Pelvic and Thoracic Injuries in Nearside Impact Crashes: Analysis of Contributory Factors

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And

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Goal of This Study

To determine whether vehicle design factors relate to thoracic and pelvic injuries from near-side impacts.
Background

- Side impacts comprise about 32% of all vehicle crashes with occupants experiencing AIS 3+ injuries.

- Thorax and pelvis are the most likely regions to be injured in near-side impacts (Samaha, ’03)

- Thoracic and pelvic injuries are probably the result of a limited stroke punch intrusion of the door, (Lau,’91 Chung ‘99).

- The predominant injurious contact in thoracic and pelvic injuries is the door (Samaha, ‘03).
Background – Variables Affecting Injury

• Crash variables
  – masses of both vehicles (Terrel, 18th ESV, ’03)
  – angle of impact
  – speed of bullet vehicle
  – Stiffness of both vehicles
  – Height of contact region on door

• Occupant variables
  - stature of occupant (Samaha 18th ESV, ’03)
  - location of occupant
  - restraint use
  - age of occupant (Austin 18th ESV, ’03)
Vehicle Design Variables

2001 Toyota Sienna, Weight = 2029 kg, Door crush = 29.7 cm
Driver TTI = 69, pelvic g = 94, No side airbag

2002 Toyota Tundra, Weight = 2229 kg, Door crush = 29.8 cm
Driver TTI = 22, pelvic g = 27, No side airbag
Background – Vehicle Variables?

- Vehicle weight
- Maximum door intrusion (Chung ’99)
- Location of maximum door intrusion
- Peak door acceleration
- Peak door velocity (Morris, ’01, Viano ‘89)
- Peak relative door to vehicle velocity
- Wheelbase (related to vehicle stiffness?)
- Armrest (panel) stiffness (Rouhana ‘89, Viano ‘91, Deng ‘96, Cavanaugh ‘96, Daniel ’95, Morris ‘01)
- Dummy H-point to door horizontal distance (Morris,’01)
- Deployed thoracic airbag (thoracic injuries)
- Stiff center console (pelvic injuries)
Basic Question

Which vehicle variables relate to dummy accelerations in side impact collisions?
Methods

NCAP side impact data

- Standard moving deformable barrier mass, height, angle, and velocity
- “Occupant” standard DOT SID
- Peak pelvic g and TTI determined as function of vehicle related variables
- Reports on 165 vehicles available at www.dms.dot.gov docket 3835
Methods – Vehicle Door Measurements
Methods – CIREN and NASS

- **CIREN**
  - Scene inspection
  - Vehicle damage, restraint use, PDOF, DV
  - Occupant interior contact locations
  - Medical records, x-rays, imaging studies of injuries

- **NASS**
  - NASS-CDS database
  - Side impacts, amount of door intrusion
  - Highest AIS (MAIS) score of three regions determined
Results – CIREN Examples
CIREN Side Impact Data and Case Reviews
Lateral Impact Mechanism
Reviews
Intrusion = Injury

Thorax Abdominal Lateral Pelvi Pelvis Bilateral Combination
Case Review
Pre-Standard

Combination

Fire Hydrant
RP

RL
Curb Edge

Scale 1cm = 2.5 M
Case Review

90’s Compact Sedan

90’s Large Sedan
Lateral door intrusion at chest and pelvis
Lower Lateral Door Intrusion

Lower lateral door intrusion

Left acetabular fx
Injuries

<table>
<thead>
<tr>
<th>AIS</th>
<th>Region</th>
<th>Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Head</td>
<td>Concussion</td>
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<tr>
<td>2</td>
<td>Spine</td>
<td>C1 fracture (non-displaced)</td>
</tr>
<tr>
<td>4</td>
<td>Chest</td>
<td>L Ribs fractures 3-8 with hemothorax</td>
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<tr>
<td></td>
<td></td>
<td>Pulmonary contusion</td>
</tr>
<tr>
<td>3</td>
<td>Pelvis</td>
<td>Ruptured L diaphragm</td>
</tr>
<tr>
<td>3</td>
<td>Pelvis</td>
<td>Sacral fx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L Acetabular Fx</td>
</tr>
</tbody>
</table>

