Child Restraint Systems in Side Impact Crashes: Injury Patterns and Causation

KB Arbogast, CM Locey, MR Zonfrillo, MR Maltese

The Center for Injury Research and Prevention
Children’s Hospital of Philadelphia

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Side Impact Protection Important for Rear Seat Child Occupants

Number of Fatalities: 0-14 year olds, 2007
Fatality Rate: rear seated 0-7 year olds, 1996-2005
Previous Research Findings

Side Impact Risk Assessment

- **Fatality risk**
  - Nearside vs. center, rear, all restraints: 2.5 [Howard, 2004]

- **Injury risk**
  - Nearside: front vs. rear, all restraints: 2.6 [Durbin, 2001]
  - Nearside vs. farside, belted rear: 1.8 [Maltese, 2005]
  - Nearside vs. center, rear, CRS: 2.2 [Kallan, 2008]
  - Nearside vs. farside, rear, FFCRS: 4.2 [Arbogast, 2004]
  - Nearside vs. center/farside, rear, CRS: 4.2 [Howard, 2004]
  - Belt vs. Booster, rear: 1.7 [Arbogast, 2005]

**Limited injury causation information**
Previous Research Findings

Injury Causation Scenarios

• 19 cases of children 0 to 12 years (Howard et al. 2004)
  – Mixing of child age, restraint status, seat position
  – Injuries occurred with and without intrusion

• 14 fatal crashes of children 0 to 5 years (Sherwood et al. 2004)
  – Contributing factors: Intrusion, forward crash component, and head contact w/ external objects

• 32 cases of CRS-restrained occupants (Arbogast et al. 2005)
  – Contributing factors: Intrusion, forward crash component, and CRS rotation

• 46 cases of belt-restrained occupants (Maltese et al. 2007)
  – Injury causation grouped into common scenarios, vehicle contact map
Project Objectives

• To delineate injury causation scenarios for rear-seated, CRS-restrained children in side impact crashes
• To create a contact map of the vehicle interior
Methods

• Retrospective case review
  – Multidisciplinary case review team

• BIOTab – CIREN Method of Biomechanical Analysis
  – Injury Causation Scenario (ICS)
  – Involved Physical Components (IPC)
  – Regional/organ level mechanisms
  – Multiple ICS / IPC possible to capture all possibilities

• Contact Point Map
  – Geometrically summarize body region specific contact points
Methods – Case Selection

- CIREN and PCPS in-depth investigations
  - CIREN MY = current year - 6 – earliest MY was 1987
  - PCPS MY = 1990+
- Side impact crash defined as general area of damage = L or R
- Principal direction of force from 7 to 11 o’clock or 1 to 5 o’clock
- Child seated in the rear row(s) of the vehicle, any seat position
- Restrained by a rear- or forward-facing CRS or booster seat
- MAIS 2+ - cases with concussion as only injury excluded

41 CASES INCLUDED IN FINAL ANALYSIS
Crash Characteristics

- 63% were right side impacts
- Mean $\Delta v$ was $37 \pm 15$ km/hr (note: mean long. $\Delta v=10$ km/hr)
Crash Characteristics - PDOF
Child Characteristics

- **Child Age**
  - 0-11 months: 27%
  - 12-47 months: 49%
  - 5-8 years: 24%

- **Restraint Type**
  - Booster seat: 37%
  - Forward Facing CRS: 46%
  - Rear facing CRS: 17%

- **Seat Position**
  - Near side: 59%
  - Center: 24%
  - Far side: 17%

8/41 were not in the right restraint for their age/size
3/15 booster seats were shield boosters
Body Region of AIS2+ Injury by Restraint Type

- 100% AIS2+
- 54% AIS3+
- 32% AIS4+
Body Region of AIS 3+ Injury by Restraint Type

![Bar Chart]

- **Head**: 10
- **Face**: 3
- **Thorax**: 3
- **Abdomen**: 3
- **Spine**: 3
- **Upper Extremity**: 3
- **Lower Extremity**: 3

**Legend**:
- Blue: Rear-facing
- Red: Forward-facing
- Green: Booster
Body Region of AIS2+ Injury by Seating Position

![Bar chart showing the number of injured body regions by body region and seating position.]

