Age Related Thresholds and Thoracic Injury

CIREN Public Meeting

March 25, 2008

Toyota – Wake Forest University
School of Medicine
CIREN Center
Impact of Age on Thoracic Injuries

- Scope of the problem
- Impact of thoracic injuries on the elderly
- Impact of age on rib fractures and pulmonary contusion in CIREN
- Impact of age on rib fractures and pulmonary contusion in NASS and NTDB
- Volumetric assessment of pulmonary contusion
Percent US Population Above 65 Years Old

Year

2000 2010 2020 2030 2040 2050

Percent (%)

0 5 10 15 20 25

US Census, 2000
Percent Change by Age: 1990 to 2000
(For information on confidentiality protection, nonsampling error, and definitions, see www.census.gov/prod/cen2000/doc/sf1.pdf)

Aging in America

- Rib fractures are most common thoracic injury in the elderly
- Pulmonary contusion is the most common soft tissue injury of the thorax in the elderly
Effect of Age on Thorax

- Less deformation in response to loading
- Rib cage morphology changes with age
  - U of Michigan, 2006 CI REN meeting
- Bone demonstrates thin cortical shell and “brittle” material properties
## Database Selection

<table>
<thead>
<tr>
<th>Database</th>
<th># of cases</th>
<th>Detail</th>
<th>Outcome data</th>
<th>Crash data</th>
<th>Image analysis</th>
<th>Physiologic data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local CI REN</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>CI REN</td>
<td>+</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>NASS</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>NTDB</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
<td>+++</td>
</tr>
</tbody>
</table>
Age-Related Mortality Thresholds

- National Trauma Databank / CIREN study
- Identification of isolated injuries in NTDB
- Creation of Receiver Operator Characteristic curves
  - Serial assessment of each age
- Identification of age that maximizes sensitivity and specificity for determining mortality
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>450232.4</td>
<td>RIB CAGE, FRACTURE, &gt; 3 RIBS ON ONE SIDE AND &lt;= 3 RIBS ON OTHER SIDE, STABLE CHEST OR NFS, WITH HEMO/PNEUMO THORAX</td>
<td>42</td>
</tr>
<tr>
<td>441406.3</td>
<td>LUNG, CONTUSION, UNILATERAL</td>
<td>68</td>
</tr>
<tr>
<td>450230.3</td>
<td>RIB CAGE, FRACTURE, &gt; 3 RIBS ON ONE SIDE AND &lt;= 3 RIBS ON OTHER SIDE, STABLE CHEST OR NFS</td>
<td>40</td>
</tr>
<tr>
<td>450222.3</td>
<td>RIB CAGE, FRACTURE, 2-3 RIBS ANY LOCATION OR MULTIPLE FRACTURES OF SINGLE RIB, WITH STABLE CHEST OR NFS WITH HEMO/PNEUMOTHORAX</td>
<td>42</td>
</tr>
<tr>
<td>450242.5</td>
<td>RIB CAGE, FRACTURE, &gt; 3 RIBS ON EACH OF TWO SIDES, WITH STABLE CHEST OR NFS, WITH HEMO/PNEUMO THORAX</td>
<td>40</td>
</tr>
<tr>
<td>442202.3</td>
<td>THORACIC CAVITY INJURY NFS WITH HEMO/PNEUMOTHORAX</td>
<td>40</td>
</tr>
<tr>
<td>441410.4</td>
<td>LUNG, CONTUSION, BILATERAL</td>
<td>40</td>
</tr>
<tr>
<td>450266.5</td>
<td>RIB CAGE, FRACTURE, FLAIL (UNSTABLE CHEST WALL), BILATERAL</td>
<td>56</td>
</tr>
<tr>
<td>450214.3</td>
<td>RIB CAGE, FRACTURE, 1 RIB, WITH HEMO/PNEUMOTHORAX</td>
<td>63</td>
</tr>
<tr>
<td>450264.4</td>
<td>RIB CAGE, FRACTURE, FLAIL CHEST (UNSTABLE CHEST WALL), WITH LUNG CONTUSION</td>
<td>41</td>
</tr>
</tbody>
</table>
NTDB Injury Thresholds

