



Toward Abdominal Injury Assessment —HBM-Based Frontal Sled Simulations—

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1. Accident data analysis and simulation conditions

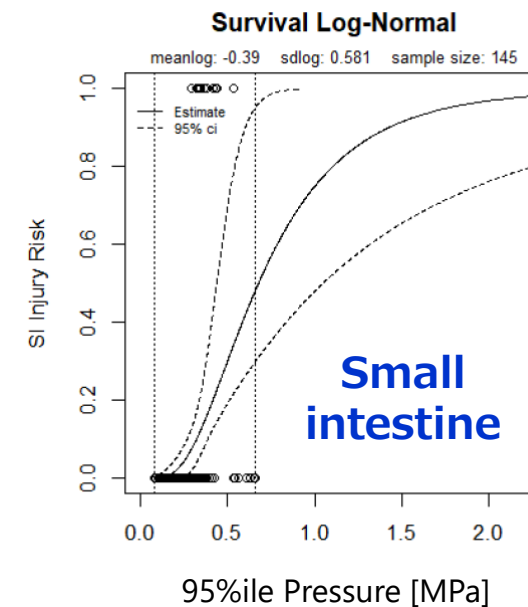
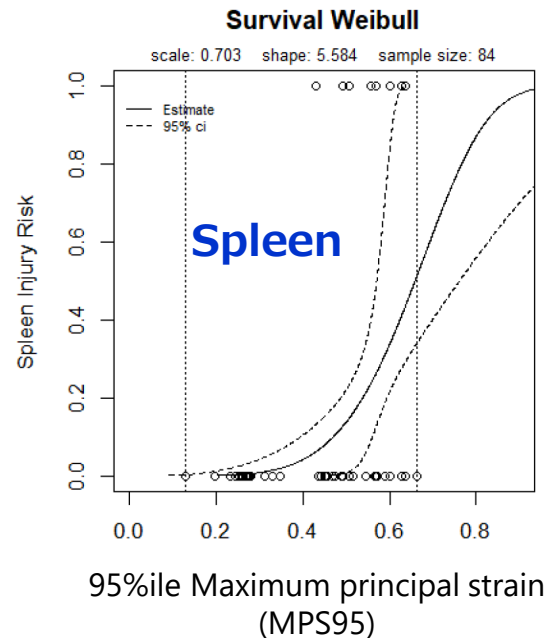
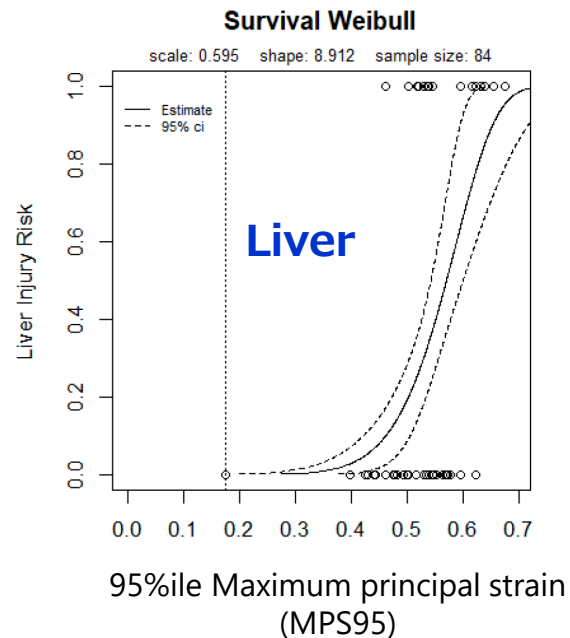
Based on accident data analysis, frontal sled simulation conditions likely to generate abdominal injuries were defined.

2. Frontal sled simulations

Sled simulations were conducted using THUMS v7.1, which includes abdominal organ models.

3. Injury metrics and injury risk

Using the IRFs presented at IRCOBI 2025, we discuss the feasibility and remaining issues for abdominal injury assessment.



