

# Age Related Thresholds and Thoracic Injury



CIREN Public Meeting  
March 25, 2008

**TOYOTA**

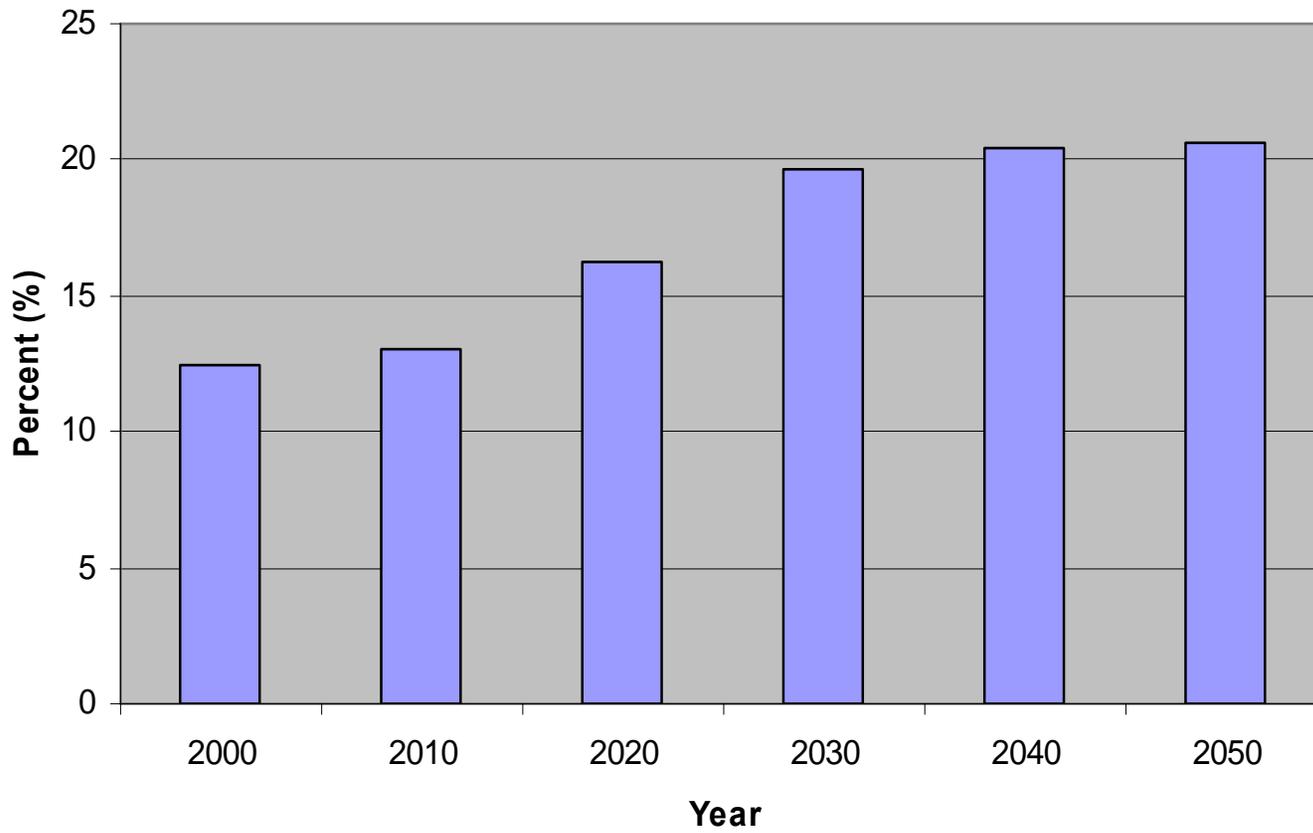
Toyota - Wake Forest University  
School of Medicine  
CIREN Center

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# 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

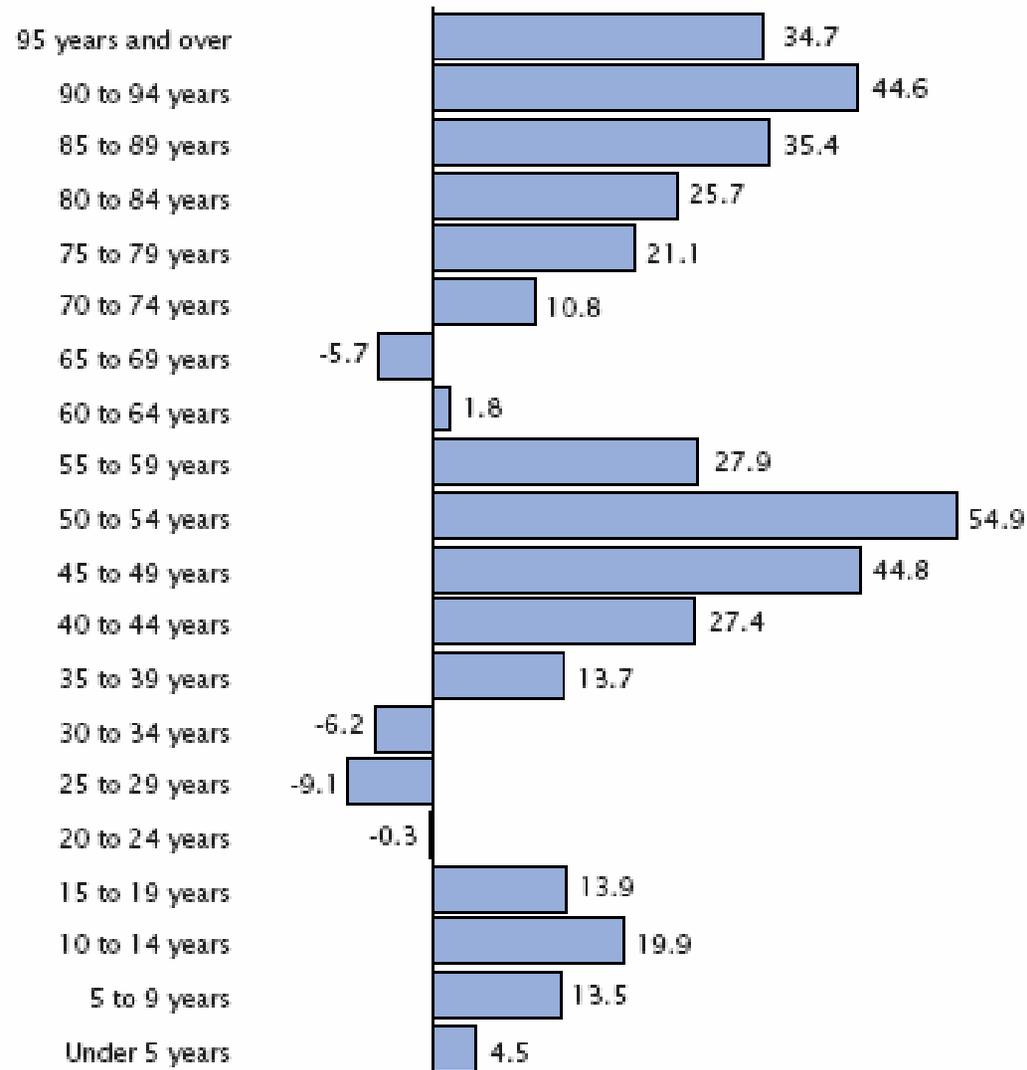
### Percent US Population Above 65 Years Old



US Census, 2000

## Percent Change by Age: 1990 to 2000

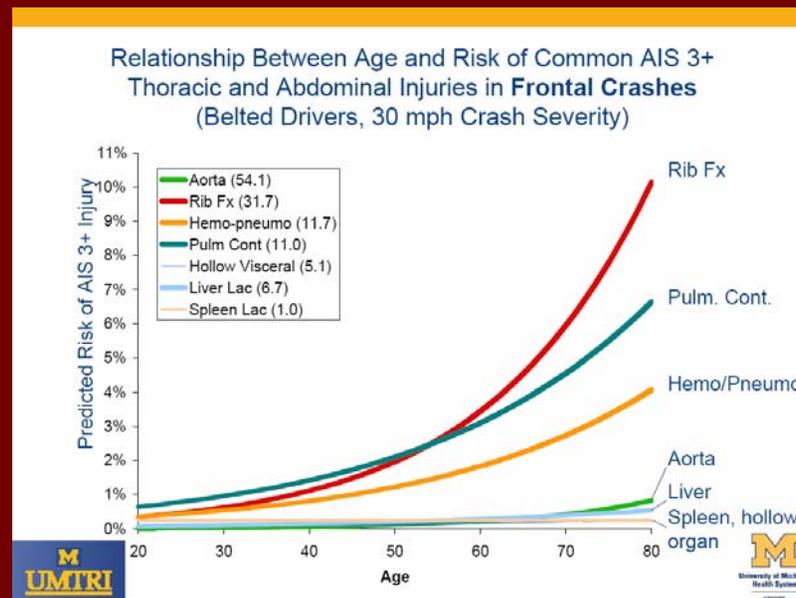
(For information on confidentiality protection, nonsampling error, and definitions, see [www.census.gov/prod/cen2000/doc/sf1.pdf](http://www.census.gov/prod/cen2000/doc/sf1.pdf))



Source: U.S. Census Bureau, Census 2000 Summary File 1; 1990 Census of Population, General Population Characteristics, United States (1990 CP-1-1).

# 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 CIREN meeting
- Bone demonstrates thin cortical shell and “brittle” material properties

# Database Selection

| Database    | # of cases | Detail | Outcome data | Crash data | Image analysis | Physiologic data |
|-------------|------------|--------|--------------|------------|----------------|------------------|
| Local CIREN |            | +++    | +++          | +++        | +++            | ++               |
| CIREN       | +          | ++     | +++          | ++         | ++             | ++               |
| NASS        | ++         | ++     | +            | ++         |                | ++               |
| NTDB        | +++        | ++     | ++           |            |                | +++              |

# 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

# Thorax Injury Thresholds

|          | Injury   | AGE |
|----------|--|-----|
| 450232.4 | RIB CAGE, FRACTURE, > 3 RIBS ON ONE SIDE AND <= 3 RIBS ON OTHER SIDE, STABLE CHEST OR NFS, WITH HEMO/PNEUMOTHORAX              | 42  |
| 441406.3 | LUNG, CONTUSION, UNILATERAL  | 68  |
| 450230.3 | RIB CAGE, FRACTURE, > 3 RIBS ON ONE SIDE AND <= 3 RIBS ON OTHER SIDE, STABLE CHEST OR NFS                                      | 40  |
| 450222.3 | RIB CAGE, FRACTURE, 2-3 RIBS ANY LOCATION OR MULTIPLE FRACTURES OF SINGLE RIB, WITH STABLE CHEST OR NFS WITH HEMO/PNEUMOTHORAX | 42  |
| 450242.5 | RIB CAGE, FRACTURE, > 3 RIBS ON EACH OF TWO SIDES, WITH STABLE CHEST OR NFS, WITH HEMO/PNEUMOTHORAX                            | 40  |
| 442202.3 | THORACIC CAVITY INJURY NFS WITH HEMO/PNEUMOTHORAX  | 40  |
| 441410.4 | LUNG, CONTUSION, BILATERAL   | 40  |
| 450266.5 | RIB CAGE, FRACTURE, FLAIL (UNSTABLE CHEST WALL), BILATERAL   | 56  |
| 450214.3 | RIB CAGE, FRACTURE, 1 RIB, WITH HEMO/PNEUMOTHORAX  | 63  |
| 450264.4 | RIB CAGE, FRACTURE, FLAIL CHEST (UNSTABLE CHEST WALL), WITH LUNG CONTUSION   | 41  |

# NTDB Injury Thresholds

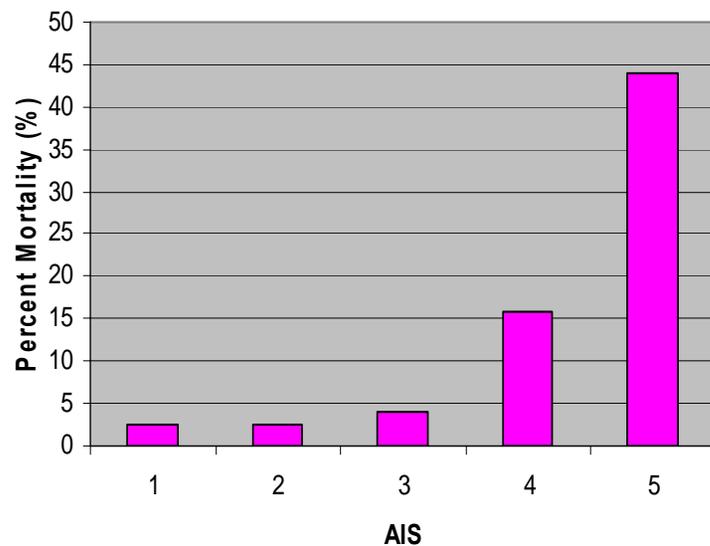
- Based on large database
- Ages appear young but represent observed inflection point
- Indicative of progressive process
- Impact of injury likely dependent on physiologic reserve

# Age Effect Controlling for AIS

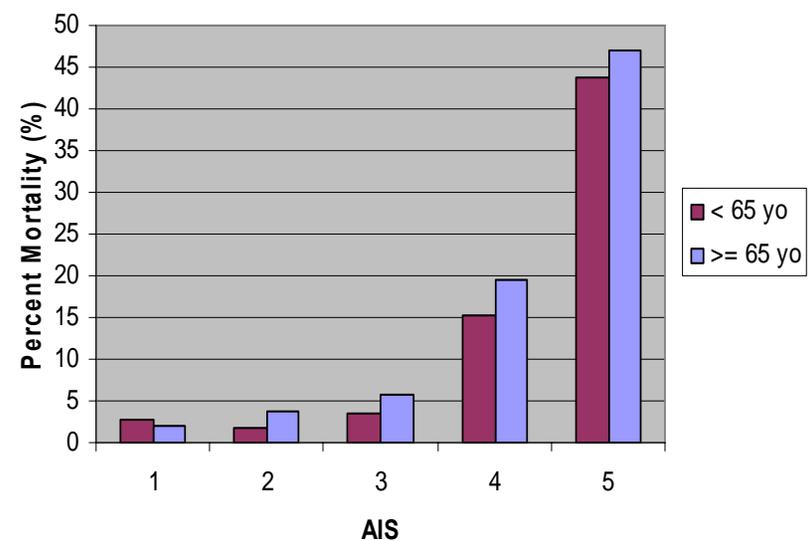
- To evaluate effects of age on thoracic injury severity
- Database: NTDB
- Severity of injury score (AIS) for thoracic injuries compared
  - Rib fractures, pulmonary contusion
- Isolated injuries
  - Impact of multiple injuries not captured