- Based on large database
- Ages appear young but represent observed inflection point
- Indicative of progressive process
- Impact of injury likely dependent on physiologic reserve
Age Effect Controlling for AIS

- To evaluate effects of age on thoracic injury severity
- Database: NTDB
- Severity of injury score (AIS) for thoracic injuries compared
  - Rib fractures, pulmonary contusion
- Isolated injuries
  - Impact of multiple injuries not captured
Mortality by Thoracic Abbreviated Injury Scale (AIS)

Mortality by Isolated Thoracic AIS in NTDB

Mortality by Isolated Thoracic AIS in NTDB
Mortality by Rib Fracture AIS

Mortality by Isolated Rib Fracture AIS in NTDB

- Percent Mortality (%)
- AIS

Mortality by Isolated Rib Fracture AIS in NTDB

- Percent Mortality (%)
- AIS
- < 65 yo
- >= 65 yo
Mortality by Pulmonary Contusion AIS

Mortality by Isolated Pulmonary Contusion AIS in NTDB

Mortality by Isolated Pulmonary Contusion AIS in NTDB

< 65 yo

>= 65 yo
Thoracic Injuries - T/WFU CIREN

- T/WFU CIREN Center cases were reviewed to characterize thoracic injuries with respect to age
- 96 total cases
- Determination of rib fracture number ($\alpha$ AIS) and presence of pulmonary contusion
  - Relationship with age
Patient Age According to Number of Rib Fractures in Patients that Sustained Rib Fractures

<table>
<thead>
<tr>
<th>Number of Rib Fractures</th>
<th>Average Patient Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 or Fewer Rib Fractures</td>
<td>44</td>
</tr>
<tr>
<td>Between 4 and 8 Rib Fractures</td>
<td>48</td>
</tr>
<tr>
<td>Greater than 8 Rib Fractures</td>
<td>52</td>
</tr>
</tbody>
</table>
Thoracic Injuries According to Age

- % Patients with Pulmonary Contusion in Each Age Range
- % Patients with Rib Fractures in Each Age Range

Patient Age (years)

Percent of Patients in Each Age Range

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

0-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80 81-90
Thoracic Injury According to Age

% of CIREN Patients with Thoracic Injury

Patient Age (years)

- 11-20
- 21-30
- 31-40
- 41-50
- 51-60
- 61-70
- 71-80
- 81-90

- Patients with PC
- Patients with Rib Fractures
Age Comparison of Thoracic Injury

Average Patient Age (years)

Both Pulmonary Contusion and Rib Fractures

ONLY Rib Fractures

ONLY Pulmonary Contusion
Thoracic Injuries in CI REN

- CI REN cases were evaluated to characterize thoracic injuries with respect to age
- 1996 to 2006
- Rib fracture and pulmonary contusion cases identified
  - Relationship with age
  - Characterization of crash severity
Thoracic Injuries in CIREN

Crash severity characterized by change in velocity (Delta V)
- Mild: Delta V 0 to 24.1 km/h
- Moderate: Delta V 24.2 to 48.2 km/h
- Severe: Delta V ≥ 48.3 km/h
Age Distribution in CI REN

![Bar graph showing age distribution]

- Frequency on the y-axis.
- The highest frequency is in the 20-29 age group, followed by 10-19, 30-39, 40-49, 50-59, 60-69, 70-79, and the lowest in the 80+ group.
Injury Distribution - CI REN

Percent of Age Group with Rib Fractures and Pulmonary Contusion

Age (years) vs. Percent of Age Group (%)

