Side Impact Simulations using THUMS and WorldSID

25th September, 2013

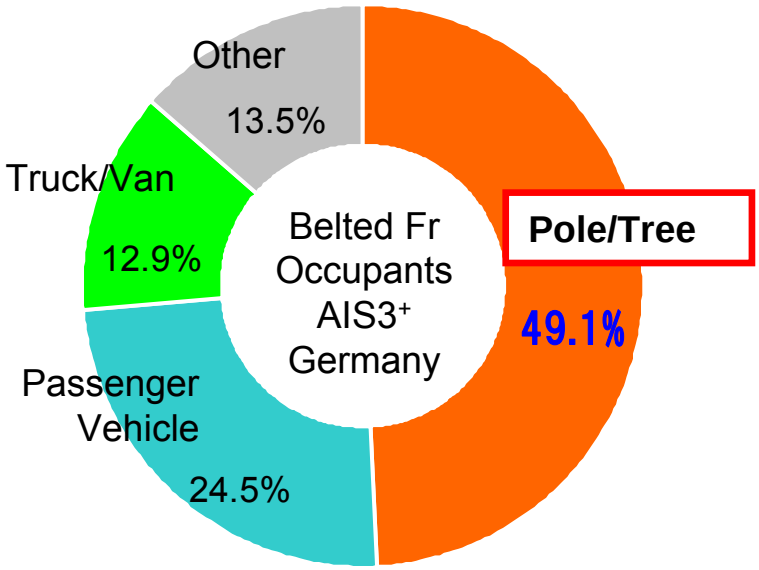
Tsuyoshi Yasuki, Yuichi Kitagawa, Shinobu Tanaka, Satoshi Fukushima

TOYOTA MOTOR CORPORATION

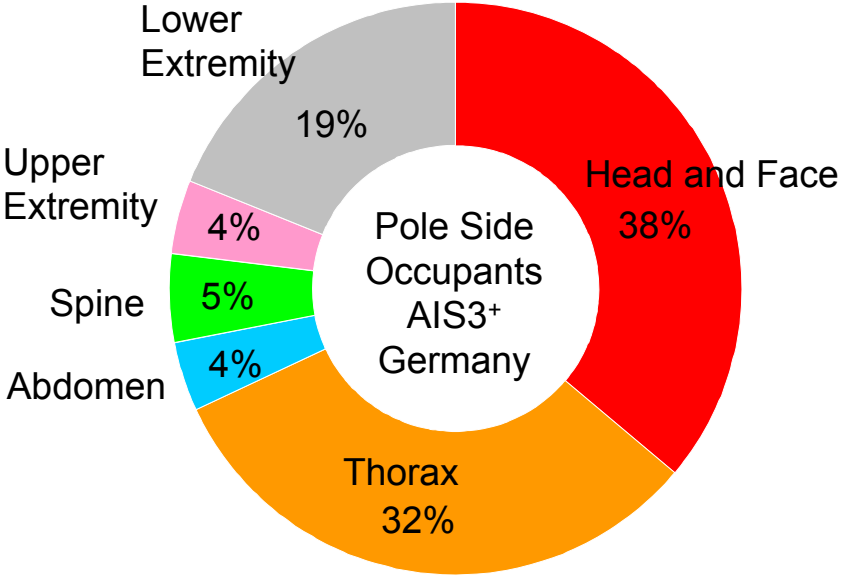
CONTENTS

1. Background

- **Occupant Injury in Side Impacts**
  - *Poles and trees are most common obstacles in side impacts.*
  - *Head, face and thorax are frequently injured.*



Obstacles in Side Impacts
Haenchen et al.(2004)



AIS3+ Body Regions in Pole Side Impacts
Otte et al. (2008)

1. Background

- **Occupant Protection in Side Impacts**
  - *Effectiveness of side airbag – Yoganandan et al. (2005)*
  - *Role of shoulder as a load path – Melvin et al. (1998)*
  - *Effectiveness of shoulder restraint – Smith et al. (2011)*

- **Development of WorldSID**
  - *Since 1997*
  - *High Biofidelity rated as “good”*
  - *To be adopted for EuroNCAP, gtr*

- **Development of THUMS (Total Human Model for Safety)**
  - *THUMS Version 1 (2000) – Mostly Skeletal Model*
  - *THUMS Version 3 (2008) – Detailed Brain Model*
  - *THUMS Version 4 (2010) – Detailed Internal Organ Model*

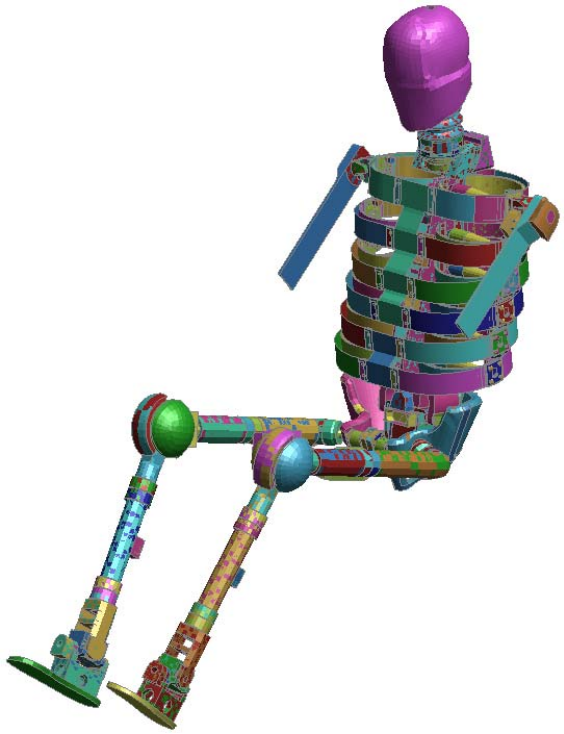
2. Objective

To examine the effectiveness of shoulder airbag to help reduce thorax injury risk in side impacts using WorldSID FE Model and THUMS Version 4.