# Mortality by Thoracic Abbreviated Injury Scale (AIS)

Mortality by Isolated Thoracic AIS in NTDB

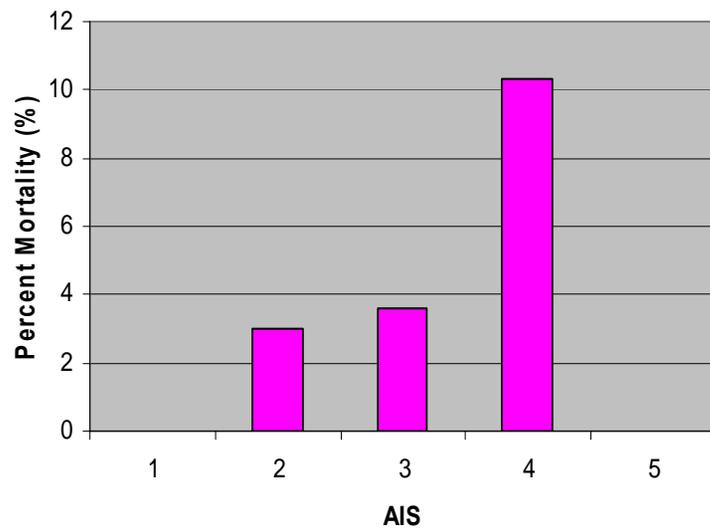


Mortality by Isolated Thoracic AIS in NTDB

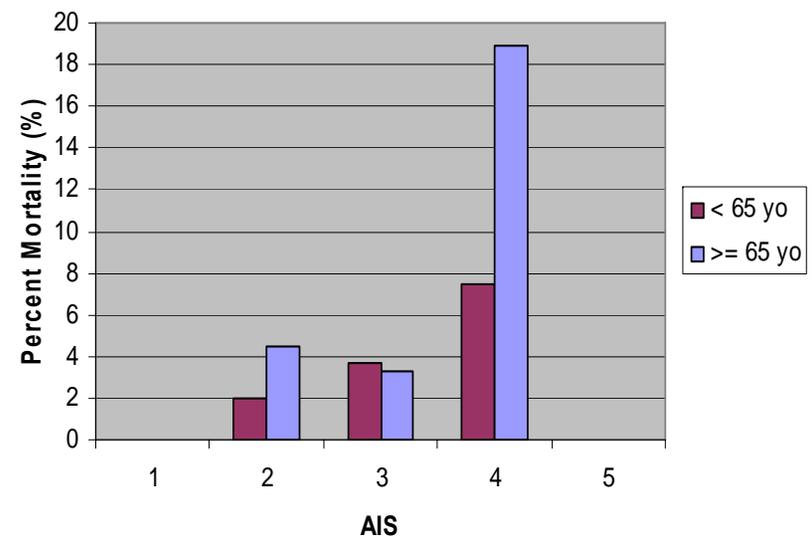


# Mortality by Rib Fracture AIS

Mortality by Isolated Rib Fracture AIS in NTDB

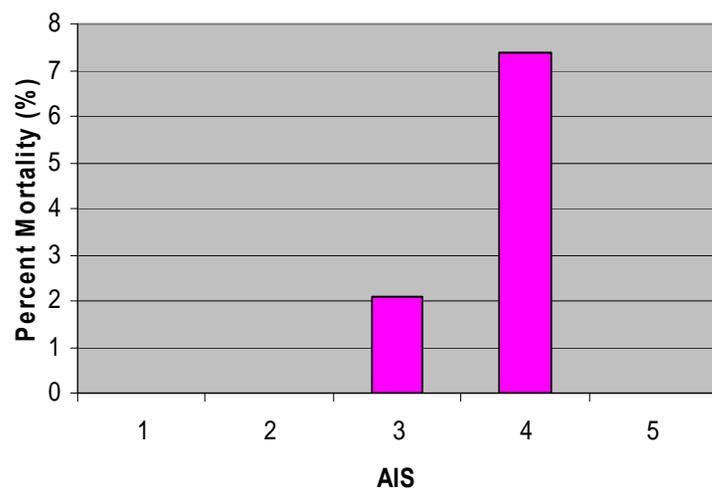


Mortality by Isolated Rib Fracture AIS in NTDB

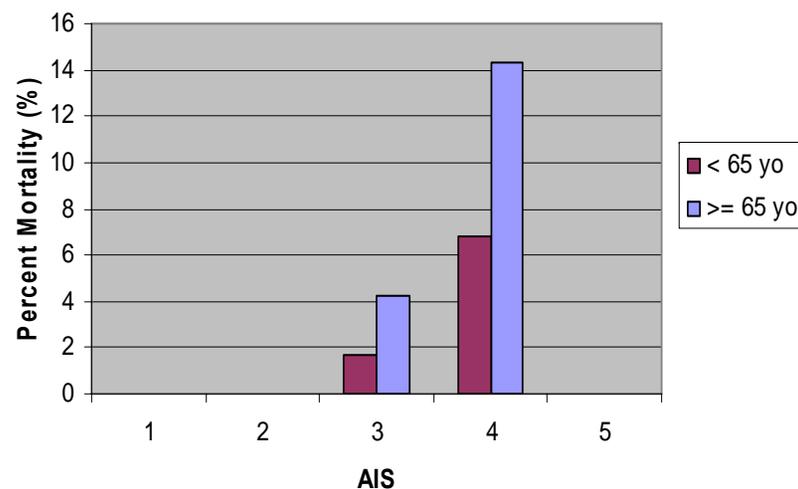


# Mortality by Pulmonary Contusion AIS

Mortality by Isolated Pulmonary Contusion AIS in NTDB



Mortality by Isolated Pulmonary Contusion AIS in NTDB



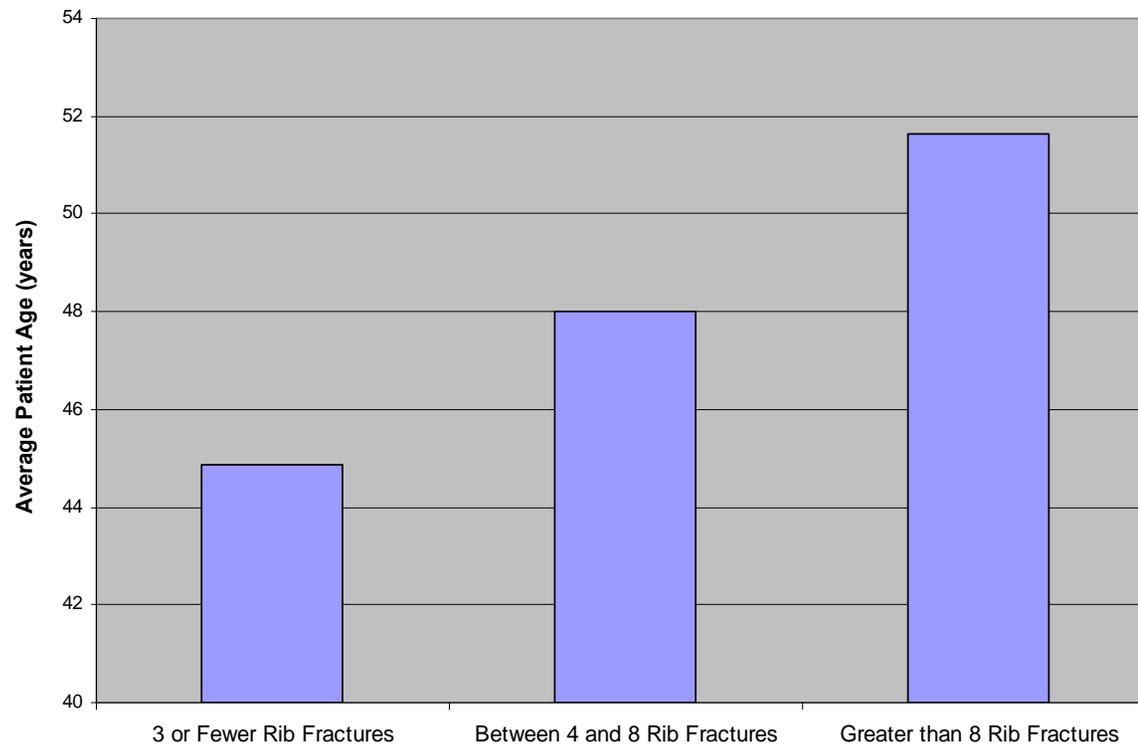
# Thoracic Injuries –T/WFU CIREN

- 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

# T/WFU-CIREN



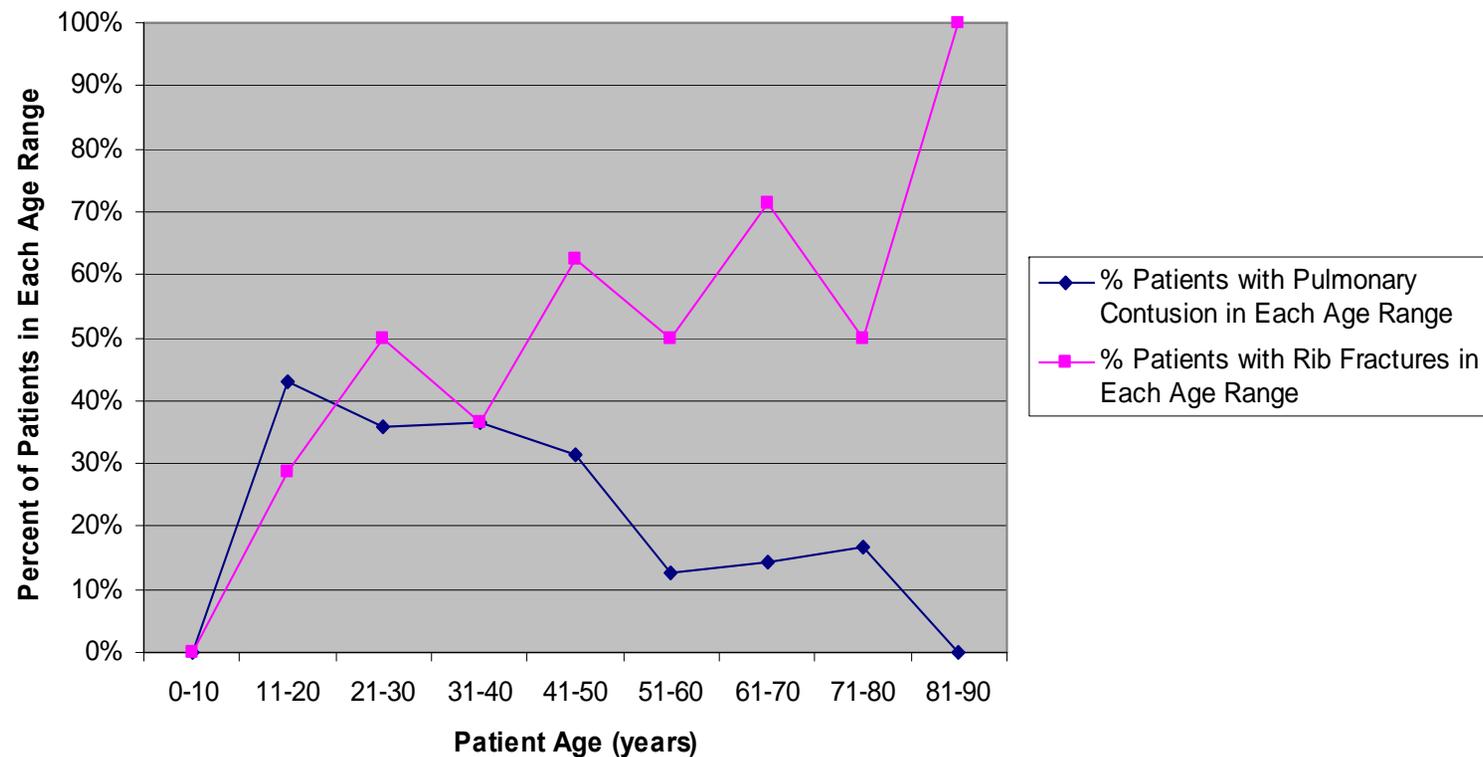
**Patient Age According to Number of Rib Fractures in Patients that Sustained Rib Fractures**