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -

Legend:
- Orange square: PC +, RibFX +
- Purple square: PC +, RibFX -
- Blue triangle: PC -, RibFX +
- Red square: PC -, RibFX -
Injury Distribution – CI REN by Crash Severity

Percent of Age Group with Rib Fractures and Pulmonary Contusion in Low Severity Crashes

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -

Age (years)
Percent of age group (%)
10-19 20-29 30-39 40-49 50-59 60-69 70-79 80+
Injury Distribution – CI REN
by Crash Severity

Percent of Age Group with Rib Fractures and Pulmonary Contusion in Moderate Severity Crashes

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -
Injury Distribution – CI REN
by Crash Severity

Percent of Age Group with Rib Fractures and Pulmonary Contusion in High Severity Crashes

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -
Percent Pulmonary Contusion by Age Among Total Study Group and Rib Fracture Patients

- Percent of total sample population
- Percent of patients with rib fractures
Thoracic Injuries in NASS

- NASS cases were evaluated to characterize thoracic injuries with respect to age
- 2000 – 2006 cases reviewed
- Rib fracture and pulmonary contusion cases identified
  - Relationship with age
  - Characterization of crash severity
  - Impact of restraint systems
Injury Distribution - NASS

Percent of Age Group with Rib Fractures and Pulmonary Contusion

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -
Injury Distribution - NASS by Crash Severity

Percent of Age Group with Rib Fractures and Pulmonary Contusion in Low Severity Crashes

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -

Age (years)
Percent of Age Group (%)

10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80+
Injury Distribution – NASS by Crash Severity

Percent of Age Group with Rib Fractures and Pulmonary Contusion in Moderate Severity Crashes

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -

Age (years) vs. Percent of Age Group (%)

10-19 20-29 30-39 40-49 50-59 60-69 70-79 80+
Injury Distribution – NASS by Crash Severity

Percent of Age Group with Rib Fractures and Pulmonary Contusion in High Severity Crashes

- PC +, RibFX +
- PC +, RibFX -
- PC -, RibFX +
- PC -, RibFX -
Pulmonary Contusion – NASS

Percent Pulmonary Contusion by Age Among Total Study Group and Rib Fracture Patients

- Percent of total sample population
- Percent of patients with rib fractures

Age (years):
- 10-19
- 20-29
- 30-39
- 40-49
- 50-59
- 60-69
- 70-79
- 80+

Percent study population (%):
- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35

This bar chart illustrates the percentage of pulmonary contusion cases among different age groups within the total study population as well as among patients with rib fractures.
Rib Fractures - NASS

Percent Rib Fractures by Age and Delta V

- Low
- Moderate
- High

Crash Severity

n = 9987, 4822, 1779
Rib Fractures - NASS

Percent Rib Fractures by Delta V and Restraint Category: Age < 40

Percent Rib Fractures by Delta V and Restraint Category: Age >= 65
Pulmonary Contusion - NASS

Percent Pulmonary Contusion by Age and Delta V

- Age < 40
- Age 40 - 64
- Age >= 65

Crash Severity: Low, Moderate, High

Percent Pulmonary Contusion (%)

n = 9987, 4822, 1779
Pulmonary Contusion - NASS

Percent Pulmonary Contusion by Delta V and Restraint Category: Age < 40

Crash Severity

Unrestrained
Seatbelt
Airbag
Both Restraints

Percent Pulmonary Contusion (%)