3. Model Description and Validation

- **DYNAmore WorldSID AM50 Ver. 2.0.1**
  - *168,673nodes and 209,802 elements.*

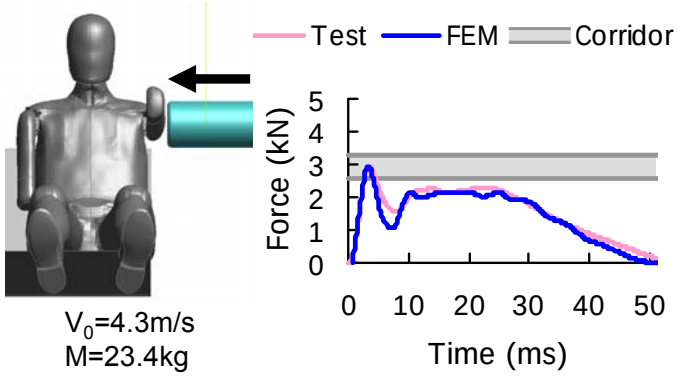
Whole Body



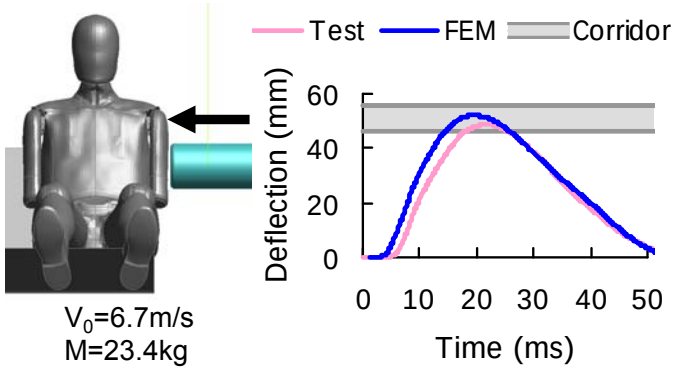
Internal Parts

3. Model Description and Validation (continued)

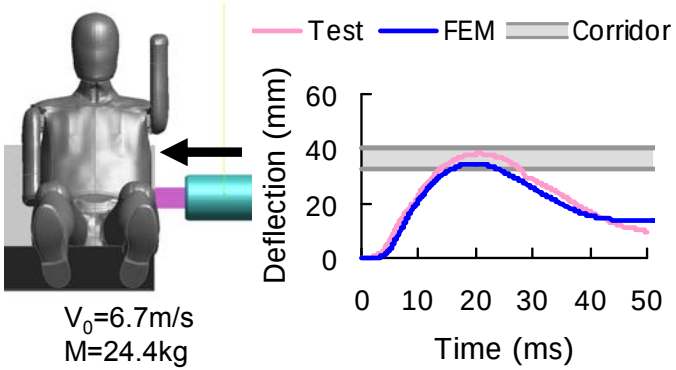
- **Validation of WorldSID FE Model**



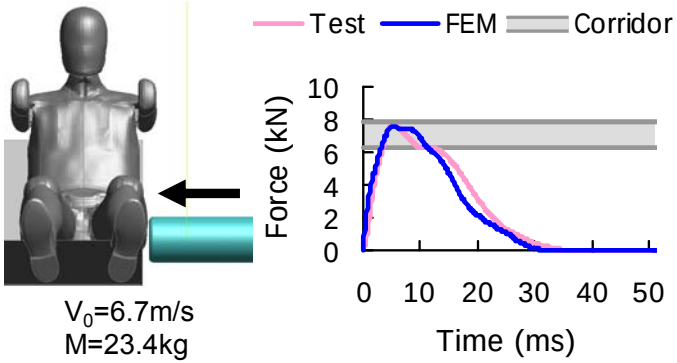
Shoulder Impact



Chest Impact



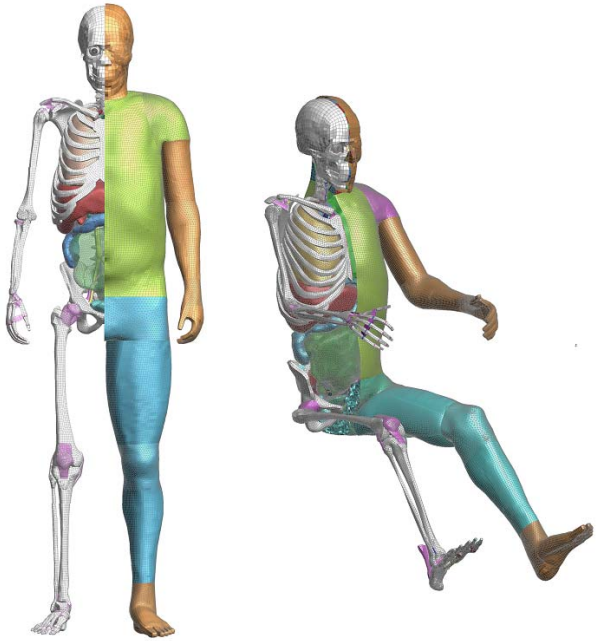
Abdomen Impact



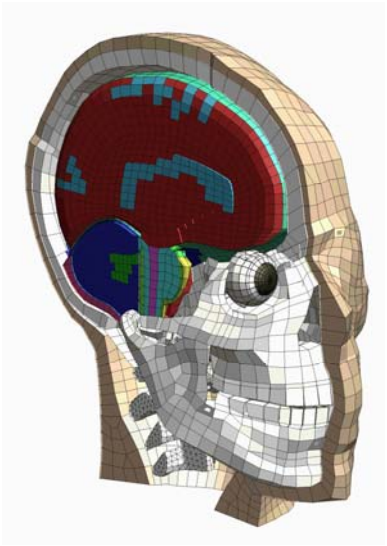
Pelvis Impact

3. Model Description and Validation (continued)

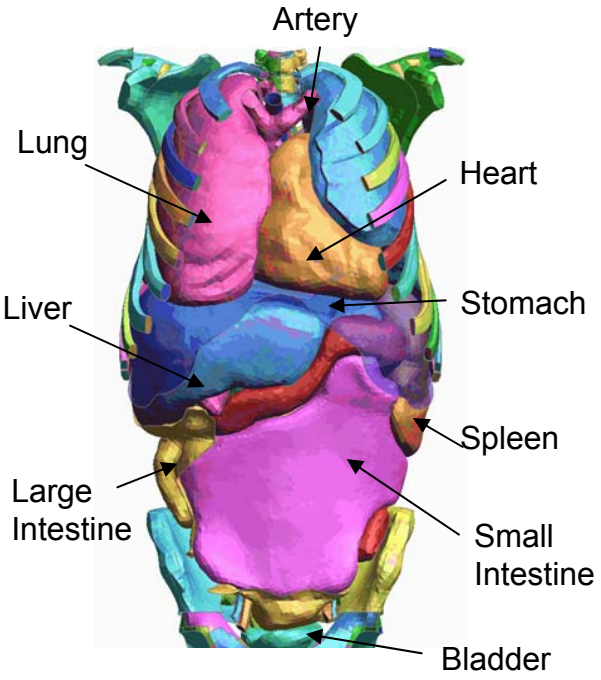
- **THUMS Version 4 AM50**
  - *629,000 nodes and 1,800,000 elements.*
  - *Aims to simulate brain and internal organ injuries as well as bony fractures and ligament ruptures.*



Whole Body



Head and Brain

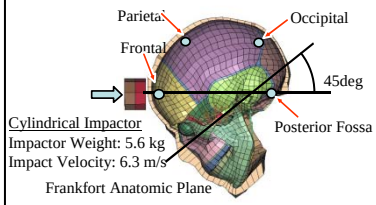


Internal Organs

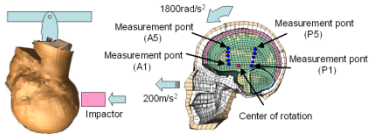
3. Model Description and Validation (continued)

- **Validations of THUMS Version4**

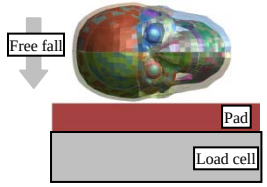
1. Head Validation (Nahum et al. 1977)



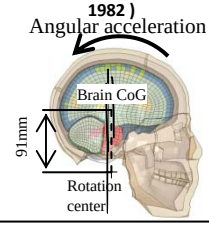
2. Head Validation (Hardy et al. 2001)



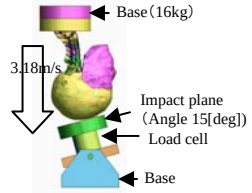
3. Head Validation (Yoganandan et al. 2004)



4. Head Validation (Gennarelli et al. 1982)

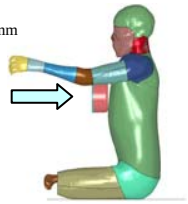


5. Neck Validation (Nightingale et al. 1997)



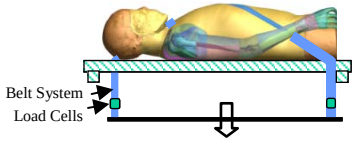
6. Thorax Validation (Kroell et al. 1974)

Cylindrical Impact
Impactor Diameter: 152 mm
Impactor Weight: 23 kg
Impact Velocity: 7.2 m/s



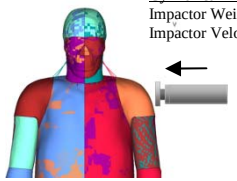
7. Thorax Validation (Cesari et al.1990)

Belt Loading
Impactor Weight: 22.4 kg
Impactor Velocity: 7.78 m/s

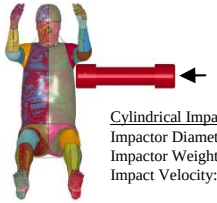


8. Shoulder Validation (Sabine et al.2004)

Cylindrical Impact
Impactor Weight: 24.8 kg
Impactor Velocity: 4.5 m/s



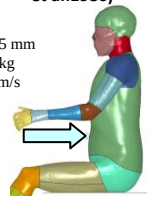
9. Thorax Validation (Shaw et al.2006)



Cylindrical Impact
Impactor Diameter: 152 mm
Impactor Weight: 23 kg
Impact Velocity: 2.76 m/s

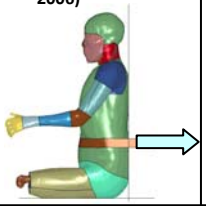
10. Abdomen Validation (Cavanaugh et al.1986)

Bar Impact
Impactor Diameter: 25 mm
Impactor Weight: 32 kg
Impact Velocity: 6.1 m/s