# T/WFU-CIREN



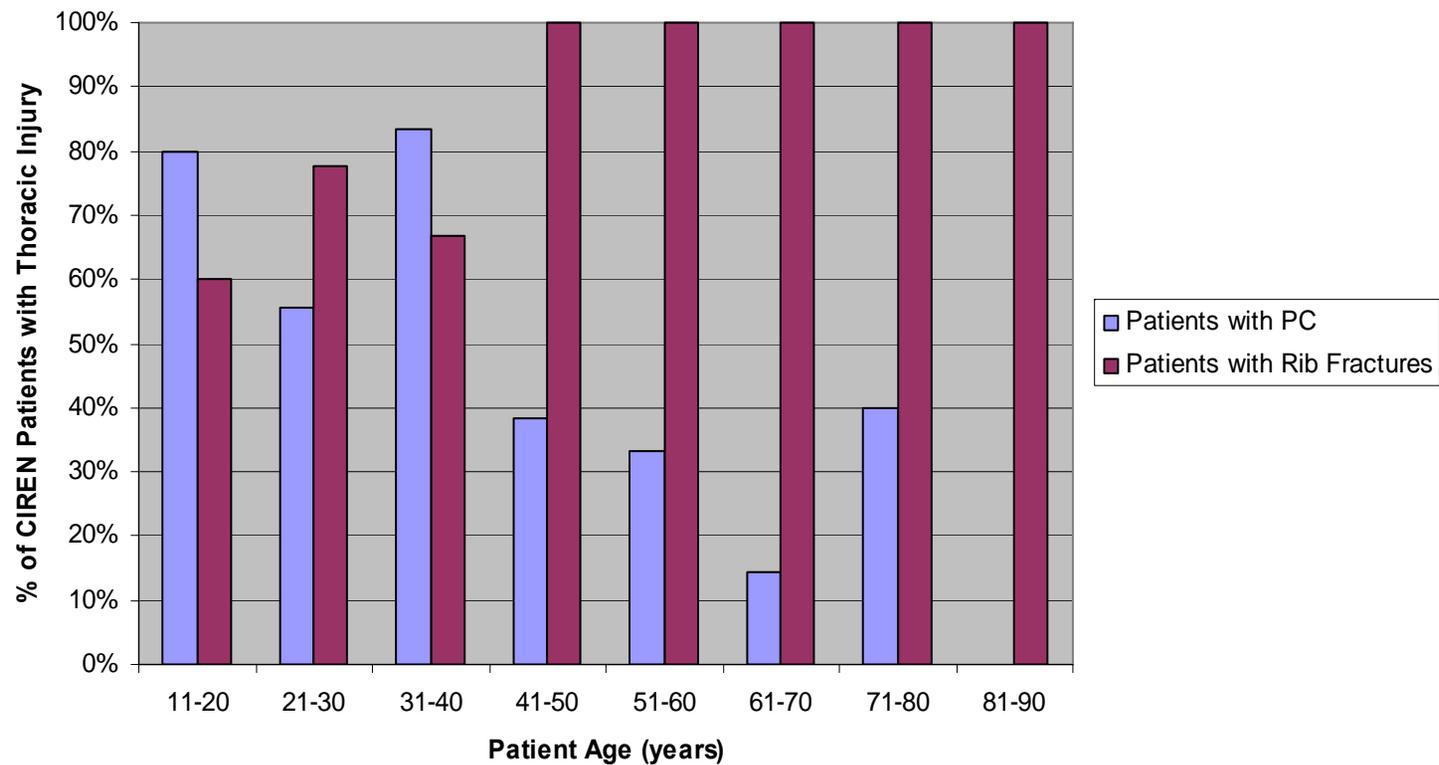
### Thoracic Injuries According to Age



# T/WFU-CIREN



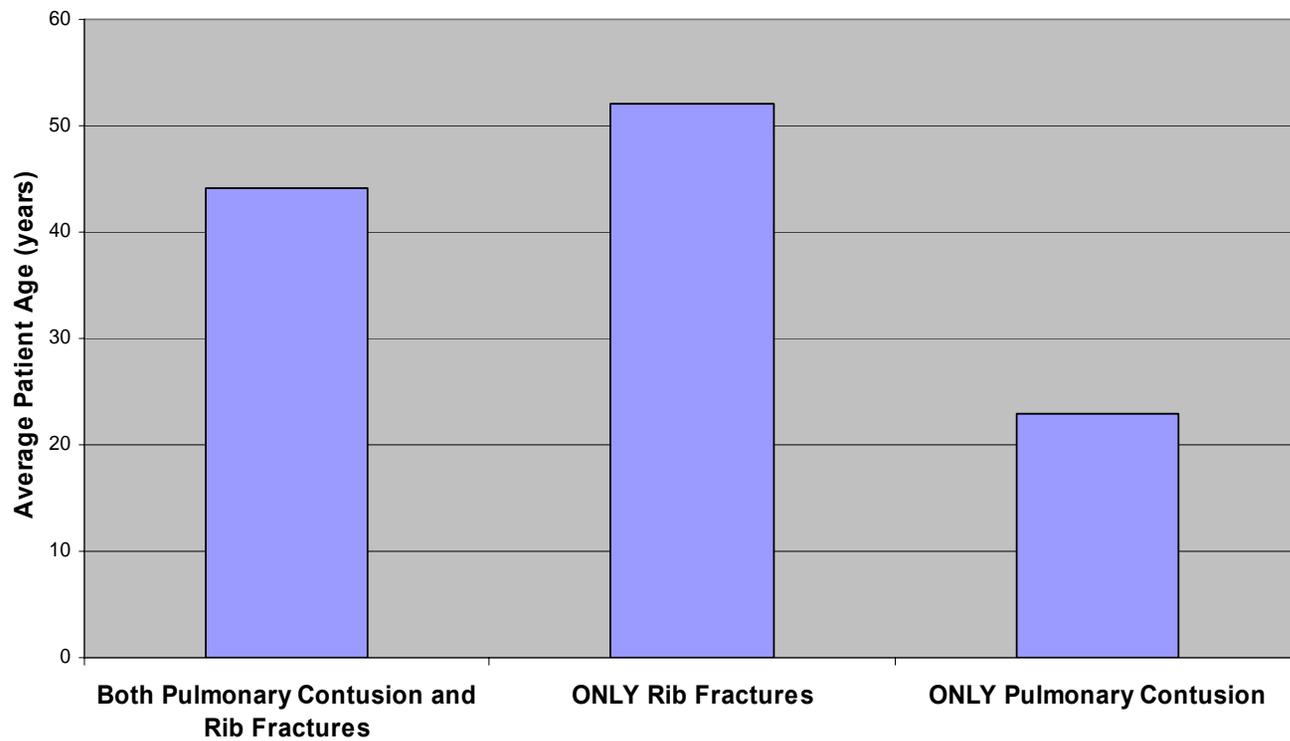
Thoracic Injury According to Age



# T/WFU-CIREN



Age Comparison of Thoracic Injury



# Thoracic Injuries in CIREN

- CIREN 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

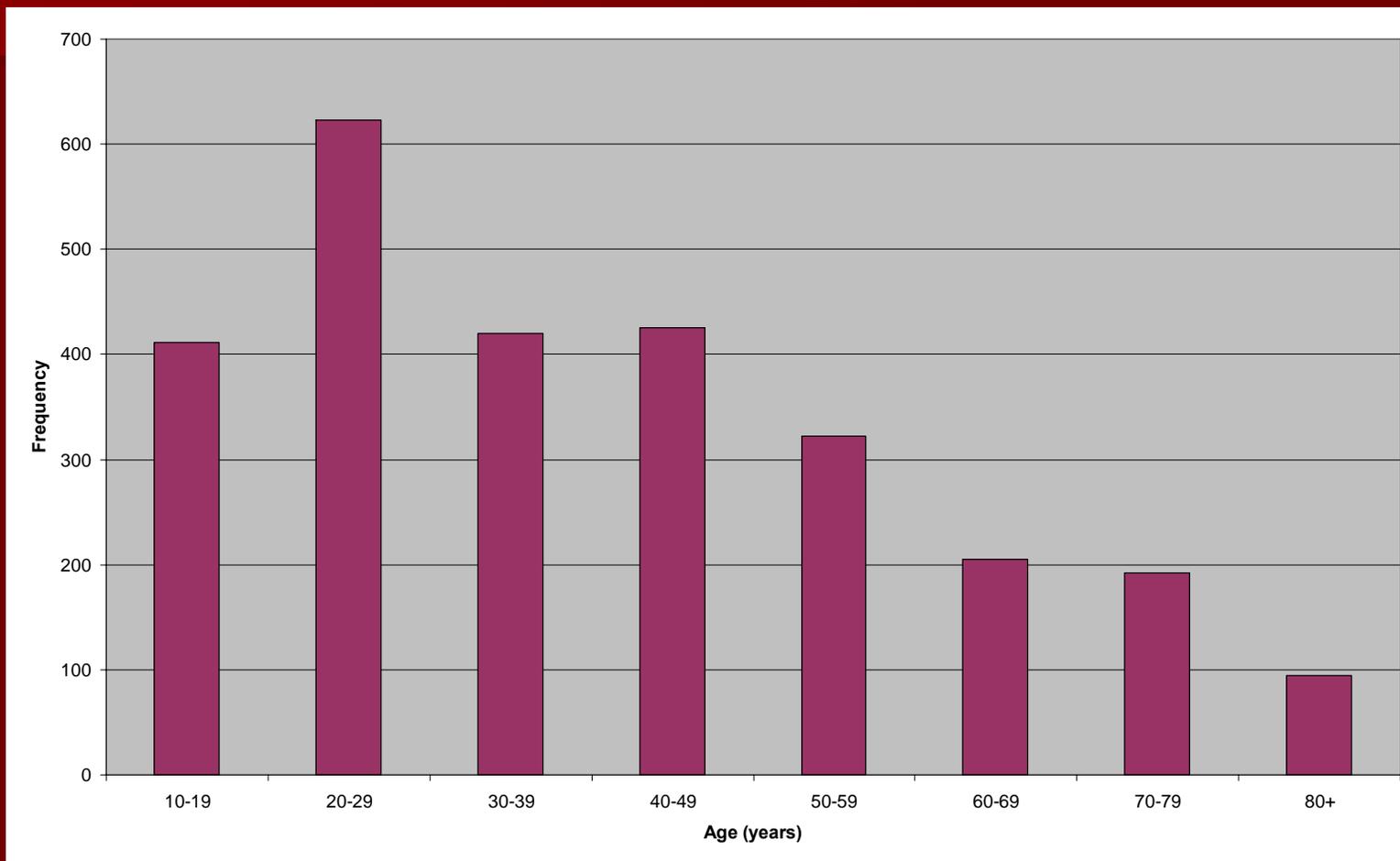


# Thoracic Injuries in CIREN

- 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  **$\geq 48.3$  km/h**



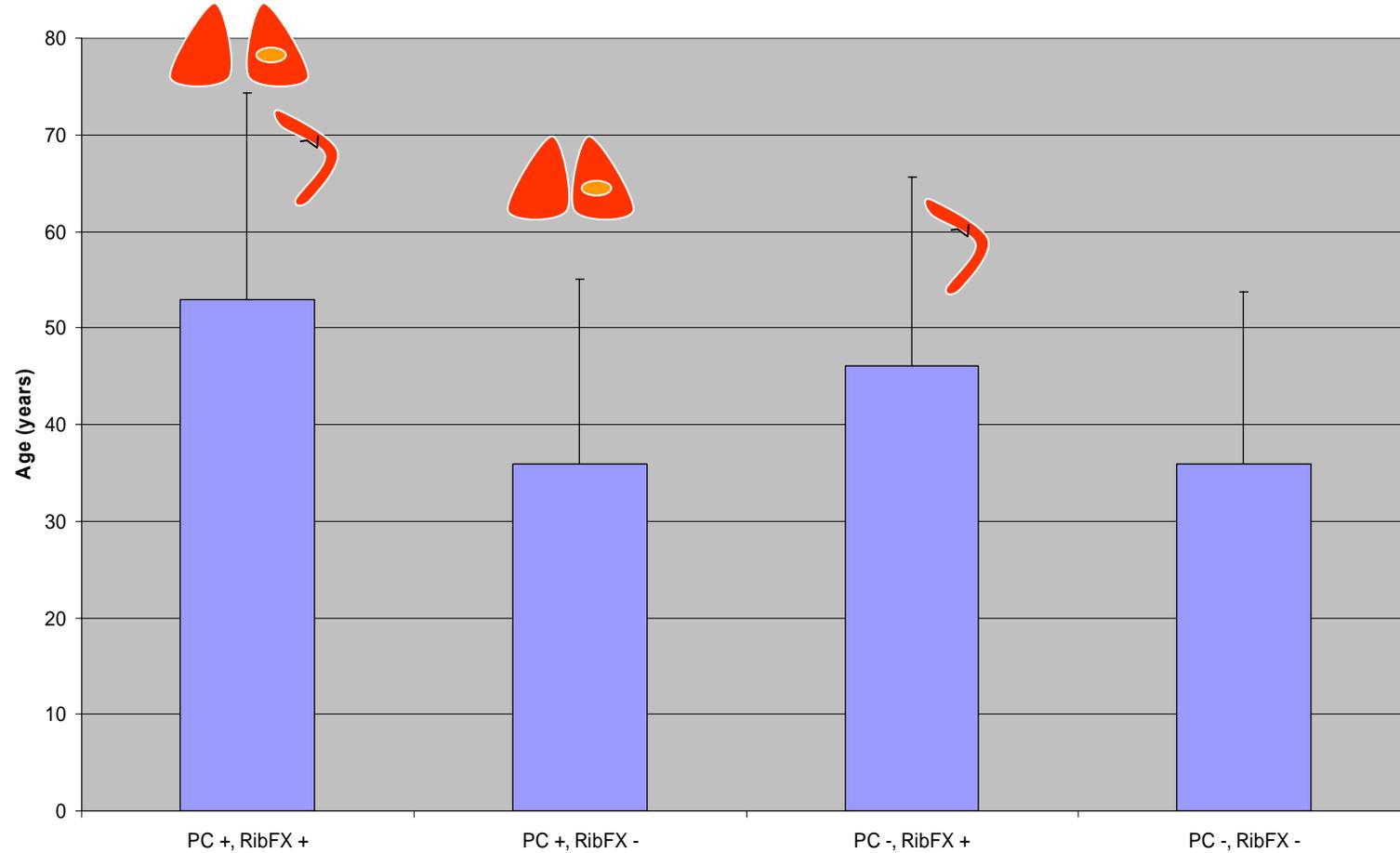
# Age Distribution in CIREN



# Mean Age -CIREN



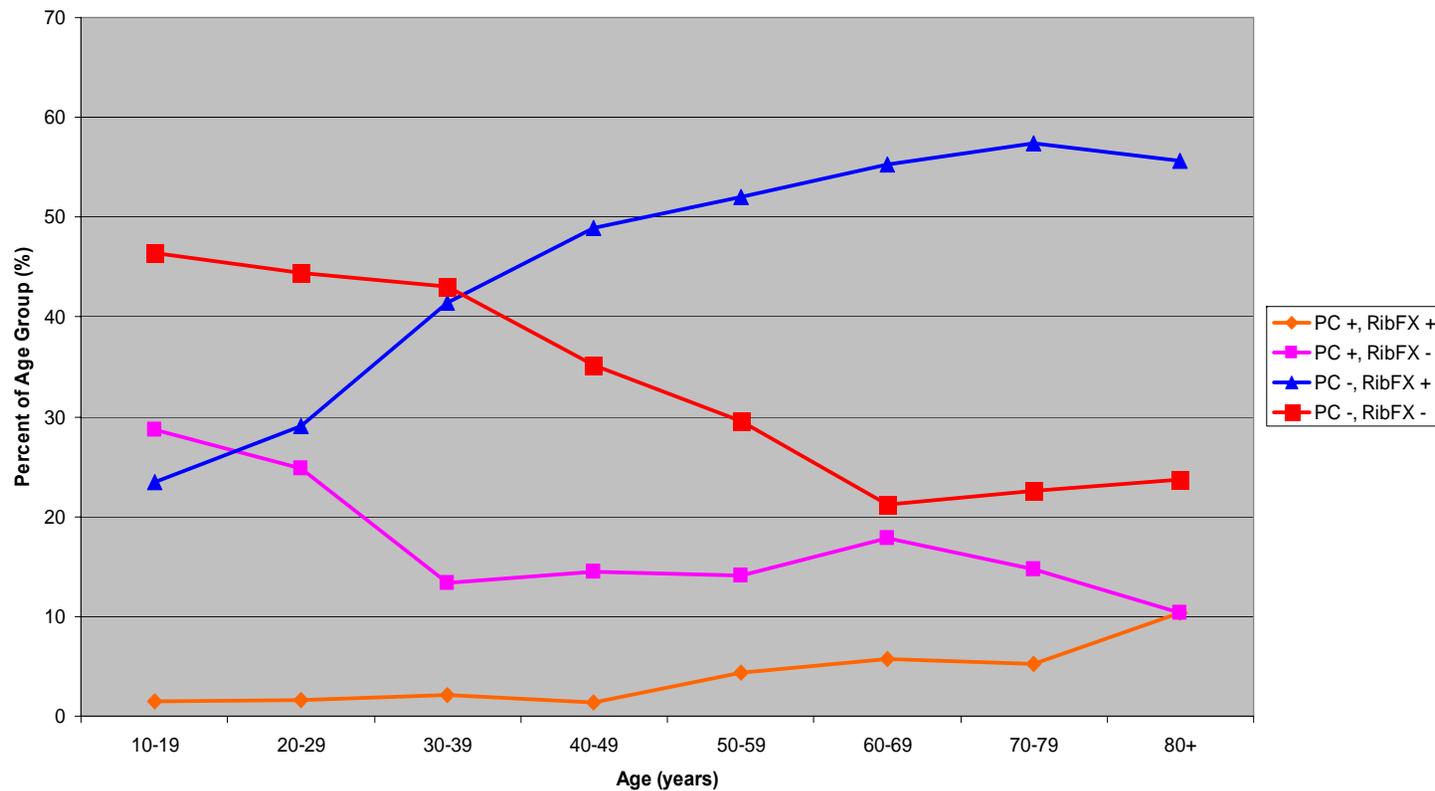
Mean Age of Thoracic Injuries in CIREN



# Injury Distribution -CIREN



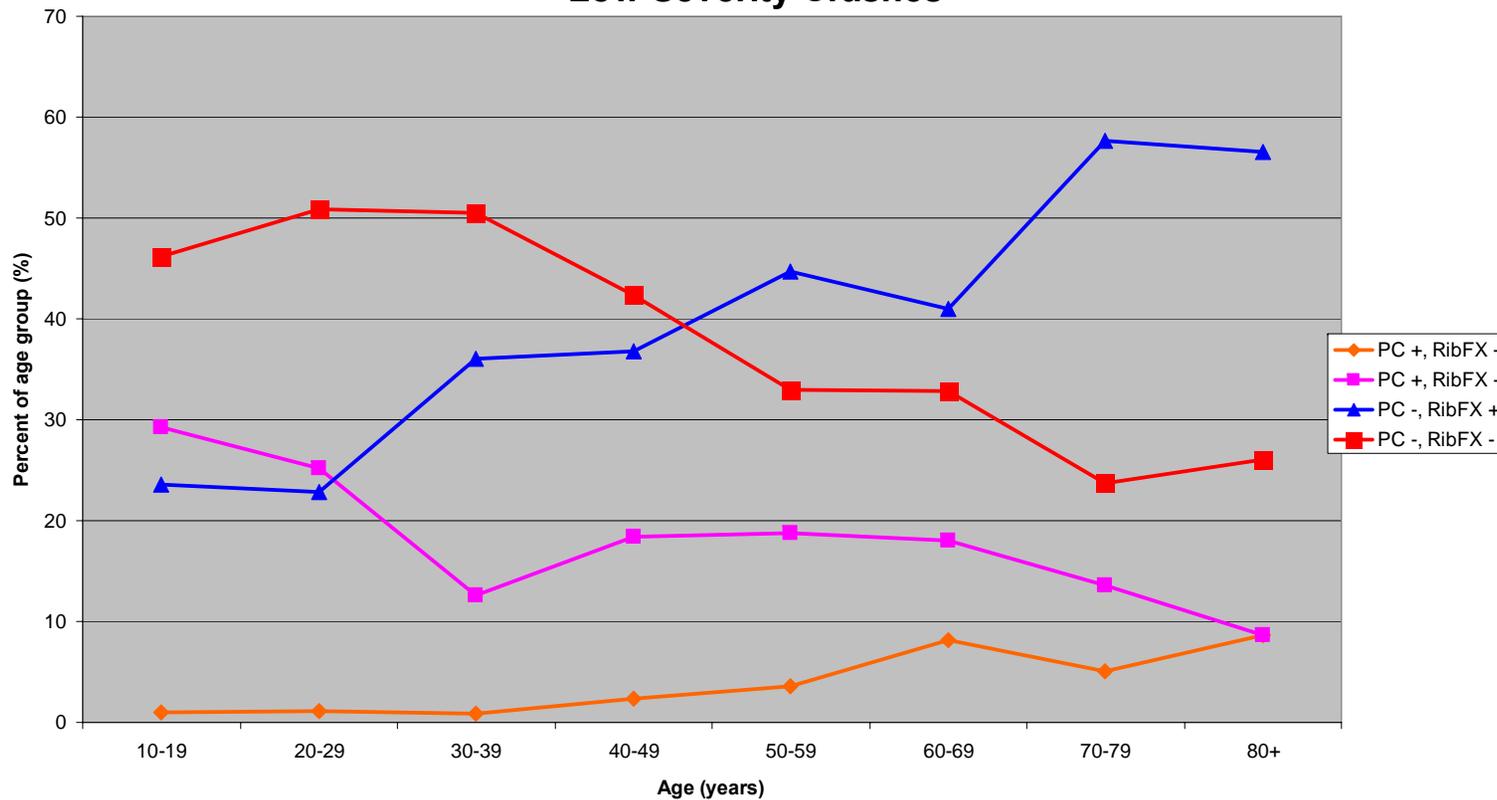
Percent of Age Group with Rib Fractures and Pulmonary Contusion



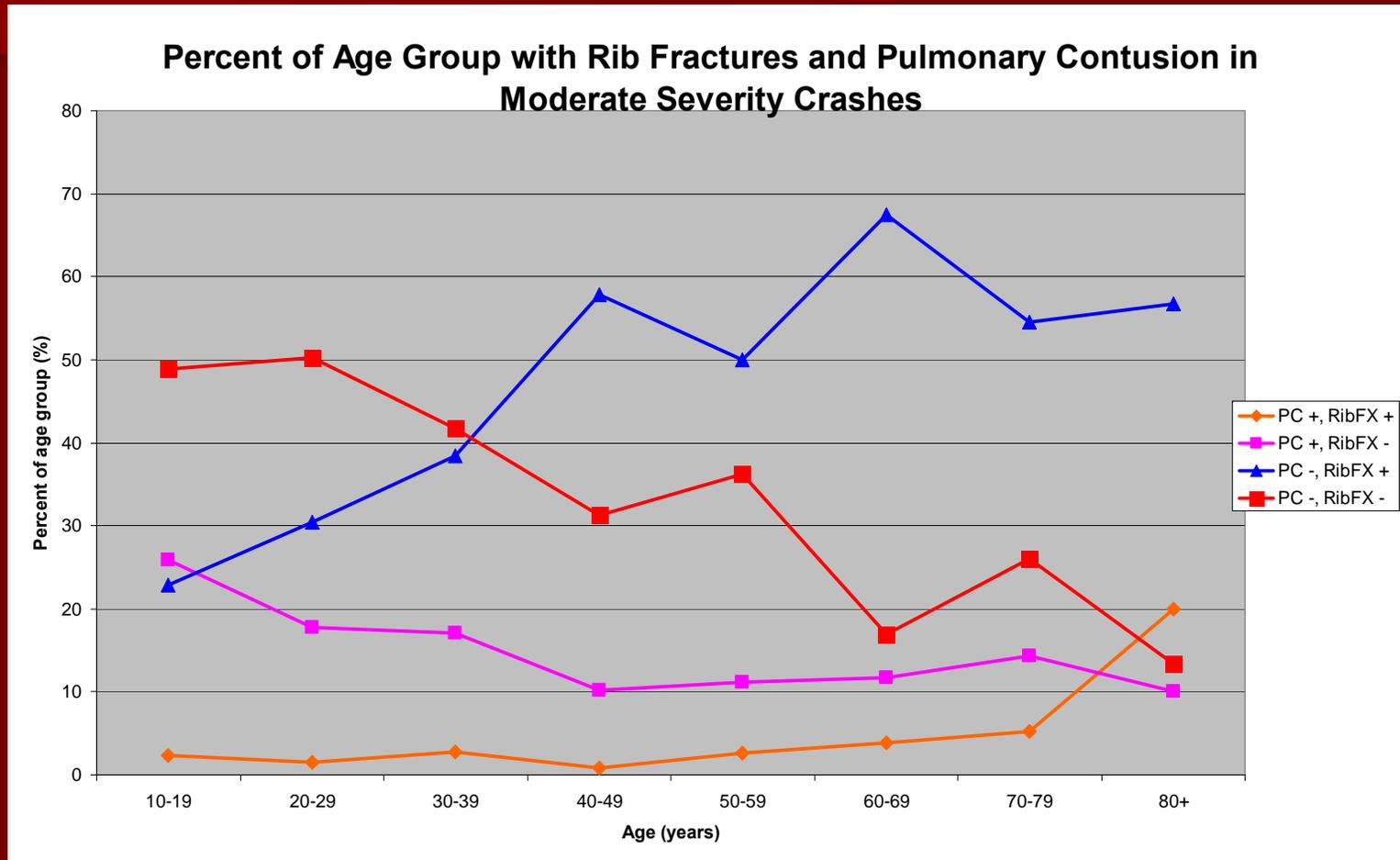
# Injury Distribution –CIREN by Crash Severity



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



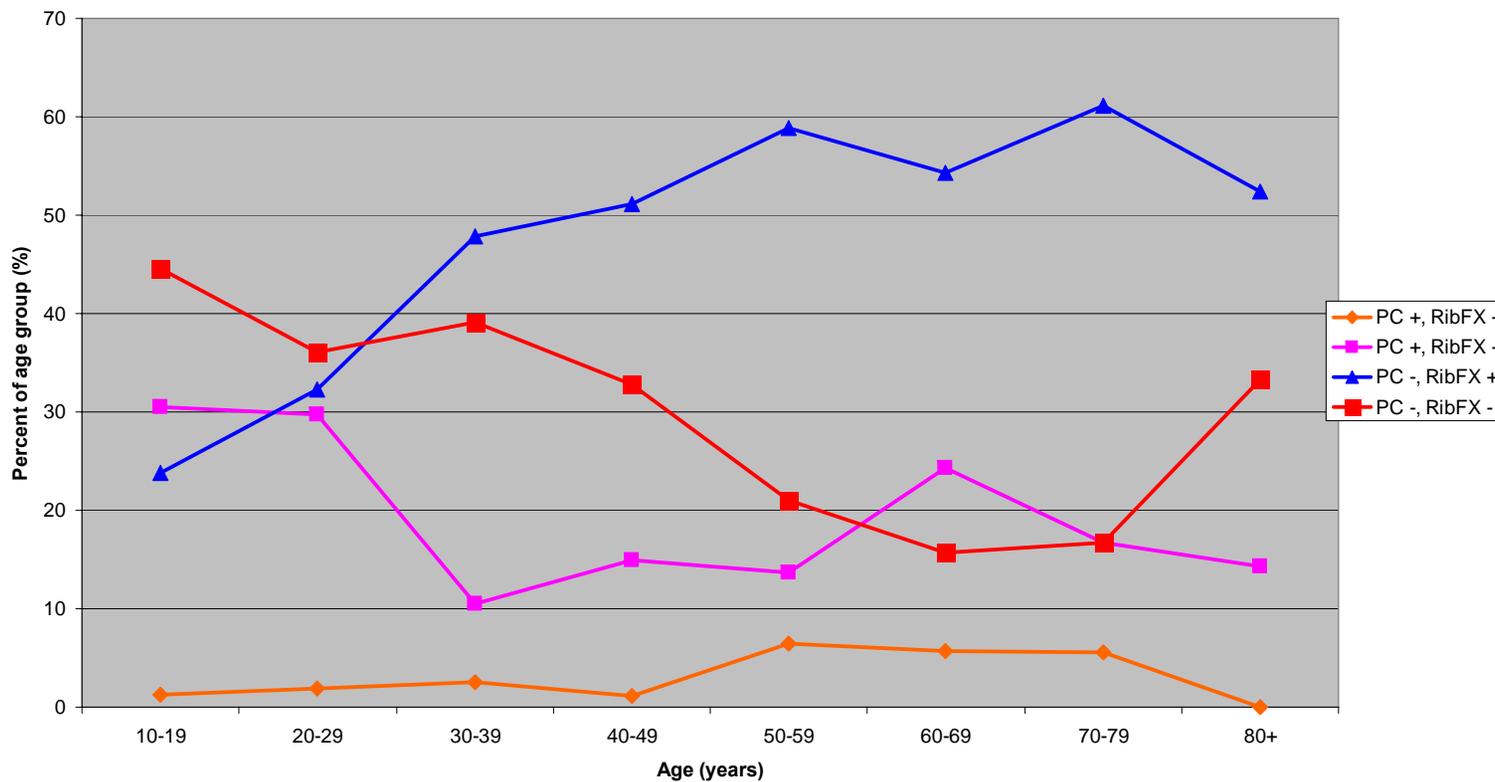
# Injury Distribution –CIREN by Crash Severity



# Injury Distribution –CIREN by Crash Severity



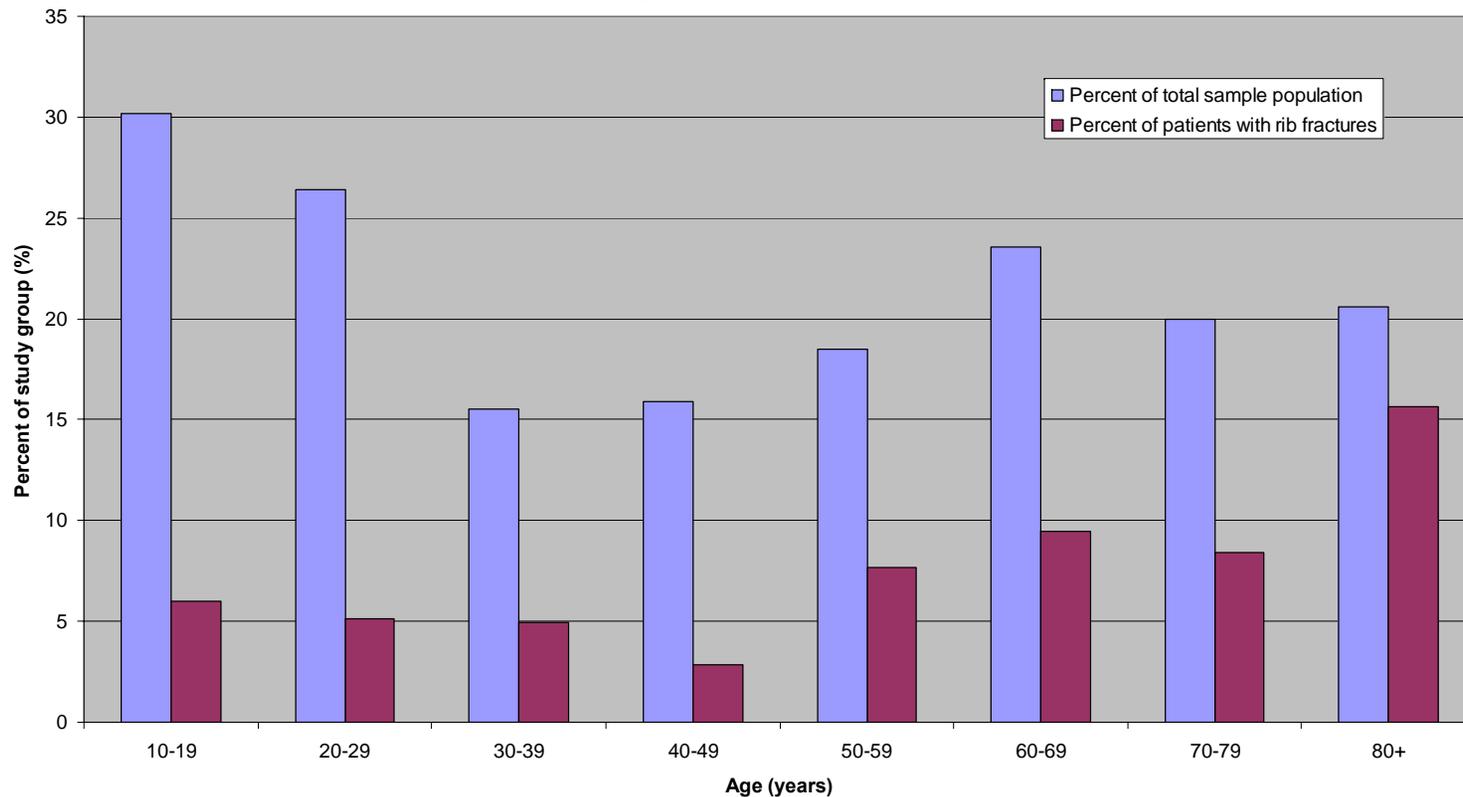
Percent of Age Group with Rib Fractures and Pulmonary Contusion in High Severity Crashes



# Pulmonary Contusion -CIREN



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



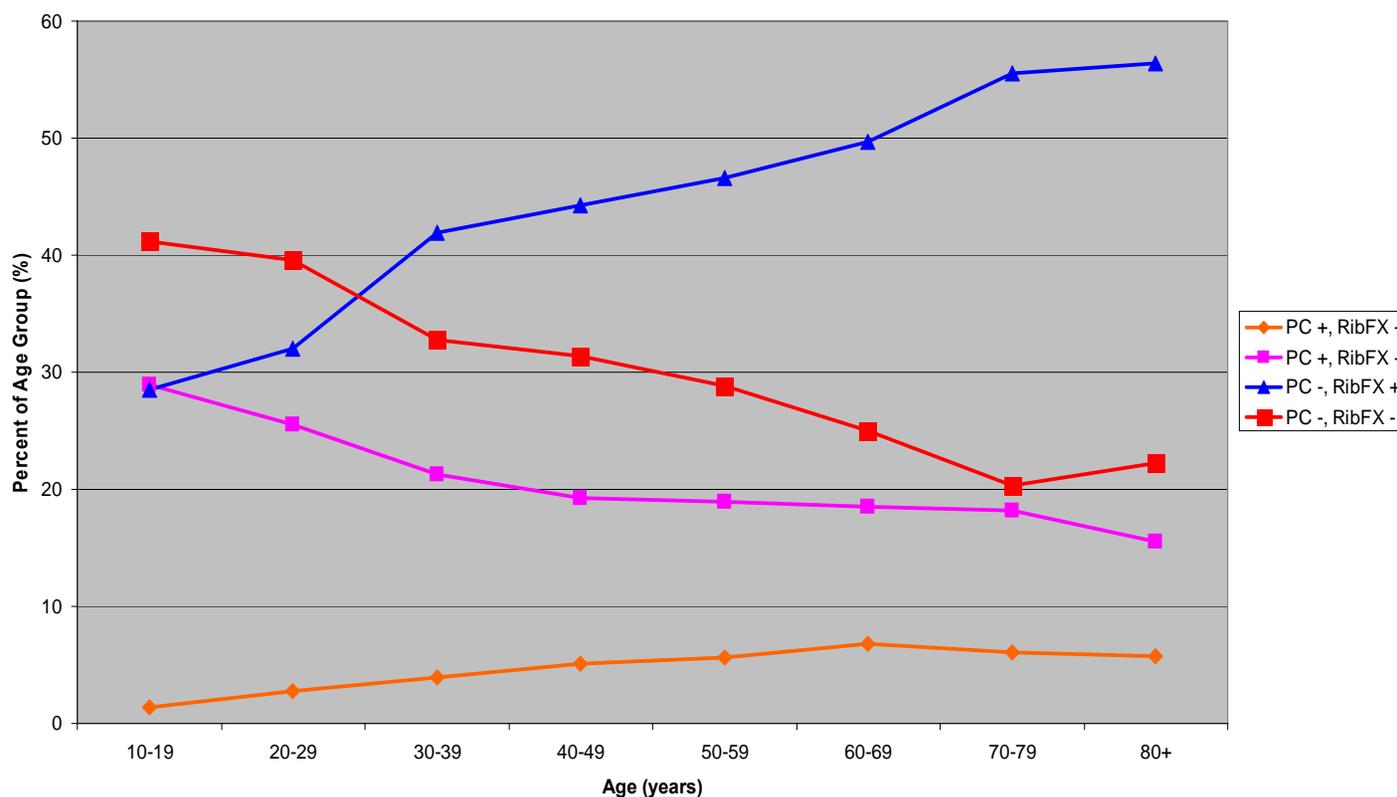
# Thoracic Injuries in NASS

- 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



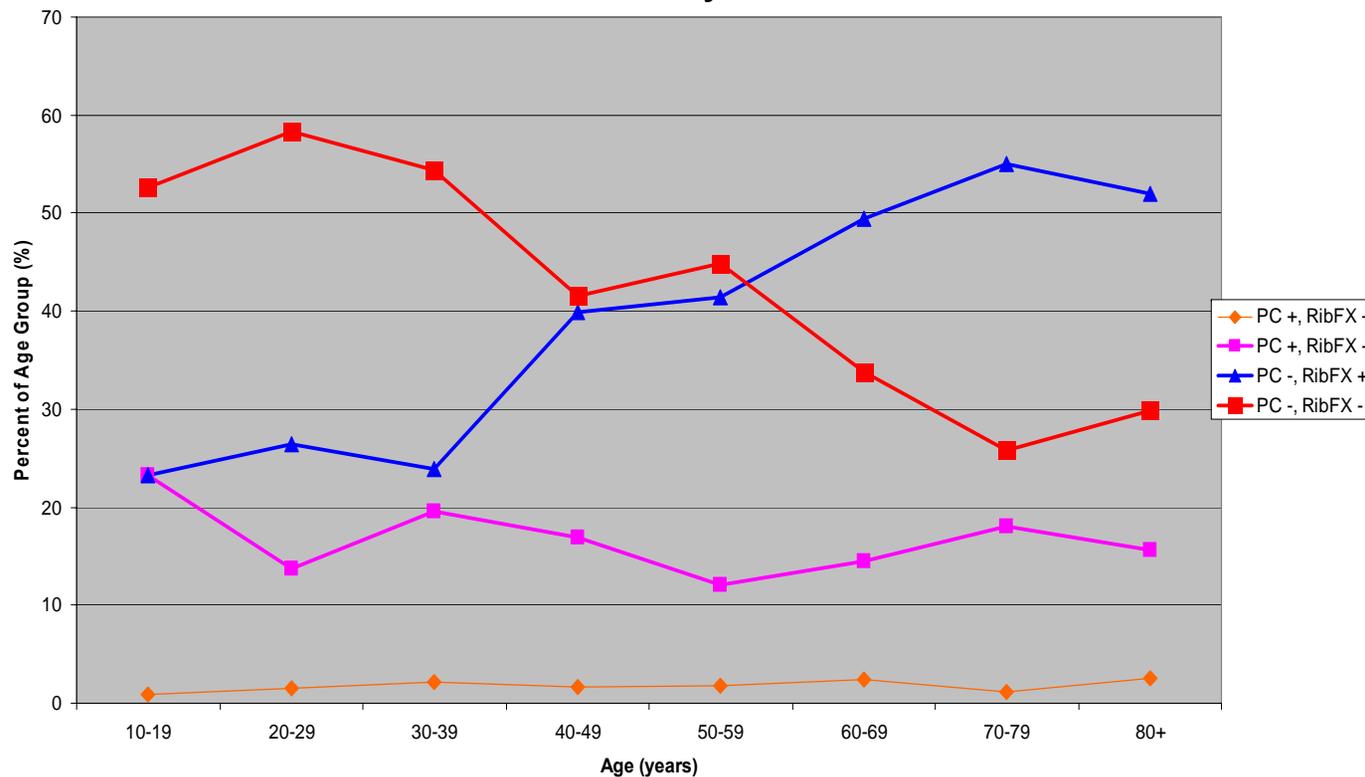
Percent of Age Group with Rib Fractures and Pulmonary Contusion



