OVERVIEW OF PEDIATRIC INJURY BIOMECHANICS: A FOCUS ON SIDE AND ROLLOVER CRASHES

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CENTER FOR INJURY RESEARCH AND PREVENTION

THE CHILDREN'S HOSPITAL OF PHILADELPHIA RESEARCH INSTITUTE

Dedicated to advancing the safety of children, youth and young adults through research and action.

Injury Research Priorities:

- Child Road Traffic Safety
- Young Driver Safety
- Pediatric Biomechanics
- Post-injury Care & Recovery
- Strengthening Communities to Prevent Injury/Promote Health
- Injury Research Methods

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Objectives

1. We've come a long way.
2. But the "Simple Story" isn't enough
3. Precision Prevention & a Future Agenda for Road Traffic Safety

PROBLEM FACING OUR YOUTH WORLDWIDE LEADING CAUSES OF DEATH BY AGE GROUP

< 1year	1-4 years	5-14 years	15-29 years
Preterm birth complications	Malaria	Road Injury	Road Injury
Lower respiratory infections	Lower respiratory infections	HIV/AIDS	Interpersonal violence
Neonatal encephalopathy	Diarrheal diseases	Diarrheal diseases	Self-harm
Neonatal sepsis	Malnutrition	Lower respiratory infections	HIV/AIDS
Diarrheal diseases	HIV/AIDS	Malaria	Tuberculosis
Congenital anomalies	Drowning	Drowning	Drowning
Malaria	Meningitis	Typhoid fevers	Malaria
Meningitis	Road Injury	Meningitis	Lower respiratory infections
Malnutrition	Measles	Congenital anomalies	Mechanical forces
Syphilis	Fire	Forces of nature	Diarrheal diseases

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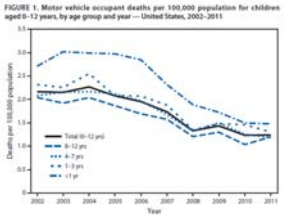
World Bank, Transport for Health: The Global Burden of Disease from Motorized Transport, 2014

US MOTOR VEHICLE DEATHS AMONG CHILDREN AGE 12 AND UNDER DECREASED BY 43% IN THE PAST DECADE



CDC Feb 2014

Increased restraint use

Highway safety laws

Advanced restraint systems

Vehicle Crashworthiness

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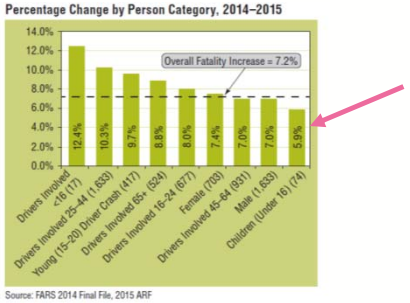
FATALITIES ARE INCREASING



Source: FARS 2014 Final File, 2015 ARF

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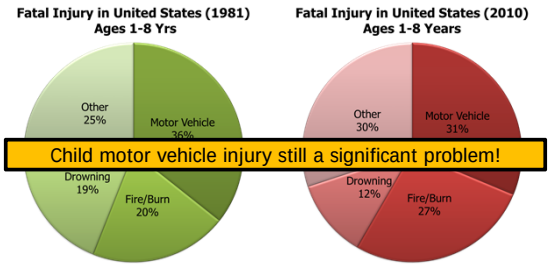
Pediatric Motor Vehicle Deaths
The Past 30 Years



Child motor vehicle injury still a significant problem!

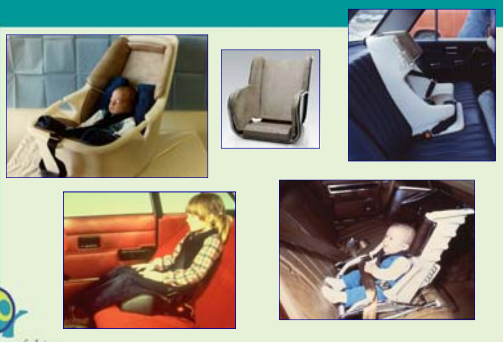
Total fatal injuries has decreased, but distribution remains

