Biomechanics and Medical Diagnosis of HVI in Adults and Children – An Illustration of the CIREN Model

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Introduction

- HVI – Hollow Viscous Injury
- Complicated diagnosis and treatment
- Common injury in automobile crashes
- Children at risk due to smaller anatomy
Abdominal Anatomy

- Diaphragm
- Liver
- Stomach
- Spleen
- Kidney
Abdominal “Solid” Organs

- Liver - 27% of total blood flow
- Spleen - 5% of total blood flow
- Kidneys - 22% of total blood flow
- Pancreas
- Adrenal Glands
Abdominal “Solid” Organs

Primary Injury Concern
Hemorrhage

Diagnosis
Accurate
Abdominal “Hollow” Organs

- Stomach
- Small Intestine
  - Duodenum, Jejunum, Ileum
- Large Intestine
  - Ascending, Transverse,
  - Descending, Sigmoid
- Gall Bladder
- Urinary Bladder
Abdominal “Hollow” Organs

Primary Injury Concern: Spillage of Contents
Sepsis

Diagnosis Inaccurate
HVI Issues

• Trauma surgeons are increasingly managing blunt abdominal trauma non-operatively
• Intestinal injuries that were previously discovered at laparotomy for solid organ injuries may be missed with non-operative management
• In older reports, delays in diagnosis of less than 12-24 hours were associated with limited morbidity and no mortality
• Longer delays result in significantly increased morbidity and mortality
Surgeon’s Dilemma

• There is no well-publicized consensus among trauma surgeons as to the optimal way to diagnose occult intestinal injury

• Debate over using exploratory surgery as a diagnostic tool focuses on whether or not the risks associated with a non-therapeutic laparotomy outweigh the morbidity and mortality associated with a delay in the diagnosis of small bowel injury
Diagnosis and Management of Blunt Small Bowel Injury: A Survey of the Membership of the American Association for the Surgery of Trauma

Brownstein, Bunting, Meyer, Fakhry

University of North Carolina, Chapel Hill, NC and the Inova Regional Trauma Center, Falls Church, VA
Conclusions

Significant variation exists in the diagnostic approach

- Surgeons underestimated the morbidity of non-therapeutic laparotomy and the mortality associated with a delay in diagnosis

- The lack of consensus regarding the diagnostic approach may have undesirable effects on injured patients
Hollow Viscous Injury and Small Bowel Injury in Blunt Trauma: An analysis of 275,557 trauma admissions from the EAST Multi-Institutional Trial

EAST Multi-Institutional HVI Research Group

Conclusions

- Motor Vehicle Crashes (MVC) was the most frequent mechanism of injury in patients with perforating SBI.
- Logistic regression models of CT data yielded no useful discriminators in predicting SBI.
- Patients from MVCs had a relative risk (RR) of SBI of 1.7.
- The non driver position increased the risk of perforating SBI (RR = 1.9, 95% CI 1.6-2.3).
- Use of a seat belt increased the risk of perforating SBI (RR = 2.4, 95% CI 2.0-2.8).
- Delay in treatment of SBI injuries increased treatment complications.
The presence of an abdominal seatbelt mark was the most significant risk factor, carrying a 4.7 increase in relative risk (95% CI 3.7 - 5.9)
Biomechanics Research
Hollow Viscous Organs
Submarining

courtesy of ESI
Reasons for Booster Seats

Practical concerns

- Prevent slouching due to leg length
- Slouching degrades fit for both lap and shoulder belt
- Reduces misuse of shoulder belt

Knees at edge of seat
Lap Belt Only – Seat Belt Syndrome

HVI

Lumbar Spine

Gumler et al., 1982
Side Impact

Near Side

Ruptured Bladder

Far Side

Belt Loading
Stolinski et al., 1998
Injuries

• Contusion, perforations, transections, lesions

• Mechanisms of Injury
  – Increased intraluminal pressure
  – Perforation from rib and pelvic fractures
  – Shearing or crushing against spine
  – Deceleration (relative motion from fixed attachments - mesentery)
“Blowout” of Intestines caused by high intraluminal pressures

Steering Wheel or Lap Belt Loading

Feliciano, 1996
AIS ≥ 2 Hollow Viscous Injury Sources - Frontal Impact

Front:
- Steering Assembly
  - Instrument Panel
    (52%)

Side Interior:
- Surface
- Armrests
  (9%)

1977-1979

Belt Restraint
  (4%)

Bondy, 1977-1979
AIS ≥ 3 Abdominal Injury Distribution - Frontal Impact

Liver (30%)

Urogenital (7%)

Kidney (22%)

Digestive (12%)

Spleen (22%)

Bondy, 1980
Early Research Focused on Steering Wheel Contact
Abdominal Injury Corridors (Trollope, 1972)