# Injury Distribution –NASS by Crash Severity



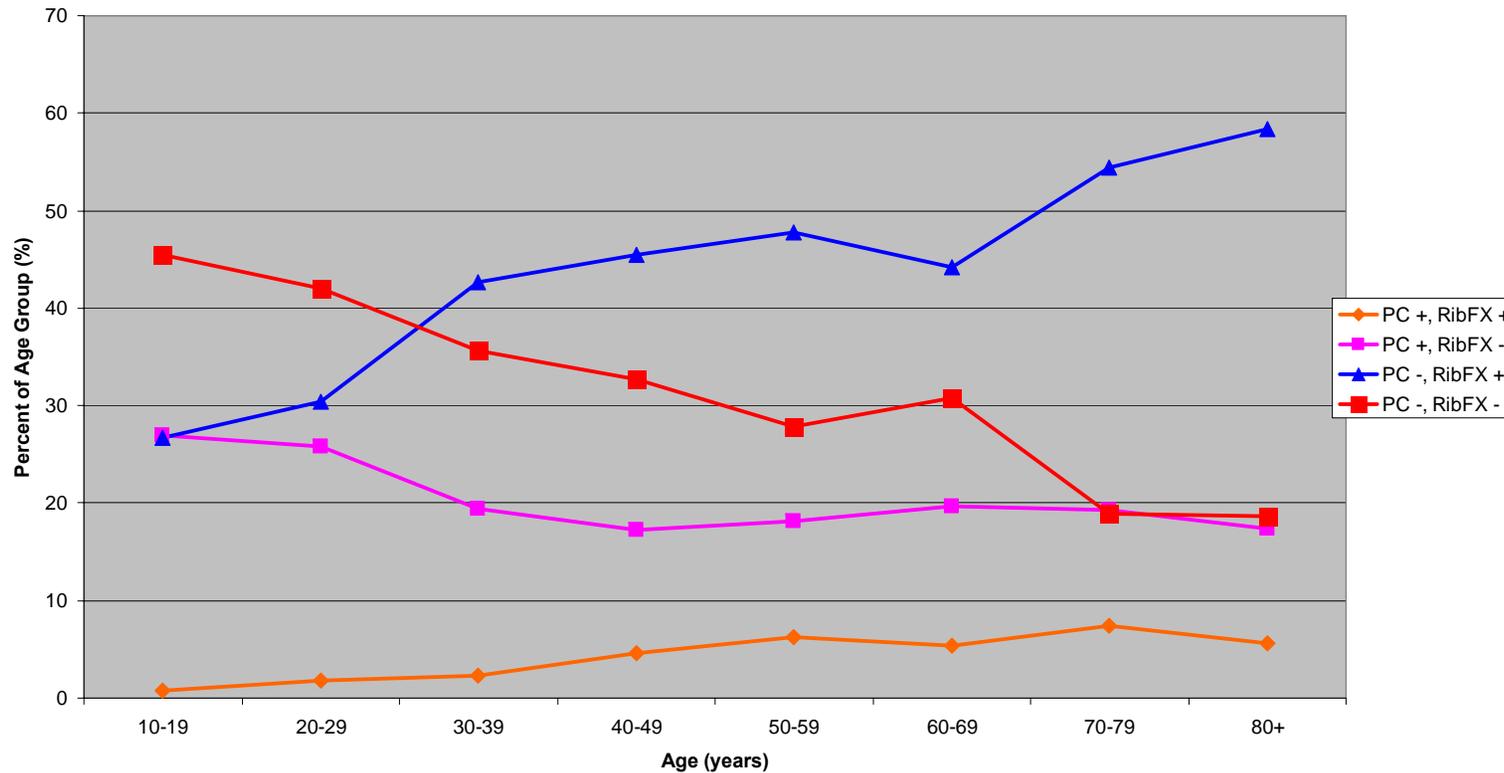
Percent of Age Group with Rib Fractures and Pulmonary Contusion in Low Severity Crashes



# Injury Distribution –NASS by Crash Severity



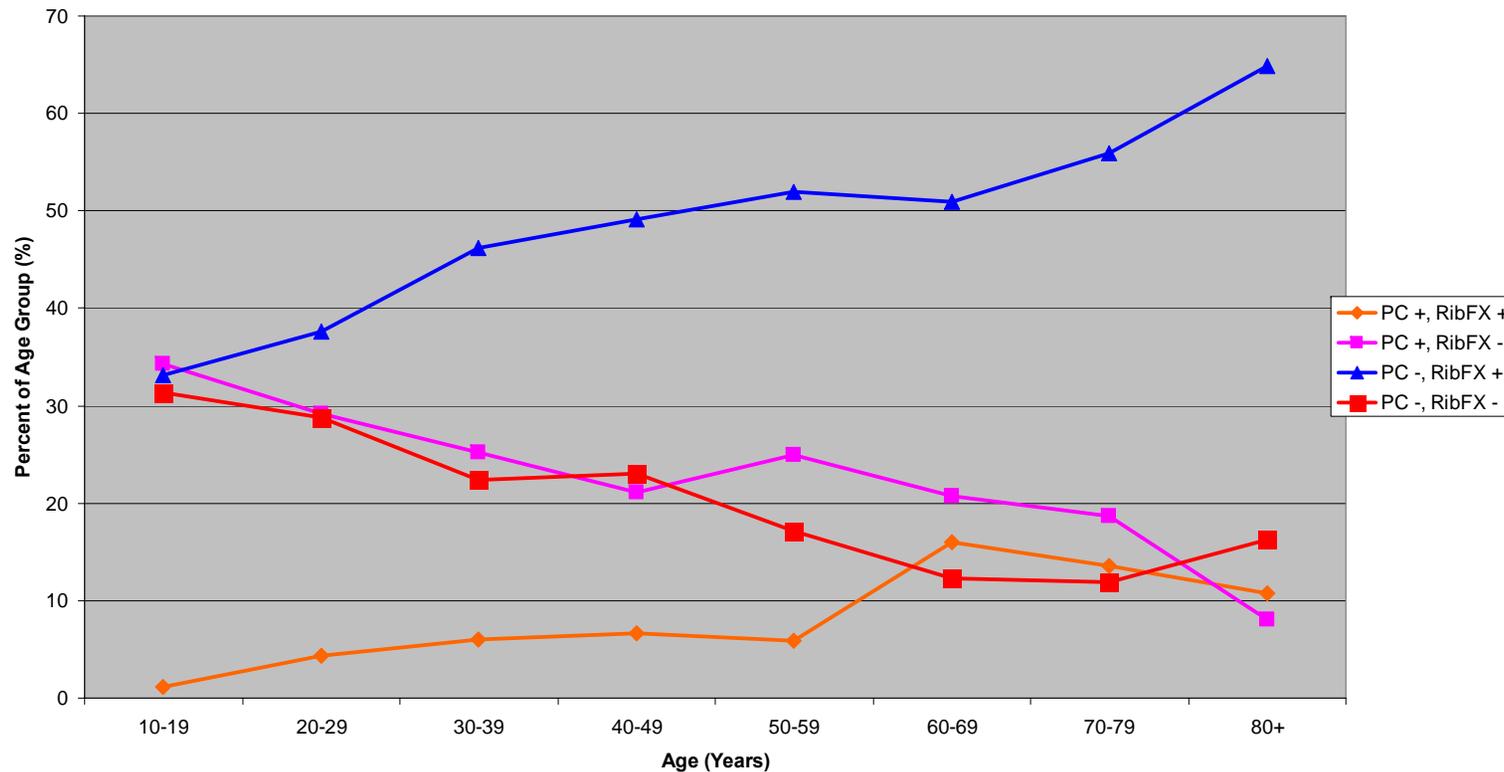
Percent of Age Group with Rib Fractures and Pulmonary Contusion in Moderate Severity Crashes



# Injury Distribution –NASS by Crash Severity



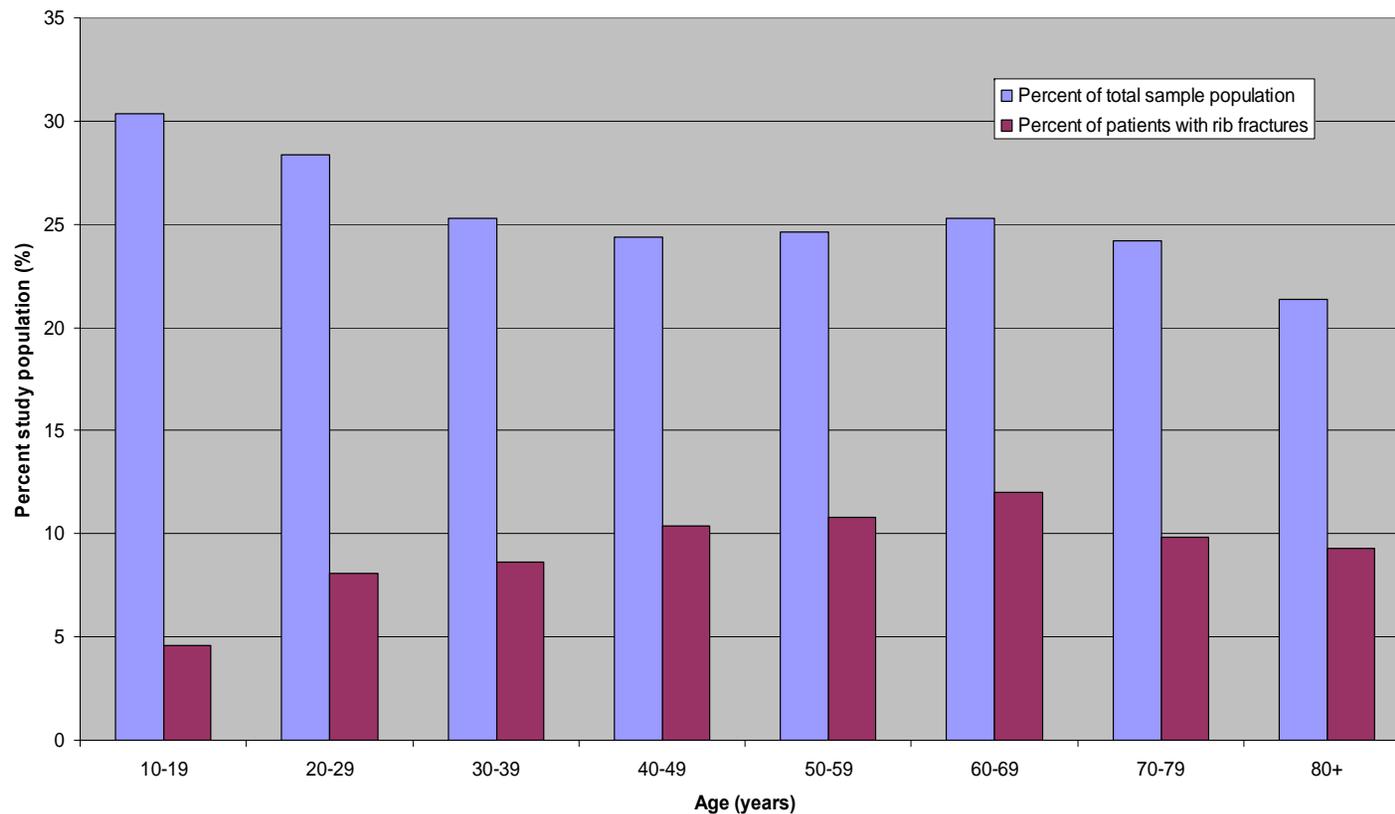
Percent of Age Group with Rib Fractures and Pulmonary Contusion in High Severity Crashes



# Pulmonary Contusion –NASS

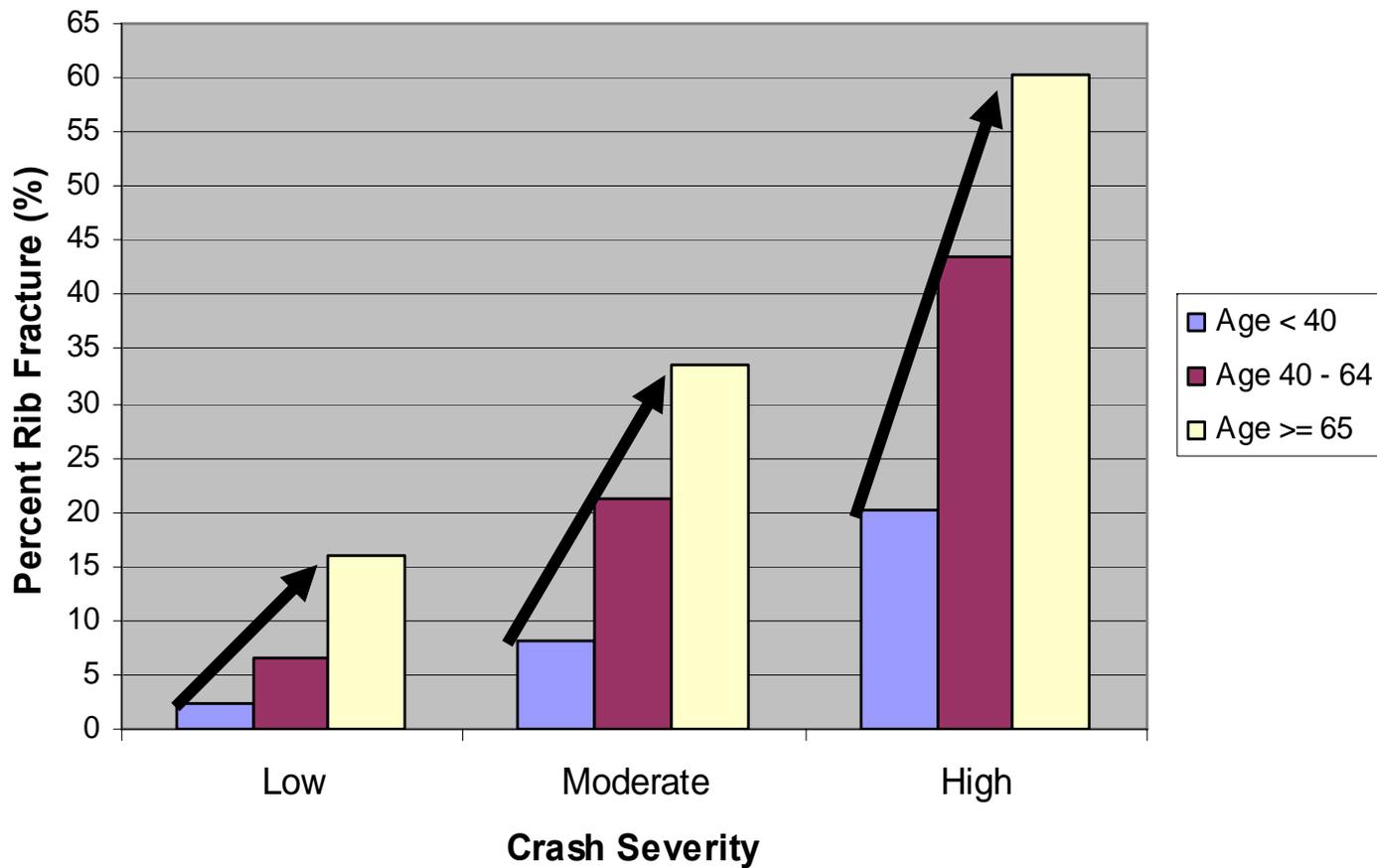


Percent Pulmonary Contusion by Age Among Total Study Group and Rib Fracture Patients



# Rib Fractures -NASS

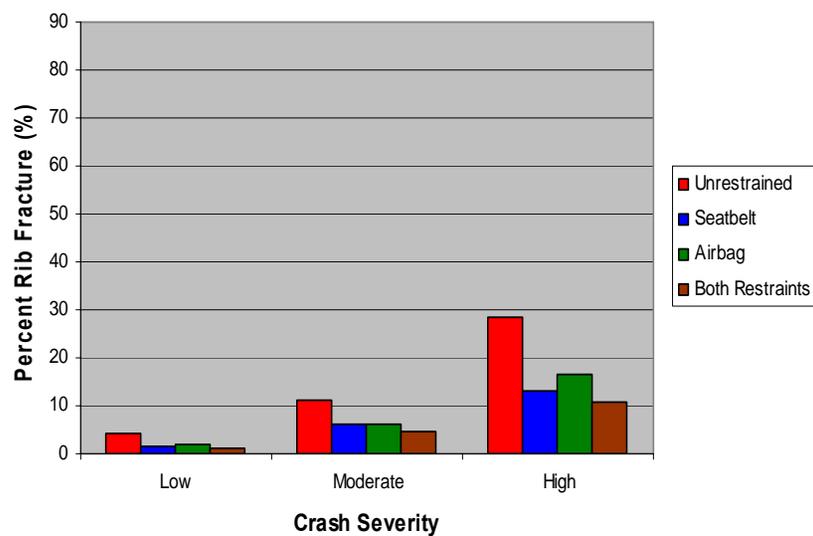
## Percent Rib Fractures by Age and Delta V