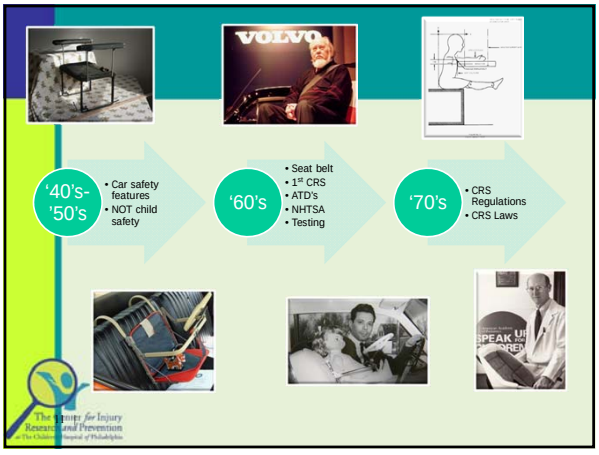
Pioneer of Automotive Safety
Col. John Paul Stapp, MD, PhD

- Human deceleration experiments using rocket sled ("Gee Whiz")
- 632 mph to 0 in 1.4 seconds
  - Experienced 46.2 *g*'s

First Crash Test

First Child Restraints





Occupant Injury Mechanisms
-Stages in a Car Crash

Typical crash consists of 3 sub-crashes:

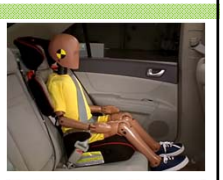
- 1st Collision – "Crash Dynamics"
  - Vehicle impacts object (car, tree, etc.)
- 2nd Collision – "Occupant Kinematics"
  - Occupant impacts vehicle structure
- 3rd Collision – "Impact Biomechanics"
  - Internal organ movement and damage

First collision
Crash dynamics


2nd Collision – Occupant Kinematics

- Occupant interacts with vehicle
- Severity determined by:
  - 1st Collision (crumple zone)
  - Initial position
    - Seat location
    - Pre-impact movement
  - Vehicle Interior

Newton's Law: Object will remain in motion until stopped



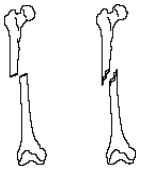
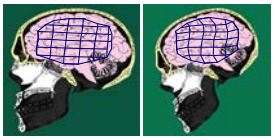

Newton's Law in Action

Unrestrained Children

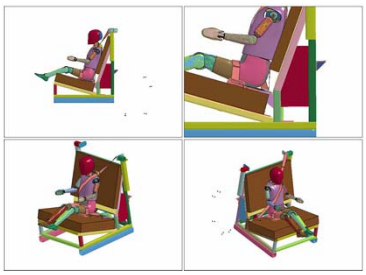
Restrained Occupant

3rd Collision – Injury Biomechanics

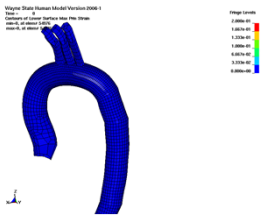
- Organ and tissue damage
  - Direct (penetration)
  - Indirect (organ motion)
- Severity determined by:
  - Magnitude
  - How force is applied
    - Compress, bend, twist, etc.
  - Surface area
  - Rate

ATD and Human Body Simulations




Computational Modeling of Organs

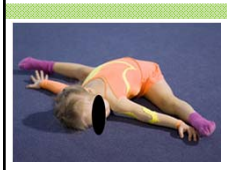



Research Question

- How different is the motion of children vs. adults in car crashes?

?

Children Demonstrate Substantial Flexibility




Photos courtesy of colleagues

What changes with age?

- Size
- Anatomy
  - Skeletal structure
- Material properties
  - Ligament laxity
  - Bone rigidity
- Physiological outcomes
  - Flexibility

Ideal Pediatric Dummy

Ideal tool should:

- **LOOK / FEEL** like human child
  - Mass, body segment lengths, tissue properties
- **MOVE** like human child
  - Overall motion should mimic children
- **PREDICT INJURY**
  - Predict injuries observed in field
  - Age-specific injuries
  - Diverse types of injuries (skeletal & soft tissue)

Potential Automotive Research Methods for Children

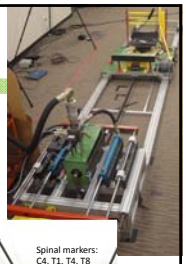
- ~~Crash Tests with PMHS (cadavers)~~
  - ~~Thankfully, no specimens~~
- ~~Animal Studies~~
  - ~~Age equivalency~~
    ~~(6 month old pig = ? year old child)~~
- Human volunteer tests

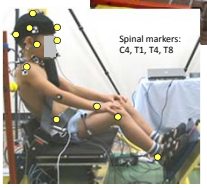
Really???