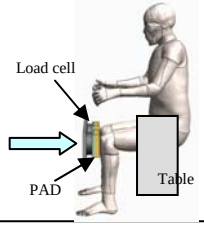


11. Abdomen Validation (Foster et al. 2006)

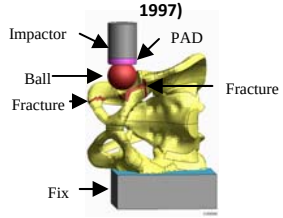
Belt Loading
Width: 50 mm
Velocity: 6.9 m/s



12. Waist Validation (Rupp et al. 2008)

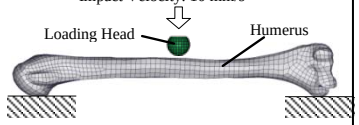


13. Waist Validation (Guillemot et al. 1997)

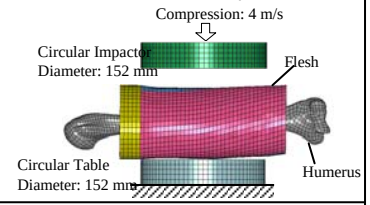


14. Humerus Validation (Kemper et al. 2005)

Bar Loading
Device Diameter: 20 mm
Impact Velocity: 10 mm/s

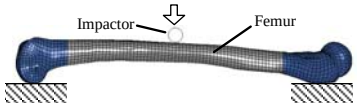


15. Humerus Validation (Kemper et al. 2005)



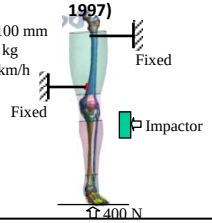
16. Femur Validation (Yamada et al. 1970)

Bar Loading
Device Diameter: 20 mm
Impact Velocity: 10 mm/s

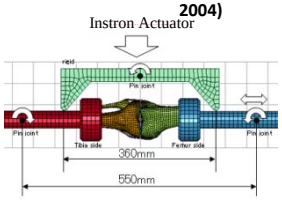


17. Knee Joint Validation (Kajzer et al. 1997)

Impactor Loading
Impactor Diameter: 100 mm
Impactor Mass: 6.25 kg
Impact Velocity: 40 km/h

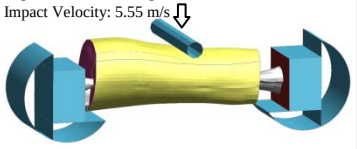


18.Knee Joint Validation (Bose et al. 2004)

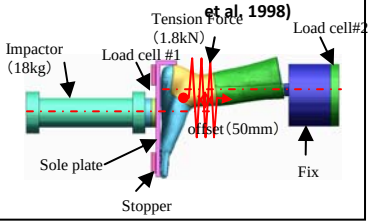


19. Tibia Validation (Schreiber et al. 1997)

Impactor Loading
Impactor Diameter: 25 mm
Impactor Mass: 9.48 kg
Impact Velocity: 5.55 m/s

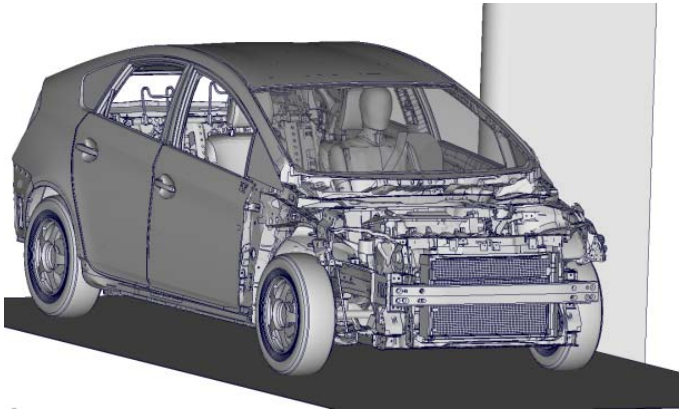


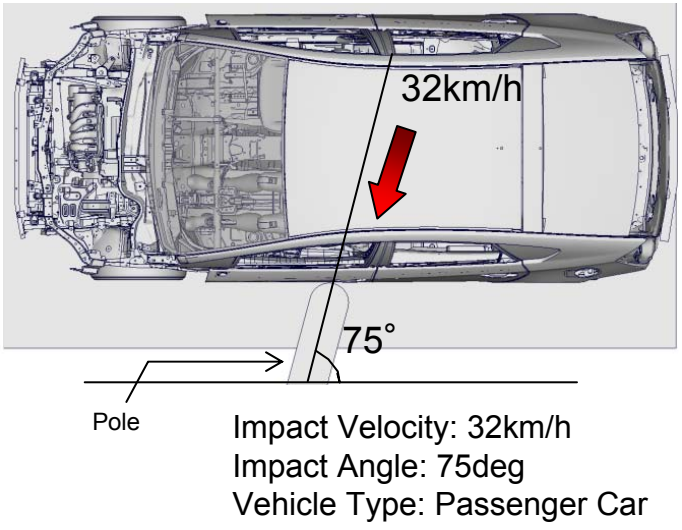
20. Ankle Joint Validation (Kitagawa et al. 1998)



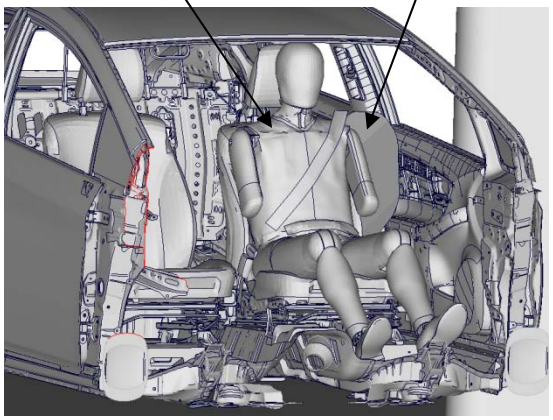
3. Model Description and Validation (continued)

- **Vehicle Model and Validation**





Impact Velocity: 32km/h
Impact Angle: 75deg
Vehicle Type: Passenger Car

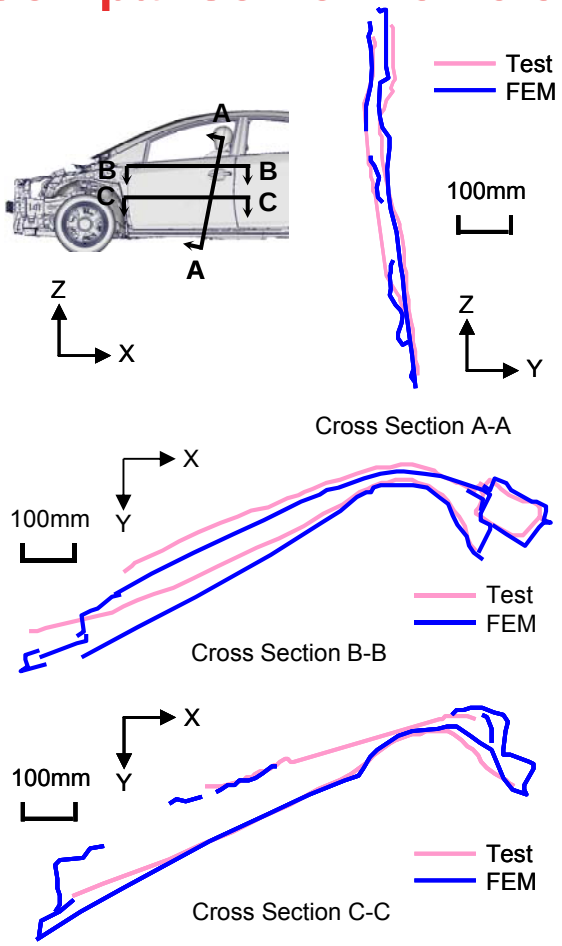


Curtain Shield Airbag (CSA) not displayed

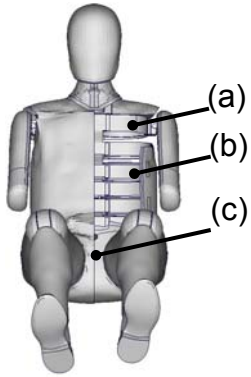
Collision Speed	32km/h
Collision Angle	75°
Car Type	Passenger Car
Dummy	WorldSID AM50
Dummy Position	Seating Procedure Ver.5.4
Torso Airbag	Prototype A
Curtain Shield Airbag	Prototype α (Not Shown)

