Elderly thoracic injuries and modelling

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What is driving safety improvements?

Courtesy of Jason Forman
What is driving safety improvements?
What is driving safety improvements?

- $\text{Acc}_{\text{head}}$
- $\text{Force}_{\text{neck}}$
- $\text{Compression}_{\text{chest}}$
- $\text{Disp}_{\text{knees}}$
- $\text{Force}_{\text{femurs}}$

Courtesy of Jason Forman
What is driving safety improvements?

Regulations:
- NHTSA FMVSS
- ECE Type Approval

Consumer tests:
- NCAPs
- IIHS

Courtesy of Jason Forman
Then, what is missing?

Obesity

Aging

Female Population
Ageing population

Ratio of elderly (65+) vs non-elderly (20-64) by country

Source: World Population Prospects, 2010
Age and biomechanics transitions

Musculo-skeletal development
Increase in muscle, bone size

Dummy risk prediction for middle aged average size males

Bone resorption, increased porosity, decreased remodeling
Sarcopenia

Fragility and frailty

Injury Tolerance

Pediatric
Adult
Advanced Age

0 10 20 30 40 50 60 70 80
Age (years)

Courtesy of Jason Forman
Fatal injuries in Elderly (USA)

Injured Body Region (MAIS 3+, All Drivers, Frontals)

- Head
- Neck
- Chest
- Abd.
- Spine
- Up. Ex.
- Lo. Ex.
- Pelvis

Percent of Injuries

- Age Group 1 (16-33)
- Age Group 2 (34-64)
- Age Group 3 (65+)

Kent et al. 2005
Fatal injuries in Elderly (USA)

Injured Body Region (Fatal, All Drivers, Frontals)

Percent of Injuries

Age Group 1 (16-33)
Age Group 2 (34-64)
Age Group 3 (65+)

Head
Neck
Chest
Abd.
Spine
Up. Ex.
Lo. Ex.
Pelvis

Kent et al. 2005
What happens to an ageing thorax?

– Some age-related changes
  • Modulus and failure stress
  • Area, thickness of cortical bone
  • Costal-Cartilage
  • Musculature (sarcopenia)
  • etc

Stein and Granik, 1976
Demographics in Japan 1990
Demographics in Japan 2010

Male

Female
Demographics in Japan 2030

Male
Female
Demographics in Japan 2050

Male

Female
Traffic crashes and deaths in Japan

Japanese Police Traffic Data

(Accidents) vs (Persons)

Motorization


Year

1500000
1250000
1000000
750000
500000
250000
0

18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0

711,374
4,113

DARI

16
Fatalities: Elderly vs Non-elderly

Elderly fatality rates highest and increasing
Fatality rates by Age

Chest injuries account for most deaths

IkARDA (2006-2008)
Japanese elderly body size

<table>
<thead>
<tr>
<th></th>
<th>US Adult AM50</th>
<th>Japanese Adult</th>
<th>Japanese Elderly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>175</td>
<td>170</td>
<td>160</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78</td>
<td>68</td>
<td>60</td>
</tr>
</tbody>
</table>

Japanese elderly are particularly small
Approach to the problem
Japanese elderly size PMHS

PMHS specimen: 71 yo, Male, 161 cm, 60kg (BMI: 22.7)

CT images

Table top tests

Component tests

- Rib bending (3)
- Costal cartilage shear (4)
- Muscle tensile (5)

Development of an elderly thorax FE model

Antona-Makoshi et al. TIP 2015

Ribcage and spine

Inner organs
Rib model development

1. CT image
2. 3D data of cortical bone
3. Measurement thickness
4. Element development and assignment of thicknesses
5. Model validation

Kato et al. JSAE 2015
Verification of rib measurement thickness

Kato et al. JSAE 2015
Rib validation in bending

Kato et al. JSAE 2015
Rib validation

![Graphs of Rib validation](image)

Kato et al. JSAE 2015
Predictability of fracture location

Kato et al. JSAE 2015

○ Simulation
× Experiment
Elderly thorax model assembly validation

Intact

Denuded

Eviscerated

Antona-Makoshi et al. JSAE 2015
Scaling of the elderly model size to AM50

Scaling Factor
1.09 in xyz
(height based)

Japanese Elderly size
60kg 161cm

AM50 size
77kg 175cm

Antona-Makoshi et al. JSAE 2015
**Age-dependent properties implementation**

**Rib cortical bone fragility**

Costal cartilage (fragility)