ISS = 29
Side Impact Standard Improvements

Use of side impact beams in doors
Case Review
Protection From Side Impact Beams

- 1997 Compact 2HB
- Minimal intrusion
- No injury to front right restrained passenger

Striking vehicle
Side Impacts From Larger Vehicles Impact Above Support Beams
Upper Door Panel Intrusion

1998 Subaru Impreza vs. SUV

Most light trucks, vans, and SUVs will collapse the upper door panel, and even override the support beam.
Door Intrusion - Thoracic Injuries
Case Review
Scene

Look back path of travel
Case Review

- Front Seat Passenger
- 74 yr. , Male
- Lap/Shoulder belt
- Struck by a large pickup
- Lateral Direction of Force

Compact Sedan
Upper Door Panel Intrusion
Case Review

Compact sedan struck by large pickup truck
Upper Door Panel Intrusion Case Review

A: R B-pillar
B: R side interior
C: R window frame
Injuries

<table>
<thead>
<tr>
<th>AIS</th>
<th>Region</th>
<th>Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Head</td>
<td>Scalp laceration</td>
</tr>
<tr>
<td>3</td>
<td>Head</td>
<td>R subarachnoid bleed/contusion -parietal/occipital</td>
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<tr>
<td>4</td>
<td>Chest</td>
<td>Rib fxs: L :1-3, R:3-9 with R pneumothorax</td>
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<tr>
<td>2</td>
<td>Abdomen</td>
<td>R perinephric hematoma -small</td>
</tr>
<tr>
<td>2</td>
<td>Abdomen</td>
<td>Pancreatic head Lac</td>
</tr>
</tbody>
</table>

ISS = 29
Hospital Course

77 year old restrained male. Confused at scene; intubated.

Day 1: Exploratory laparotomy:
   Small hemoperitoneum,
   Small R perinephric hematoma

Day 2-25: Prolonged respiratory failure:
   Pneumonia
   Tracheostomy on day 12
   Trach pulled on day 25

Day 26: Transfer to Geriatrics
Day 32: Transfer to Rehab
## CIREN Thoracic Injury Summary

<table>
<thead>
<tr>
<th>No</th>
<th>age</th>
<th>sex</th>
<th>height (M)</th>
<th>occupant position</th>
<th>restraint</th>
<th>PDOF</th>
<th>delta V (kph)</th>
<th>intrusion (cm)</th>
<th>AIS</th>
<th>thoracic injuries</th>
<th>contact point</th>
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<tbody>
<tr>
<td>T1</td>
<td>62</td>
<td>M</td>
<td>1.85</td>
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<td>2-3 rib fractures with hemo/pneumothorax</td>
<td>door panel</td>
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<tr>
<td>T2</td>
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<td>F</td>
<td>1.73</td>
<td>driver</td>
<td>none</td>
<td>280</td>
<td>24.1</td>
<td>16</td>
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<td>driver</td>
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<td>280</td>
<td>unk</td>
<td>23</td>
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<td>70</td>
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<tr>
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<td>M</td>
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<td>16.8</td>
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<td>5</td>
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<td>FR pass.</td>
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<td>50</td>
<td>46.7</td>
<td>40</td>
<td>5</td>
<td>flail chest with lung contusion</td>
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<td>27</td>
<td>M</td>
<td>1.93</td>
<td>driver</td>
<td>none</td>
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<td>54.7</td>
<td>37</td>
<td>5</td>
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<td>door panel</td>
</tr>
<tr>
<td>T8</td>
<td>26</td>
<td>F</td>
<td>1.65</td>
<td>driver</td>
<td>lap+shldr</td>
<td>290</td>
<td>54.7</td>
<td>43</td>
<td>3</td>
<td>2-3 rib fx, hemo/pneumothorax, lung contusion</td>
<td>door panel</td>
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<td>F</td>
<td>1.52</td>
<td>driver</td>
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<td>300</td>
<td>33.8</td>
<td>40</td>
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<td>23</td>
<td>4</td>
<td>&gt;3 rib fractures with hemo/pneumothorax</td>
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<td>4M,7F</td>
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<td>36.8</td>
<td>34.1</td>
<td>4.2</td>
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**Mean Age**: 44 yrs.  
**Mean Delta V**: 36.8 kph/22.8 mph  
**Mean Intrusion**: 34.1 cm/13.4 inches  
**Mean AIS**: 4.2