0 5 10 15 20

Low Moderate High

Percent Pulmonary Contusion by Delta V and Restraint Category: Age >= 65

Crash Severity

Unrestrained
Seatbelt
Airbag
Both Restraints

Percent Pulmonary Contusion (%)
Pulmonary Contusion - NASS

Percent Pulmonary Contusion Per Rib Fracture by Age and Delta V

- Low
- Moderate
- High

Crash Severity

Age < 40
Age 40 - 64
Age >= 65

n = 623, 695, 423
Pulmonary Contusion - NASS

This needs further investigation
Incidence within Thoracic Injury Cohort - NTDB

Incidence of PC and Rib FX Among Patients Who Sustained At Least One of These

- PC+RIB+
- PC+RIB-
- PC-RIB+

Percent Within Group vs. Age Midpoint
Injury Incidence - NTDB

In incidence of PC and Rib FX Among All MVC Patients

Percent Within Group

Age Midpoint

PC+RIB+
PC+RIB-
PC-RIB+
PC-RIB-
Mortality of Chest Injuries - NTDB

Mortality Rate by Injury Combination and Age

- PC+RIB+
- PC+RIB-
- PC-RIB+
- PC-RIB-
Logistic Regression - NASS

- Determination of independent effect of variables on rib fractures and pulmonary contusion
- Univariate assessment to determine inclusion variables
- Stepwise multivariate logistic regression
  - Significance: $p < 0.05$
## Logistic Regression – Rib Fractures

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>95 % Confidence Interval</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>1.05</td>
<td>1.04 – 1.05</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>ISS</td>
<td>1.09</td>
<td>1.08 – 2.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Pt Height</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Pt Weight</td>
<td>1.01</td>
<td>1.005 – 1.013</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>GCS</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Vehicle weight</td>
<td>0.99</td>
<td>0.992 – 0.997</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Delta V</td>
<td>1.01</td>
<td>1.004 – 1.014</td>
<td>0.0001</td>
</tr>
<tr>
<td>Intrusion</td>
<td>1.22</td>
<td>1.14 – 1.29</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Rollover</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Airbag</td>
<td>0.81</td>
<td>0.69 – 0.96</td>
<td>0.01</td>
</tr>
<tr>
<td>Seatbelt</td>
<td>0.84</td>
<td>0.71 – 0.99</td>
<td>0.04</td>
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</table>

ROC = 0.90, GOF = < 0.0001
### Logistic Regression - Pulmonary Contusion

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>ISS</td>
<td>1.06</td>
<td>1.06 – 1.07</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Pt Height</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Pt Weight</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>GCS</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Vehicle weight</td>
<td>0.996</td>
<td>0.994 – 0.999</td>
<td>0.02</td>
</tr>
<tr>
<td>Delta V</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Intrusion</td>
<td>1.22</td>
<td>1.13 – 1.32</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Rollover</td>
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<td>NS</td>
</tr>
<tr>
<td>Airbag</td>
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<td>NS</td>
</tr>
<tr>
<td>Seatbelt</td>
<td></td>
<td></td>
<td>NS</td>
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</table>

ROC = 0.90, GOF = < 0.0001
<table>
<thead>
<tr>
<th><strong>T/WFU CI REN PC Data</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean percent high radiopacity lung tissue (%)</td>
</tr>
<tr>
<td>Percent left, right, bilateral contusion (%)</td>
</tr>
<tr>
<td>Incidence of rib fractures (%)</td>
</tr>
<tr>
<td>Incidence of pneumothorax, hemothorax (%)</td>
</tr>
<tr>
<td>Mean CT scan time post-crash (hrs)</td>
</tr>
</tbody>
</table>
Distribution of components contacted by PC+ cases T/WFU CI REN

Number of Patients

- Airbag: 4
- Center console: 3
- Instrument Panel: 2
- Near side B-pillar: 2
- Near side door: 7
- Seat belt: 2
- Steering wheel: 2
PDOF and Delta-V in T/WFU CI REN PC+ cases
Distribution of the impact mode for PC+ cases T/WFU CI REN

- Far side impact: 11%
- Frontal impact: 11%
- Near side impact: 50%
- Rollover: 28%
**Motivation for future research**

- Strategies for mitigation &/or prevention of PC require knowledge about PC Volume (outcome data)
  - Volume, spatial distribution
- Also require knowledge about exposure (crash data)
- CI REN is the place to get these together
CT Segmentation Algorithm
### Categories of Lung Tissue for Segmentation Algorithm