Flesh properties (sarcopenia)

Antona-Makoshi et al. TIP 2015
Full body model validation (AM50)

Full body FE model validation: Hub Impactor (AM50)

Simulation Elderly 12 fractures
Force [kN]
Deflection [mm]
Kroell Elderly Corridor
Elderly & Younger

Simulation Younger 2 fractures
Force [kN]
Deflection [mm]
Kroell Younger Corridor
Elderly & Younger

Full body FE model validation: Frontal Sled (AM50)

Multipoint chest deflection
PMHS 1358
PMHS 1359
PMHS 1360
Elderly model
Younger model

Body Trajectories

Displacement
AM50 Elderly Evaluation
AM50 Younger Evaluation
AM50 Elderly Evaluation
Head
0.012
Good
0.053
Good
0.013
Good
0.013
Good
T1
1.162
Good
1.479
Good
1.162
Good
1.479
Good
T5
1.207
Good
1.574
Good
1.207
Good
1.574
Good
L2
1.228
Good
1.320
Good
1.228
Good
1.320
Good
L4
0.605
Good
0.726
Good
0.605
Good
0.726
Good
Pelvis
0.534
Good
0.562
Good
0.534
Good
0.562
Good

Antona-Makoshi et al. TIP 2015
Application for restraint system research

Conventional Seatbelt
Force Limit: 2, 3, 4, 5kN

Driver models:
Adult AM50, Elderly AM50, Elderly Small

NCAC Airbag geometry & JARI test data
Pressure: Low, Mid, High

56 km/h full overlap frontal NCAP test pulse

Belt anchor & seat slide based on JAMA survey data

3 occupants x 4 belt force limits x 3 airbag settings = 36 cases

Antona-Makoshi et al. IRCOBI 2016
Front crash simulation (Elderly AM50)

Belt Force Limit 4kN, Low Airbag Pressure

Antona-Makoshi et al. IRCOBI 2016
Front crash simulation (Small Elderly)

Belt Force Limit 4kN, Low Airbag Pressure

Antona-Makoshi et al. IRCOBI 2016
Chest deflection and excursion

As belt force limit ↑, excursion ↓ and chest deflection ↑

Antona-Makoshi et al. IRCOBI 2016
Number of fractured ribs and head excursion

**Adult AM50**

- Airbag Pressure:
  - Low: High NFR for FL 4/5 kN
  - Medium: High NFR for FL 4/5 kN
  - High: Head strikethrough for low FL

**Elderly AM50**

- Airbag Pressure:
  - Low: High NFR for FL 4/5 kN
  - Medium: High NFR for FL 4/5 kN
  - High: Head strikethrough for low FL

**Elderly Small**

- Airbag Pressure:
  - Low: High NFR for FL 4/5 kN
  - Medium: High NFR for FL 4/5 kN
  - High: No head impact

Antona-Makoshi et al. IRCOBI 2016
Rib fractures pattern and timing

Most rib fractures along belt path and before full contact with airbag

Antona-Makoshi et al. IRCOBI 2016
Effect of belt force limit

Elderly AM50, Low Airbag Pressure

Increasing Belt Force Limit

2 kN  3 kN  4 kN  5 kN

NFR 0  NFR 3  NFR 8  NFR 9

Decreasing the belt force limit from 4 kN to 3kN produced a large drop of number of fractures in the elderly but resulted in head strikethrough.

Accident data by Foret-Bruno et al. 2001, Forman et al. 2006, Mertz et al. 2007

THOR vs HIII sled tests by Sunnevang et al. 2014

Antona-Makoshi et al. IRCOBI 2016
Effect of airbag pressure settings

Elderly AM50, Belt Force Limit 2kN

Increasing Airbag Pressure

Low          Mid          High

NFR 0        NFR 0        NFR 0

Increased airbag pressure had minimal effect on chest deflections (and rib fractures) and prevented head strikethrough.

Accident data by Carrol et al. 2010
Summary

◆ Elderly are fragile and frail
◆ Modern cars are becoming safer for all body regions
◆ Elderly are under protected, particularly in the thorax
◆ Developed a tool for elderly thoracic safety evaluation
◆ Restraint systems settings optimal for young AM50 are sub-optimal for elderly, regardless of body size
◆ Future safety standards need to prioritize elderly, particularly in ageing countries

Thank you!
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