Auriault et al.
IRCOBI 2025

Accident data analysis and simulation conditions

Extraction of accident data (ITARDA micro data)

◆ Selection criteria

Data collection: 2013-2022

Crash configuration: vehicle-to-vehicle and single-vehicle crashes

Vehicle types: passenger cars, light trucks, kei passenger cars, kei trucks

Impact direction (CDC code): 11F, 12F, 01F

Seating position: driver

Restraint use: seat belt worn

Injury region/type: abdominal injury AIS 2+

◆ Extraction results

➤ Occupants: 19

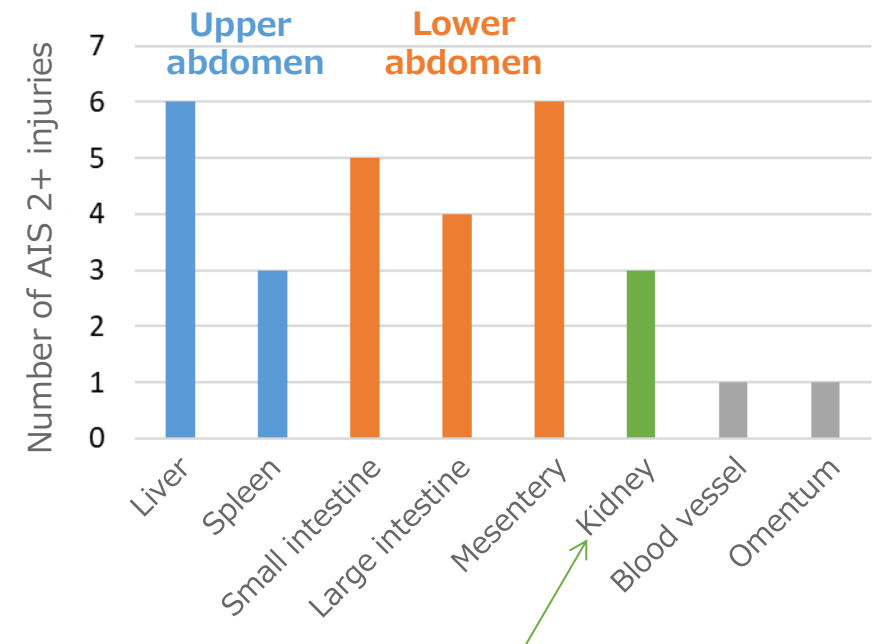
Male: 18

Female: 1

➤ Cases of abdominal injury AIS 2+: 28

※ Multiple injured body regions can be counted for one occupant.

Abdominal injuries with AIS 2+ (n = 28)



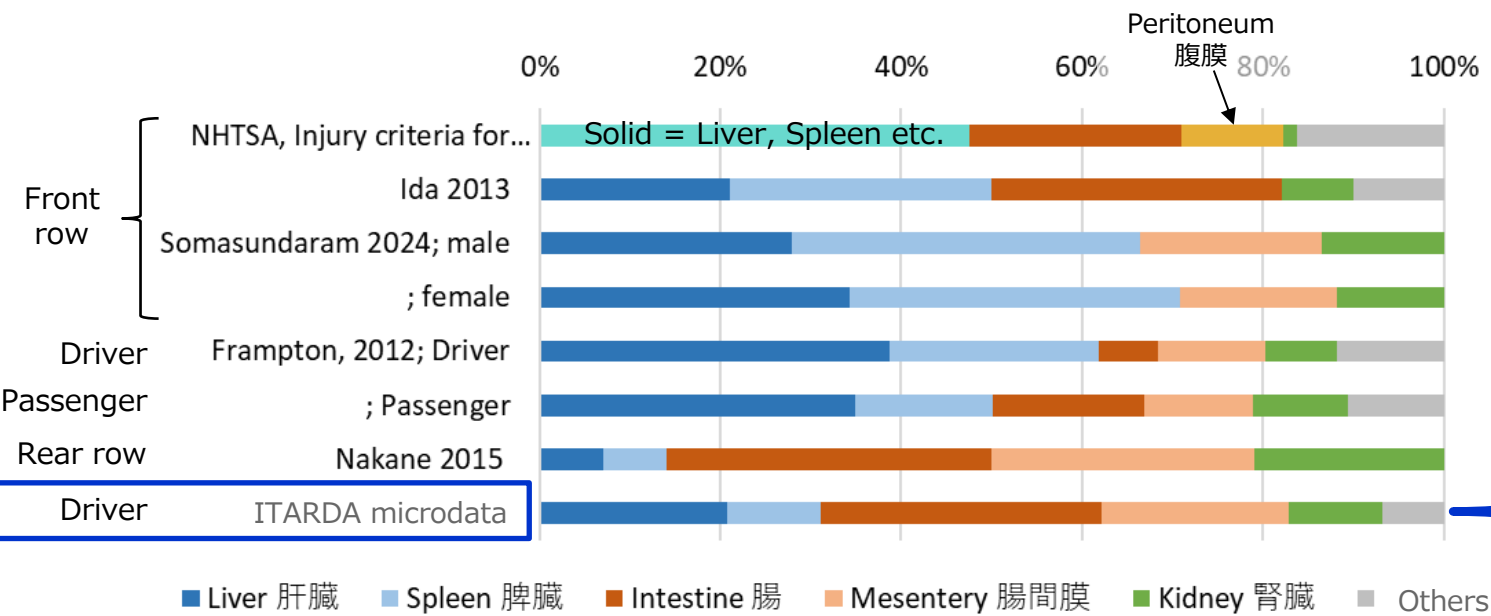
Kidney is located between the upper and lower abdomen.