Derived by Thoracic Injury  
All thoracic injury patterns associated with the door panel.
Side Impact - Abdominal Injuries (Associated With the Armrest)
Abdominal Injury Case Review

Delta V = 15 mph
Front Right Pass.
Lap/Shoulder belt
71 yr. , Female

90’s Sedan
Abdominal Injury Case Review

Injuries associated with armrest:

R kidney laceration
Liver laceration

Other: Splenic laceration, Flail chest, ruptured aorta
Abdominal Armrest Injury Case Review

1998 Jeep Grand Cherokee
Subject V1
1998 Jeep Grand Cherokee

V2
1986 Ford F250 PU

V1 impacted the curb then rotated 180 degrees.

V2 impacted V1 again
Vehicle Damage

Door Extrication - low profile
Delta V = 15 mph
PDOF = -80
Demographic - Interior Contacts

Driver
Near side SS214
Unrestrained
30 yr., Female
5’8”, 140 lbs.
Intrusions

Left B pillar - 22cm - Lat
Driver Door - 16cm - Lat
Roof rail - 12cm - Lat
Occupant Contacts

- Upper Door Panel Scuff
- Protruding Armrest scuffed
- B pillar / Door panel cracked
Treatment - Hospital Course

28 year old Female: Unrestrained in side impact. Alert at scene. Tachypneic (RR 40); tachycardic (125); SBP 100. Intubated in field.

Initial Evaluation: Intubated, BP 145/108
   L eye brow laceration

Hospital Course: 
   Abdominal CT: small liver and spleen lacs
   Extubated on day of admission
   Nonoperative management of pelvic fx
   Day 6: Discharged home (WB as tolerated)
## Injuries

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>AIS</th>
<th>MAIS</th>
<th>ISS</th>
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<td><strong>Face</strong></td>
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<td></td>
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<tr>
<td></td>
<td>L eye brow laceration</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chest</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>L rib fxs (2-12)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>w/hemothorax</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Abdomen</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L liver laceration</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Splenic laceration</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td><strong>Lower Extremity</strong></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>L iliac crest fx (comminuted)</td>
<td>3</td>
<td>4</td>
<td>29</td>
</tr>
</tbody>
</table>
Injury Contacts
Observation Summary

L Ribs 2-12 w/ hemothorax
L sup/inf splenic lacerations
L liver laceration
L iliac wing fracture
L pubic ring fracture
CIREN Abdominal Injury Summary