- **Head**: Nearside (18), Center (6), Farside (2)
- **Face**: Nearside (6), Center (4), Farside (2)
- **Thorax**: Nearside (4), Center (2), Farside (2)
- **Abdomen**: Nearside (2), Center (1), Farside (1)
- **Spine**: Nearside (1), Center (1), Farside (1)
- **Upper Extremity**: Nearside (2), Center (1), Farside (1)
- **Lower Extremity**: Nearside (1), Center (1), Farside (1)
Body Region of AIS 3+ Injury by Seating Position

The bar chart shows the number of injured body regions categorized by seating position. The categories include Head, Face, Thorax, Abdomen, Spine, Upper Extremity, and Lower Extremity. The chart distinguishes between Nearside, Center, and Farside injuries.

- **Head**: The most common injury location, with Nearside having the highest number of injuries.
- **Face**: Fewer injuries compared to other regions, with similar counts for Nearside and Center.
- **Thorax**: More injuries than Face, with Nearside having the highest count.
- **Abdomen** and **Spine**: Lesser injuries, with Nearside again having the highest count for Abdomen.
- **Upper Extremity** and **Lower Extremity**: Minimal injuries, with Nearside having the highest counts.
Involved Physical Components
Near Side Crashes – AIS2+

![Bar chart showing counts of injured body regions for different physical components and body regions.]

- **Counts of Injured Body Regions**
  - Spine
  - Lower Extremity
  - Abdomen
  - Thorax
  - Face
  - Head

**Physical Components**
- Belt/harness
- Pillars
- CRS structure
- Door interior
- Intruding object
- Other occupant
- Roof rail
- Sill
- Unknown/other injury
- Window frame
Involved Physical Components
Near Side Crashes – AIS3+

Counts of injured body regions

- Belt/harness
- Pillars
- CRS structure
- Door interior
- Intruding object
- Other occupant
- Roof rail
- Sill
- Unknown/other injury
- Window frame

Legend:
- Red: spine
- Dark purple: Lower Extremity
- Light green: Abdomen
- Yellow: Thorax
- Blue: Thorax
- Purple: Face
- Pink: Head
Near Side Crush Profile

Avg Max intrusion (as critical or contributing factor) = 34 ± 17 cm
Exemplar Near Side Crash

• 2002 Toyota Camry
• Making left turn
  – Delta V = 28 kph
    • Lat. Comp. = 24 kph
    • Long. Comp. = 14 kph
  – PDOF = 60°
  – Intrusion at occupant seating position: 39 cm

• Occupant
  – 5 year old (21 kg, 46 lbs)
  – Right rear
  – Restrained in booster seat
Exemplar Near Side Crash

• Head
  – Cerebral subarachnoid hemorrhage
  – Cerebellar subarachnoid hemorrhage
  – Hemorrhage in midbrain/brainstem

• Thorax/Abdomen
  – Bilateral pulmonary contusions
  – Diaphragm laceration
  – Liver laceration
  – Renal vein transection
## Exemplar Near Side Crash

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Impact Side</th>
<th>Body Region</th>
<th>ICS</th>
<th>IPC to Body Region Contacted</th>
<th>IPC Confidence</th>
<th>Specific Injury Description</th>
<th>AIS Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>377044651</td>
<td>R</td>
<td>Head</td>
<td>Contact with vehicle interior</td>
<td>Door interior to head</td>
<td>Probable</td>
<td>Cerebrum subarachnoid hemorrhage</td>
<td>140684.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cerebellum subarachnoid hemorrhage</td>
<td>140466.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cerebellum hematoma/hemorrhage subdural</td>
<td>140442.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thorax</td>
<td>Contact with CRS shell</td>
<td>CRS shell to thorax</td>
<td>Probable</td>
<td>Lung contusion bilateral with or without hemo/pneumothorax</td>
<td>441410.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Diaphragm laceration (OIS Grade II thru IV)</td>
<td>440604.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Abdomen</td>
<td>Contact with CRS shell</td>
<td>CRS shell to abdomen</td>
<td>Probable</td>
<td>Liver venous transection</td>
<td>521499.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Liver laceration minor (OIS Grade I or II)</td>
<td>541022.2</td>
</tr>
</tbody>
</table>
Involved Physical Components
Far Side/Center Crashes – AIS2+

counts of injured body regions

- Belt/harness
- CRS structure
- Other occupant
- Roof rail
- Unknown/other injury
- Seat back
- Center console