Extraction of accident data (ITARDA microdata)

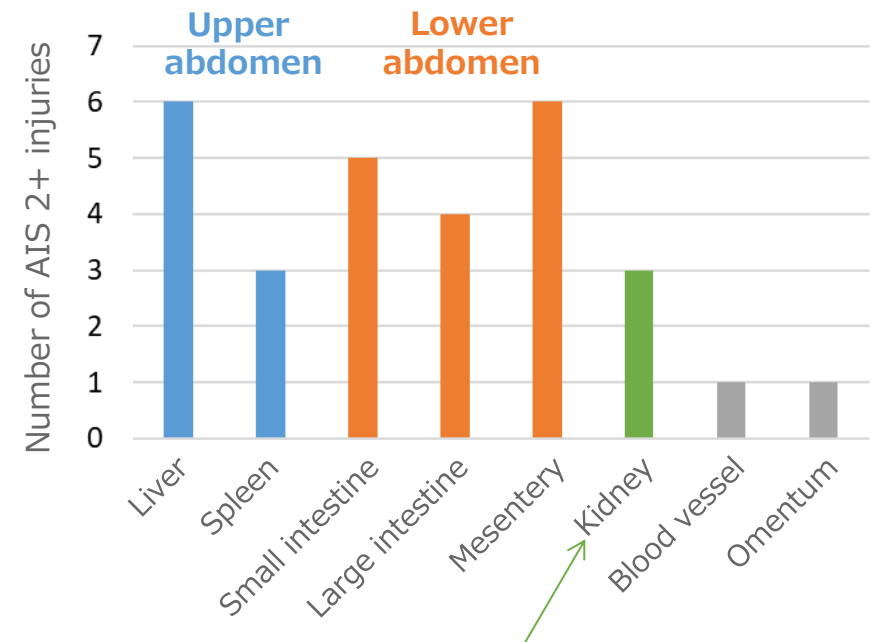
◆ Compared with the literature, the microdata show a larger proportion of lower abdominal injuries (intestine, mesentery) than upper abdominal injuries (liver, spleen).

→ For right-front occupants, liver injuries tend to decrease and intestinal injuries tend to increase. However, because the number of cases is small, further examination is needed to determine whether this reflects the overall trend.

Comparison with literature



Abdominal injuries with AIS 2+ (n = 28)



Kidney is located between the upper and lower abdomen.

Further-filtered ITARDA microdata and simulation conditions jama Japan Automobile Manufacturers Association

