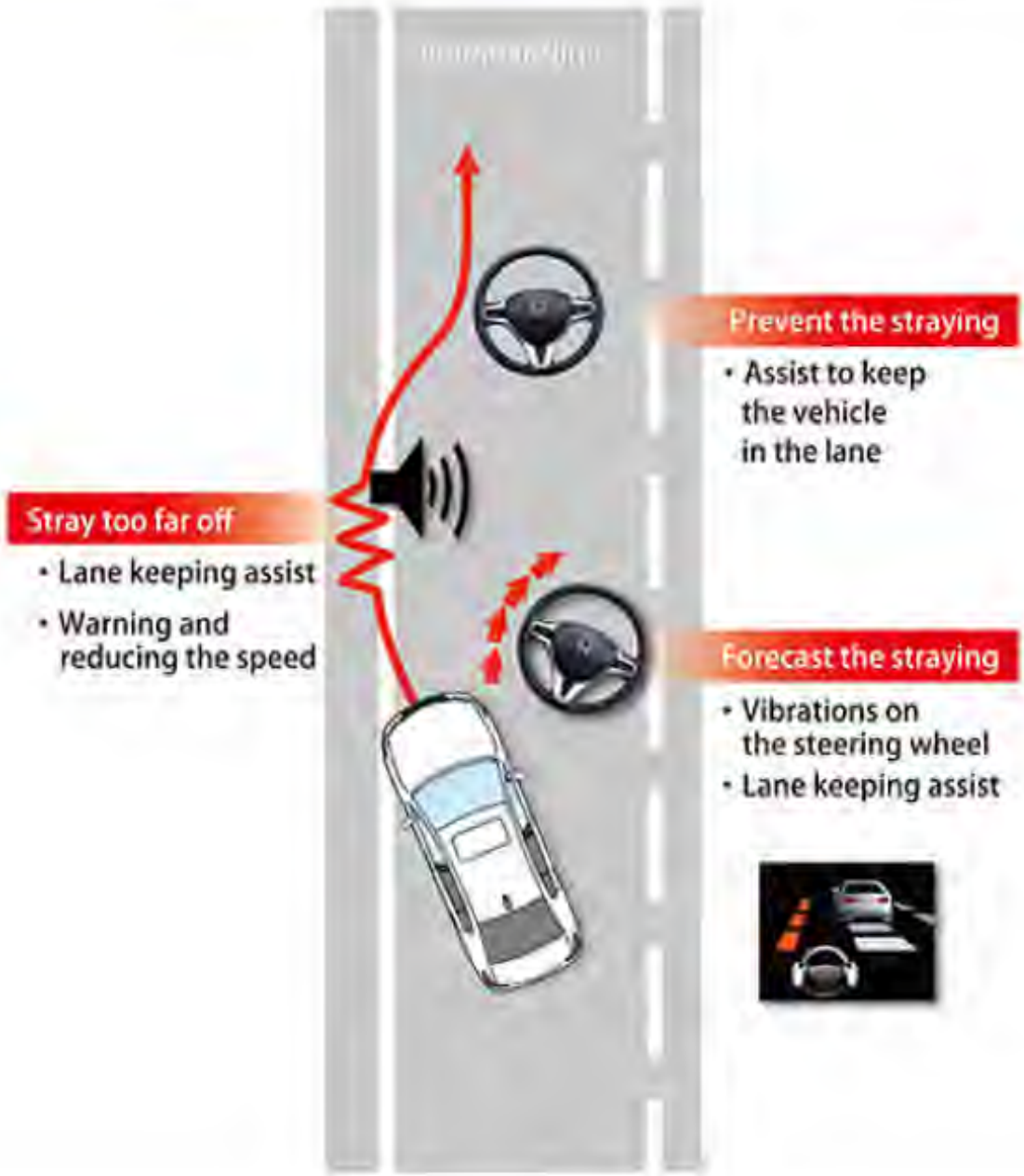
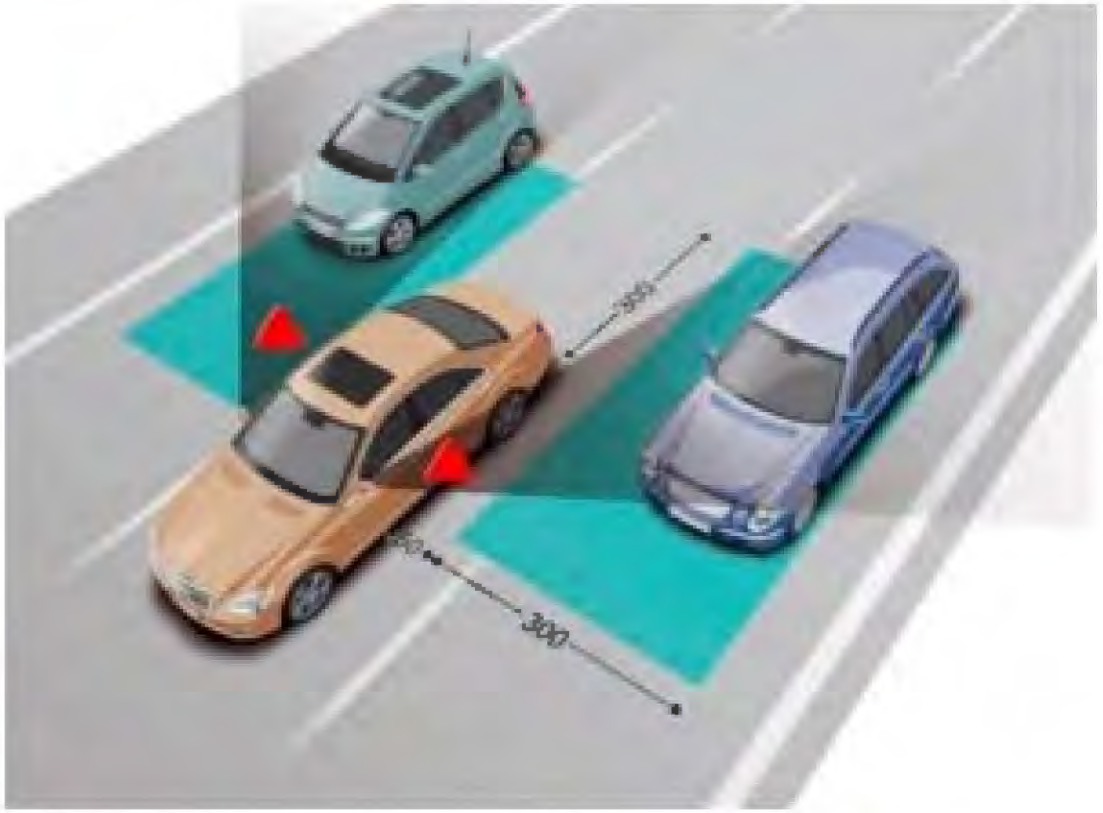