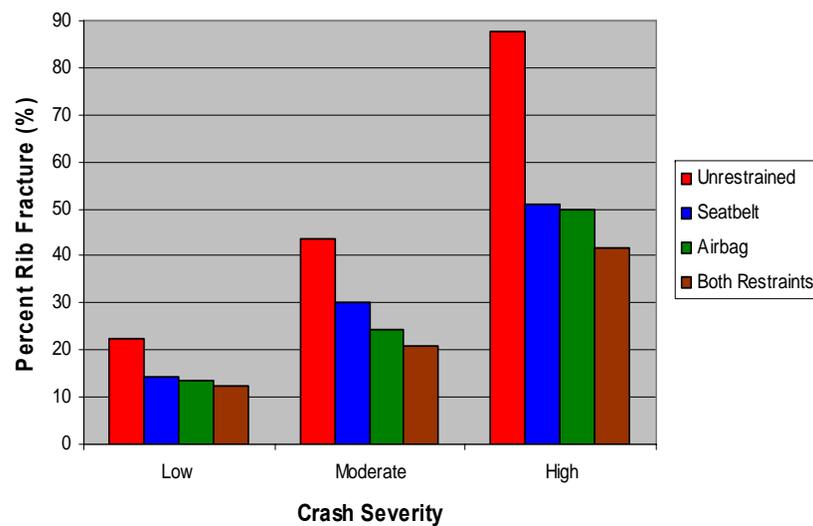
n = 9987, 4822, 1779

# Rib Fractures -NASS

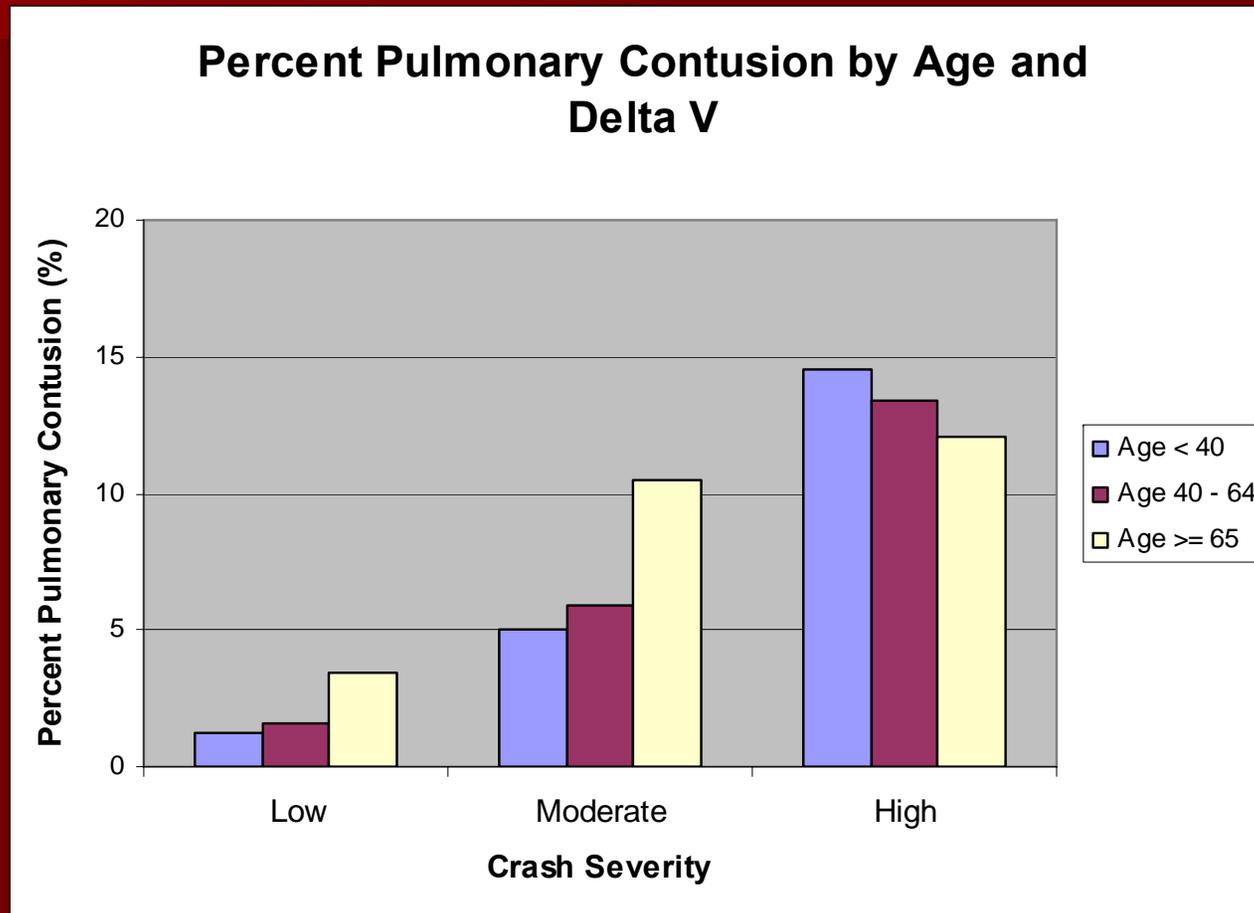
Percent Rib Fractures by Delta V and Restraint Category: Age < 40



Percent Rib Fractures by Delta V and Restraint Category: Age >= 65



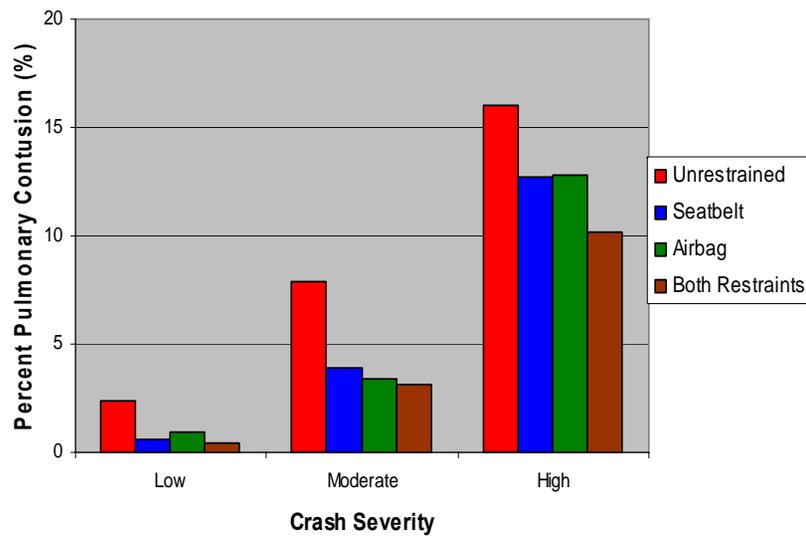
# Pulmonary Contusion -NASS



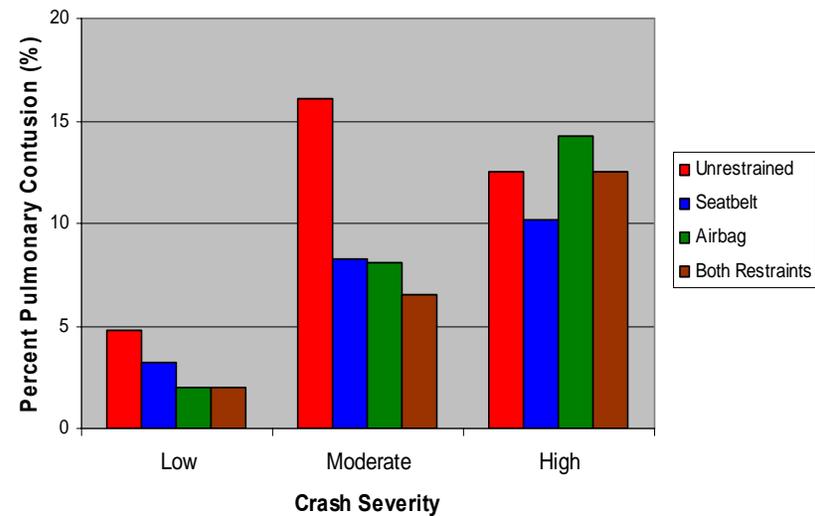
n = 9987, 4822, 1779

# Pulmonary Contusion -NASS

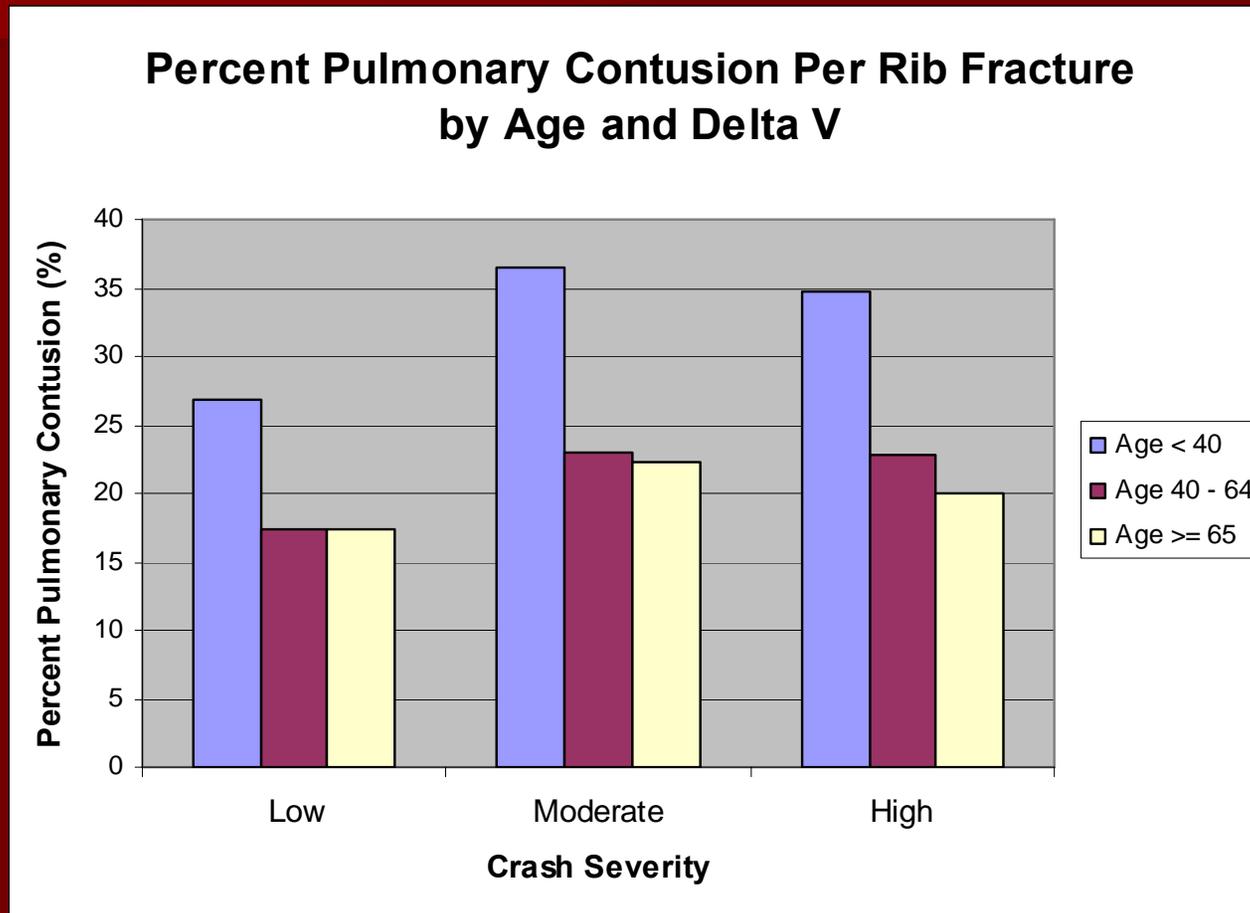
Percent Pulmonary Contusion by Delta V and Restraint Category: Age < 40



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



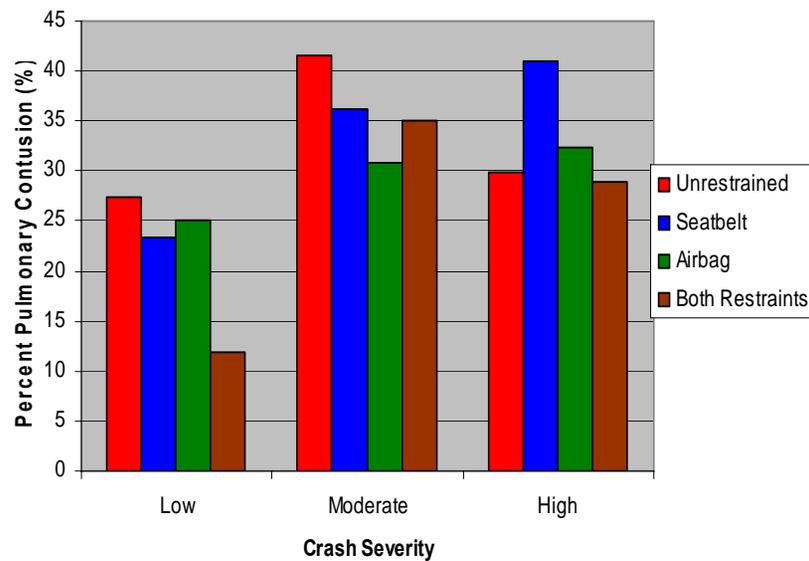
# Pulmonary Contusion -NASS



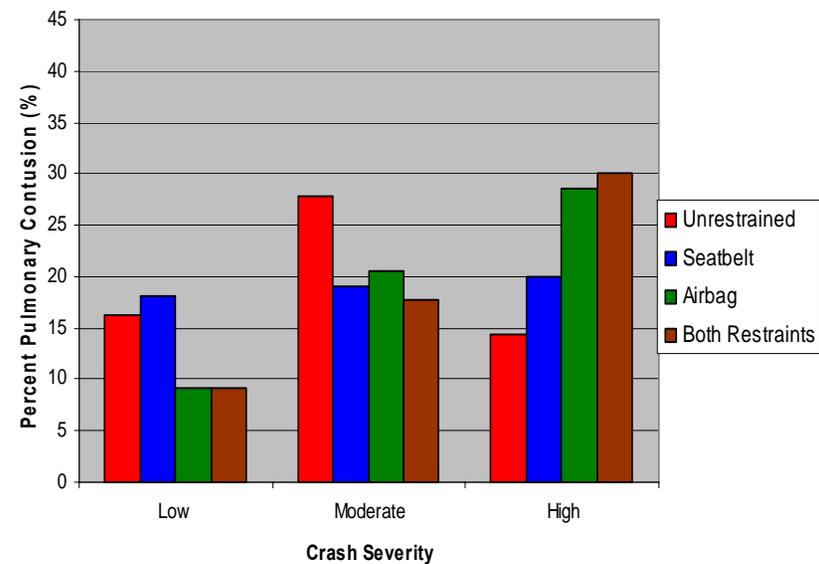
n = 623, 695, 423

# Pulmonary Contusion -NASS

Percent Pulmonary Contusion per Rib Fracture by Delta Vand Restraint Category: Age < 40



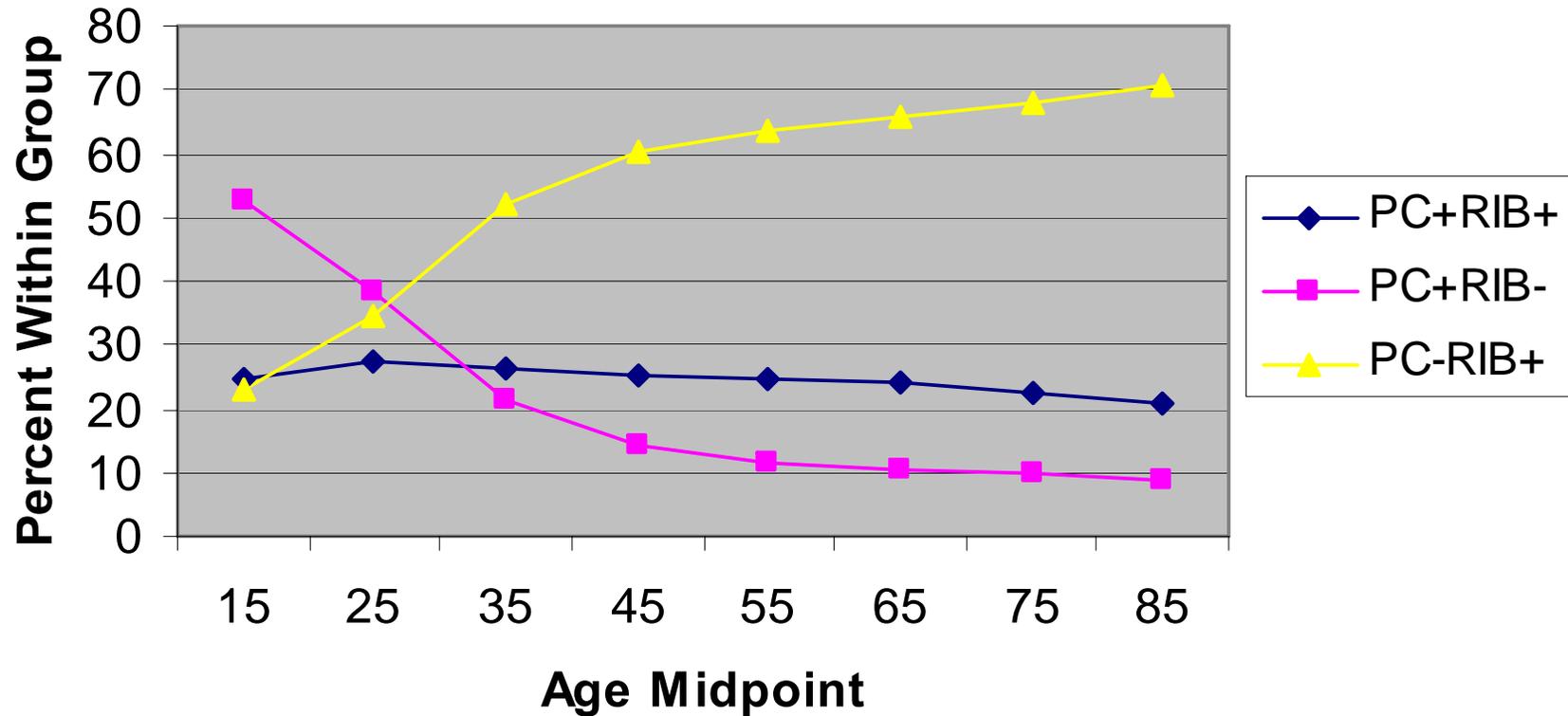
Percent Pulmonary Contusion per Rib Fracture by Delta V and Restraint Category: Age >= 65



This needs further investigation

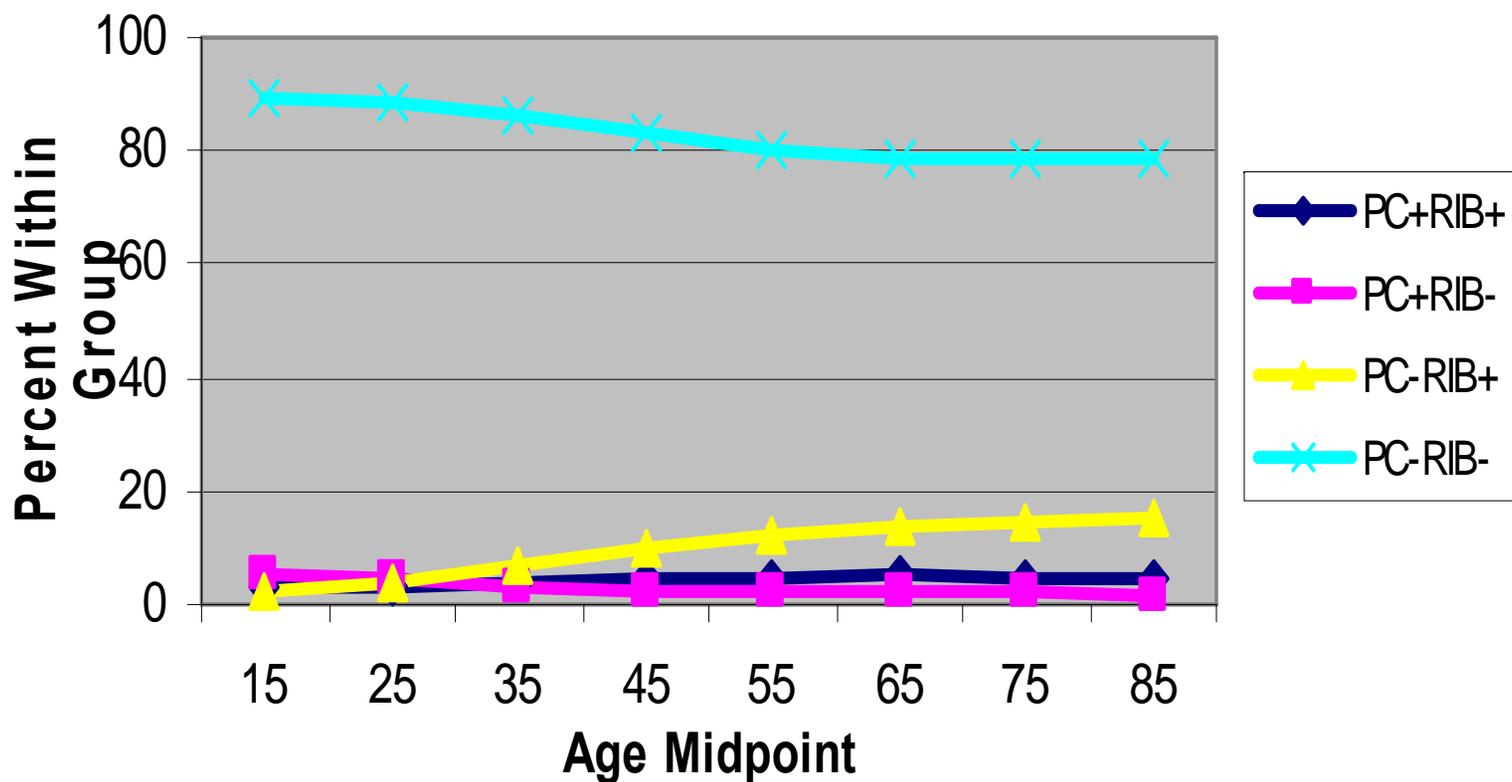
# Incidence within Thoracic Injury Cohort -NTDB