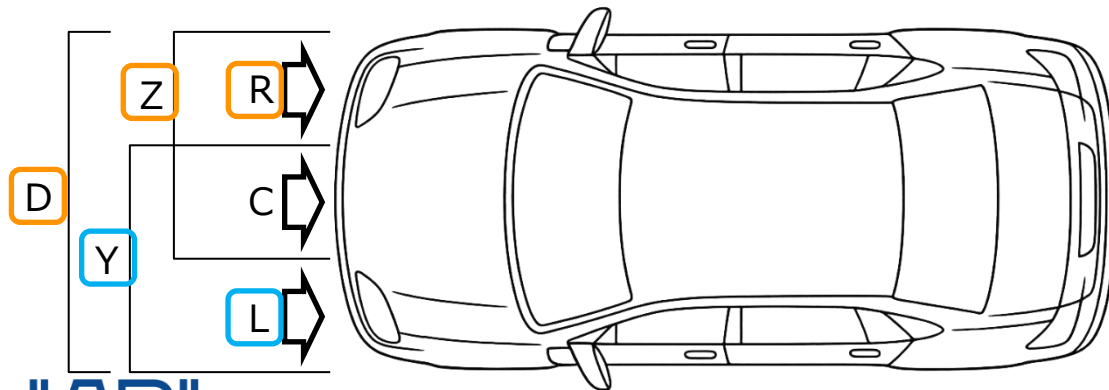
- ◆ To facilitate reproduction in sled simulations, cases with small deformation of the driver-side occupant compartment were extracted from the microdata.
- ◆ For the extracted abdominal injury cases, crash patterns and possible injury mechanisms were hypothesized, and simulation conditions were defined accordingly.

Cases considered to have small driver-side occupant compartment deformation:

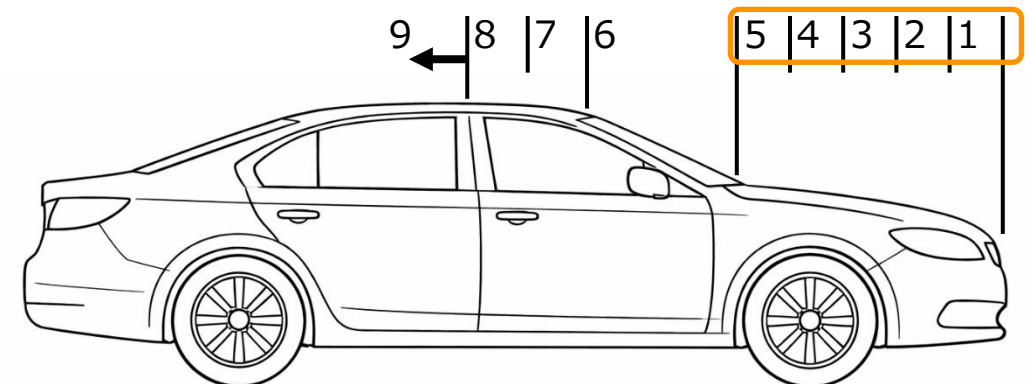
- ✓ No driver-side loading (Lateral location = **Y, L**)
- ✓ Driver-side loading present (Lateral location = **R, Z, D**), but no deformation behind the A-pillar (Extent of penetration **1~5**)

➡ Of the 28 abdominal injury AIS 2+ cases, 16 cases (9 occupants) met these criteria.

Lateral location



Extent of penetration



◆ Breakdown of the 16 abdominal injury AIS 2+ cases and hypothesized injury mechanisms

Injury source	Injury region	Details	ΔV	Hypothesized injury mechanism	
Seat belt 15 cases	Upper abdomen 2 cases	Liver : 2	41-50 km/h: 1 51-60 km/h: 1	Vehicles with relatively high load-limiter settings may have been included. As a result, shoulder-belt load increased, leading to upper abdominal injury.	(a)
	Lower abdomen 13 cases	Small intestine: 3 Large intestine: 4 Mesentery: 6	21-30 km/h: 4 31-40 km/h: 0 41-50 km/h: 5 51-60 km/h: 1 61-70 km/h: 1 71- km/h: 2	Submarining may have occurred. As a result, direct load from the lap belt increased, leading to lower abdominal injury.	(b)
Steering assembly 1 case					

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Steering assembly 1 case				

◆ Simulation conditions

	Impact speed, test config	Lap belt path	Knee-dash-board panel contact	Load limiter
Scenario 1 Base condition	50 km/h FRB	Standard	Yes	Default (Accord FE)
Scenario 2 Higher LL	-	-	-	High (2x default)
Scenario 3 Base condition	35 km/h FWDB	Standard	Yes	Default (Accord FE)
Scenario 4 pseudo-submarining	-	Raised above standard	No	-

Higher load-limiter setting (bracketed under Scenario 2)

Adjusted to induce submarining (pseudo-submarining) (bracketed under Scenario 4)