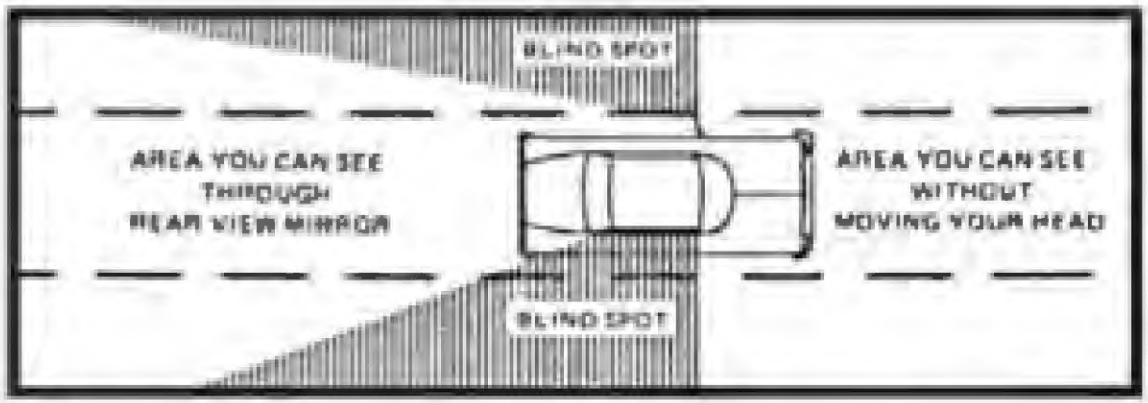