Safe Child Crash Tests???

Dynamic Response

- Low speed human volunteer crash sled
- Pneumatically driven, hydraulically controlled
- "Crash" similar to that of an amusement park bumper car
- Study motion/ kinematics of children 6-14 – compared to adults



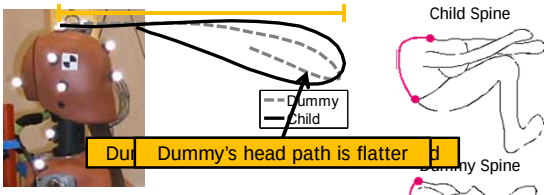


Arbogast et al, Stapp 2009

Arbogast et al, Stapp 2009

Head Top Motion Comparison

Comparison to Crash Test Dummy



Other observations:

- Dummy has more head rotation
- Dummy has little thoracic spine flexibility

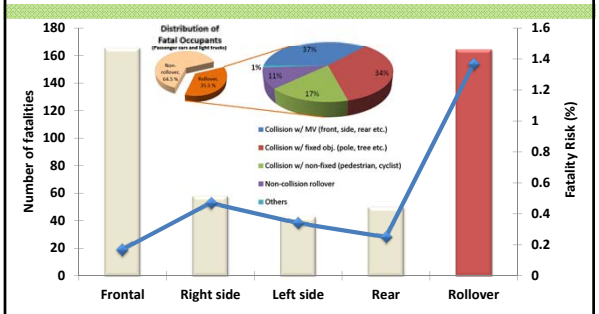
Sherwood et al. 2003

Disclaimer – Dummies are NOT Bad

- Predict forward head motion well
  - Head is primary concern for children
  - Different mechanism, but same result

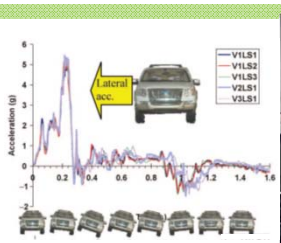
- All devices can be improved
  - Accurately predict other injuries
  - Use for other impact directions and severities

Background



- Viano and Parenteau, 2008; FARS (1996-2005) 0-7 year old
  - **Rollovers - highest fatality risk at 1.37%**; followed by right side (0.47%), left-side impacts (0.34%)

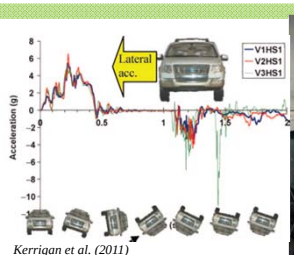
Dummy Kinematics – Without Roll



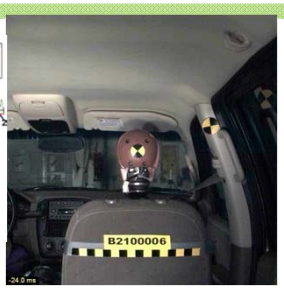
Kerrigan et al. (2011)

No roll

Dummy Kinematics – With Roll



Kerrigan et al. (2011)

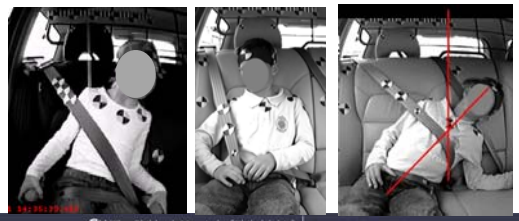


With roll

Occupant Pre-Positions

- Children are more vulnerable during night
  - (upto 80%; Forman et al. 2011)

Andersson et al; Jakobsson et al.