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



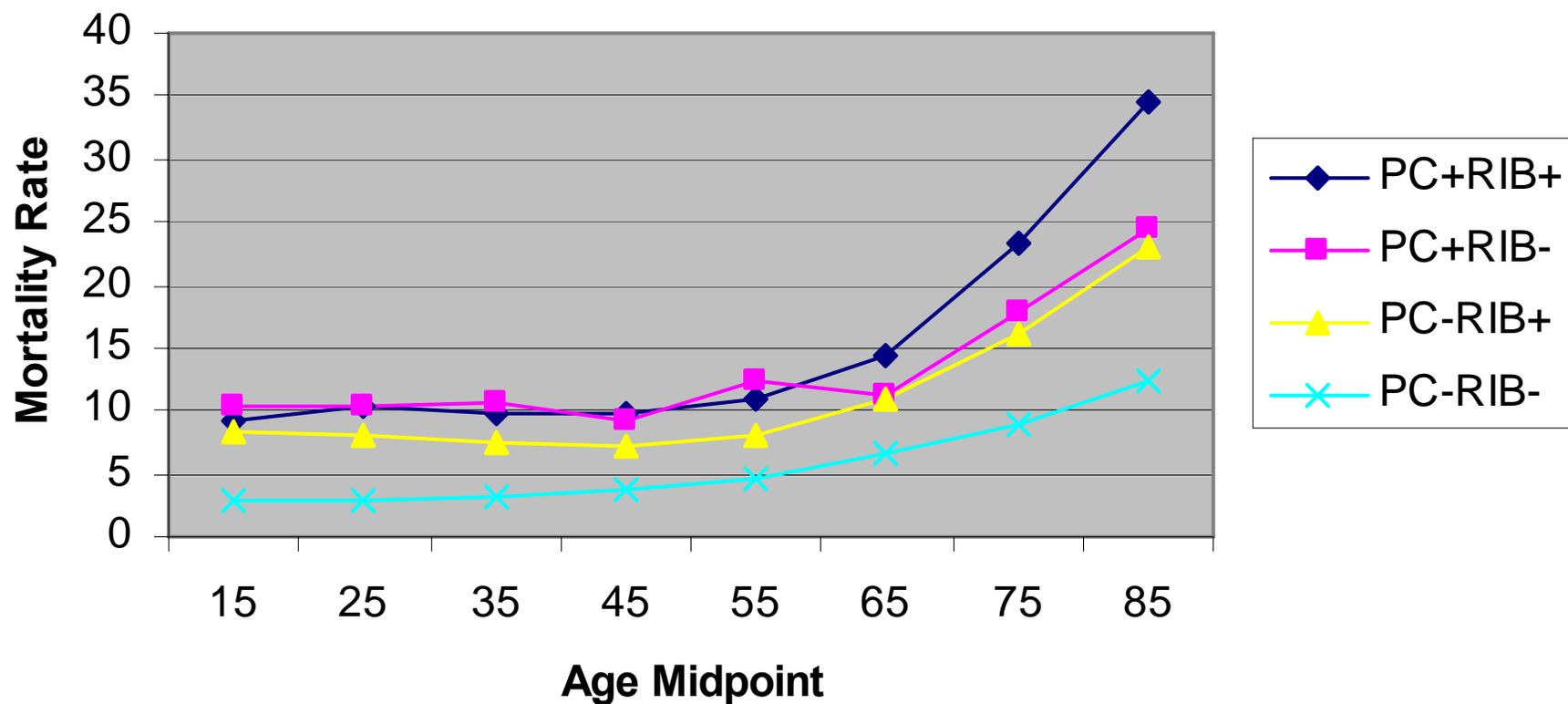
# Injury Incidence -NTDB

## Incidence of PC and Rib FX Among All MVC Patients



# Mortality of Chest Injuries -NTDB

## Mortality Rate by Injury Combination and Age



# 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

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

ROC = 0.90, GOF = < 0.0001

# Logistic Regression –Pulmonary Contusion

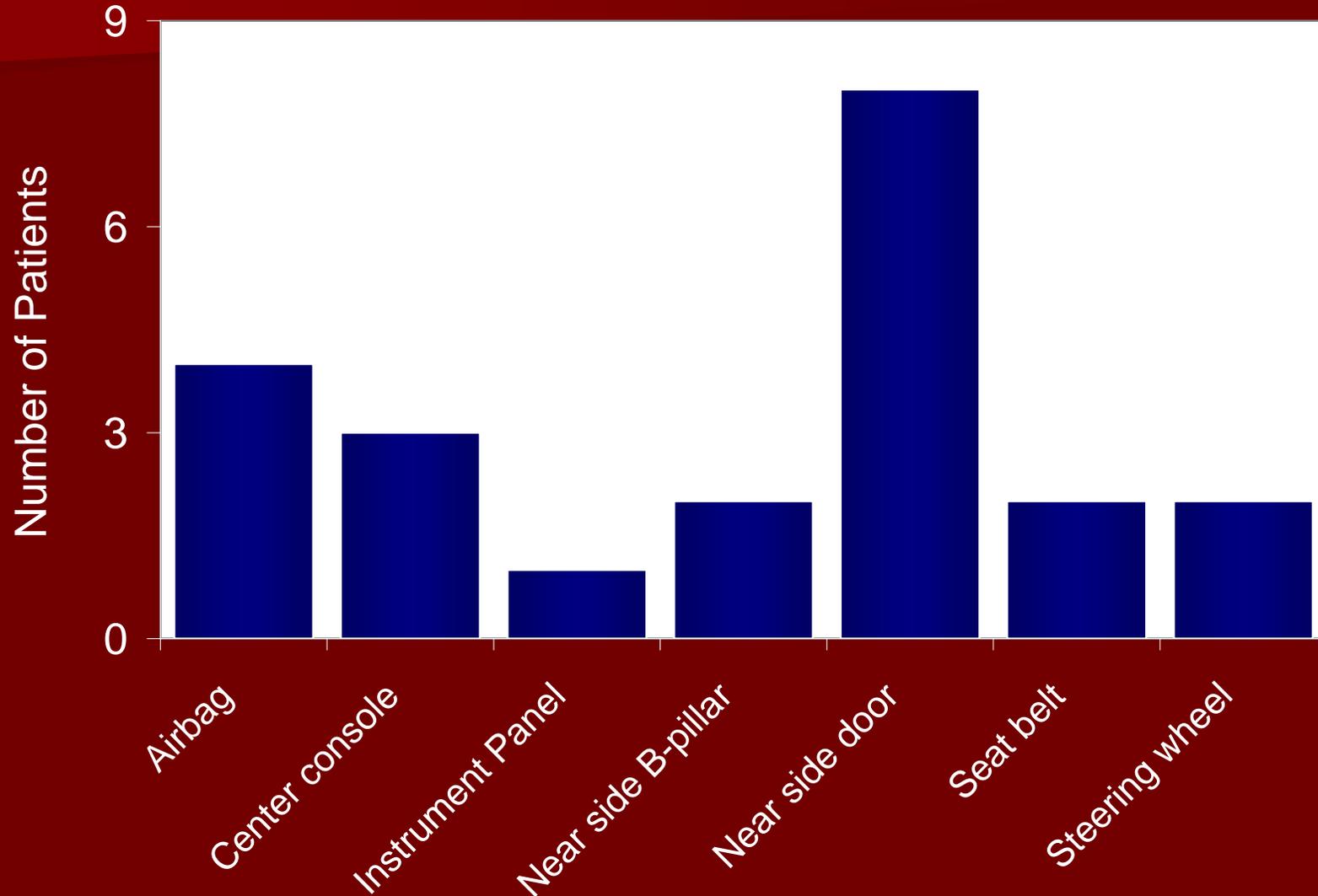
| Variable       | Odds Ratio | 95 % Confidence Interval | p-value  |
|----------------|------------|--------------------------|----------|
| Age            |            |                          | NS       |
| ISS            | 1.06       | 1.06 – 1.07              | < 0.0001 |
| Pt Height      |            |                          | NS       |
| Pt Weight      |            |                          | NS       |
| GCS            |            |                          | NS       |
| Vehicle weight | 0.996      | 0.994 – 0.999            | 0.02     |
| Delta V        |            |                          | NS       |
| Intrusion      | 1.22       | 1.13 – 1.32              | < 0.0001 |
| Rollover       |            |                          | NS       |
| Airbag         |            |                          | NS       |
| Seatbelt       |            |                          | NS       |

ROC = 0.90, GOF = < 0.0001

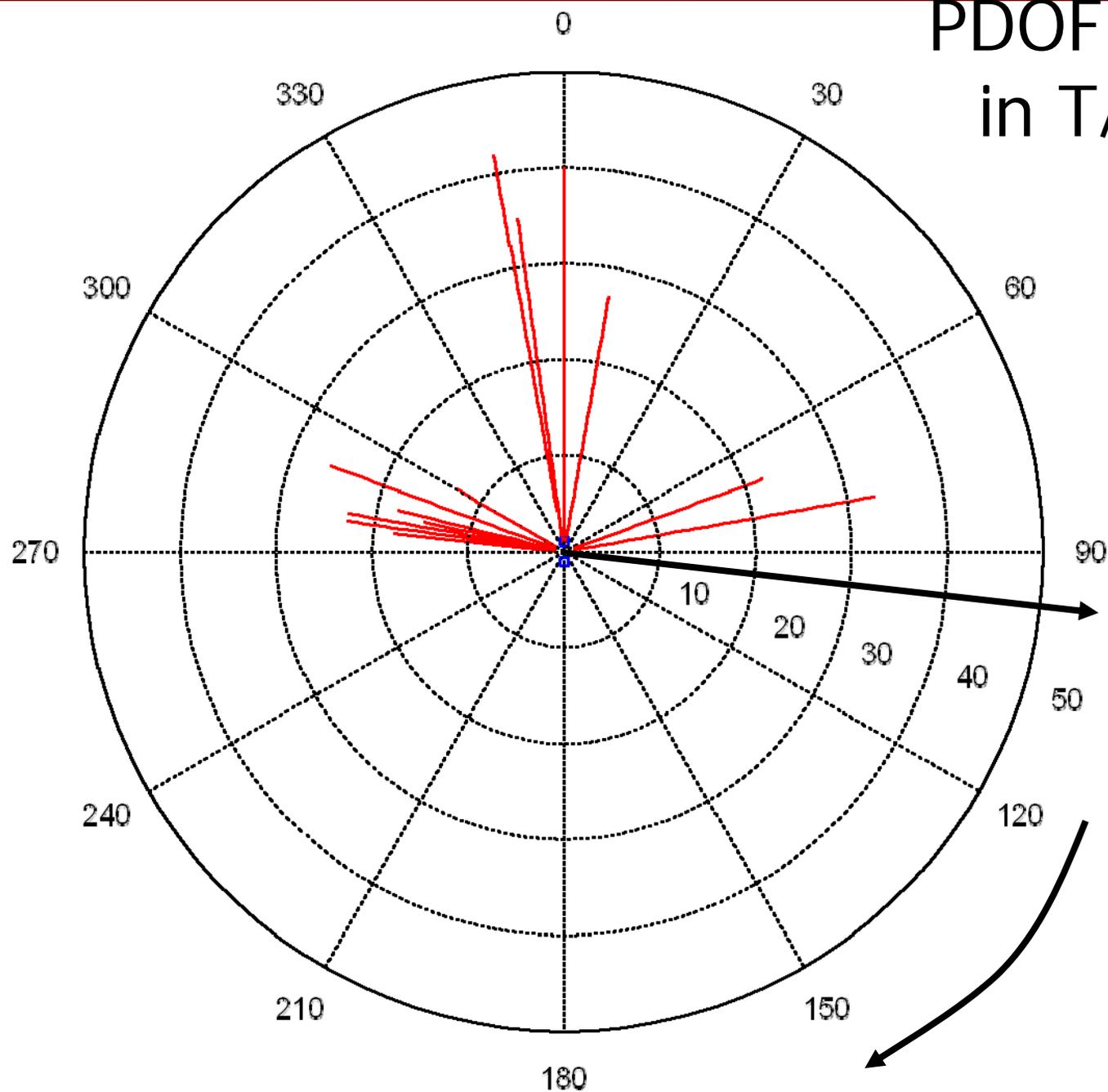
# T/WFU CIREN PC Data

|  |            |                                      |       |
|--|------------|--------------------------------------|-------|
| <b>Mean percent high radiopacity lung tissue (%)</b> | 14.6       | <b>Male: Female ratio</b>            | 1.3:1 |
| <b>Percent left, right, bilateral contusion (%)</b>  | 28, 33, 39 | <b>Average patient age (yrs)</b>     | 39±17 |
| <b>Incidence of rib fractures (%)</b>                | 72         | <b>Occupant position, driver (%)</b> | 78    |
| <b>Incidence of pneumothorax, hemothorax (%)</b>     | 50, 17     | <b>Seat belt usage (%)</b>           | 61    |
| <b>Mean CT scan time post- crash (hrs)</b>           | 8.4        | <b>Air bag deployment (%)</b>        | 56    |

# Distribution of components contacted by PC+ cases T/WFU CIREN



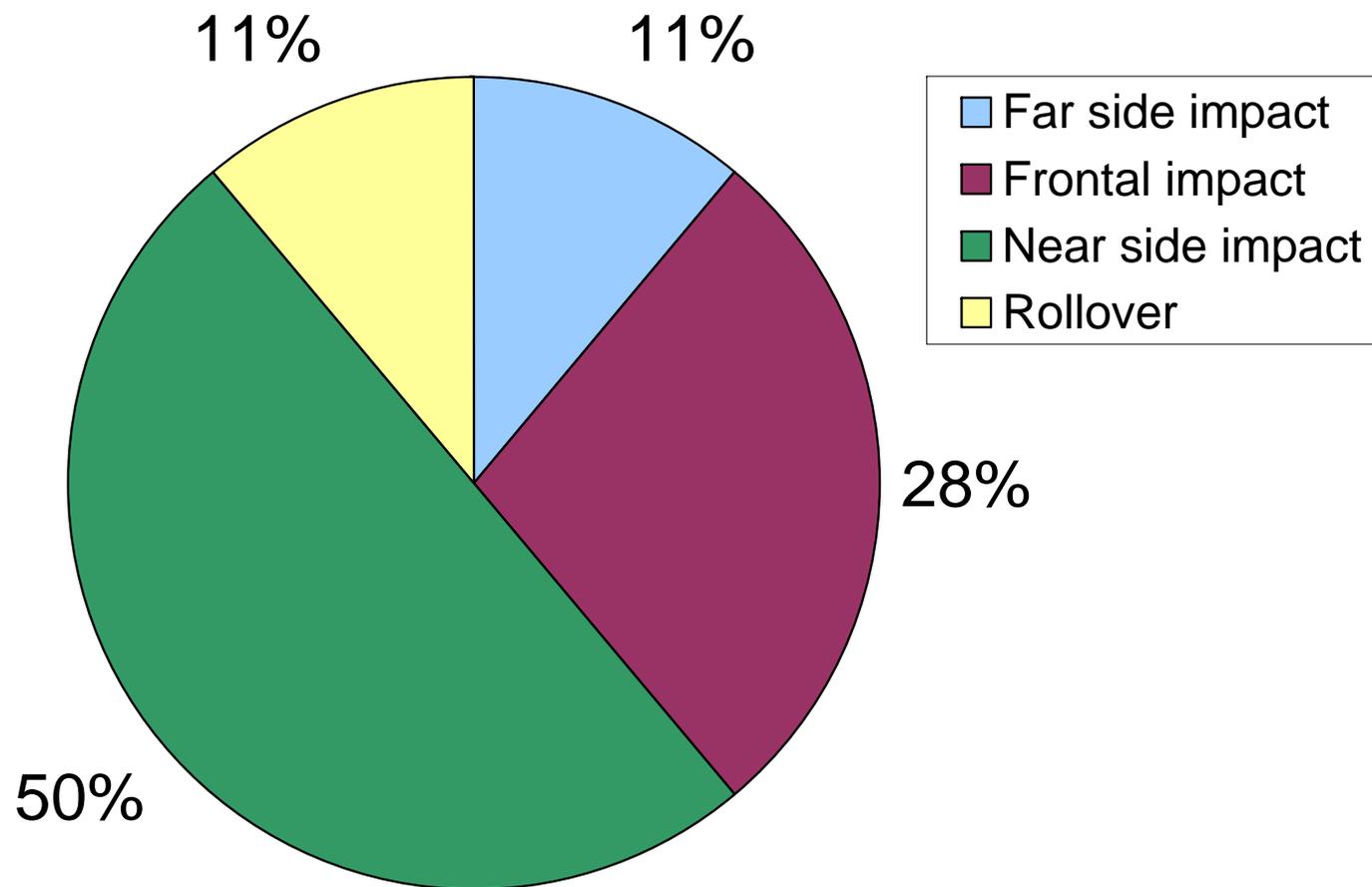
# PDOF and Delta-V in T/WFU CIREN PC+ cases



Delta V, MPH

PDOF, Degrees

# Distribution of the impact mode for PC+ cases T/WFU CIREN



# 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)
- CIREN is the place to get these together

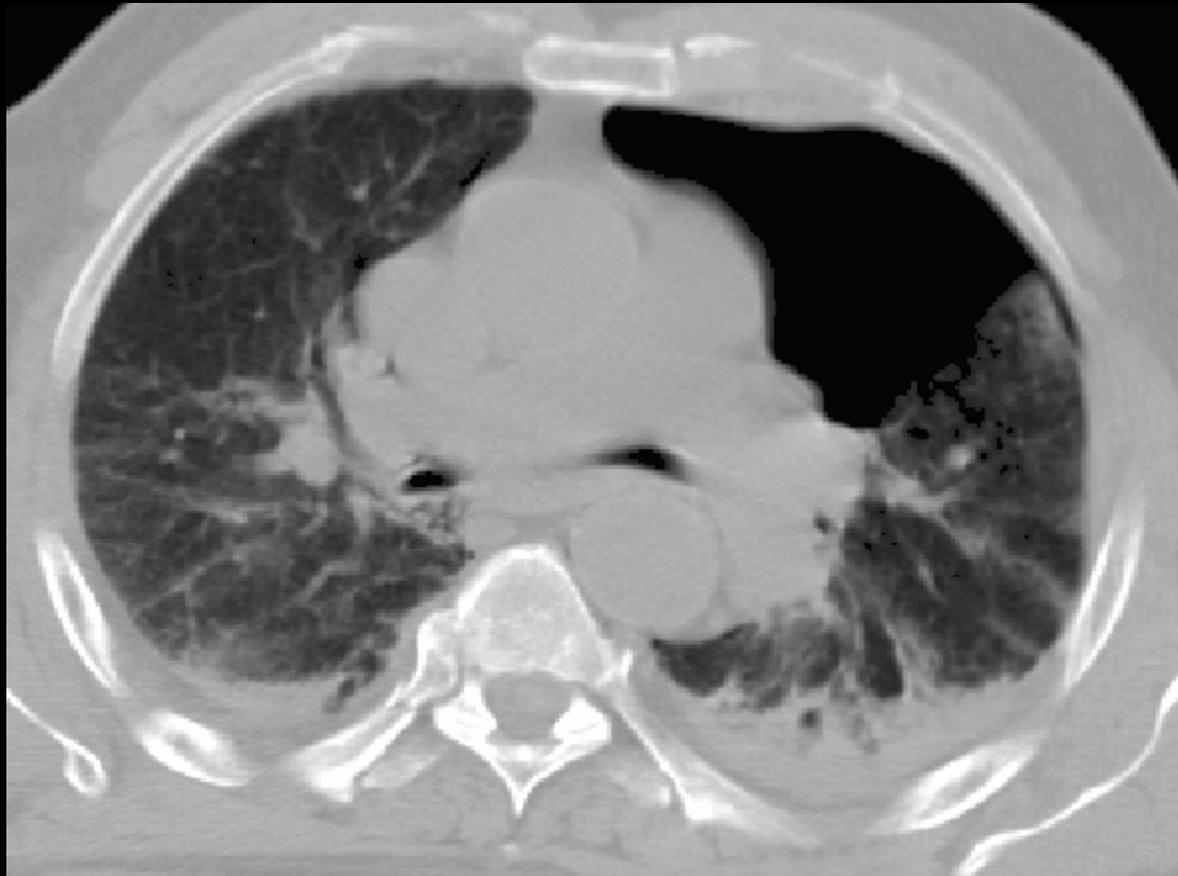
# CT Segmentation Algorithm

# Categories of Lung Tissue for Segmentation Algorithm

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

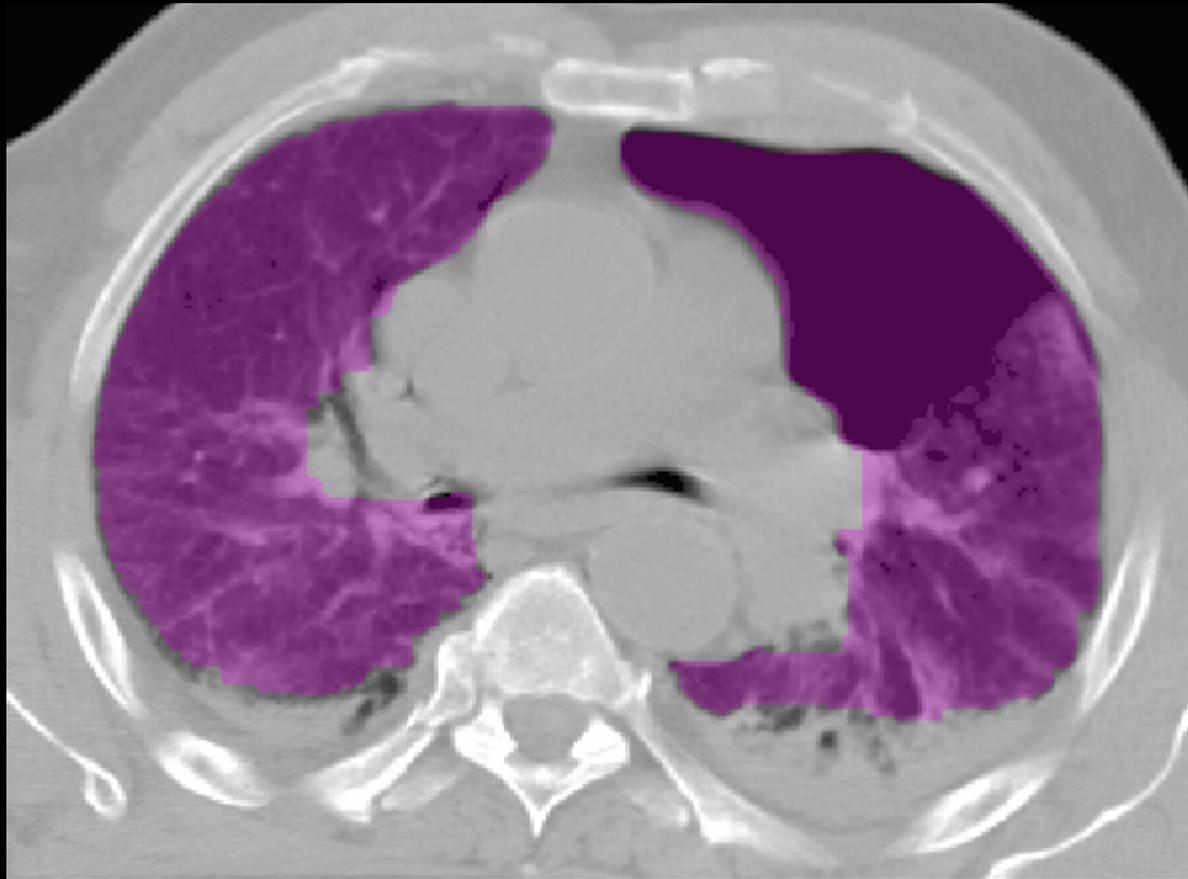
*M. Daly et al., Clinical Imaging, 2007 (in press)*