<table>
<thead>
<tr>
<th>No</th>
<th>age</th>
<th>sex</th>
<th>height (M)</th>
<th>occupant position</th>
<th>restraint</th>
<th>PDOG</th>
<th>delta V (kph)</th>
<th>intrusion (cm)</th>
<th>AIS</th>
<th>abdominal injuries</th>
<th>contact point</th>
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<tbody>
<tr>
<td>A1</td>
<td>16</td>
<td>M</td>
<td>1.73</td>
<td>driver</td>
<td>lap+shldr</td>
<td>290</td>
<td>32.2</td>
<td>29</td>
<td>3</td>
<td>major spleen contusion</td>
<td>armrest</td>
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<tr>
<td>A2</td>
<td>17</td>
<td>F</td>
<td>1.65</td>
<td>FR pass.</td>
<td>none</td>
<td>50</td>
<td>46.7</td>
<td>40</td>
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<td>moderate liver and spleen lacerations</td>
<td>armrest/door panel</td>
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<tr>
<td>A3</td>
<td>24</td>
<td>F</td>
<td>1.65</td>
<td>driver</td>
<td>lap+shldr</td>
<td>330</td>
<td>54.7</td>
<td>61</td>
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<td>spleen and diaphragm lac, kidney cont.</td>
<td>armrest/door panel</td>
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<tr>
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<td>M</td>
<td>1.88</td>
<td>driver</td>
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<td>280</td>
<td>unk</td>
<td>14</td>
<td>4</td>
<td>major spleen laceration</td>
<td>armrest</td>
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<td>1.63</td>
<td>driver</td>
<td>lap+shldr</td>
<td>250</td>
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<td>15</td>
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<td>moderate spleen laceration</td>
<td>armrest</td>
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<td>89</td>
<td>M</td>
<td>1.57</td>
<td>driver</td>
<td>lap+shldr</td>
<td>280</td>
<td>37</td>
<td>29</td>
<td>4</td>
<td>major lac, abdominal arteries, kidney cont</td>
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<td>3</td>
<td>spleen and liver contusions</td>
<td>armrest</td>
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<td>7</td>
<td>M</td>
<td>1.27</td>
<td>Rear L pass</td>
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<td>48.3</td>
<td>50</td>
<td>3</td>
<td>moderate spleen laceration</td>
<td>armrest</td>
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<td>A9</td>
<td>54</td>
<td>F</td>
<td>1.68</td>
<td>driver</td>
<td>lap+shldr</td>
<td>left lat</td>
<td>unk</td>
<td>26</td>
<td>3</td>
<td>minor kidney cont, retroper, hematomata</td>
<td>armrest</td>
</tr>
<tr>
<td>A10</td>
<td>28</td>
<td>F</td>
<td>1.68</td>
<td>Rear L pass</td>
<td>lap+shldr</td>
<td>270</td>
<td>30.6</td>
<td>19</td>
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<td>43</td>
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<td>47</td>
<td>F</td>
<td>1.70</td>
<td>driver</td>
<td>lap+shldr</td>
<td>270</td>
<td>19.3</td>
<td>10</td>
<td>3</td>
<td>moderate spleen laceration</td>
<td>armrest</td>
</tr>
</tbody>
</table>

| means | 34 | 6M,6F | 1.68 | 36.7 | 30 | 3.3 |

Derived from Abdominal Injuries

Most of all abdominal injury patterns associated with the armrest

Mean Age 34 yrs.
Mean Delta V 36.7 kph/22.8 mph
Mean Intrusion 30.0 cm/11.8 inches
Mean AIS 3.3
Side Impacts and Pelvic Injuries

Lateral Pelvis

Bilateral Pelvis
Pelvic Fracture Case Review
Door Panel Intrusion
Pelvic Fractures

Pelvic fx

Left Femur Fx
Lower Lateral Door Intrusion Associated With Pelvic Fractures

Comminuted pubic rami fracture
Left side impact with Light Truck - Unrestrained Driver
Case Vehicle - 2001 Toyota Tacoma
Struck by a 1994 Toyota Pickup

Bilateral Pelvis

Case occupant - 21 year old, female

Front right passenger - Lap/shoulder belt
Vehicle Inspection

Smash Missing-\(\Delta v\) = 30kph/18.6mph
BES = 39kph/24.4mph

Lateral PDOF
Door panel intrusion = 45 cm/17.7 inches
Contact evidence on door/center console
Case Vehicle - 2001 Toyota Tacoma
Pelvis

Comminuted fracture of the superior ramus of the right obturator ring which extends into the pubic symphysis. The fracture also extends into the inferior ramus. Comminuted fracture within the superior ramus of the left obturator ring extending into the pubic symphysis.
### CIREN Pelvic Injury Summary