Body regions:
- Spine
- Upper extremity
- Lower extremity
- Abdomen
- Thorax
- Face
- Head
Involved Physical Components
Far Side/Center Crashes – AIS3+

Counts of injured body regions

- Head
- Face
- Thorax
- Abdomen
- Lower Extremity
- Upper Extremity
- Spine

Bar chart showing counts of injuries for different components:
- Belt/harness
- CRS structure
- Other occupant
- Roof rail
- Seat back
Exemplar Far Side Crash

- 1996 Dodge Intrepid
- Straight through intersection
  - Delta V = 34 kph
    - Lat. Comp. = 29 kph
    - Long. Comp. = 17 kph
  - PDOF = 60°
  - Max. intrusion: 36 cm @ B-Pillar

- Occupant
  - 2 year old (89 cm, 13 kg)
  - Center rear
  - Restrained in FFCRS
Exemplar Far Side Crash

• Head/Face
  – Right frontal lobe contusion
  – Right superior, medial orbital wall fracture
  – Right maxillary fracture

• Lower Ex
  – Left fibular fracture
  – Comminuted left tibia fracture
# Exemplar Far Side Crash

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Impact Side</th>
<th>Relation to Crash</th>
<th>Body Region</th>
<th>ICS</th>
<th>IPC to Body Region Contacted</th>
<th>IPC Confidence</th>
<th>Specific Injury Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1061256</td>
<td>R</td>
<td>Center</td>
<td>Head</td>
<td>Contact with vehicle interior</td>
<td>Seatback to head</td>
<td>Probable</td>
<td>R frontal lobe contusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Face</td>
<td>Contact with vehicle interior</td>
<td>Seatback to face</td>
<td>Probable</td>
<td>Maxilla fracture R Orbit fracture</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L Extremity</td>
<td>Contact with vehicle interior</td>
<td>Seatback to leg</td>
<td>Probable</td>
<td>Salter-Harris type fracture of L distal tibia L fibula fracture</td>
</tr>
</tbody>
</table>
Involved Physical Components
Rear Facing CRS – AIS2+

Belt/harness  CRS structure  Other occupant  seatback

Counts of injured body region:

- Spine
- Face
- Head
Involved Physical Components
Forward Facing CRS – AIS2+

counts of injured body region:

- spine
- upper extremity
- Lower Extremity
- Abdomen
- Thorax
- Face
- Head

Belt/harness
pillars
CRS structure
Door interior
Intruding object
Other occupant
Roof rail
Sill
seat back
center console

Body regions:
- Abdomen
- Thorax
- Face
- Lower Extremity
- Upper Extremity
- Head
- Spine
Involved Physical Components
Booster Seats – AIS2+

Counts of injured body regions

- Belt/harness
- Pillars
- CRS structure
- Door interior
- Intruding object
- Other occupant
- Roof rail
- Sill
- Window frame
- Seat back

- Upper extremity
- Lower extremity
- Abdomen
- Thorax
- Face
- Head
On the left, you see an artist’s rendering of the interior of a motor vehicle that was involved in a crash, with one or more numbers in the picture. The numbers signify the location inside the vehicle where an occupant contacted the vehicle interior. Your task is to estimate the position of the numbers relative to the position of the seatback, locate the corresponding cell in the image on the left, and type the number in the cell.
Near Side – All Body Regions
Comparison to Belted Children

Current Study

Belted Children (Maltese et al)
Far Side/Center – All Body Regions
Previous Research
NASS-CDS 1993-2007

Head and Face Contacts for Children in CRS – Near Side Impacts

Scullion et al., 2009
Previous Research
NASS-CDS 1995-2007

Injury Sources – Side Impacts, $\Delta v > 30$ kph
1 to 3 year olds in FFCRS

McCray et al., 2007
Conclusions

- Head and face injury most common – all restraints/seat position
  - Far side more equal distribution among body regions
- Non-contact inertial head/spine injuries rare but present in all seat positions
  - Often accompanied by lung contusions
  - May indicate frontal loading
- Common IPC
  - Near side – CRS Structure and Door Interior
  - Far side/center – Seat back and Harness/Belt
Acknowledgements

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NHTSA Crash Injury Research & Engineering Network

Partners for Child Passenger Safety