Motivation for Rollover Project

- *Limited* pediatric data (0-19 years) on rollover crashes
- Risk of fatality and injury for children in rollovers is *nearly twice* that of non-rollover crashes
- Existing data relevance to contemporary vehicles questionable in light of changes to rollover mitigation

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Specific Aims

1. To calculate AIS 2+ and AIS 3+ ***risk of injury*** for children and adolescents in rollover crashes using the *NASS-CDS dataset*
2. To create a ***contact map of the vehicle interior*** from CIREN cases, documenting occupant body region in the interior structure
3. To use ***finite element*** (FE) modeling technique to evaluate kinematics of the occupant

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Aim 1 : NASS/CDS Variables and Inclusion Criteria

Vehicle		Occupant/Restraint	
1) Vehicle Type	Minivan/van, Passenger Car, Pickup/Light Truck, SUV	6) Age Group (yr)	0-2, 3-5, 6-8, 9-15, 16-19
2) Event Number	1 (Single Vehicle Single Event) and >1	7) Restraint Type	RFCRS, FFCRS, Booster, Lap Belt only, Lap-Shoulder Belt
3) Rollover Type	Longitudinal, End over End	8) Seating Position	Front (L, R), Row 2 (L, C, R), Row 3 (L, C, R)
4) Rollover Direction	Left Sided, Right Sided, End over End	9) Occupant Role	Driver, Passenger
5) Quarter Turns	1 through 16	10) Sidedness	Farside, Nearside, Center

1998-2011 vehicle model and case years (1560 unweighted occupants)
AIS 2+ and AIS 3+ outcomes

Univariate Analysis

- By Restraint type
- Age Group
- Seating Position
- Quarter Turns

Significant Outcomes

- Univariate logistic regression models
  - association between variables of interest and MAIS 2+ and MAIS 3+ outcomes

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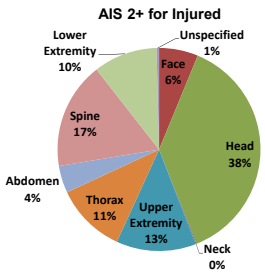
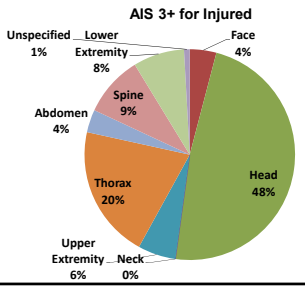
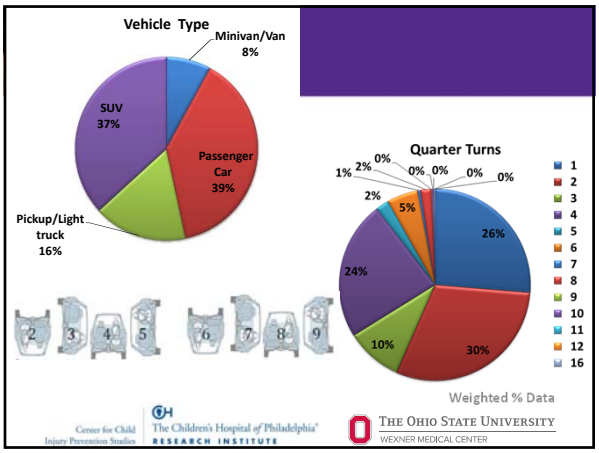
Injury Distribution by Body Region