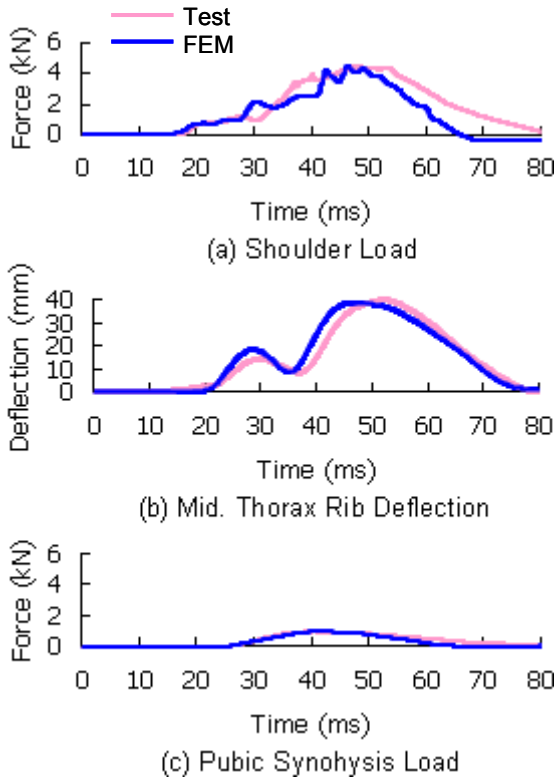
3. Model Description and Validation (continued)

- **Comparison of Vehicle Deformation and Injury Response**



Vehicle Body Deformation

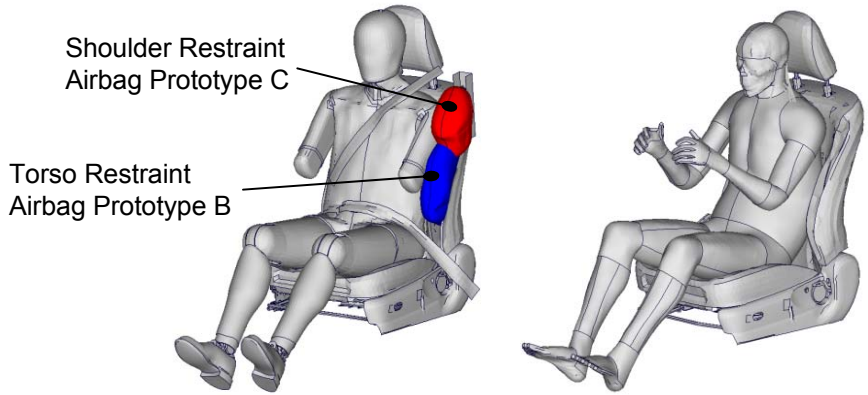




WorldSID Injury Response

4. Simulation Matrix

- **Effectiveness of Shoulder Restraint Airbag … Study I**
- **Effect of Shoulder Force (Airbag Vent Hole) … Study II**



WorldSID THUMS

Study I

Case	Dummy	Torso	Shoulder
1	WorldSID	B	none
2		B	C
3	THUMS	B	none
4		B	C

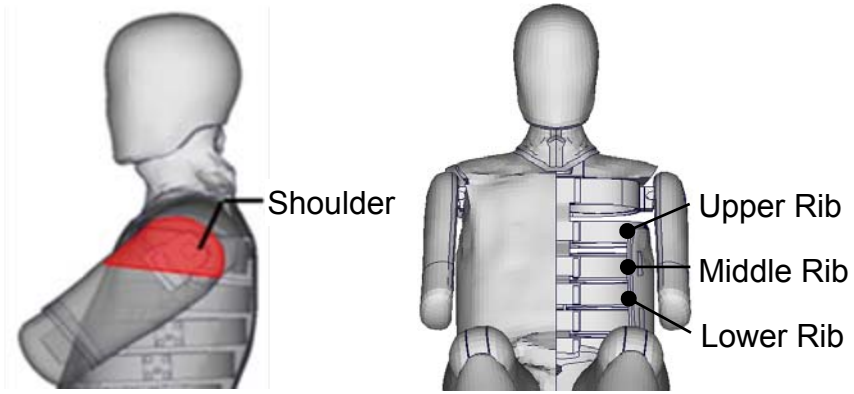
Study II

Case	Vent Hole*	Case	Vent Hole*
2a	4.0	4a	4.0
2b	3.3	4b	3.3
2c	2.7	4c	2.7
2d	2.0	4d	2.0
2e	1.1	4e	1.1
2	1.0	4	1.0
2f	0.9	4f	0.9
2g	0.7	4g	0.7
2h	0.3	4h	0.3
2i	0.0	4i	0.0

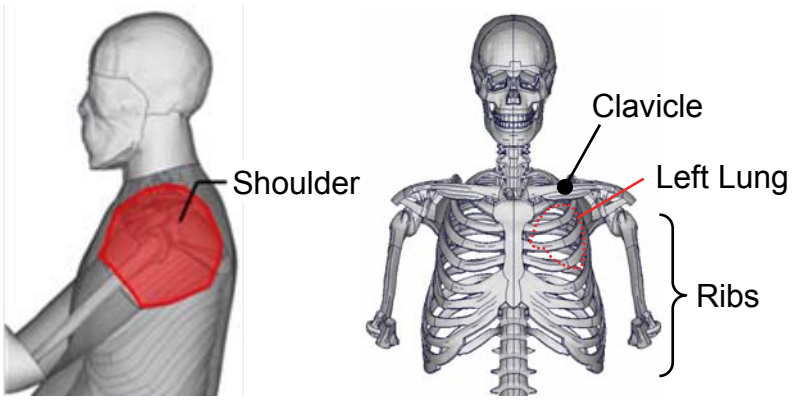
* Assumed Vent Hole in Cases 2 and 4 as 1.0. (0.0 = Closed).

4. Simulation Matrix (continued)

- **Estimate of Injury Risk**



WorldSID



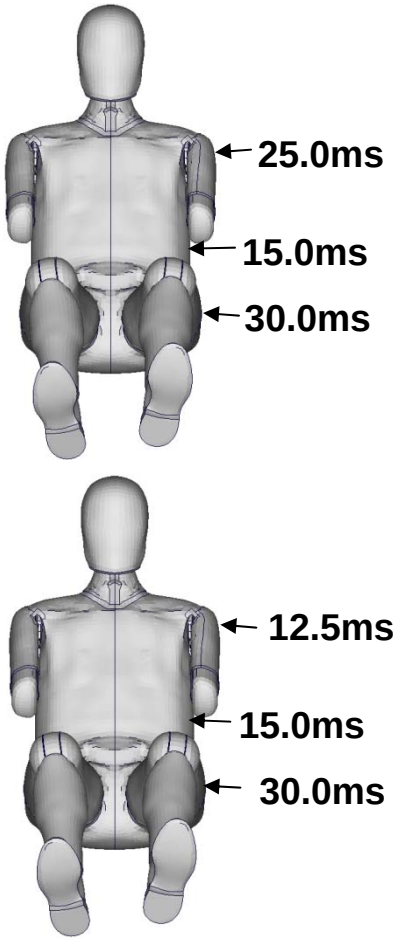
THUMS

	WorldSID	THUMS Version 4
Shoulder Injury	Force Magnitude	Occurrence of Clavicle Fracture (Strain > 3%)
Chest Injury	Upper Rib Deflection Middle Rib Deflection Lower Rib Deflection	Number of Rib Fractures (Strain > 3%) Left Lung Strain (> 20%)

5. Results: WorldSID

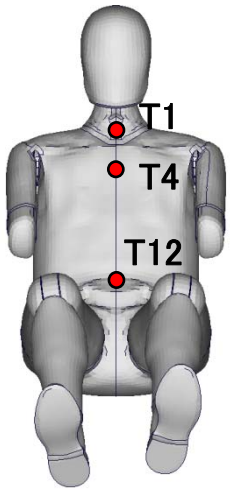
- **Whole Body Kinematics – Interaction with Airbag**
  - *Shoulder airbag contacts shoulder earlier than chest and abdomen.*

