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

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

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

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

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

FATALITIES ARE INCREASING
Pediatric Motor Vehicle Deaths
The Past 30 Years

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

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?

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 = 7-year-old child
- Human volunteer tests

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

Head Top Motion Comparison

6-Year-Old

30-Year-Old

Child moves further downward

Comparison to Crash Test Dummy

Dummy’s head path is flatter

Other observations:
• Dummy has more head rotation
• Dummy has little thoracic spine flexibility

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

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
Research-driven change for safer roads

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

Null roll

Dummy Kinematics - 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

### 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

### Aim 1: NASS/CDS Variables and Inclusion Criteria

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

1998-2011 vehicle model and case years (1560 unweighted occupants)

### 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

### Injury Distribution by Body Region

- AIS 2+ for Injured
- AIS 3+ for Injured
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

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

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
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

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Side Impact Testing

- Side Impact Testing

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

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”
Averaged from points identified by ten researchers

**CONTACT MAP DEVELOPMENT**

Belwadi et al.
Maltese et al.
Arbogast et al.

**OCCUPANT-TO-VEHICLE CONTACT MAP**

Front Right Seating Position

Injury Region

- 25: LC, 2, 10°
- 25: LC, 1, 10°
- 20: LC, 2, 10°
- 20: LC, 1, 10°
- 15: LE, 3, 10°
- 15: LE, 2, 10°
- 10: LE, 2, 0°
- 10: LE, 1, 0°
- 5: LE, 2, 0°
- 4: LE, 2, 0°
- 3: LE, 2, 0°
- 3: LE, 1, 0°
- 3: LE, 0, 0°
- 2: LE, 2, 0°
- 2: LE, 1, 0°
- 1: LE, 2, 0°
- 1: LE, 1, 0°
- 1: LE, 0, 0°
- 0: LE, 2, 0°
- 0: LE, 1, 0°
- 0: LE, 0, 0°

**OCCUPANT-TO-VEHICLE CONTACT MAP**

Rear Right + Left Seating Position

**BODY CONTACT MAP**

Head Injury Map – Right Curtain Airbag

- Shows mostly bilateral or injuries opposite the airbag
- Concentration of injuries is farside to the airbag
- Head trauma is more likely to be caused by the initial impact and occupant-to-occupant impact

**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

**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
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
- Openness
- Find those partners that share mutual interest in common achievable goal

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

INSURANCE INSTITUTE FOR HIGHWAY SAFETY

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