**Mean Age** 30 yrs.

**Mean Delta V** 36.1 kph/22.5mph

**Mean Intrusion** 24.9 cm/9.8 inches

**Mean AIS** 3.1

Various pelvic fracture patterns associated with the door panel injury source

<table>
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<th>occ. pos.</th>
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<th>delta V (kph)</th>
<th>intrusion (cm)</th>
<th>AIS</th>
<th>pelvic injury</th>
<th>Contact point</th>
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<tr>
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<td>50</td>
<td>F</td>
<td>1.68</td>
<td>driver</td>
<td>lap+shldr</td>
<td>290</td>
<td>40.2</td>
<td>23</td>
<td>3</td>
<td>Bilateral obturator ring and sacral fx</td>
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<td>L parasympathetic/pubic ramus fx</td>
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<tr>
<td>P3</td>
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<td>25</td>
<td>3</td>
<td>Fx Sacrum/coccyx; Fx L pubis-closed</td>
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<td>1.65</td>
<td>driver</td>
<td>shldr only</td>
<td>320</td>
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<td>10</td>
<td>3</td>
<td>L Fx acetabulum; L Fx of pubis w/SI widening</td>
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<td>P5</td>
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<td>1.55</td>
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<td>lap+shldr</td>
<td>280</td>
<td>38.6</td>
<td>24</td>
<td>3</td>
<td>L pelvic root fx/SI widening; Zone I Sacral Fx</td>
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<td>19</td>
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<td>1.75</td>
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<td>26</td>
<td>3</td>
<td>L zone III sacral fx (buckle); L superior/inferior rami fx</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P7</td>
<td>36</td>
<td>F</td>
<td>1.57</td>
<td>driver</td>
<td>lap+shldr</td>
<td>280</td>
<td>41.8</td>
<td>20</td>
<td>4</td>
<td>R SR/IR buckle fx; R zone II sacral fx; R acetabular buckle vs pubic root with arterial bleeding</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P8</td>
<td>18</td>
<td>F</td>
<td>1.63</td>
<td>driver</td>
<td>shldr only</td>
<td>280</td>
<td>22.5</td>
<td>13</td>
<td>3</td>
<td>L displ. Acetabular fx; L iliac wing fx; L inf. Pubic ramus</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P9</td>
<td>30</td>
<td>F</td>
<td>1.73</td>
<td>driver</td>
<td>none</td>
<td>280</td>
<td>24.1</td>
<td>16</td>
<td>3</td>
<td>L iliac wing fx / pubic ring fx inf.</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P10</td>
<td>31</td>
<td>M</td>
<td>1.70</td>
<td>driver</td>
<td>lap+shldr</td>
<td>270</td>
<td>28.9</td>
<td>36</td>
<td>2</td>
<td>Both zone I sacral alar fx; R pubic rami fx; L sup/inf pubic ramus and pubic root fx; L ant. wall and pubic root fx</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P11</td>
<td>23</td>
<td>F</td>
<td>1.73</td>
<td>driver</td>
<td>lap+shldr</td>
<td>290</td>
<td>46.7</td>
<td>34</td>
<td>5</td>
<td>Pelvic fx w/large ruptured retroperitoneal hematoma</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P12</td>
<td>22</td>
<td>F</td>
<td>1.78</td>
<td>driver</td>
<td>lap+shldr</td>
<td>300</td>
<td>35.4</td>
<td>27</td>
<td>3</td>
<td>L pelvic fx extending to sup/inf pubic ramus, L acetabulum, L iliac wing, w/Sl, symphysis pubis disp.</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P13</td>
<td>35</td>
<td>F</td>
<td>1.60</td>
<td>driver</td>
<td>lap+shldr</td>
<td>330</td>
<td>25.7</td>
<td>9</td>
<td>3</td>
<td>Bilateral pubic root fx, superior; L zone 5 sacral alar fx</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P14</td>
<td>23</td>
<td>M</td>
<td>1.88</td>
<td>driver</td>
<td>lap+shldr</td>
<td>290</td>
<td>33.8</td>
<td>24</td>
<td>3</td>
<td>L zone II sacral fx; L inf/sup pubic rami fx</td>
<td>Door Panel</td>
</tr>
<tr>
<td>P15</td>
<td>24</td>
<td>M</td>
<td>1.83</td>
<td>driver</td>
<td>lap+shldr</td>
<td>240</td>
<td>30.6</td>
<td>47</td>
<td>3</td>
<td>L zone I sacral fx; L inf. Pubic root fx; L parasympathetic fx; L inf. Pubic rami fx</td>
<td>Door Panel</td>
</tr>
</tbody>
</table>