Vehicle Type
Minivan/Van 8%
SUV 37%
Passenger Car 39%
Pickup/Light truck 16%
Quarter Turns
1% 2% 0% 0% 0% 0% 0%
2% 5%
26%
24%
10%
30%
1 2 3 4 5 6 7 8 9 10 11 12 16
2 3 4 5 6 7 8 9
Weighted % Data
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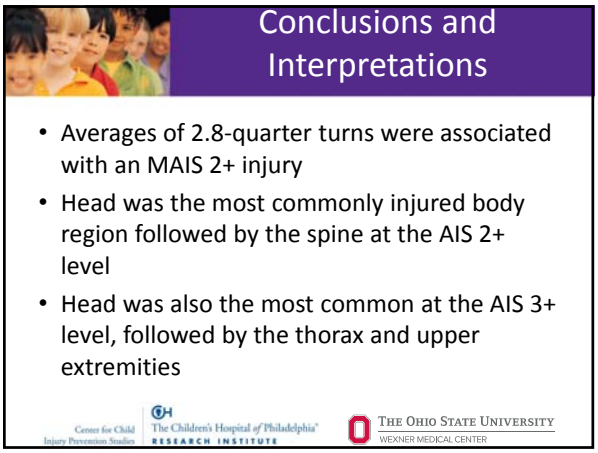
Conclusions and Interpretations
• Averages of 2.8-quarter turns were associated with an MAIS 2+ injury
• Head was the most commonly injured body region followed by the spine at the AIS 2+ level
• Head was also the most common at the AIS 3+ level, followed by the thorax and upper extremities
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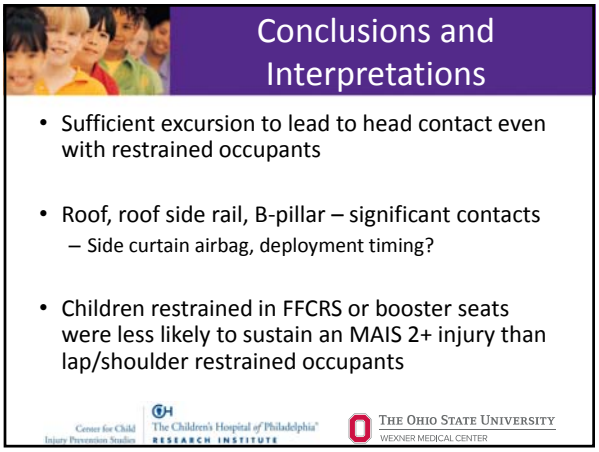
Conclusions and Interpretations
• Sufficient excursion to lead to head contact even with restrained occupants
• Roof, roof side rail, B-pillar – significant contacts
– Side curtain airbag, deployment timing?
• Children restrained in FFCRS or booster seats were less likely to sustain an MAIS 2+ injury than lap/shoulder restrained occupants
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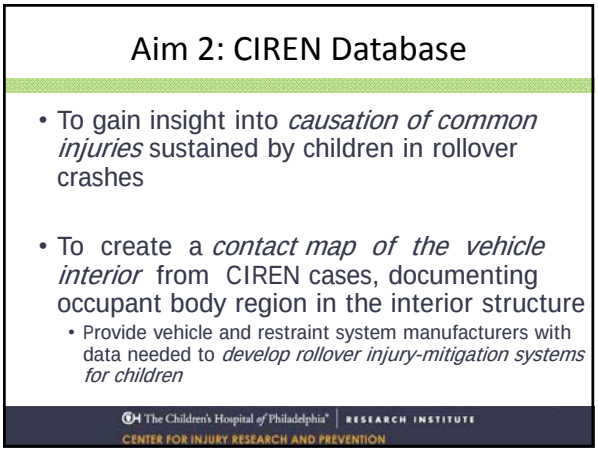
Aim 2: CIREN Database
• To gain insight into causation of common injuries sustained by children in rollover crashes
• To create a contact map of the vehicle interior from CIREN cases, documenting occupant body region in the interior structure
• Provide vehicle and restraint system manufacturers with data needed to develop rollover injury-mitigation systems for children
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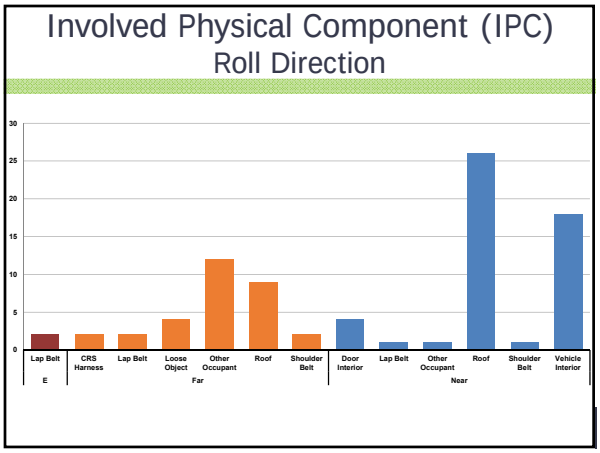
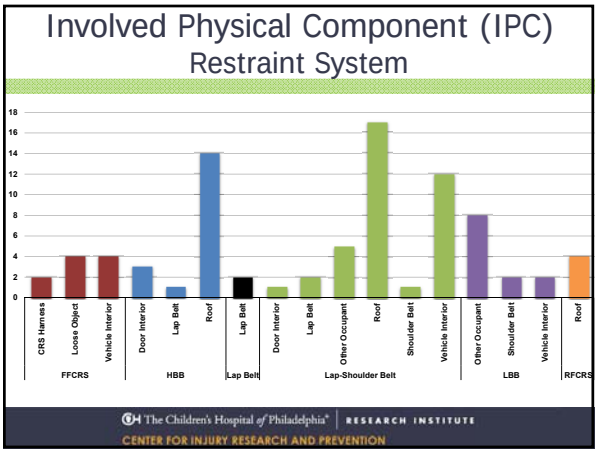

