Lower Extremity Injuries in Small Overlap Crashes

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Introduction

- Crashworthiness improvements

<table>
<thead>
<tr>
<th>Full engagement (rigid)</th>
<th>40% overlap (deformable)</th>
</tr>
</thead>
</table>

Longitudinal members

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NHTSA
www.nhtsa.gov

safercar.gov
U.S. Department of Transportation

Insurance Institute for Highway Safety

Euro NCAP
www.euroncap.com

ANCAP
Crash testing for safety
Introduction

- Continued frontal impact fatalities
  - NHTSA (2009) \( n = 122 \)
What do we know from Crash Tests?
SOI Crash – Midsize Car
SOI Crash – Midsize Car
SOI Crash – Midsize Car

Fx Frame Capture

0170msec
SOI Crash – Small Car
SOI Crash – Small Car

Frame0060
SOI Crash – Small Car
SOI Crash – Small Car
Occupant Kinematics – SOI Crash
PDOF from Small Overlap Crash
SOI Occupant Kinematics

- Occupant moves initially forward in response to frontal crash vector
- Occupant moves laterally due to vehicle sideways translation
- Vehicle rotation occurs late and usually does not influence occupant motion until late in event
- Suspect lower extremity moves laterally either before dash impact or dash impact with body lateral movement induces bending moment
US Data: NASS and CIREN
- “FLEE” and “FREE” designations (CDC)

NASS

CIREN

Pintar et al. (2008)
Aims: Lower Extremity Injuries

- Small Overlap Crashes – Occupant Kinematics
- NASS study – SOI vs Frontal-208
- CIREN Injury examination
- Laboratory Crash Tests
NASS Query (2005 – 2009)

Any Lower Extremity Injury
Only Belted Drivers

Both rails engaged
12-o’clock impacts
FDEW and DVD=0

No rail engaged
Frontal plane impacts
SOI filter defined
## Demographic Results

<table>
<thead>
<tr>
<th></th>
<th>Small Overlap</th>
<th>Frontal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupants (raw)</td>
<td>536</td>
<td>243</td>
</tr>
<tr>
<td>Occupants (weighted)</td>
<td>125,055</td>
<td>49,842</td>
</tr>
<tr>
<td>Mean age</td>
<td>41.6</td>
<td>40.0</td>
</tr>
<tr>
<td>Age range</td>
<td>16-92</td>
<td>15-91</td>
</tr>
<tr>
<td>Lo. Ex. Injuries (raw counts)</td>
<td>1111</td>
<td>666</td>
</tr>
</tbody>
</table>
Statistical Analysis

- SAS 9.2
- Logistic regression
  - Considered crash type only (SOI vs. Frontal)
- Computed odds ratio (OR) for lower extremity anatomic regions
  - Pelvis
  - Hip
  - Thigh
  - Knee
  - Shank
  - Ankle
  - Forefoot
Anatomic Regions (BioTab Style)

Pelvis
- e.g., Open/closed fx
- Sacroilium fx
- Pubic fx

Hip/Proximal Femur
- e.g., Sprain
- Dislocation
- Femoral head, neck, trochanters

Thigh
- e.g., Femur: shaft fx
- Subtrochanteric fx
- Supercondylar fx
- Nerves & vasculature

Knee
- e.g., Tibial platea fx
- Femoral condyle fx
- Meniscii
- Ligaments

Leg
- e.g., Tibial shaft
- Fibula shaft
- Vasculature

Foot
- e.g., Toe
- Metatarsals
- Foot
- Calcaneus

Ankle
- e.g., Joint
- Ligaments
- Malleoli
- Talus
Odds Ratio: AIS 1+ Occupants

- Pelvis
- Hip/Proximal Femur
- Pelvis + Hip/Prox. Femur
- Thigh
- Knee
- Leg
- Ankle
- Foot

Front-208 = Greater Risk
SOI = Greater Risk
Odds Ratio: AIS 2+ Occupants

Front-208 = Greater Risk

SOI = Greater Risk

- Pelvis
- Hip/Proximal Femur
- Pelvis + Hip/Prox. Femur
- Thigh
- Knee
- Leg
- Ankle
- Foot
## Pelvis + Hip/Femur

### Top 5 injury codes (by occupant counts)

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Small Overlap</th>
<th>Frontal</th>
</tr>
</thead>
<tbody>
<tr>
<td>852604.3</td>
<td>Pelvis fracture (open, displaced, and/or comminuted)</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>852602.2</td>
<td>Pelvis fracture (closed)</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>852600.2</td>
<td>Pelvis fracture (NFS)</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>850614.2</td>
<td>Hip dislocation (no articular cartilage involvement)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>851810.3</td>
<td>Femur fracture (intertrochanteric)</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>
CIREN Database Methods

- **CIREN Database**
  - Occupant data
    - Gender
    - Age
    - Injury severity score (ISS)
    - Seat position
    - Injury patterns
  - Vehicle/crash data
    - Extent zone
    - Collision partner
- Only Small Overlap Impacts
CIREN Results

