Abdominal Injuries in Children in Belt-Positioning Booster Seats

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Abdominal Injuries to Children in Belts

- Abdominal wall contusions
- Solid and hollow organ injury
Booster Seats Reduce Injury Risk

59% reduction

Durbin *JAMA* 2003
Field Experience

  - Pelvis & abdomen made up 13% of AIS 2+ injuries in boosters
  - Identified 9 cases of abdominal injury in boosters but provided no crash/restraint details

- European study (CHILD) identified 4 cases of abdominal injury in children in boosters (Johannsen *IRCOBI* 2005)
  - All frontal impacts
  - Injuries were both upper and lower abdomen
  - At least 2 cases involved improper routing/placement of the belt
  - CHILD data finds no difference between belts and boosters for abdominal injury (*CHILD Dissemination Workshop* 2006)
Field Experience continued

- Australian study of children in high back boosters identified 2 cases of abdominal injury (Brown AAAM 2006)
  - Frontal crash with bowel injury with belt misuse present
  - Near-side crash with multiple thorax and abdomen injuries
Previous effectiveness analyses

Known limitations

- Overall low booster use (10%)
- Mostly high back boosters (80%)
- Unable to evaluate effectiveness by age within age group
- Unable to evaluate variation in effectiveness by impact direction and other important factors
- Continued evolution of vehicle fleet and booster designs
Trends in CRS Use
3 to 8 year old children
Project Objective

- Determine injury mechanisms and restraint factors influencing the abdominal injuries in children in belt-positioning booster seats
  - Real world case review and modeling
  - Parametric analysis and evaluation of pretensioners and load limiters
Project Methods

- Identify frontal impact cases of children in booster seats with abdominal injuries
  - CIREN – NHTSA’s Crash Injury Research and Engineering Network
  - PCPS – CHOP’s Partners for Child Passenger Safety
- Cases modeled using MADYMO to examine injury metrics
Cases

• 4 year old male
• Right rear
• High back BPB
• Injuries:
  liver laceration
  pancreas contusion

\[ \Delta V = 22 \text{ km/h} \]

• 5 year old male
• 3\textsuperscript{rd} row right
• Low back BPB
• Injuries:
  spleen laceration
  lung contusion

\[ \Delta V = 72 \text{ km/h} \]

• 4 year old female
• Left rear
• High back BPB
• Injuries:
  liver laceration
  lung contusions
  rib fx

\[ \Delta V = 50 \text{ km/h} \]
<table>
<thead>
<tr>
<th>Injuries</th>
<th>Injury Causation Scenario</th>
<th>Confidence/ Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case 1</strong></td>
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<tr>
<td><strong>Abdomen</strong></td>
<td>Shoulder belt loading to abdomen</td>
<td>Probable / chest abrasions and right clavicle fracture</td>
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<tr>
<td>Liver laceration</td>
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<td>Pancreas contusion</td>
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<td><strong>Case 2</strong></td>
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<tr>
<td><strong>Abdomen</strong></td>
<td>Shoulder belt loading to abdomen</td>
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<tr>
<td>Liver laceration</td>
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<tr>
<td><strong>Chest</strong></td>
<td>Shoulder belt loading to chest</td>
<td>Certain / chest abrasions and contusions</td>
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<tr>
<td>Bilateral lung contusions</td>
<td></td>
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<tr>
<td>Right rib fractures #6, 7, 8</td>
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<td><strong>Case 3</strong></td>
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<td>Spleen laceration</td>
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</table>
Case Vehicle: 2000 Pontiac Bonneville
Vehicle 2: Flatbed trailer
Delta-V: 50 km/h
Max crush: 52 cm
Max intrusion: None for case occupant
Case Occupant

- 4yr old female
- 109 cm: 90%
- 22 kg: 95%
- Left rear seat
- High back booster w/ lap and shoulder belt

Other occupant: 54 year old female driver
lap/shoulder belt + airbag
injuries: leg laceration, abdomen contusion
Injuries