Involved Physical Component (IPC)
Roll Direction
30
25
20
15
10
5
0
Lap Belt
CRS Harness
Lap Belt
Loose Object
Other Occupant
Roof
Shoulder Belt
Door Interior
Lap Belt
Other Occupant
Roof
Shoulder Belt
Vehicle Interior
E
Far
Near


Involved Physical Component (IPC)
Restraint System
18
16
14
12
10
8
6
4
2
0
CRS Harness
Loose Object
Vehicle Interior
Door Interior
Lap Belt
Roof
Lap Belt
Door Interior
Lap Belt
Other Occupant
Roof
Shoulder Belt
Vehicle Interior
Other Occupant
Shoulder Belt
Vehicle Interior
Roof
FFCRS
HBB
Lap Belt
Lap-Shoulder Belt
LBB
RFCRS
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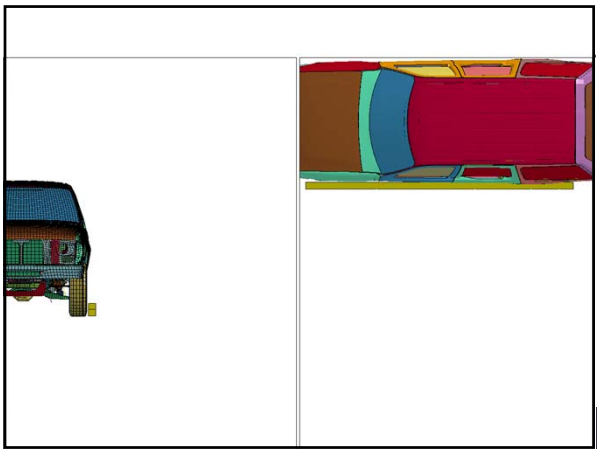
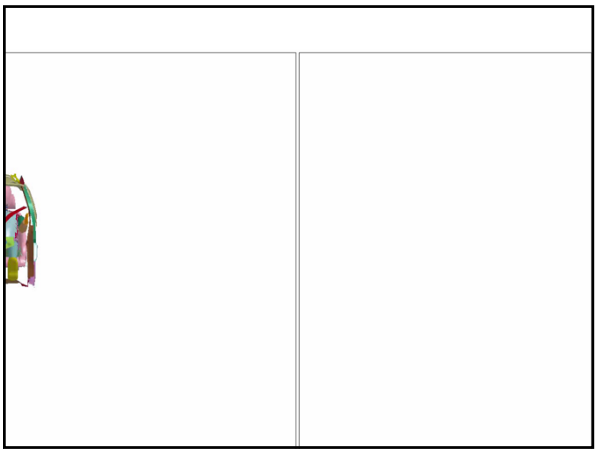




Conclusions

- Irrespective of the restraint type, the head was the most commonly injury body region.
- Injuries include skull fracture, contusions, subdural hematoma, diffuse axonal injury and subarachnoid hemorrhages.

Conclusions

- Contacts for occupants seated in the first row were primarily head-to-roof or roof side rail.
- Second row-seated passengers sustained similar head-to-roof contacts, although the average age (and therefore stature) of these occupants was significantly less (18.2 years vs. 4.1 years).