Roadway Departure Avoidance



Lane Change/Merge Collision Avoidance





The Future of EDR's Shift to FlexRay

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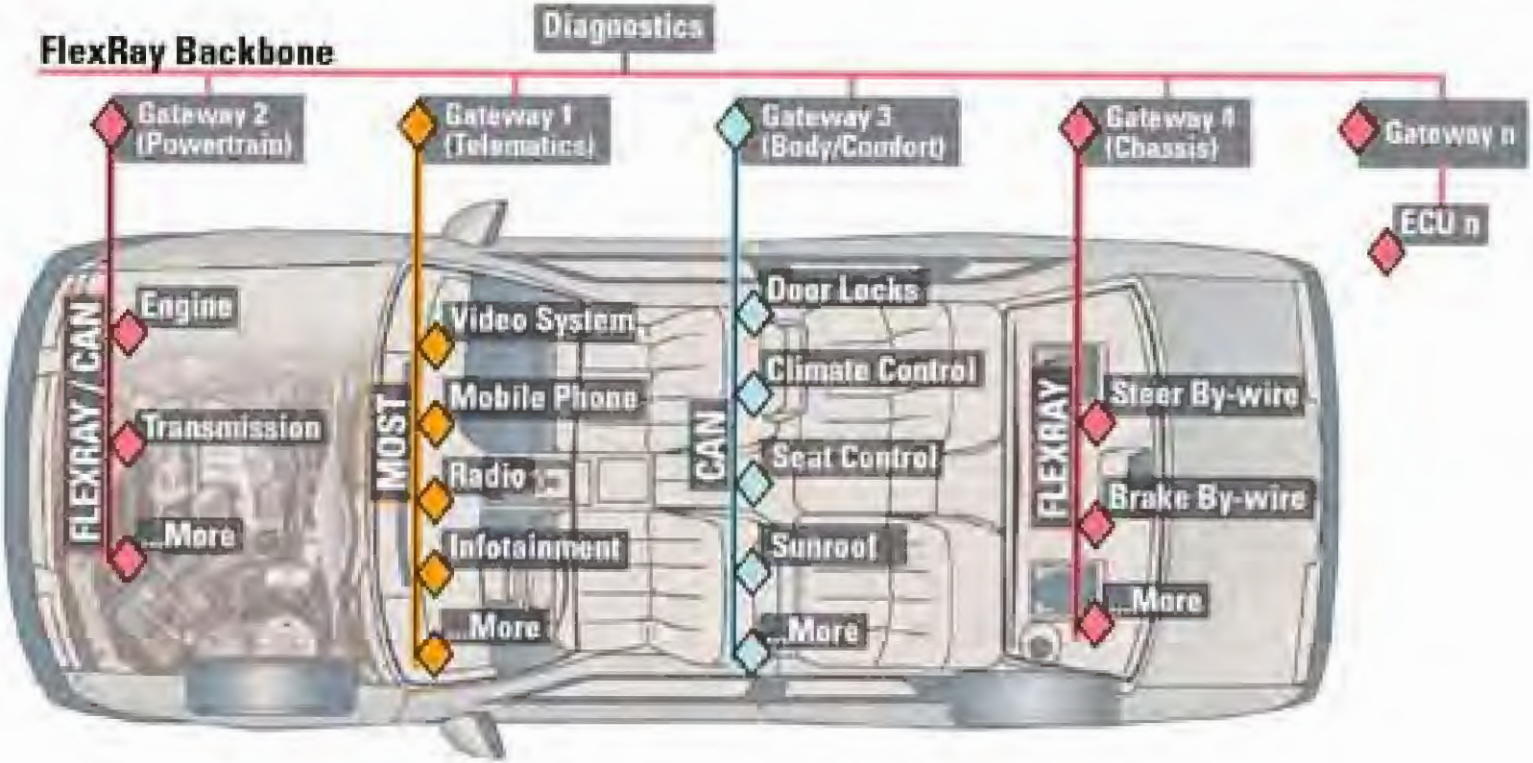
Example of a Backbone Architecture with FlexRay