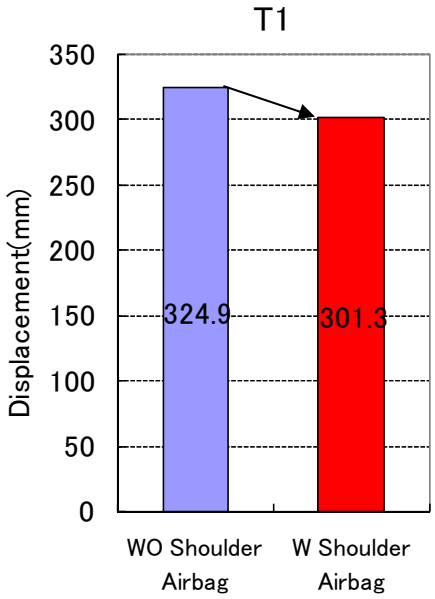
WO Shoulder Airbag	Chest-Abdomen	Shoulder	Pelvis	Bottoming Out
	15.0ms	25.0ms	30.0ms	35.0ms
With Shoulder Airbag	Shoulder	Chest-Abdomen	Pelvis	Bottoming Out
	12.5ms	15.0ms	30.0ms	40.0ms

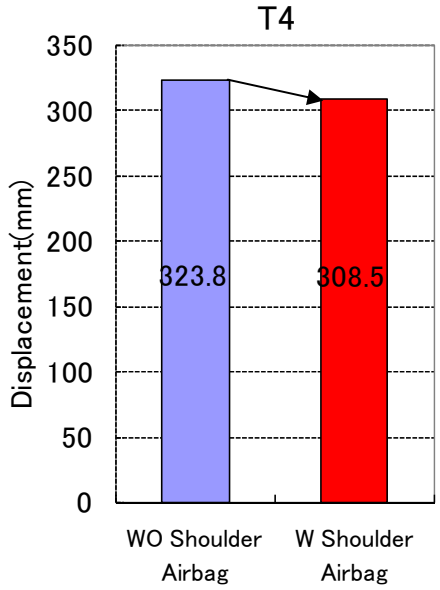


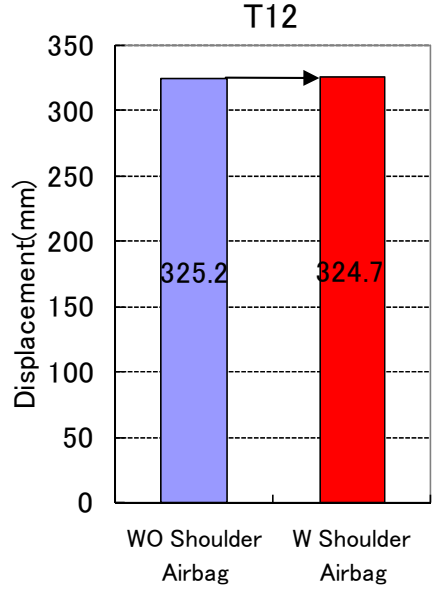
5. Results – Study I: WorldSID (continued)

- **Whole Body Kinematics – Lateral Displacement**
  - *With shoulder airbag, displacement at T1, T4 and T12 were smaller than that without.*



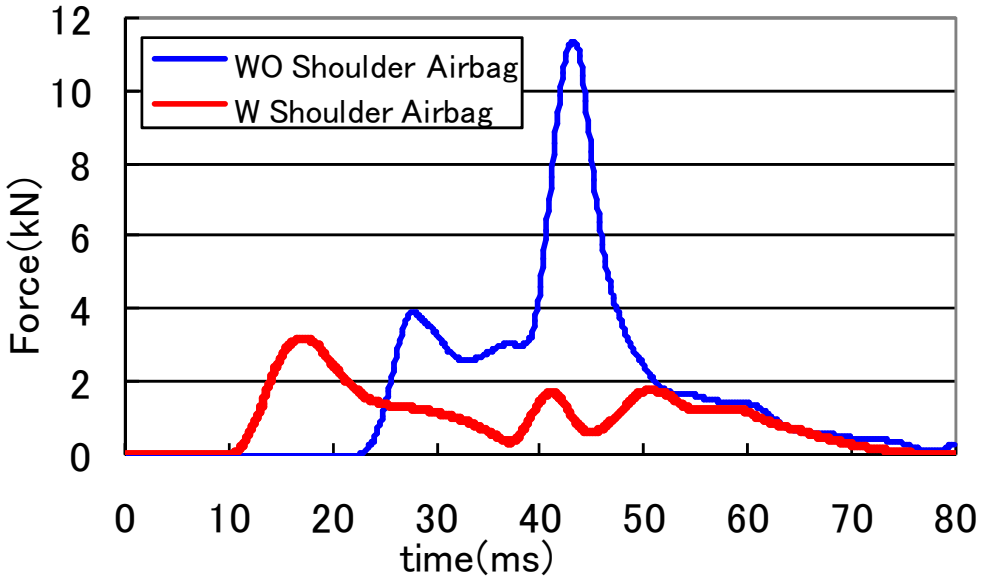




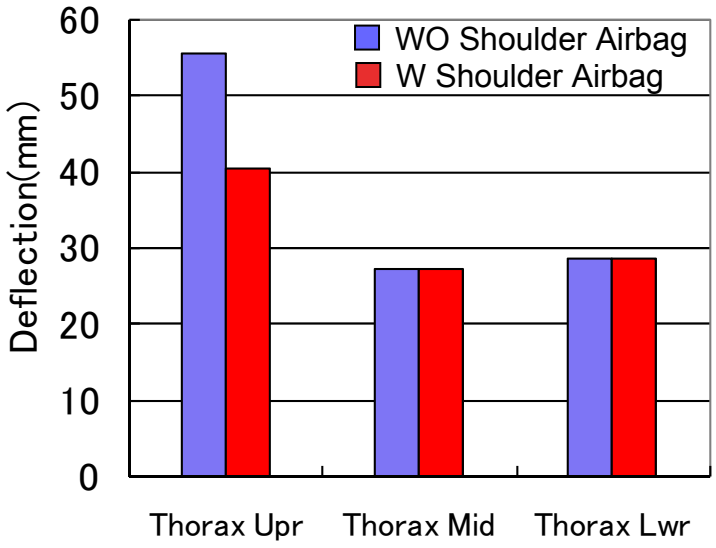


5. Results – Study I: WorldSID (continued)

- **Shoulder Force**
  - *With shoulder airbag, shoulder force rose earlier peaked lower.*
- **Rib Deflections**
  - *With shoulder airbag, deflection of upper rib was smaller than without.*



Shoulder Force

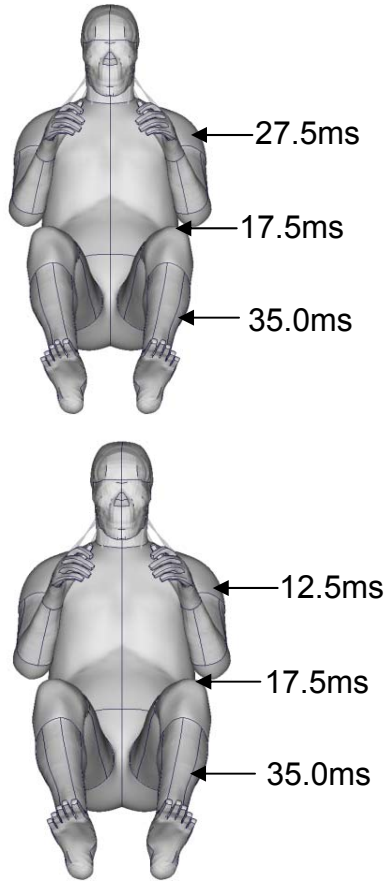


Rib Deflections

5. Results – Study I: THUMS Version 4

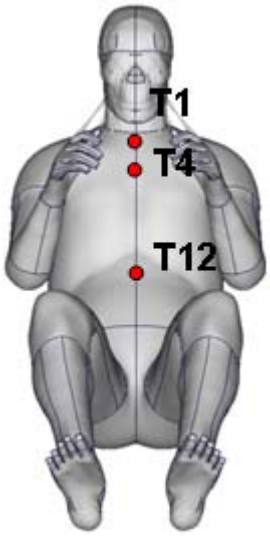
- **Whole Body Kinematics – Interaction with Airbag**
  - *Shoulder airbag contacts shoulder earlier than chest and abdomen.*