Conclusions

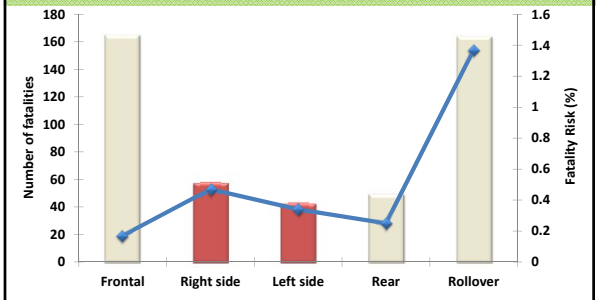
- For children seated in FFCRSs, the vehicle interior, loose objects and CRS harness were the primary IPC for injury.
- However, for RFCRS and High Back Booster (HBB), the roof was the primary IPC for MAIS 2 injury.

Side Airbag Interaction with Children Seated in the Vehicle Environment

Aditya Belwadi, PhD; Matthew R. Maltese, PhD;
Kristy B. Arbogast, PhD

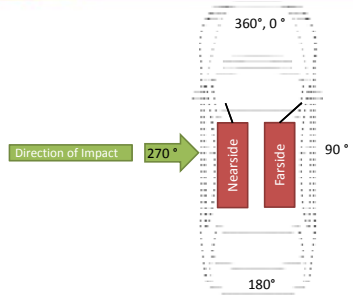
Biostatistician: Michael Kallan, MS (Univ. of Pennsylvania)
Students: Todd Hullfish, Ryan Garvin, Richard Hanna (Drexel Co-ops)

Background



- Viano and Parenteau, 2008; FARS (1996-2005) 0-7 year old
  - **Rollovers - highest fatality risk at 1.37%**; followed by right side (0.47%), left-side impacts (0.34%)

Side Impact Testing



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Side Impact Testing

IIHS
Insurance Institute for Highway Safety

Background

- Side Airbags (SAB)
  - mid 1990's as a protective measure against head and torso injuries for adult occupants
- Roof side rail-mounted "curtain" airbag is the preferred method of head protection, and is often accompanied by a seat-mounted "torso" bag in the front row

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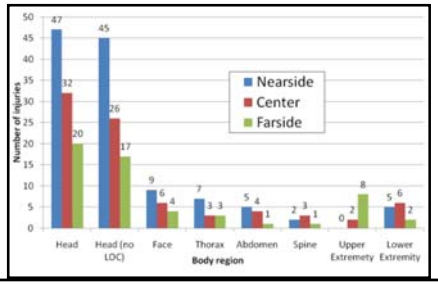
Background

- According to NHTSA study (Louden, Sullivan, 2008) side impact represent 60% of AIS 3+ injuries for children



Research Question

The specific research question is

"to evaluate the effectiveness of roof rail mounted Side Curtain Airbags in mitigating injury to children seated nearside in lateral motor vehicle crashes"

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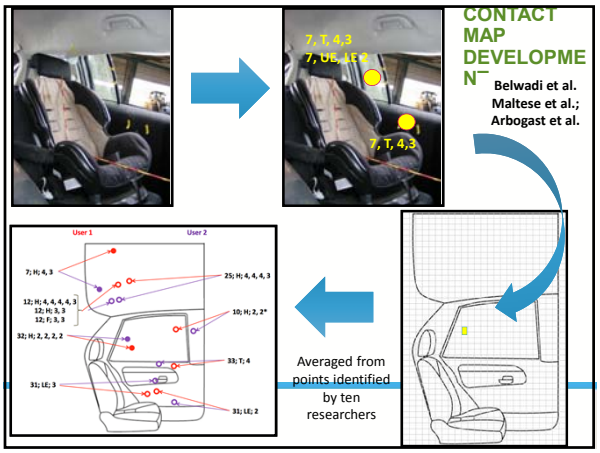