Future EDR Images Questions

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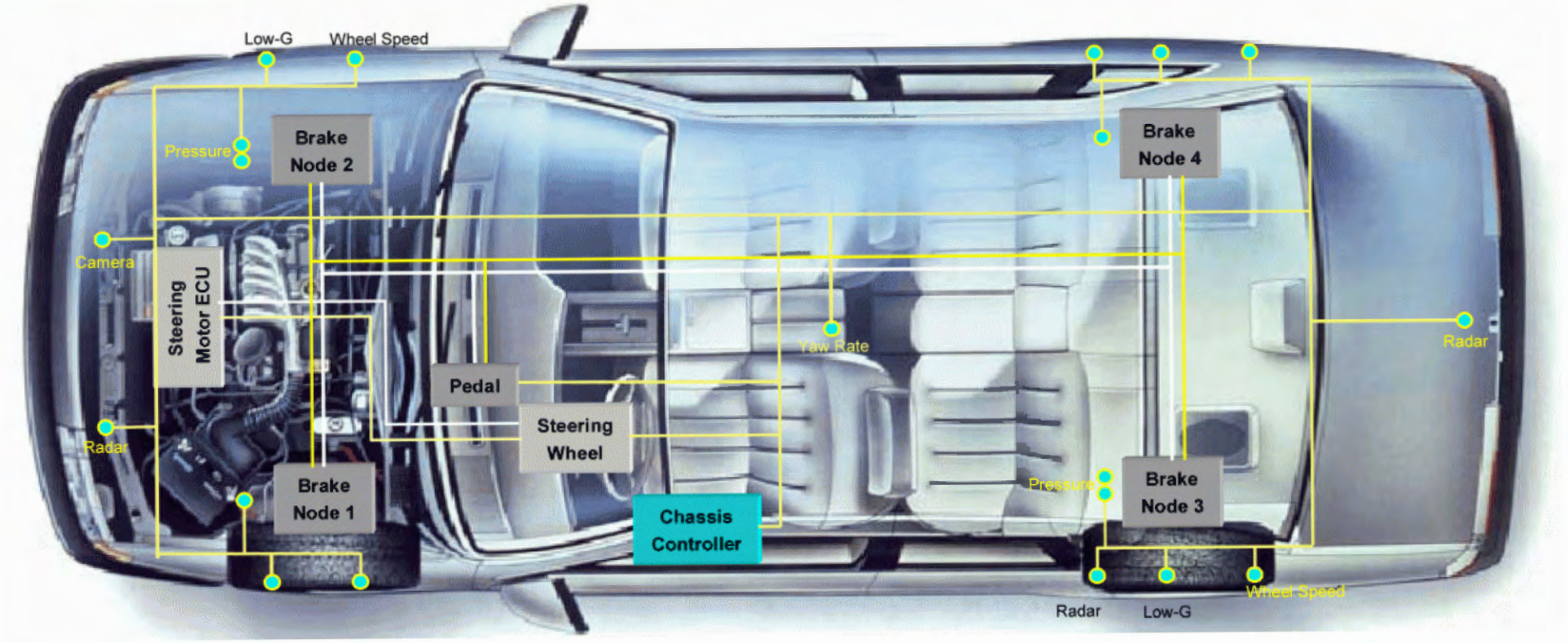

Will crash avoidance activation and/or radar data be reported?

Will video images be stored?

Crash Avoidance Devices: Built-in & Aftermarket

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Crash Avoidance Devices: Built-in & Aftermarket

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Future Technology…The Driver

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Visual and Ocular Measures of Driver Impairment

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- 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
  - ???

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

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Uber

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 NEWS SPORTS LIFE MONEY TECH TRAVEL OPINION 62° SUBSCRIBE MORE

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

Nathan Bomey, USA TODAY Published 10:25 a.m. ET June 20, 2017 | Updated 7:24 p.m. ET June 20, 2017