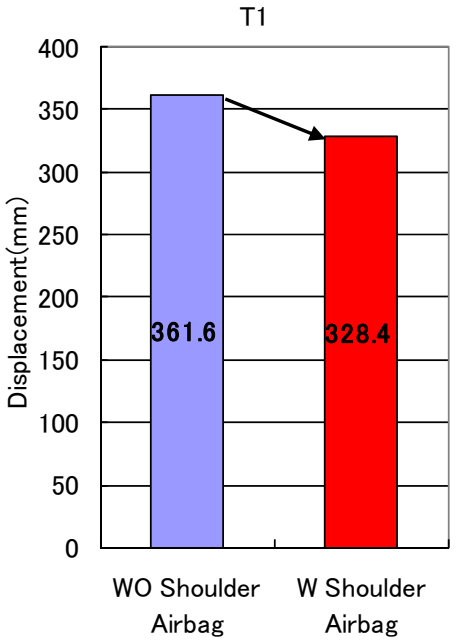
WO Shoulder Airbag	Chest-Abdomen	Shoulder	Pelvis	Bottoming Out
	17.5ms	27.5ms	35.0ms	37.5ms
With Shoulder Airbag	Shoulder	Chest-Abdomen	Pelvis	Bottoming Out
	12.5ms	17.5ms	35.0ms	42.5ms

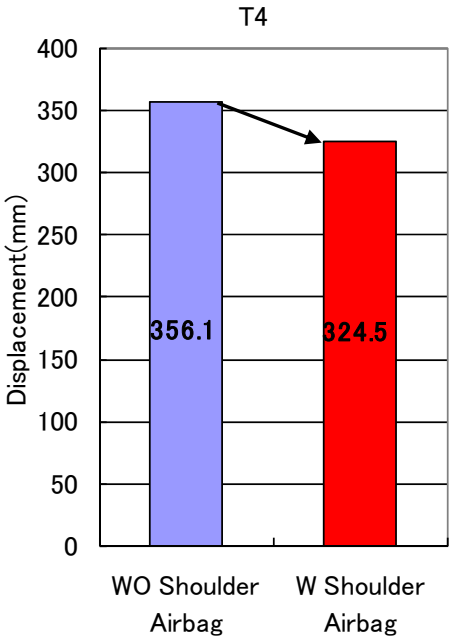


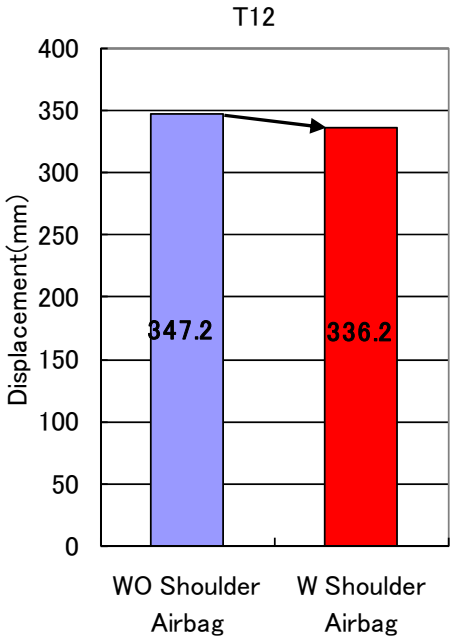
5. Results – Study I: THUMS (continued)

- **Whole Body Kinematics – Lateral Displacement**
  - *With shoulder airbag, displacement at T1, T4 and T12 were smaller than that without.*



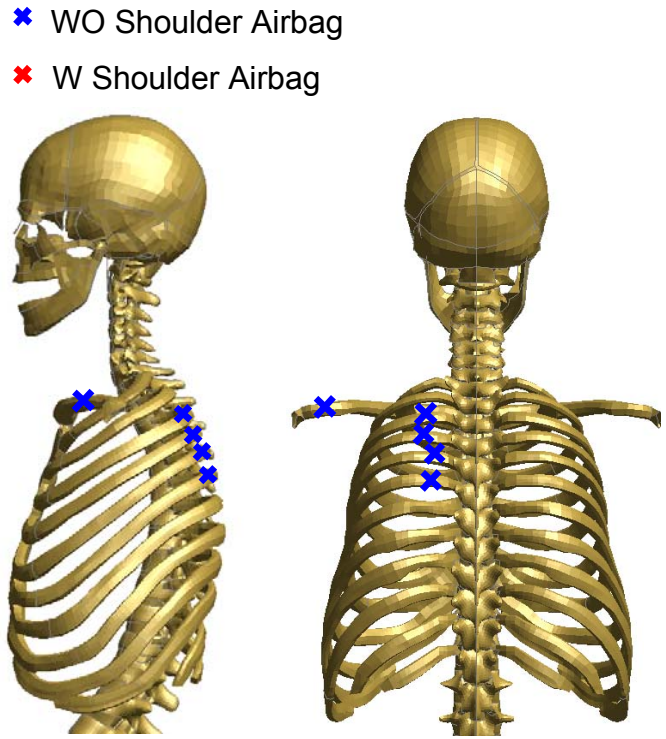




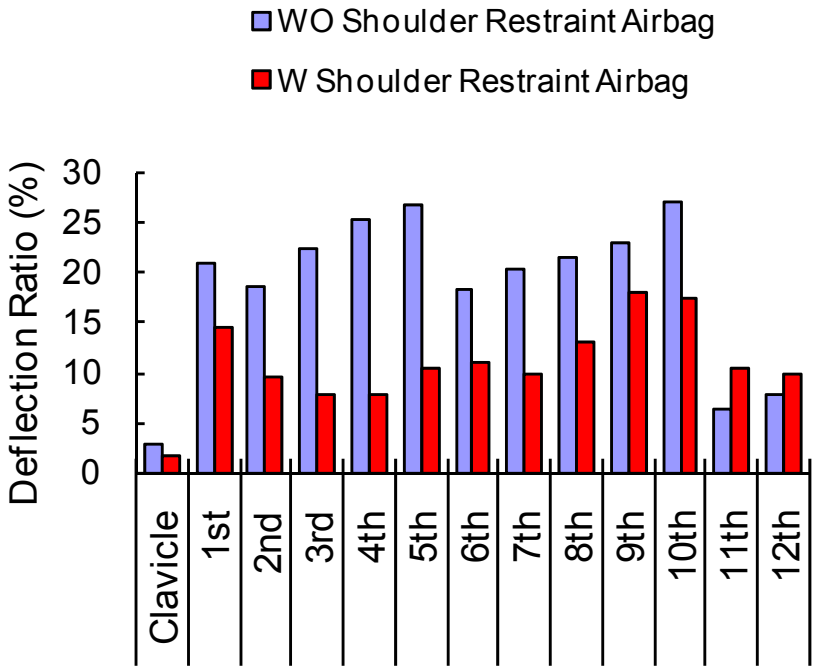


5. Results – Study I: THUMS Version 4 (continued)

- **Fractures of Clavicle and Ribs**
  - *With shoulder airbag, number of fractures was fewer than that without.*



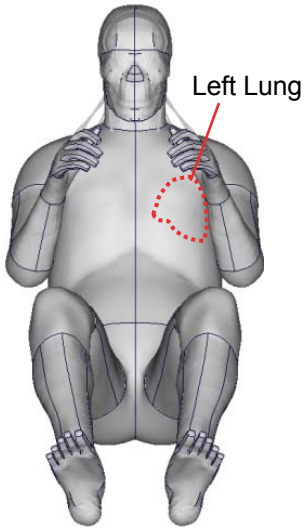
Location of Rib Fractures

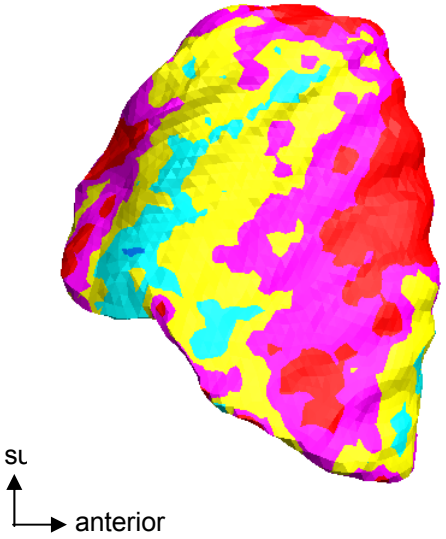


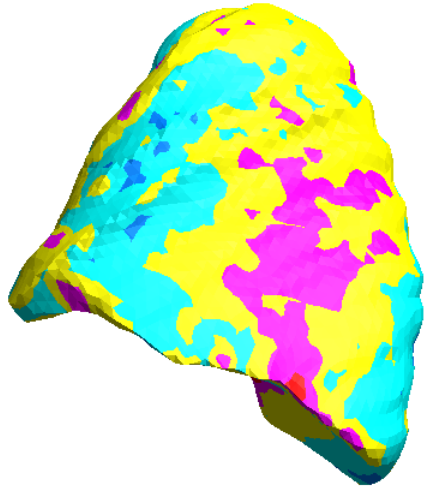
Deflection Ratio

5. Results – Study I: THUMS Version 4 (continued)

- **Left Lung Strain**
  - *With shoulder airbag, area of strain (max principal strain) higher than 20% was smaller than that without.*