**Means** 30 3M,12F 1.69

<table>
<thead>
<tr>
<th>delta V (kph)</th>
<th>intrusion (cm)</th>
<th>AIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.1</td>
<td>24.9</td>
<td>3.1</td>
</tr>
</tbody>
</table>
San Diego CIREN Project

Principal Investigators:
David B. Hoyt, MD, FACS
Brent Eastman, MD, FACS

Presenter:
Carol Conroy, MPH, PhD
Research Question

Are vehicles with raised center consoles associated with pelvic injury in nearside crashes?
Selection Criteria

- NASS CDS and CIREN databases used

- Identify vehicles with raised center consoles
  - Assumed no change over +/- 2 model years
  - Assumed console standard equipment
  - Only 1998-2004 model years included
Selection Criteria

- Only nearside impact crashes
- Only drivers or front right seat passengers included
- Only pelvic and hip injuries included
Methods

- Missing data excluded from analyses

- Injury assessed by Abbreviated Injury Scale (AIS)

- Total Delta V used to assess speed at impact
  - BES used when Total Delta V was missing
Profile: Occupants with moderate (AIS 2) and serious (AIS 3) pelvic injury in nearside crashes

<table>
<thead>
<tr>
<th></th>
<th>Console (41 occupants)</th>
<th>No console (21 occupants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age and range</td>
<td>40 years (15-89 years)</td>
<td>43 years (15-80 years)</td>
</tr>
<tr>
<td>Gender</td>
<td>33 (80%) women</td>
<td>11 (52%) women</td>
</tr>
<tr>
<td>Single pelvic injury</td>
<td>16 (39%)</td>
<td>8 (38%)</td>
</tr>
<tr>
<td>Driver</td>
<td>29 (71%)</td>
<td>13 (62%)</td>
</tr>
<tr>
<td>Seatbelt Use</td>
<td>36 (88%)</td>
<td>19 (90%)</td>
</tr>
<tr>
<td>Total Delta V (kmph)</td>
<td>Mean 36</td>
<td>Mean 35</td>
</tr>
<tr>
<td></td>
<td>Median 33</td>
<td>Median 31</td>
</tr>
</tbody>
</table>
Moderate (AIS 2) and serious (AIS 3) pelvic injury in nearside crashes by magnitude of intrusion
Limitations

- Results may not be representative
- Small sample size
- Possible misclassification bias of console status
- NASS intrusion is measured at the maximum point of intrusion on the door panel
  - May not be at the occupant’s seat location
Conclusion

This exploratory study found it may be important to continue researching the role of consoles and pelvic injury in nearside crashes.
Results – CIREN Summary

• Thoracic injuries, AIS of 4.2, door panel main injury source, intrusion 34cm, \( \Delta V \) of 25 mph. Injuries multiple rib fractures with hemothorax, or pneumothorax, with lung contusions and lacerations.

• Abdominal injuries, AIS of 3.3 armrest main injury source, intrusion 30cm, \( \Delta V \) 23 mph. Injuries, 9 spleen lacerations or contusions, 3 liver lacerations or contusions, 3 kidney contusions, 2 diaphragm lacerations, and 2 retroperitoneal hemorrhage.