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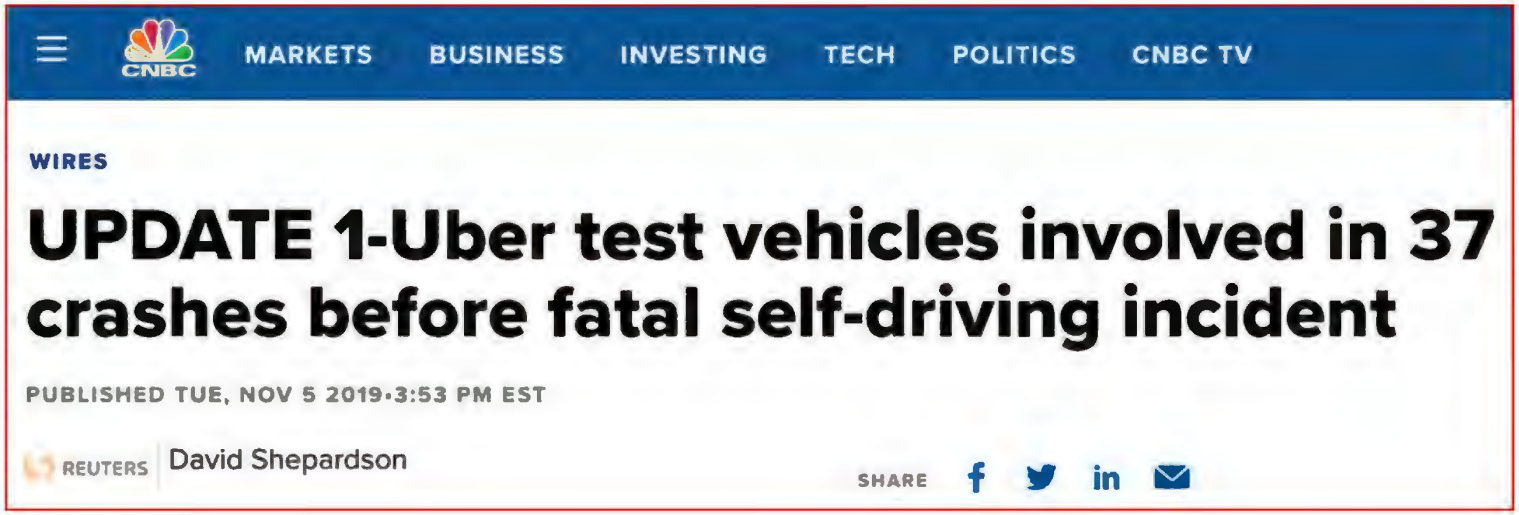

CNBC MARKETS BUSINESS INVESTING TECH POLITICS CNBC TV

WIRES

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

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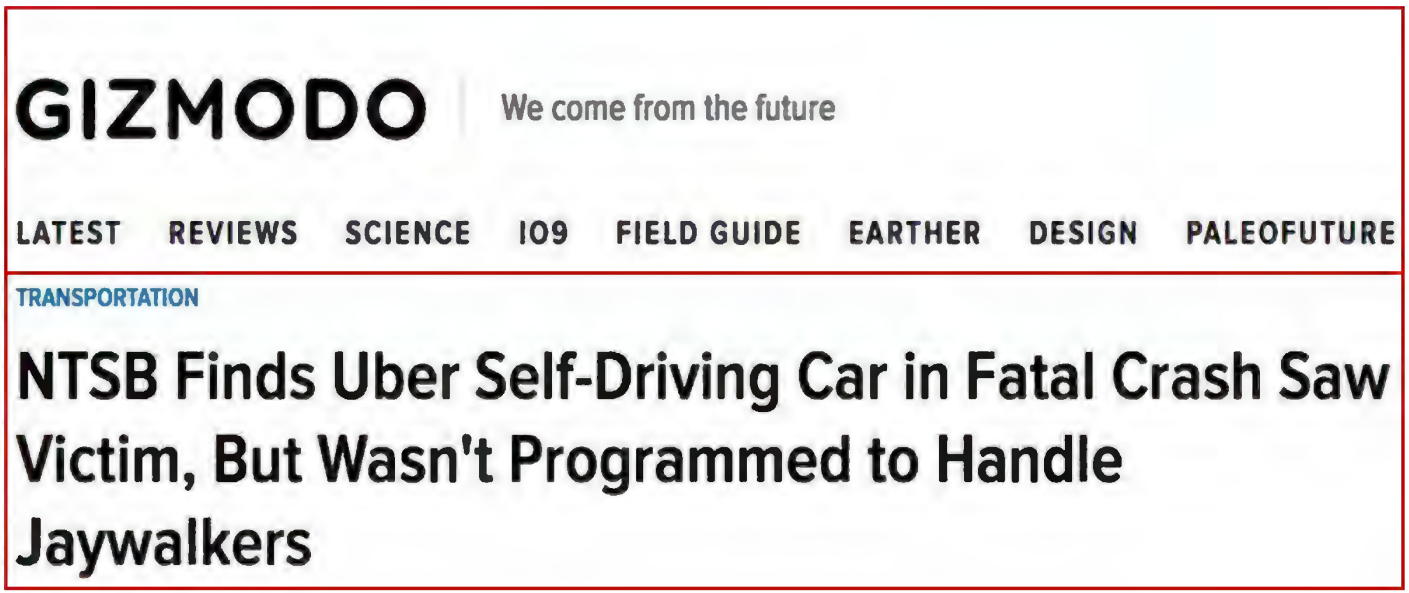

GIZMODO We come from the future

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TRANSPORTATION

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

Summary

MEDICAL COLLEGE OF WISCONSIN

- 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

How far have we come?