Squirrel Monkeys, Rhesus Monkeys, Baboons, Pigs

Estimated Severity Index
(ESI 3 = moderate)

\[
\frac{Ft^2}{MA^{0.5}}
\]

F = force of impact
\( t = \) duration of impact
M = Mass of test subject
A = Contact area
Porcine Test

- Test frame mounted on Hyge sled ($\Delta V=32 \text{ km/h}$)
- Anesthetized subject supported by suspension suit attached to trolley
- Lower steering wheel rim impacted torso at liver

Abdominal Impact Tests

(Nusholtz, 1985)
AIS ≥ 3 Hollow Viscous Injury Sources - Frontal Impact

Front:
- Steering Assembly (39%)

Side Interior:
- Surface
- Armrests (5%)

Belt Restraint (56%)

Elhagediab and Rouhana 1988-1994
AIS ≥ 3 Abdominal Injury Distribution - Frontal Impact

Liver (38%)

Urogenital (3%)

Kidney (4%)

Spleen (23%)

Digestive (17%)

Elhagediab & Rouhana 1988-1994
Seatbelt Loading of Abdomen

Injuries

Mesentery
Duodenum
Small bowel
Large bowel
Cecum

Miller (1988)
AIS ≥ 2 Hollow Viscous Injury Sources - Frontal Impact

Front:
- Steering Assembly (27%)
- Instrument Panel

Side Interior:
- Surface (15%)
- Armrests

Belt Restraint (59%)

Lee & Yang, 2002
AIS ≥ 3 Abdominal Injury Distribution - Frontal Impact

Liver (35%)

Kidney (7%)

Spleen (31%)

Urogenital (N/A)

Digestive (15%)

Lee and Yang, 2002
Unbelted occupant with airbags
Steering Wheel Contact Despite Airbag
Airbag Loading of Abdomen

Cadaveric tests with loading to abdomen
Hardy et al. (2001)

Injuries
Colon, Mesentery, Peritoneum
Recent Advances

Force Limiter

Improve torso pitch

Lap belt pretensioners

Reduce slack and submarining

Trosseille et al. (2002)

Steffan et al. (2002)
Steering wheel impacts to abdomen
Dummy and cadaver
Shaw et al. (2004)
Hollow Viscous Injury
Analysis of CIREN Data
CIREN Query

- Hollow Viscous Injury
- No rollovers
- No ejections
- 16 years and older
- Driver and Front Right Passenger

Stomach
Small Intestine
• 61% of HVI in Frontal Crash with PDOF 330-30
• 33% in Right (30-150) or Left (210-330)
Demographics of CIREN HVI Cases

FRONTAL CRASHES

• Incidence  39 / 856 drivers had HVI (4.6%)
   12 / 224 pass had HVI (5.4%)

• Injuries  62 injuries - 39 drivers
   25 injuries - 12 passengers

• 39 drivers – 50% Belted, 50% Unbelted
• 12 pass – All Belted
### Demographics of CIREN HVI Cases

**SIDE CRASHES**

- **Incidence**
  - 18/348 NEAR Side had HVI (4.6%)
  - 9 / 132 FAR Side had HVI (6.8%)

- **Injuries**
  - 24 injuries - 18 NEAR Side
  - 23 injuries - 9 FAR Side

- **SEAT BELT USE**
  - 18 NEAR Side – 72% Belted, 18% Unbelted
  - 9 FAR Side – 55% Belted, 45 % Unbelted
## Frontal Crashes

<table>
<thead>
<tr>
<th></th>
<th>Driver</th>
<th></th>
<th>Passenger</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>% all HVI</td>
<td>N</td>
<td>% all HVI</td>
</tr>
<tr>
<td>Colon</td>
<td>13</td>
<td><strong>21</strong></td>
<td>7</td>
<td>28</td>
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<tr>
<td>Mesentery</td>
<td>27</td>
<td><strong>44</strong></td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Small Bowel</td>
<td>12</td>
<td><strong>19</strong></td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>Bladder</td>
<td>4</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Duodenum</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stomach</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Omentum</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Driver Injury Source** – 53% SW (11 belt, 22 unbelt)

**Pass Injury Source** – 36% Belt

80% Belt
## Side Crashes

<table>
<thead>
<tr>
<th></th>
<th>Near Side</th>
<th></th>
<th>Far Side</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>N</td>
<td>% all HVI</td>
<td>N</td>
<td>% all HVI</td>
</tr>
<tr>
<td>Colon</td>
<td>5</td>
<td>21</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>Mesentery</td>
<td>8</td>
<td>33</td>
<td>8</td>
<td>35</td>
</tr>
<tr>
<td>Small Bowel</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td>Bladder</td>
<td>8</td>
<td>33</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Duodenum</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stomach</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Omentum</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Near Side Injury Source – 50% Interior, Belt 21%