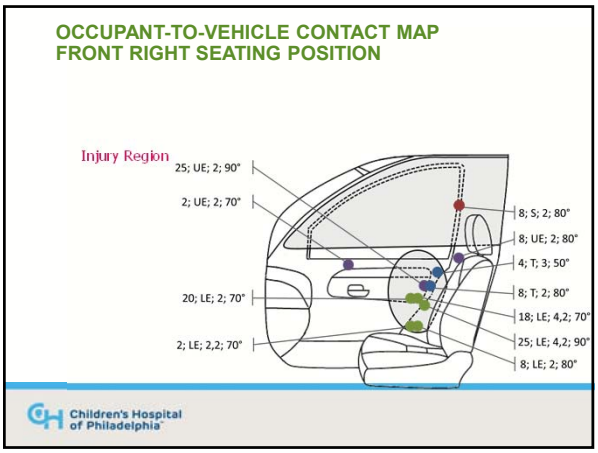

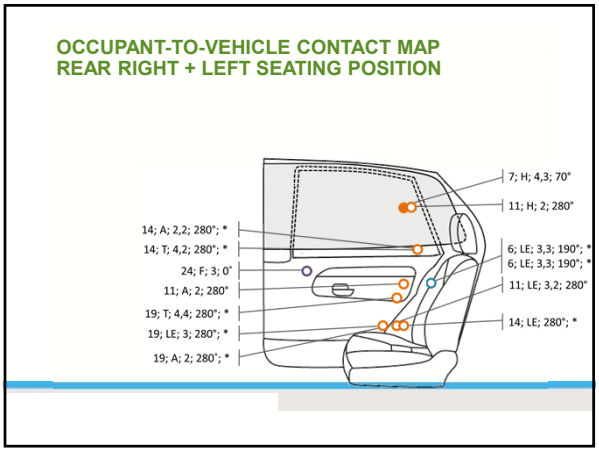

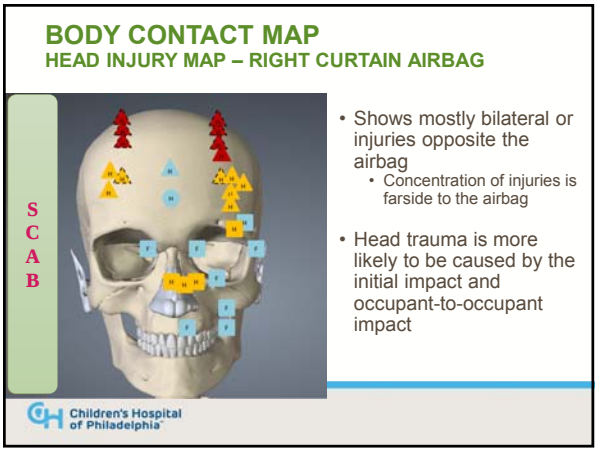

SEATING POSITION IMPLICATION

- Statistically speaking the rear center position is still the safest position for a child seat
- However, with the advent of advanced side curtain airbags, and side impact protection systems, along with advances in child seats
  - They provide sufficient protection in event of a nearside collision
  - Contact with near side occupant is a bigger concern

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LATERAL SLED TESTS

- Advanced Side Impact System (ASIS)
- Side impact sled tests were performed using a novel side impact testing apparatus (*supported by mentor Honda*)
  - a door fixture mounted on an acceleration sled is deformed by four pneumatically actuated cylinders in order to replicate intrusion profiles and crash speeds seen in full-vehicle crashes

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Results/conclusions

- Side curtain airbag aided reduction in peak head and chest g's
- High-back booster CRSs have similar injury responses as low-back booster seats exposed to deploying side curtain airbag highlighting the protective nature of the side curtain airbag.
- Further, when tested without a side curtain airbag, the ATD consistently displayed higher injury numbers for the low-back booster CRS (as compared to high-back booster) due to its interaction with the intruding door.

Principles for successful academic-industry-consumer partnerships

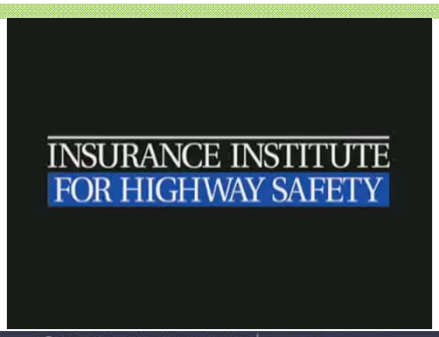
- Professional obligation
  - Highest quality research
- [illegible]
  - openness
- Find those partners that share mutual interest in common achievable goal

We need each other to make a difference!

Action for CPS Techs?

- **Stay current with the research**
  - **Injury.research.chop.edu**
    - Subscribe to *Research in Action* Blog
  - **Cchips.research.chop.edu**

Where does safety stand today



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https://injury.research.chop.edu/

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OVERVIEW OF PEDIATRIC INJURY BIOMECHANICS: A FOCUS ON SIDE AND ROLLOVER CRASHES

February 28, 2018

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