• Pelvic injuries, AIS of 3, door panel main injury source, intrusion 25cm, \( \Delta V \) 22 mph. Injuries included pelvic fx with 11 involving the sacrum.
Vehicle weight, door intrusion, wheelbase correlate to pelvic g

All variables explain about 58% of pelvic g variation
CIREN Example and Console Data
Pelvic Acceleration and Console Trapping
Results - Peak Pelvic g vs Center Console

without center consoles, 69.4g
sd = 19.7g, n = 41

with center consoles, 77.3g
sd = 21.8g, n = 96

(p = 0.05)
## Results - Vehicle Variables and NCAP Thoracic Trauma Index (TTI)

<table>
<thead>
<tr>
<th>variable</th>
<th>TTI</th>
</tr>
</thead>
<tbody>
<tr>
<td>overall r squared</td>
<td>0.410</td>
</tr>
<tr>
<td>overall p value</td>
<td>0.030</td>
</tr>
<tr>
<td>vehicle weight</td>
<td>0.064</td>
</tr>
<tr>
<td>max door intrusion</td>
<td>0.191</td>
</tr>
<tr>
<td>max intrusion height</td>
<td>0.976</td>
</tr>
<tr>
<td>max intrusion level</td>
<td>0.779</td>
</tr>
<tr>
<td>max door velocity</td>
<td>0.049</td>
</tr>
<tr>
<td>door velocity diff</td>
<td>0.756</td>
</tr>
<tr>
<td>door acceleration</td>
<td>0.128</td>
</tr>
<tr>
<td>wheelbase</td>
<td>0.926</td>
</tr>
<tr>
<td>panel deflection</td>
<td>0.866</td>
</tr>
<tr>
<td>dummy H point</td>
<td>0.550</td>
</tr>
</tbody>
</table>

- Vehicle weight and max door velocity correlate to TTI.
- All variables explain about 41% of TTI variation.

\[
\text{TTI} = 60.595 - 0.029 \times \text{weight} + 0.928 \times \text{door velocity} - 0.121 \times \text{door acceleration} + 0.702 \times \text{door intrusion}
\]
Results – NCAP TTI and Thoracic Airbags

without thoracic airbag, 63.7g
ds = 20.7g, n = 108

with thoracic airbag, 55.6g
ds = 13.7g, n = 54
(p = 0.003)
Results - Is Door Intrusion Related to Vehicle Weight or Wheelbase?

Door intrusion, weak correlation to wheelbase ($r^2 = 0.15$)
Door intrusion, none to vehicle weight ($r^2 = 0.003$, NS)
Results – Does Peak Pelvic g Correlate to Peak TTI?

\[ y = 0.76x + 29. \]

\[ R^2 = 0.4 \]
Results – NASS MAIS v Door Intrusion

\[ y = 0.05x + 1.6 \]

\[ R^2 = 0.9 \]
Discussion - Limitations

- NCAP tests, moving barrier simulates smaller vehicle
- NCAP doesn’t consider door beam over-ride from high SUV and truck bumpers
- More biofidelic dummies than DOT-SID available
- TTI may not correlate well with actual injuries
- Effects of occupant stature and age not considered
- NASS, plot of data only of those in group who were injured (ie AIS 1+)
Summary of Findings

• For a given vehicle weight, door intrusion, wheelbase correlate to pelvic g, and door velocity to TTI

• Vehicle variables studied only account for 41% of TTI, 58% of pelvic g variation

• A center console increases peak pelvic g

• A thoracic airbag lowers peak TTI

• Real-world crash studies also show correlation of door intrusion and thoracic and pelvic injury

• Door intrusion is not directly related to vehicle weight but increases with greater wheelbase
Future Work

There is still considerable debate over appropriate chest injury criteria, Favg * Cmax, Cmax, stored energy (Cheung '99)

Using highly detailed CIREN crash data and data from equivalent NCAP tests, to model actual crashes and compare real life injuries to crash dummy measurements in the same crash.