Far Side Injury Source – 83% Belt
### All Crash Types, AIS 2+ HVI

**Bondy 1977-79 – 7% belted**

**CIREN 1996-2003 – 64% belted**

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Frontal</th>
<th>Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bondy</td>
<td>63 %</td>
<td>24.4 %</td>
</tr>
<tr>
<td>CIREN</td>
<td>65 %</td>
<td>34.6 %</td>
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</table>

<table>
<thead>
<tr>
<th>Injury Source</th>
<th>SW</th>
<th>Belt</th>
<th>Side</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bondy</td>
<td>46 %</td>
<td>4 %</td>
<td>18 %</td>
<td>33 %</td>
</tr>
<tr>
<td>CIREN</td>
<td>25 %</td>
<td>50 %</td>
<td>11 %</td>
<td>13 %</td>
</tr>
</tbody>
</table>
## Frontal Crashes

Elhagediab & Rouhana 1988-94 – AIS 3+
CIREN 1996-2003 – AIS 2+

<table>
<thead>
<tr>
<th></th>
<th>Unbelted No Airbag</th>
<th>Belted No Airbag</th>
<th>Unbelted Airbag</th>
<th>Belted Airbag</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elhagediab</strong></td>
<td>40 %</td>
<td>60 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td><strong>CIREN</strong></td>
<td>15 %</td>
<td>14 %</td>
<td>21 %</td>
<td>51 %</td>
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</tbody>
</table>
HVI Injury Source Changes Over Time

Contact Structure % of HVI

- Front/SW
- Side Interior
- Belt Restraint

NASS Years:
- 1977-1979
- 1988-1994
- 1993-1997

- Steering Wheel
- Belts
CIREN Case Examples
Case # 1 – Frontal Crash
Belted Adult in Rear Seat

1997 Honda Accord
CDC: 12FYEW3
PDOF: 10 degrees
ΔV: 33 km/h/21 mph
Scene Diagram Showing Point of Impact
Age: 53
Gender: Female
Position: Right Rear
Weight: 120 lbs.
Height: 5’4”
Safety Device: 3-point restraint

Clavicle fx
Jejunal perforation
<table>
<thead>
<tr>
<th>Injuries (ICD)</th>
<th>AIS Severity</th>
<th>Info Source</th>
<th>Aspect</th>
<th>Contact Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jejunal perforation (863.20)</td>
<td>541424.3</td>
<td>Surgery</td>
<td>Right</td>
<td>SB</td>
</tr>
<tr>
<td>Flank contusion (922.8)</td>
<td>590402.1</td>
<td>Exam</td>
<td>Left</td>
<td>SB</td>
</tr>
</tbody>
</table>
Case # 2 – Frontal Crash
Belted Adult Driver

1999 Kia Sportage SUV
CDC: 12FDEW4
PDOF: 350
ΔV: 37 kmph/23 mph
Scene Diagram Showing Point of Impact

Case Vehicle in red
<table>
<thead>
<tr>
<th>Age</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
</tr>
<tr>
<td>Position</td>
<td>Driver</td>
</tr>
<tr>
<td>Weight</td>
<td>340 lbs.</td>
</tr>
<tr>
<td>Height</td>
<td>6’2”</td>
</tr>
<tr>
<td>Safety Devices:</td>
<td></td>
</tr>
<tr>
<td>3-point restraint</td>
<td></td>
</tr>
<tr>
<td>Pretensioner</td>
<td></td>
</tr>
<tr>
<td>Airbag</td>
<td></td>
</tr>
<tr>
<td>Knee Airbag</td>
<td></td>
</tr>
</tbody>
</table>
Steering Wheel Contact
340 pound driver

Concussion
Liver contusion
Mesentery, Duodenum Lacerations
Bilateral Femur fractures
Metatarsal, navicular, cuboid fxs
Case # 3 – Frontal Crash
Misuse of Shoulder Belt, Child

2001 Toyota 4Runner SUV
CDC: 11LYEW44
PDOF: 330
ΔV: 34 kmph/21 mph
Scene Diagram Showing Point of Impact

Case Vehicle in red
Age: 6
Gender: Male
Position: Right Rear
Weight: 42 lbs.
Height: 42”
Safety Device:
3-point restraint with shoulder belt worn behind back

Jejunum serosal laceration
Mesentery contusion
Colon contusion
Retroperitoneal hematoma
Case # 4 – Side Crash
Belted Far Side Adult

1998 Toyota Camry
CDC: 02RYAW3
PDOF: 50
ΔV: 44 kmph/27 mph
Scene Diagram Showing Point of Impact
Colonic laceration
Pelvic fracture

Belt Load on Abdomen

Age: 56
Gender: Female
Position: Driver
Weight: 146 lbs.
Height: 5’4”
Safety Device: 3-point restraint
Questions?