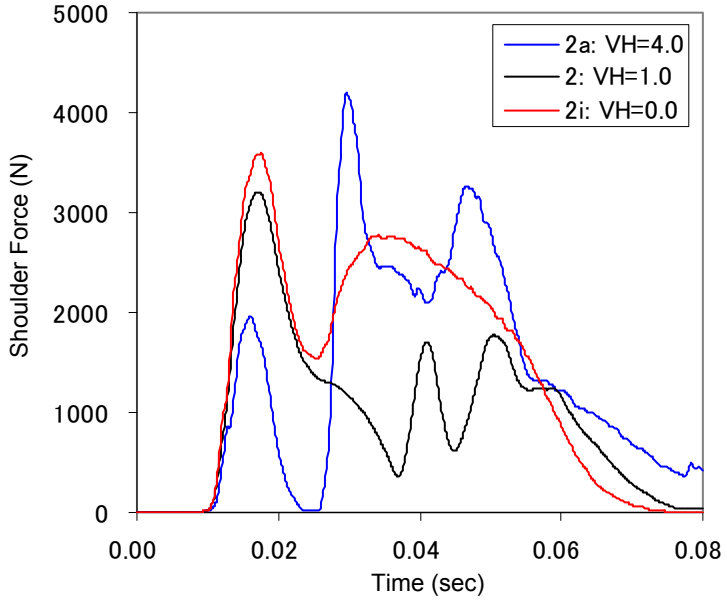


Without Shoulder Airbag

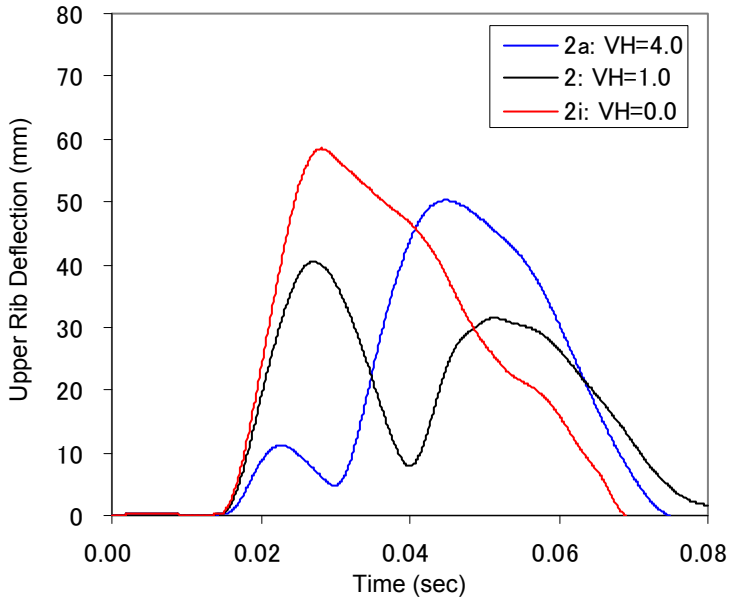
With Shoulder Airbag

5. Results – Study II

- **Shoulder Force and Upper Rib Deflection (WorldSID)**
  - *Large vent hole (VH=4.0): Initial force peak low, second peak high. Initial deflection small, later deflection great.*
  - *No vent hole (VH=0.0): Initial force peak high, second peak medium. Initial deflection great, later deflection small.*



Shoulder Force



Upper Rib Deflection

5. Results – Study II (continued)

- **Maximum Values of Shoulder Force and Rib Deflection**

WorldSID

Case	Vent Hole	Shoulder F*	Upr Rib Def
2a	4.0	2.0 kN	50.2 mm
2b	3.3	2.2 kN	45.6 mm
2c	2.7	2.5 kN	38.0 mm
2d	2.0	2.7 kN	33.6 mm
2e	1.1	3.1 kN	38.0 mm
2	1.0	3.2 kN	40.0 mm
2f	0.9	3.3 kN	43.0 mm
2g	0.7	3.3 kN	47.0 mm
2h	0.3	3.5 kN	53.8 mm
2i	0.0	3.6 kN	58.5 mm

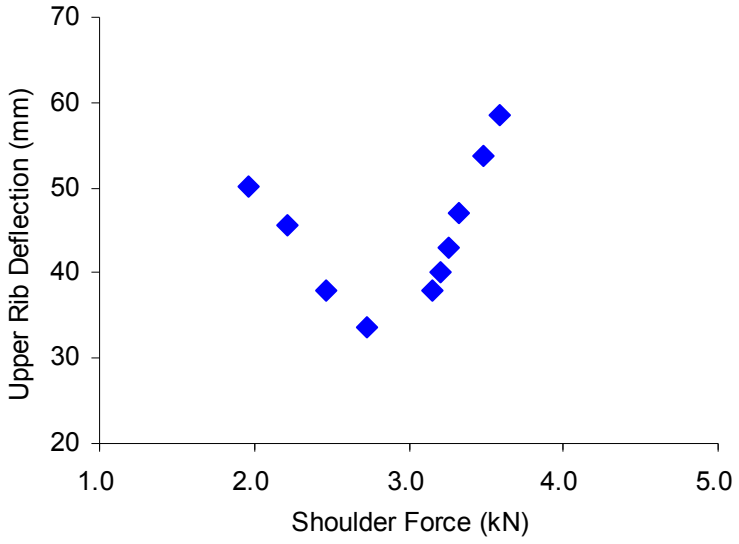
THUMS Version 4

Case	Vent Hole	Shoulder F*	3rd Rib Def
4a	4.0	1.5 kN	17.3 %
4b	3.3	1.6 kN	16.3 %
4c	2.7	1.7 kN	16.0 %
4d	2.0	1.9 kN	14.5 %
4e	1.1	2.4 kN	9.1 %
4	1.0	2.7 kN	7.8 %
4f	0.9	3.0 kN	6.2 %
4g	0.7	3.6 kN	5.6 %
4h	0.3	4.8 kN	7.2 %
4i	0.0	6.3 kN	11.7 %

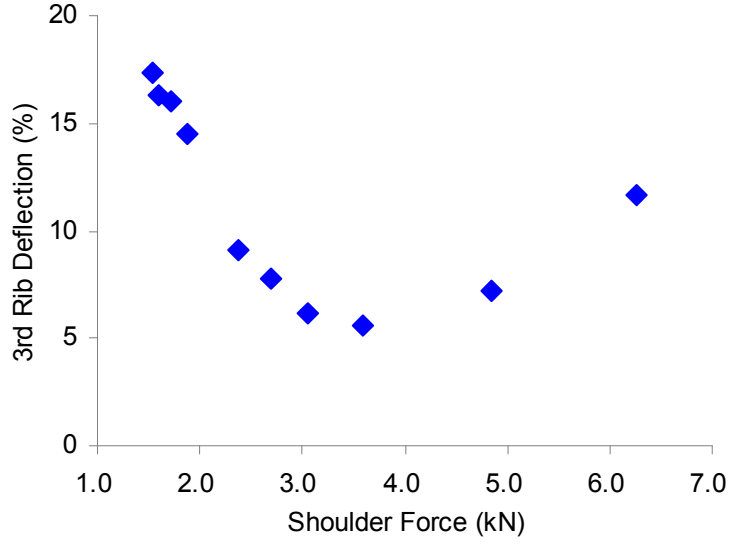
*Peak value up to 30ms before bottoming out.