- CIREN SOI cases = 84

- Shotgun beam (deformed)
- Suspension tower (deformed)
- Longitudinal member (undeformed)
- Wheel (deformed)
CIREN Results 84 SOI Cases

● 70 out of 84 occupants had lower extremity injury
● Of the 70:
  – 26 had Pelvis trauma
  – 17 had Hip trauma
  – 27 had Thigh trauma
  – 15 had Knee trauma
  – 24 had Leg trauma
  – 17 had Ankle trauma
  – 19 had Foot trauma
Pelvis Injuries

- Closed pelvis fx
  - Sacrum or pubis: 5-left, 3-right, 4-bilateral
- Open/displaced/comminuted fx
  - Acetabulum or ilium: 12-left, 2-right, 1-bilateral
  - Sacrum or pubis: 0-left, 6-right, 1-bilateral
- Hip dislocation
  - 5-left, 0-right, 1-bilateral
- Sacroilium fx
  - 5-left, 3-right, 2-bilateral
- Symphysis Pubis
  - Separation – 5
Thigh and Knee Injuries

- Mid Shaft Femur fx
  - 22-left, 2-right
- Head, Neck or subtrochanteric
  - 5-left, 0-right
- Condylar or supracondylar
  - 4-left, 1-right
- Patella or knee condyles
  - 10-left, 5-right
Foot and Ankle Injuries

- Tibial condyle fx
  - 7-left, 4-right
- Tibia – Fibula shaft fx
  - 9-left, 6-right, 2-bilateral
- Ankle single, bi, or tri-malleolar
  - 2-left, 5-right
- Ankle or foot joint dislocation
  - 2-left, 1-right
- Calcaneous or Talus fx
  - 3-left, 4-right
- Tarsal or Metatarsal fx
  - 20-left, 12-right
Associated Injuries

% Associated with Pelvis Injury

- Hip
- Thigh
- Knee
- Leg
- Ankle
- Foot
- Isolated

Graph showing the percentage of associated injuries with pelvis injury for different body parts.
Associated Injuries

% Associated with Hip Injury

Pelvis: 50%
Thigh: 15%
Knee: 20%
Leg: 5%
Ankle: 5%
Foot: 5%
Isolated: 5%
Associated Injuries

% Associated with Thigh Injury

Pelvis | Hip | Knee | Leg | Ankle | Foot | Isolated

0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45
Associated Injuries

% Associated with Leg Injury

Pelvis  Hip  Thigh  Knee  Ankle  Foot  Isolated
Methods: Vehicle Tests

- Four vehicles

<table>
<thead>
<tr>
<th>Test</th>
<th>Model year</th>
<th>Class</th>
<th>Weight (kg)</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2006</td>
<td>Mid-sized</td>
<td>1742.7</td>
<td>Normal</td>
</tr>
<tr>
<td>2</td>
<td>2010</td>
<td>Sub-Compact</td>
<td>1268.2</td>
<td>Normal</td>
</tr>
<tr>
<td>3</td>
<td>2005</td>
<td>Compact</td>
<td>1445.6</td>
<td>Normal</td>
</tr>
<tr>
<td>4</td>
<td>2010</td>
<td>Compact</td>
<td>1446.0</td>
<td>Enhanced*</td>
</tr>
</tbody>
</table>

* As advertised by manufacturer
Methods: Vehicle Tests

- THOR-NT occupant (driver)
  - 50th percentile
Results: Vehicle deformation

Lab

Lab

Field

Field
Typical JARI sled test

![Graph showing X and Y displacement with time t1 and t2.](image)
SOI Test 1 (Mid-sized)

X displacement (mm)

Y displacement (mm)

\( t_1 \)

\( t_2 \)
Test 3 (Compact)

X displacement (mm)

Y displacement (mm)
THOR-NT Lower Extremity Results

Acetabulum Forces  N=4
THOR-NT Lower Extremity Results
Femur Loads  N=4

The diagram shows the forces and moments on the femur for different conditions and sides. The y-axis represents force (N) or moment (Ncm), and the x-axis lists conditions such as SO1-Fz, SO1-Mx, SO1-Fz, SO1-Mx, 208-Fz, 208-Mx, 208-Fz, and 208-Mx. The forces and moments are compared for left and right sides.
Mechanisms of Lower Extremity Injury
Conclusions

- NASS analysis
  - Lower Extremity injuries substantial problem
  - SOI higher odd ration for Pelvis, Hip, Proximal Femur, and Knee

- CIREN analysis
  - Pelvis injuries more severe and more left side
  - Proximal femur fractures more prevalent and associated with pelvis fractures
  - Mid-shaft femur fractures more severe

- Vehicle crash tests
  - Occupant kinematics altered toward side
  - THOR dummy indicates higher off-axis loads
    - Shear in acetabulum; bending moment in femur
Acknowledgments

- US Department of Transportation
  - DTNH22-10-H00292
- VA Medical Research
  - MCW Neuroscience Laboratories Staff