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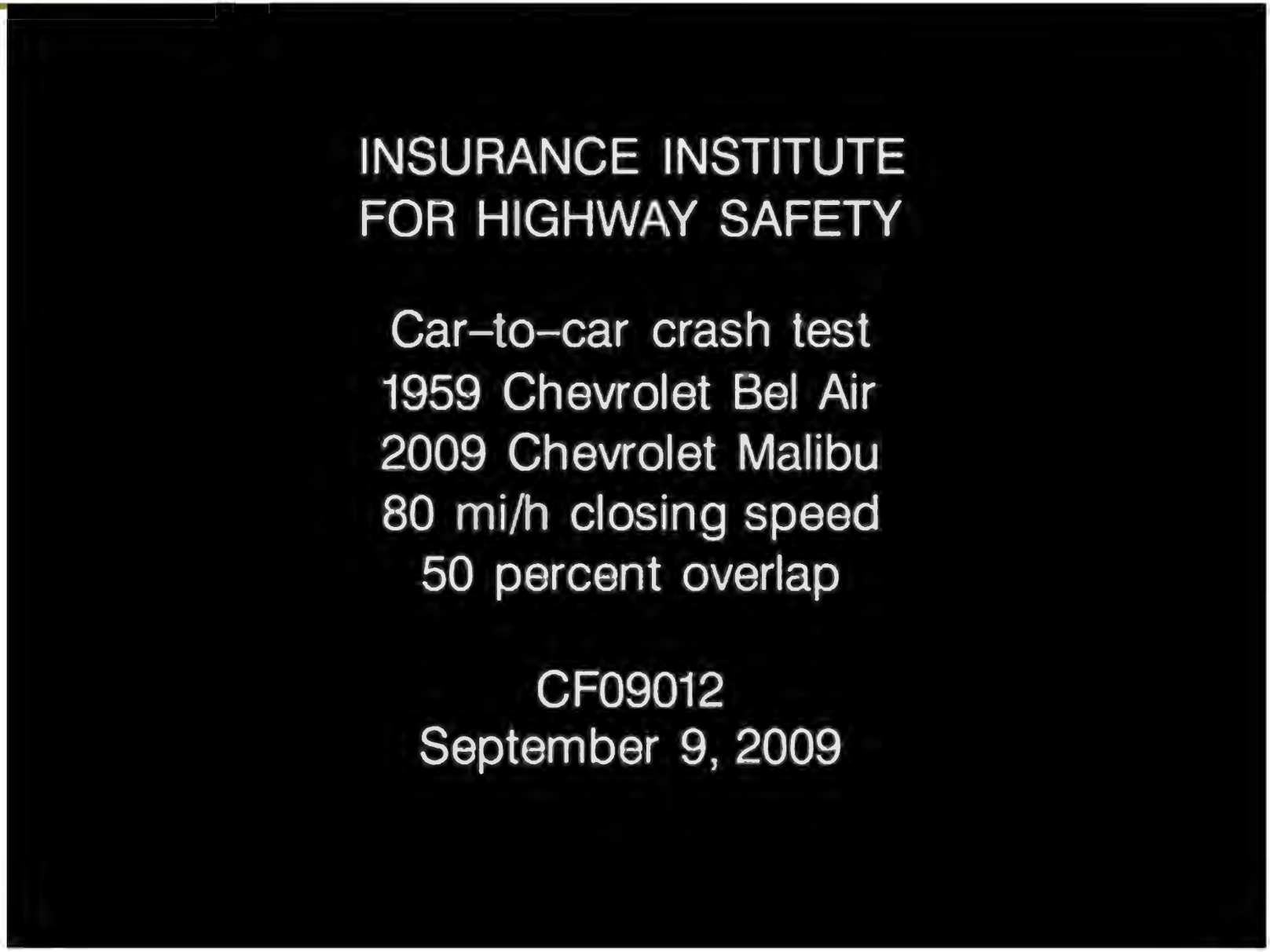

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Acknowledgment

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