# CT Segmentation Algorithm



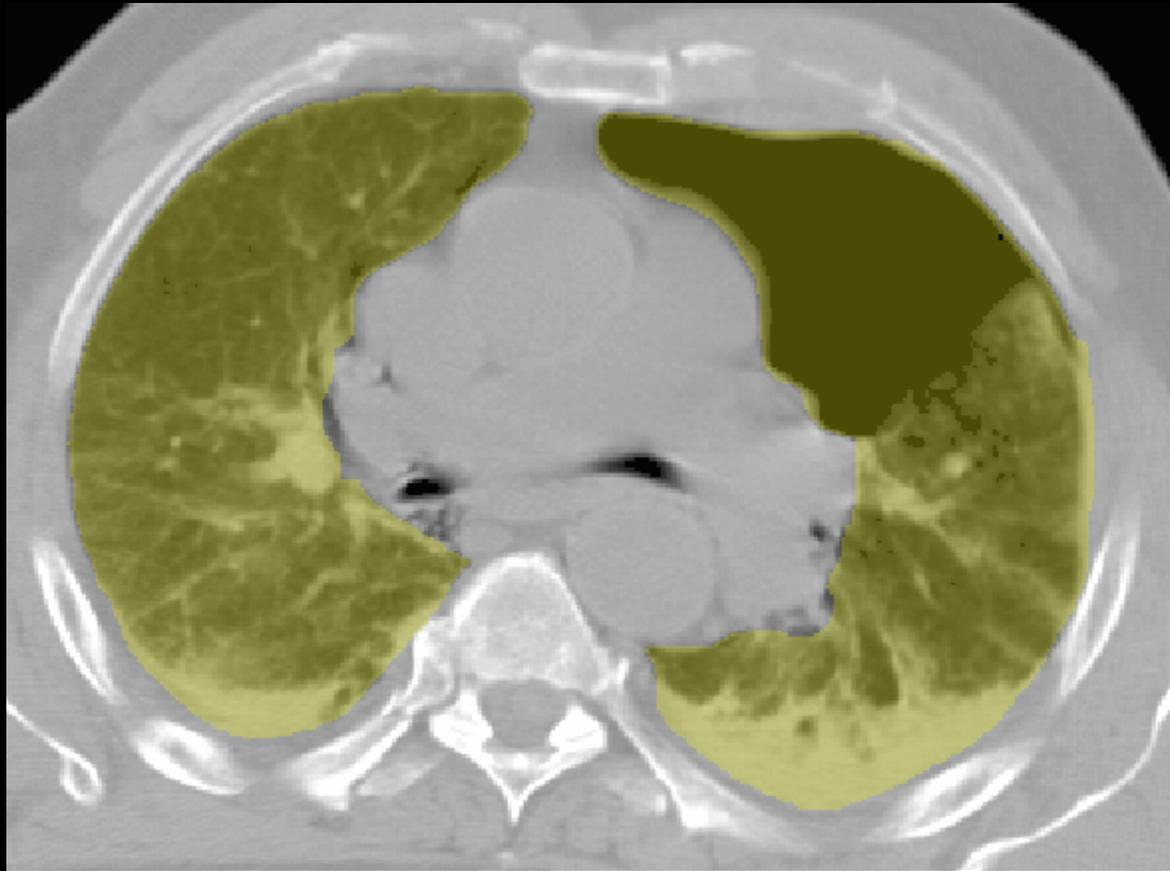
1. Original CT scan

# CT Segmentation Algorithm



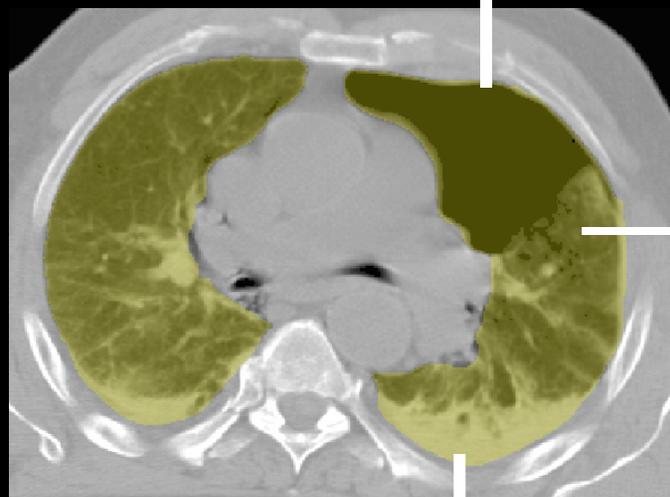
2. Select all pixels with in 200 HU of selected pixel

# CT Segmentation Algorithm

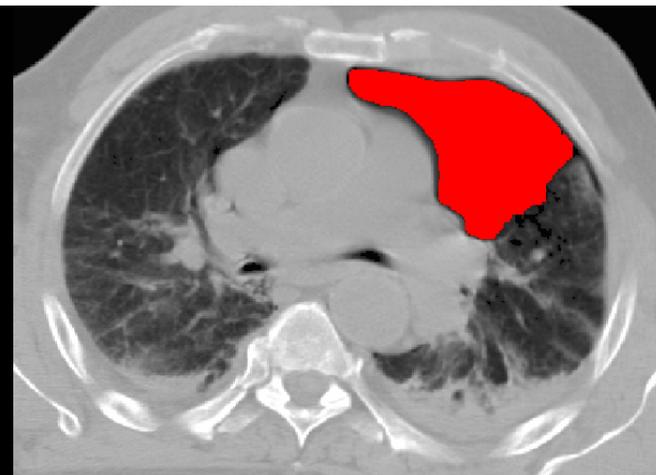


3. Edit until the entire chest cavity is selected, the resulting mask is the **Total Chest Cavity** mask

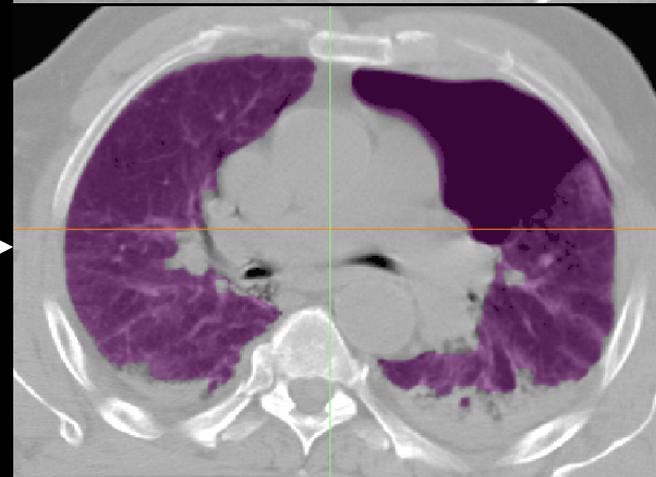
# Algorithm Continued



Low Attenuation  
HU = -1024



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



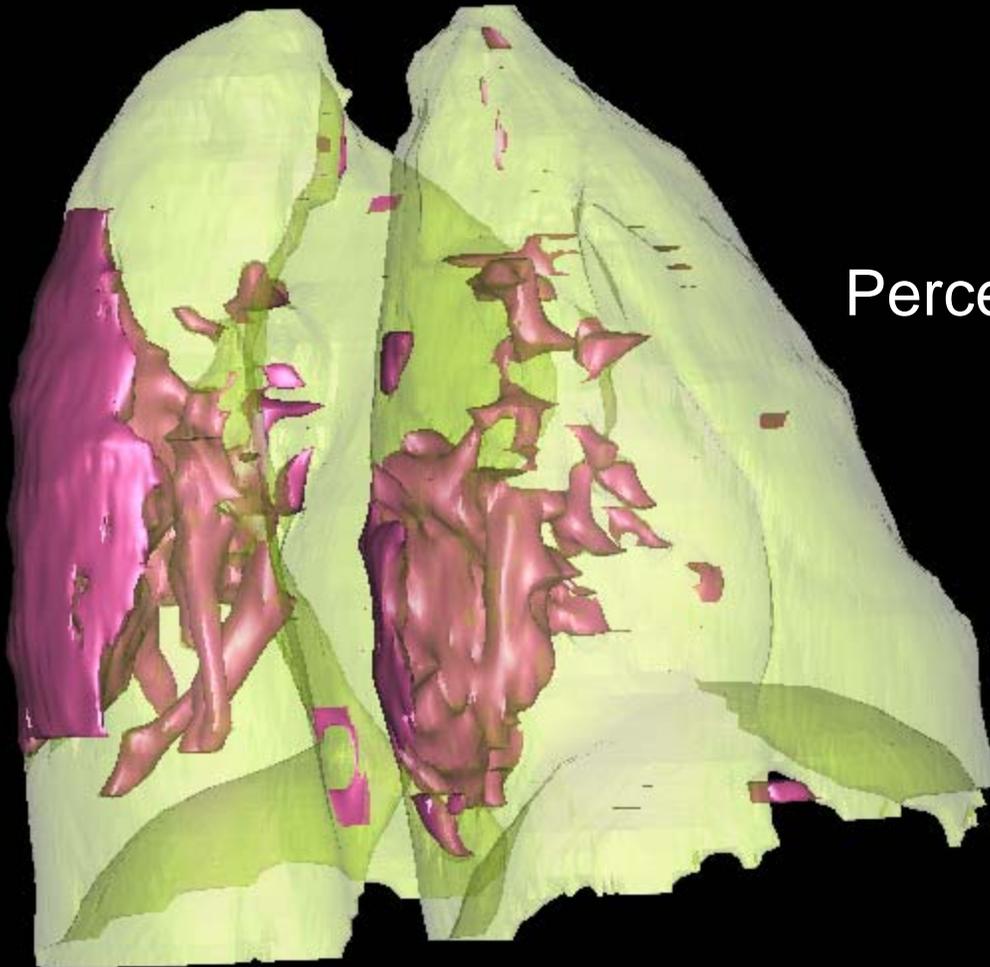
Partition Total Chest Cavity into:

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

High Attenuation  
HU  $\geq -350$



# Calculation of Percent Pulmonary Contusion



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

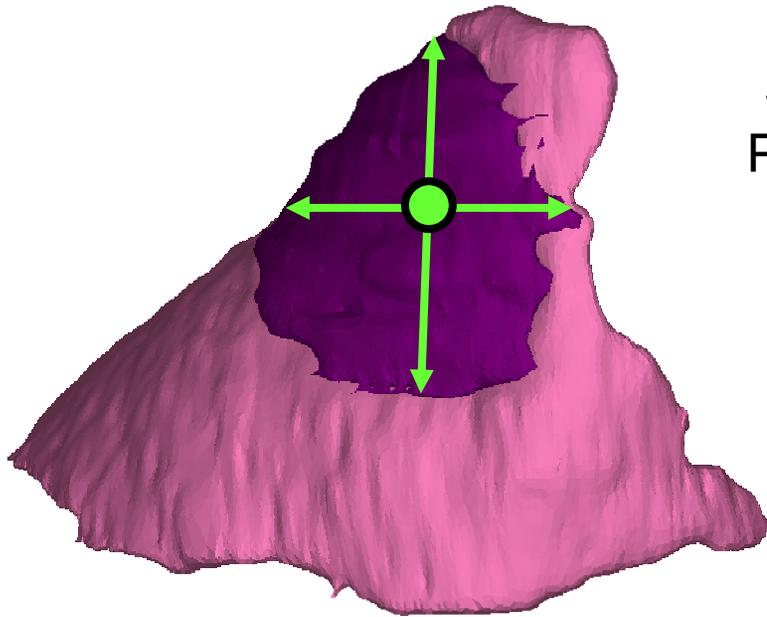
High Attenuation Volume

Total Lung Volume

High Attenuation Volume + Lung Attenuation Volume

*Three Dimensional Reconstruction, Mimics*

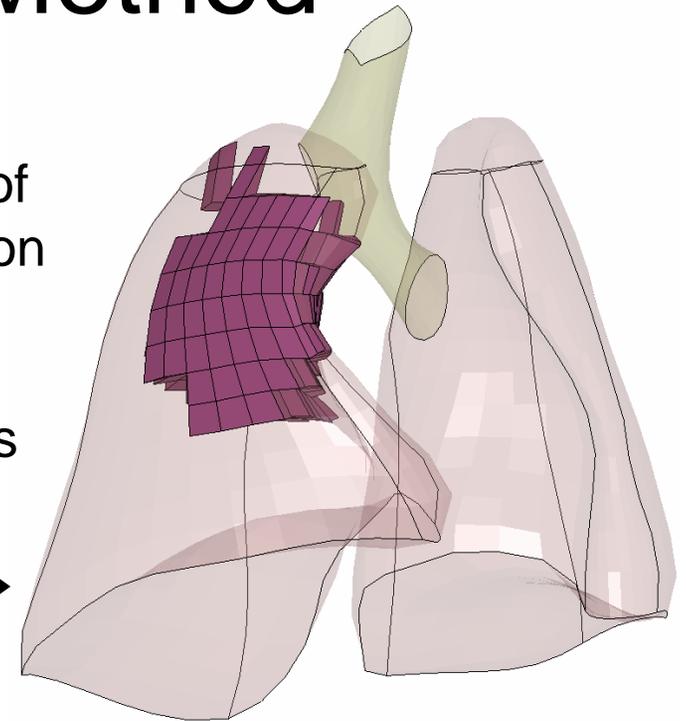
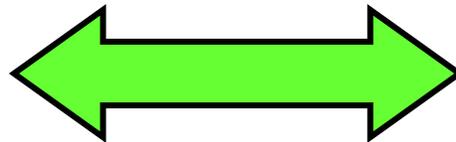
# Contusion Characterization and CT-FEA Registration Method



**CT Reconstruction**

- 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



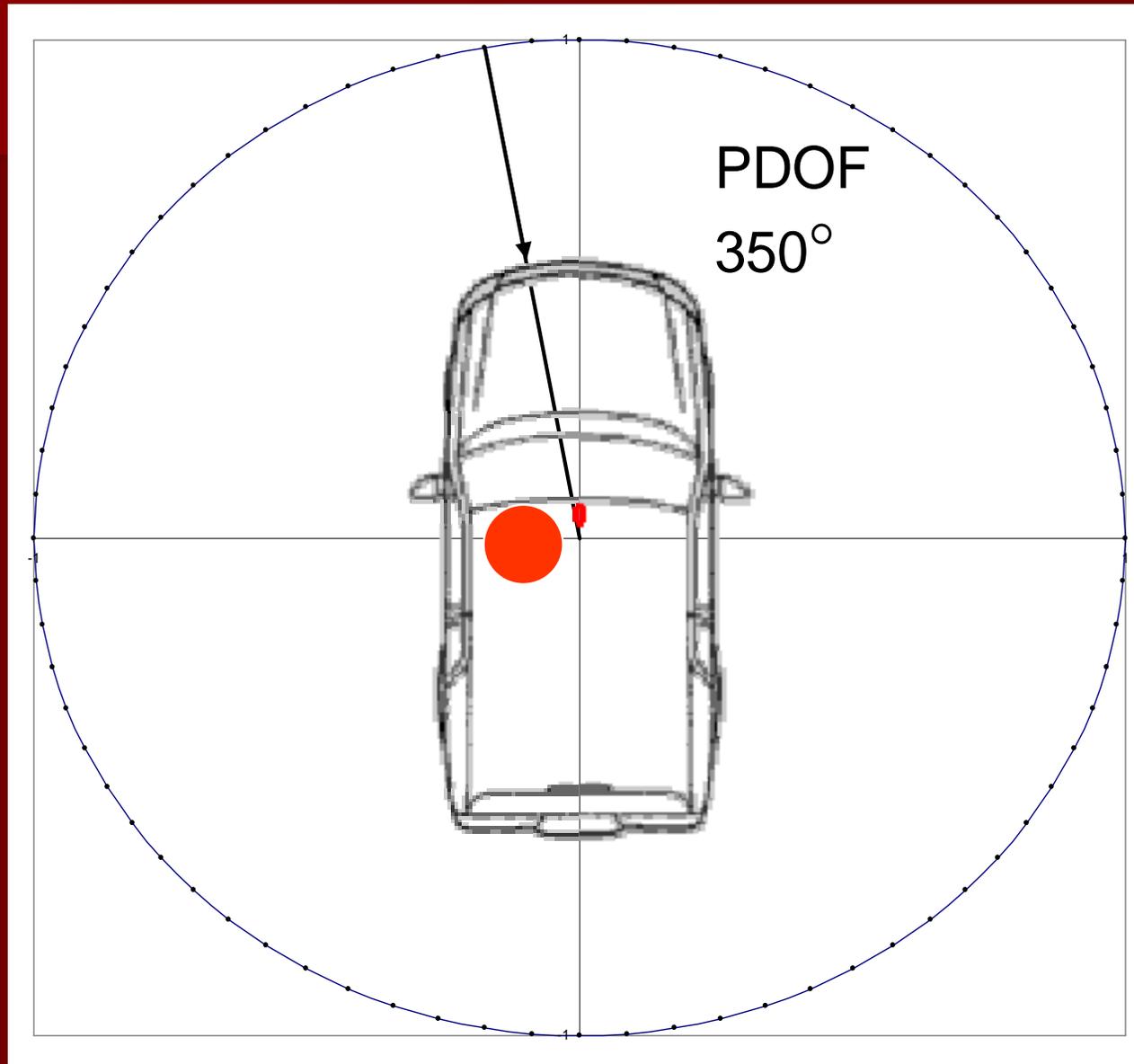
**FEA model showing predicted contusion**

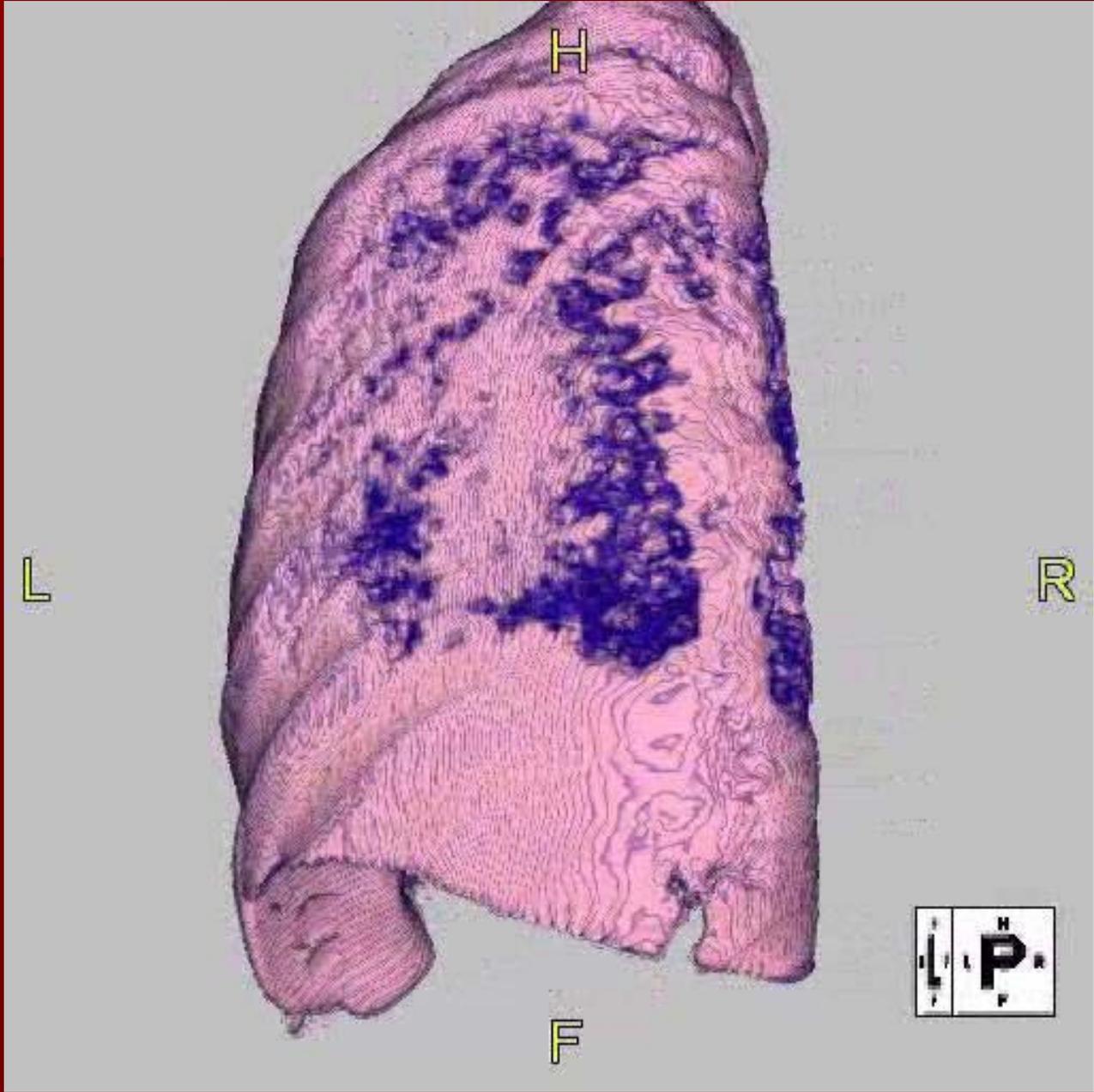
- Lung model and PC threshold developed from CT