<table>
<thead>
<tr>
<th>Term Used</th>
<th>HU Description</th>
<th>Medical Description</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low attenuation</strong></td>
<td>-1024 HU*</td>
<td>Pneumothorax</td>
<td>This is not lung tissue, it is trapped air</td>
</tr>
<tr>
<td><strong>Lung attenuation</strong></td>
<td>-1024 HU to 351 HU*</td>
<td>Functional lung tissue</td>
<td>Aerated lung, uninvolved in trauma</td>
</tr>
<tr>
<td><strong>High attenuation</strong></td>
<td>350 HU to 3071 HU*</td>
<td>Contusion, atelectasis, aspiration, etc</td>
<td>Damaged lung, not aerated</td>
</tr>
</tbody>
</table>

*M. Daly et al., Clinical Imaging, 2007 (in press)*
CT Segmentation Algorithm

1. Original CT scan
2. Select all pixels with in 200 HU of selected pixel
3. Edit until the entire chest cavity is selected, the resulting mask is the **Total Chest Cavity** mask.
Algorithm Continued

Partition Total Chest Cavity into:

- Low Attenuation Pixel set
- Lung Attenuation Pixel set
- High Attenuation Pixel set

- Low Attenuation
  
  $$\text{HU} = -1024$$

- Lung Attenuation
  
  $$-1024 < \text{HU} \leq -351$$

- High Attenuation
  
  $$\text{HU} \geq -350$$
Calculation of Percent Pulmonary Contusion

\[
\text{Percent PC} = \frac{\text{High Attenuation Volume}}{\text{Total Lung Volume}}
\]

Three Dimensional Reconstruction, Mimics
Contusion Characterization and CT-FEA Registration Method

- Segmented Lung showing PC and normal tissue
- Determine spatial distribution of PC from radiology in A-P, M-L, H-F

Spatial distribution of PC from segmentation can be used in determining FEA-based injury metrics

CT Reconstruction

- Lung model and PC threshold developed from CT

FEA model showing predicted contusion

Gayzik et al., Stapp Car Crash Journal, 2007
T/WFU CIREN Elderly Pulmonary Contusion – Case 85

- 75 yr old female
- Driver (belted, airbag deployed)
- Frontal impact with another vehicle
- PDOF = 350 degrees
- Delta V = 42.3 mph
- MAIS = 4
- ISS = 18
- IPC for thoracic injuries listed as steering wheel
- Injuries Included:
  - Right pulmonary contusion
  - Bilateral Rib Fractures (R2-8, L2-3)
Radiological investigation of interaction between rib fractures and pulmonary contusion

For WFU CIREN patients with Rib Fx and PC in nearside and frontal crash
Case 1: Nearside impact

- Case occupant: Driver, 60, male
- Thorax Loads B-Pillar
- Crush = 33cm, PDOF = 290, Delta V = 19.4 kph
- Restraint = Seat belt
- PC by Vol = 6%

Area of detail:
Case 2: Frontal impact

- Case occupant: Driver, female, 79
- Thorax Loads Seat Belt
- Crush = 27 cm, PDOF = 0, Delta V = 37.2 kph
- Restraint = Seat belt
- PC by vol = 33%

Area of detail:

- Lung Contusion
- Rib Fractures (Right side 6th -10th)
Conclusions

- Incidence of rib fracture is greater with age.
- Age not a factor in incidence of PC.
- Mortality higher despite lower incidence of PC.
- Clear effect of airbag / seatbelt in mitigating Rib Fx.
- Higher crash severity result in increased rib fx & pc independent of age.
Future Direction

- Chest wall injuries in the elderly are a substantial problem with much opportunity for improvement
- Further characterization of the mechanism of chest wall injuries
- Identification of the involvement of restraint systems on chest wall injuries
Acknowledgements

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