5. Results – Study II (continued)

- **WorldSID**
  - *Smallest upper rib deflection at shoulder force of 3 kN.*
- **THUMS Version 4**
  - *Smallest 3rd rib deflection at shoulder force of 3.5 kN.*



WorldSID

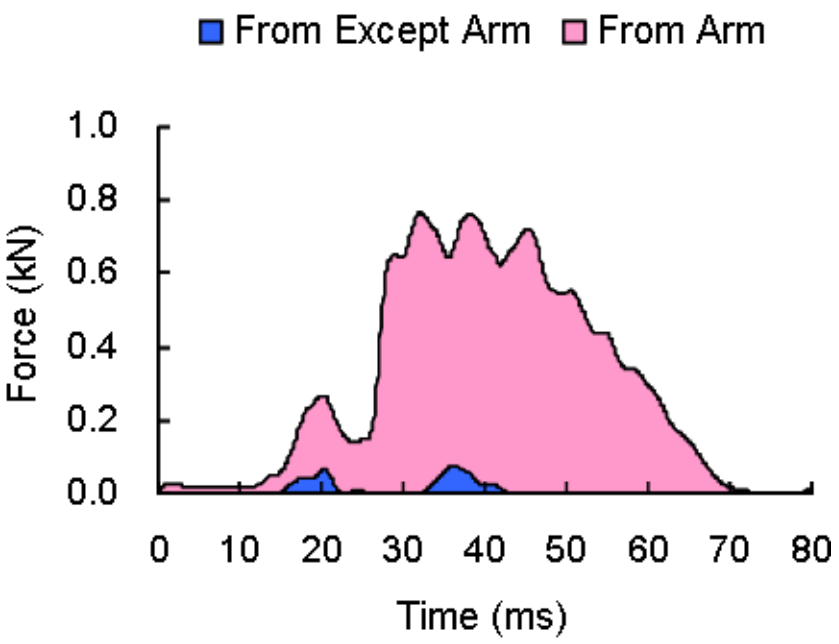


THUMS

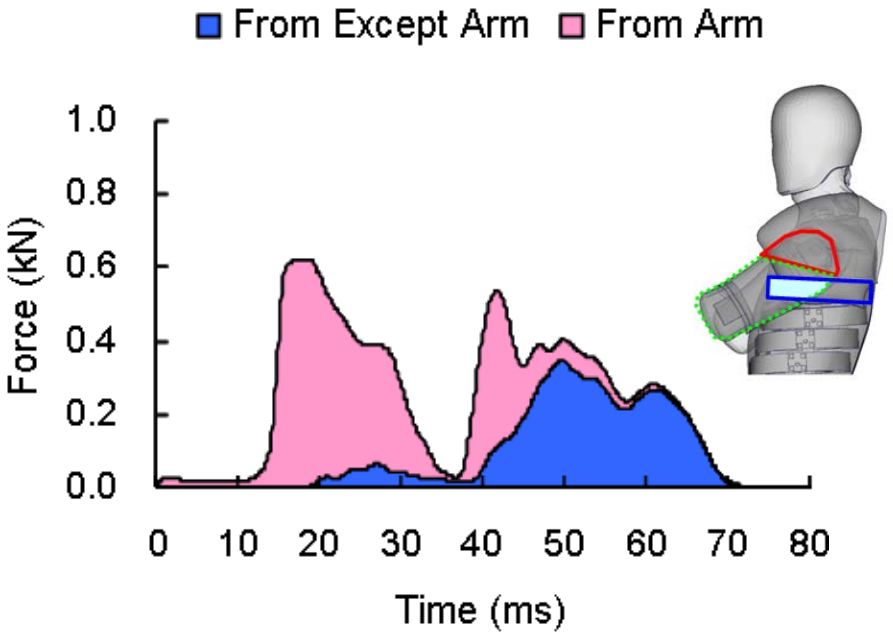
6. Discussion: from WorldSID Results

- **Effectiveness of Shoulder Restraint Airbag**
  - *Transmits some force to shoulder without going through arm.*
  - *Raises initial force peak while reduces later one.*

  → *Helps reduce rib deflection especially upper region overlapping arm.*



Without Shoulder Restraint Airbag



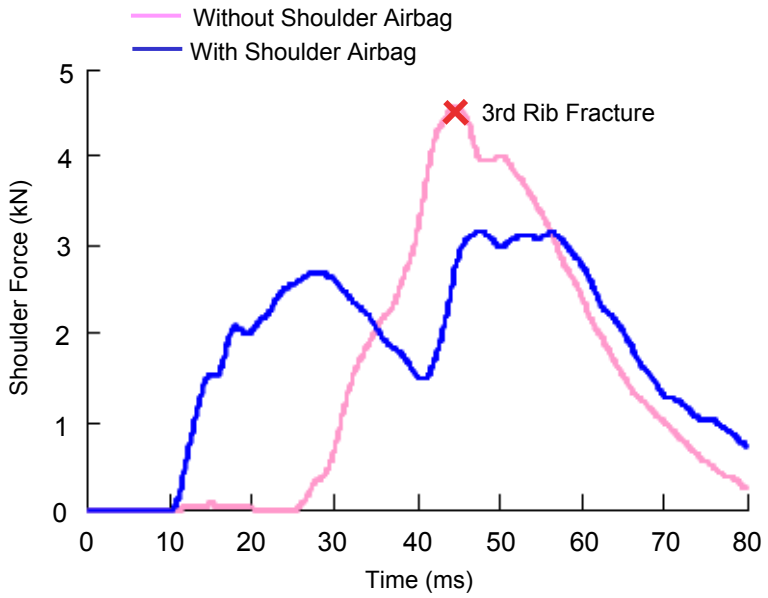
With Shoulder Restraint Airbag

6. Discussion: from THUMS Version 4 Results

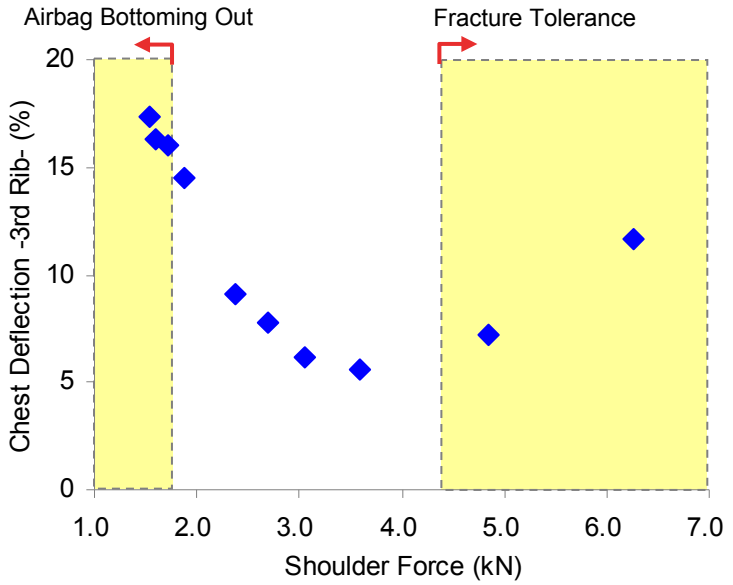
- **Shoulder Force Range (assumption)**
  - *Smaller than 1.8 kN: Airbag may bottom out.*
  - *Greater than 4.3 kN: Bony fracture may occur.*

  → *Force range to be controlled around 3 kN.*

} *under condition assumed in this study*



Shoulder Forces With/Without Shoulder Airbag



Relationship between Force and Deflection

7. Conclusion

- Effectiveness of shoulder restraint airbag in reducing chest injury risk was examined through pole side impact simulations using WorldSID and THUMS Version 4.
- With shoulder restraint airbag, magnitude of force applied to shoulder and upper rib deflection in WorldSID were lower than that without; number of bony fractures was fewer and left lung strain was lower in THUMS Version 4 compared to case without.
- Shoulder restraint airbag helped reduced rib fracture risk by transmitting some force to shoulder without going through arm.
- Chest injury risk could be lowered by controlling magnitude of force applied to shoulder around 3 kN.