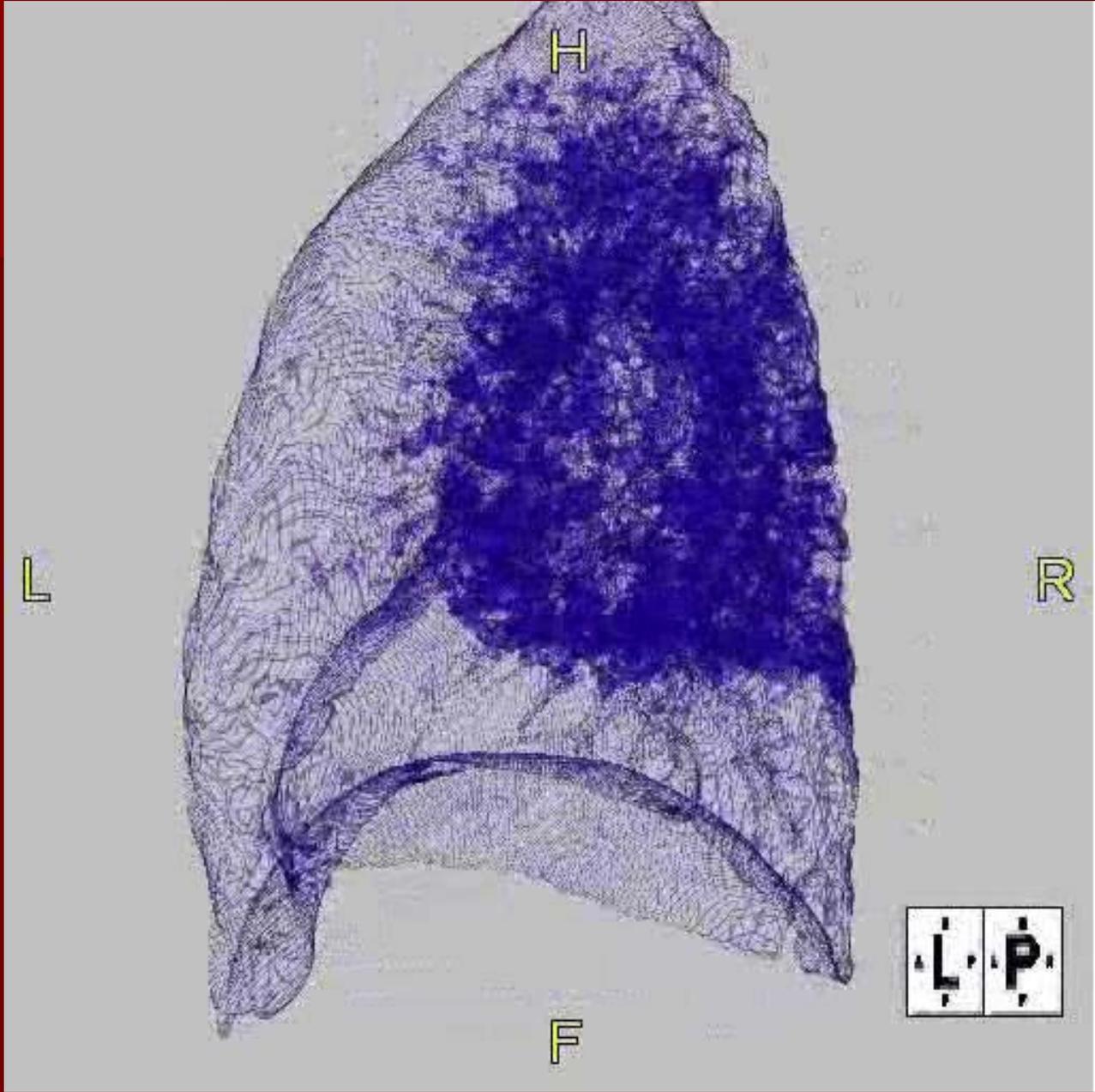
# T/WFU CIREN Elderly Pulmonary Contusion – Case 85

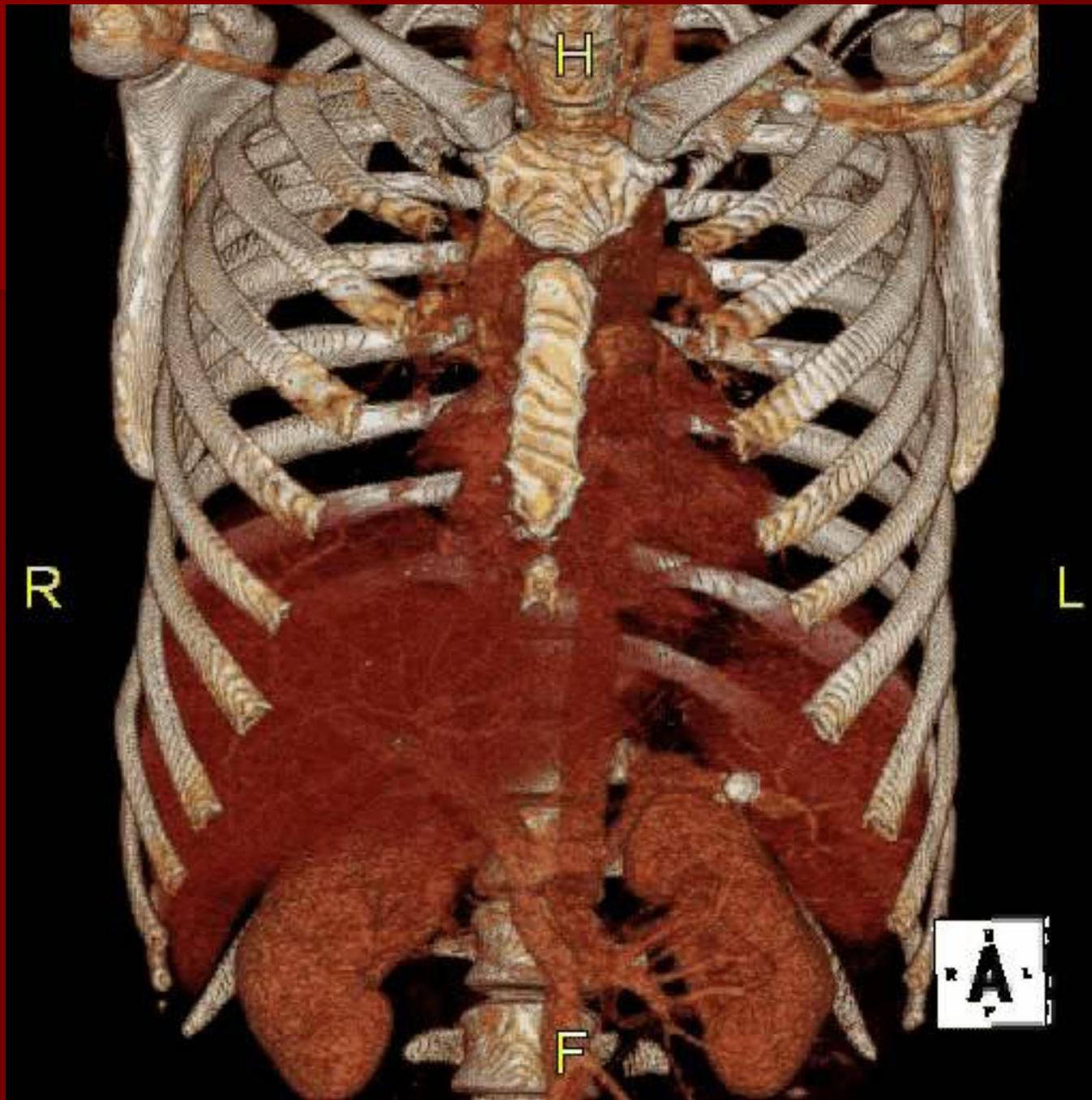
- 75 yr old female
- Driver (belted, airbag deployed)
- Frontal impact with another vehicle
- PDOF = 350 degrees
- Delta V = 42.3 mph
- MAIS = 4
- ISS = 18
- IPC for thoracic injuries listed as steering wheel
- Injuries Included:
  - Right pulmonary contusion
  - Bilateral Rib Fractures (R2-8, L2-3)

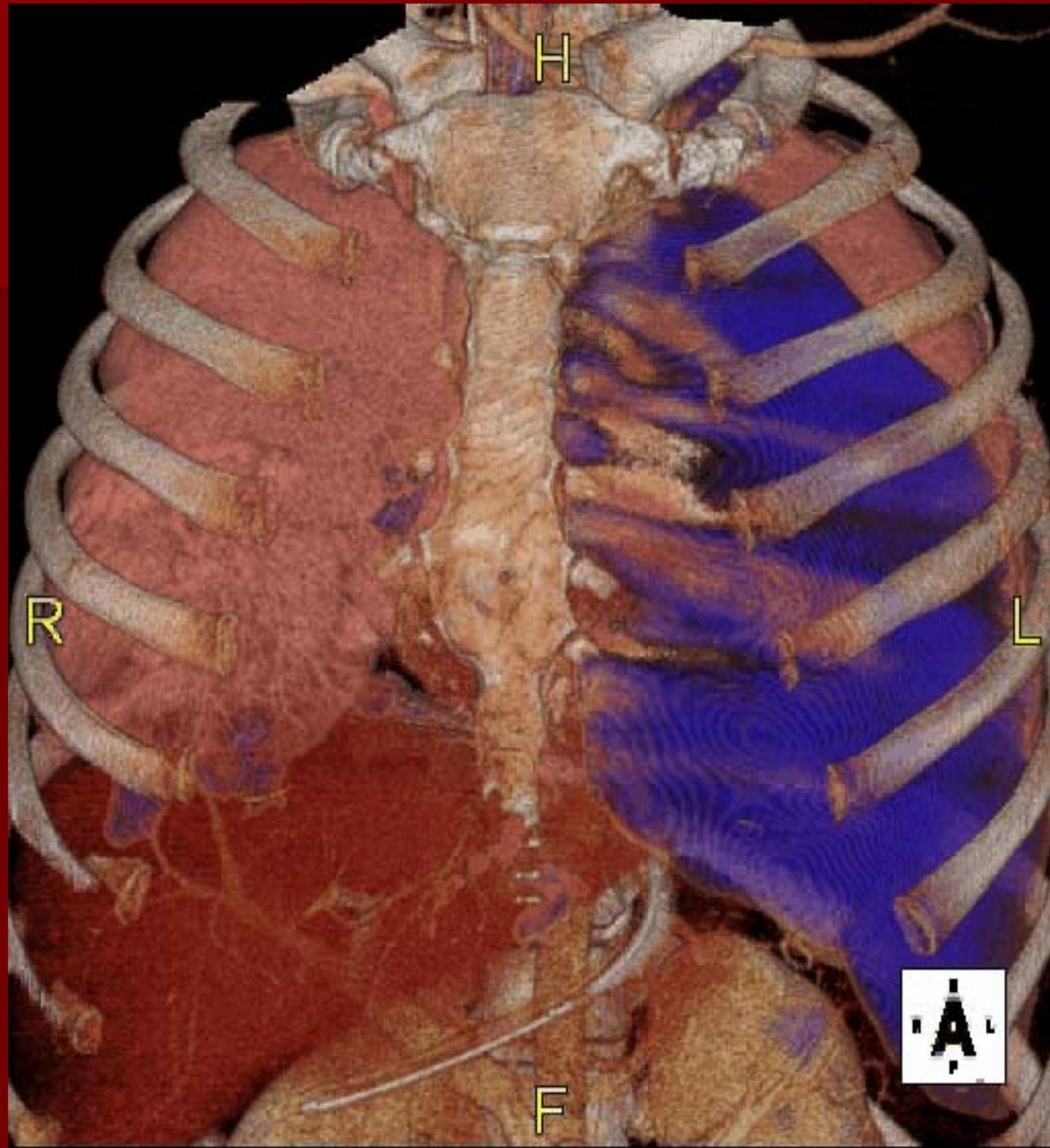
# PDOF CIREN 085











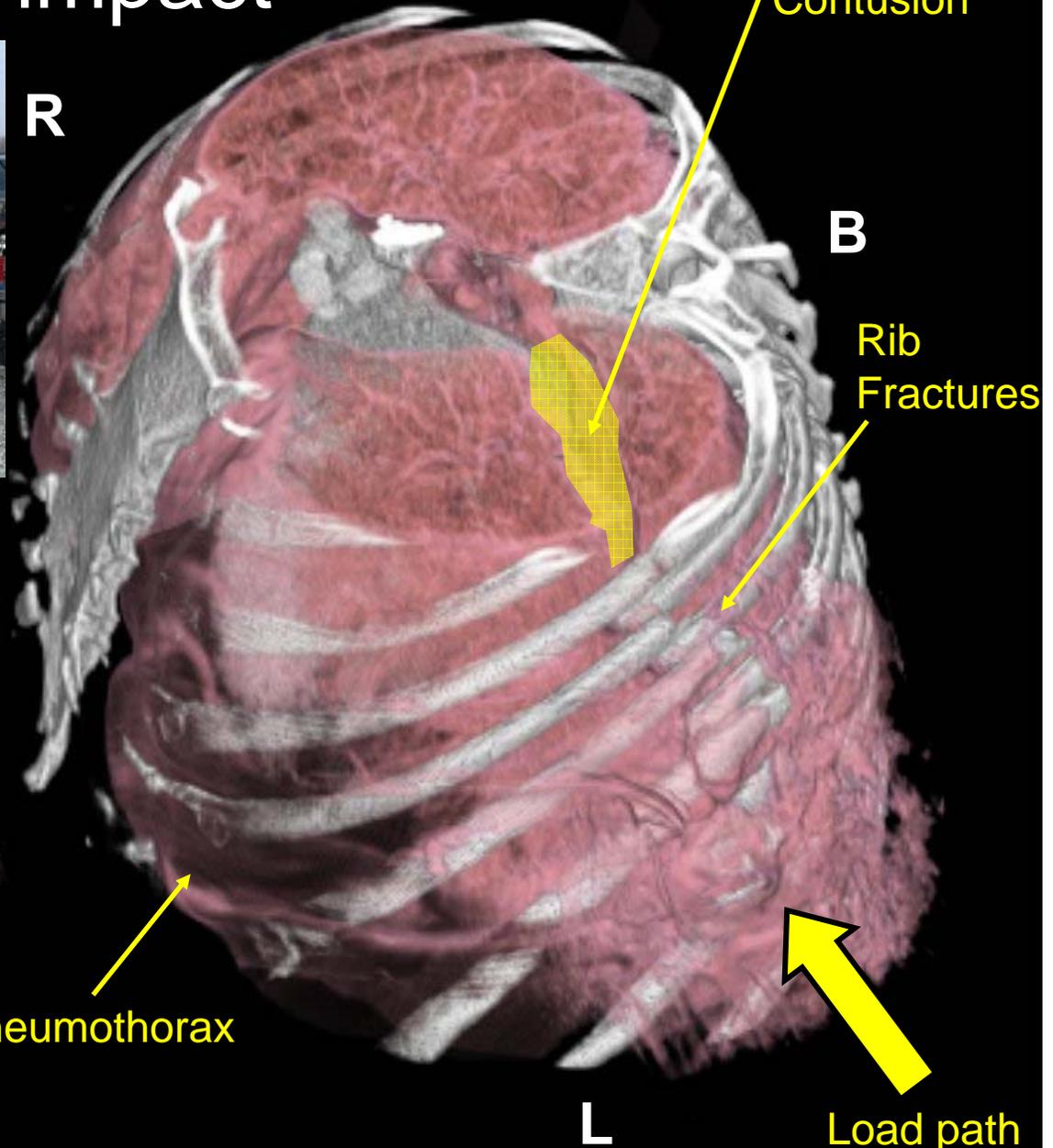
# Radiological investigation of interaction between rib fractures and pulmonary contusion

For WFU CIREN patients with Rib Fx and PC in nearside and frontal crash

# Case 1: Nearside impact



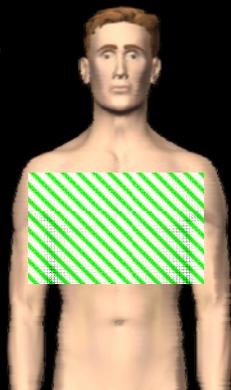
R



- 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%

F

Area of detail:

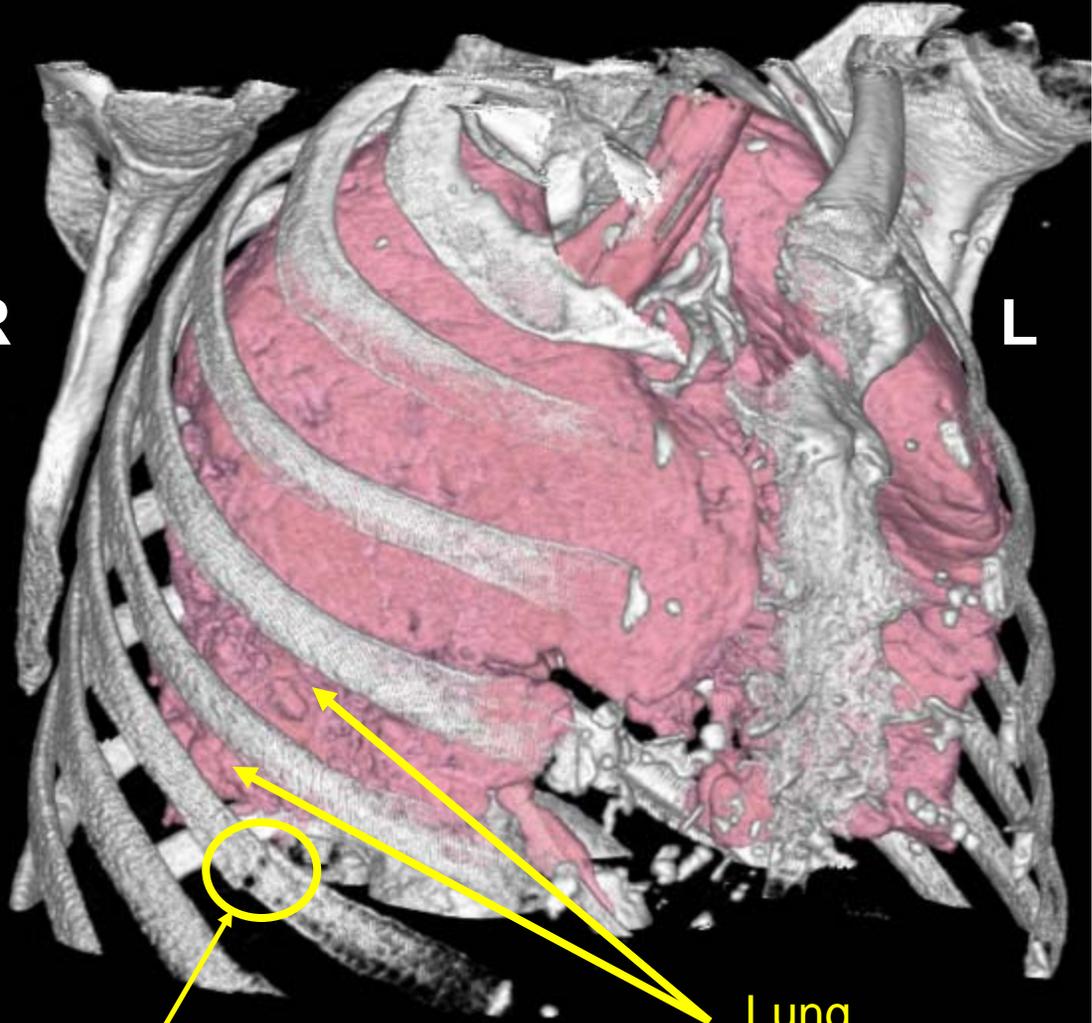


# Case 2: Frontal impact



R

L



- 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:



Rib Fractures (Right side 6<sup>th</sup> -10<sup>th</sup>)

Lung Contusion

# 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

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