Face
- AIS 1: Superficial tongue laceration

Thorax
- AIS 4: Bilateral lung contusion
- AIS 3: R rib fractures (#6,7,8)
- AIS 1: Chest skin contusion

Abdomen
- AIS 2: Liver laceration, small
- AIS 1: Abdominal skin contusion

Extremity
- AIS 1: L hip laceration
Methods – Case Reconstruction

• **Goal:** define injury causation scenarios for real world crashes

• **Reconstruction of frontal impacts**
  – Vehicle dynamics from HVE and EDR data
  – Occupant kinematics from MADYMO
    • Scaled ATD
    • Appropriate seatbelt and booster seat geometry
  – Varied belt slack, front seat track position, shoulder belt anchor position, and front seat back inclination

• **Output**
  • Head – excursion, HIC
  • Chest – acceleration, compression, compression rate
  • Abdomen – compression, compression rate
  • Seat belt loads
Chest Injury Metrics

- Ouyang et al (2006) blunt hub impacts to the thorax of nine pediatric PMHS
  - 2-4 year olds – suggested tolerance of 45 mm
  - 5-12 year olds – no clear deflection tolerance
  - lung injuries not rib fractures
Kent et al (2008) used a juvenile porcine model
- 50% risk of injury = normalized deflection of 0.32 (4.5 mm) and an abdominal velocity of 2 m/s.
- Relationship between velocity and injury not strong.
Methods – Parametric Study

- Goal: identify the sensitivity of output variables to specified input parameters
- Common crash pulse – US NCAP
- Backless and highback booster
- Standard Hybrid III 6 year old model
- Lap belt Buckle Pretensioner: 25mm, 40mm, 50mm, 75mm
- Shoulder Belt Load Limiter: 2500N, 3500N, 4500N
- Baseline: no LL and no PT
Chest Compression

% of Baseline Case

Load Limit

- No LL
- 4500N
- 3500N
- 2500N

- No PT
- 25 mm PT
- 40 mm PT
- 50 mm PT
- 75 mm PT
Chest Compression Rate

% of Baseline Case

Load Limit

No LL  4500N  3500N  2500N

0% 200% 400% 600% 800%

No PT 25 mm PT 40 mm PT 50 mm PT 75 mm PT

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Abdominal Compression

% of Baseline Case

Load Limit

- No PT
- 25 mm PT
- 40 mm PT
- 50 mm PT
- 75 mm PT

Abdominal compression load limit comparison for different proximal (PT) and load limit (LL) cases.
Abdominal Compression Rate

The chart shows the percentage of baseline case for different load limits and abdominal compression rates.

- **No PT**
- **25 mm PT**
- **40 mm PT**
- **50 mm PT**
- **75 mm PT**

Load Limits:
- No LL
- 4500N
- 3500N
- 2500N

% of Baseline Case:
- 50%
- 150%
- 250%
- 350%
- 450%
- 550%
Summary
Real World cases

- Belt-positioning boosters are effective in preventing seat belt syndrome injuries
- Anecdotal evidence of upper abdominal injuries in belt-positioning booster seat restrained children
  - Not common is US databases
  - Injuries due to shoulder belt loading to thorax and upper abdomen
- Can be used to provide insight into tolerance levels
Summary
Parametric Analyses

- Chest deflection
  - Small decrease with PT (~5%), more substantial decrease with LL (up to 30%)
- Chest deflection rate
  - Increased substantially with PT>40 mm
- Abdominal deflection
  - Small increases for all PT and LL except for 75 mm and 2500N which had large increases
- Abdominal deflection rate
  - Higher levels of PT had great increase of deflection rate; muted in backless boosters
- Need to consider trade-offs with head excursion
  - Parametric study suggests it can be done
  - Differing response in backless and highback boosters
  - Location of abdominal deflection important
Acknowledgements

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NHTSA Crash Injury Research & Engineering Network

Partners for Child Passenger Safety