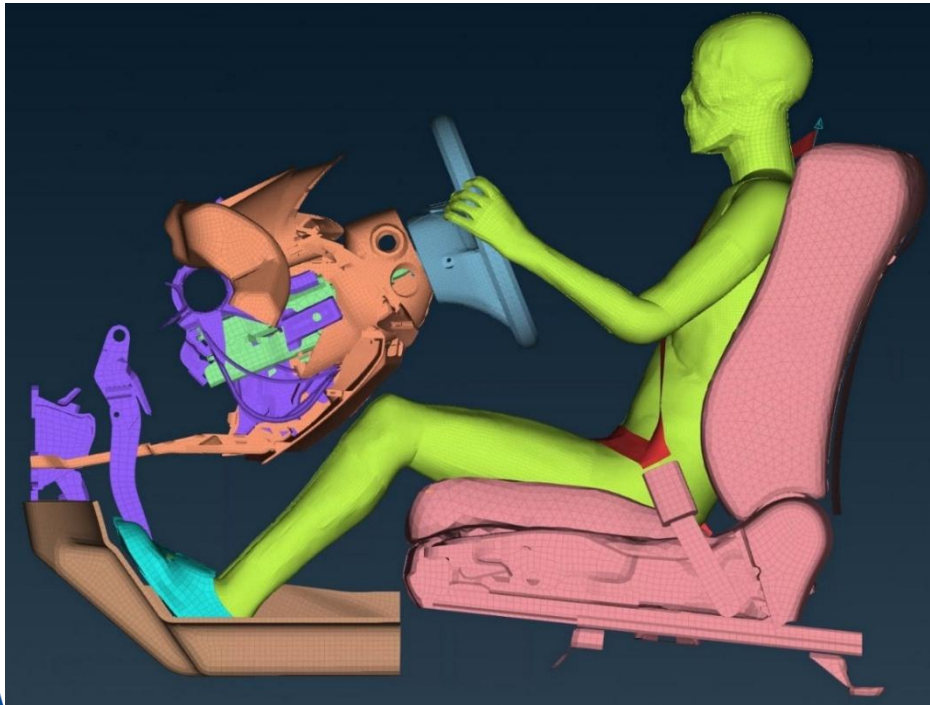
(a)

(b)

Frontal sled simulations

Frontal sled simulations

- ✓ THUMS AF05 v7.1, which includes abdominal organ models, was installed in a sled model based on the NHTSA Accord model.
- ✓ Acceleration pulses obtained from full-scale crash tests of a midsize SUV were applied:
 - 50 km/h FRB (Full-width Rigid Barrier)
 - 35 km/h FWDB (Full-Width Deformable Barrier)



Lap belt path

Standard

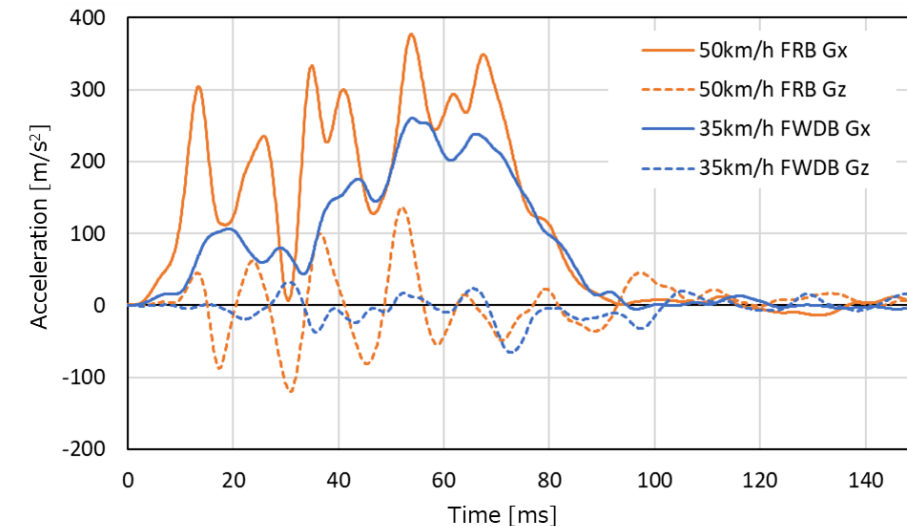


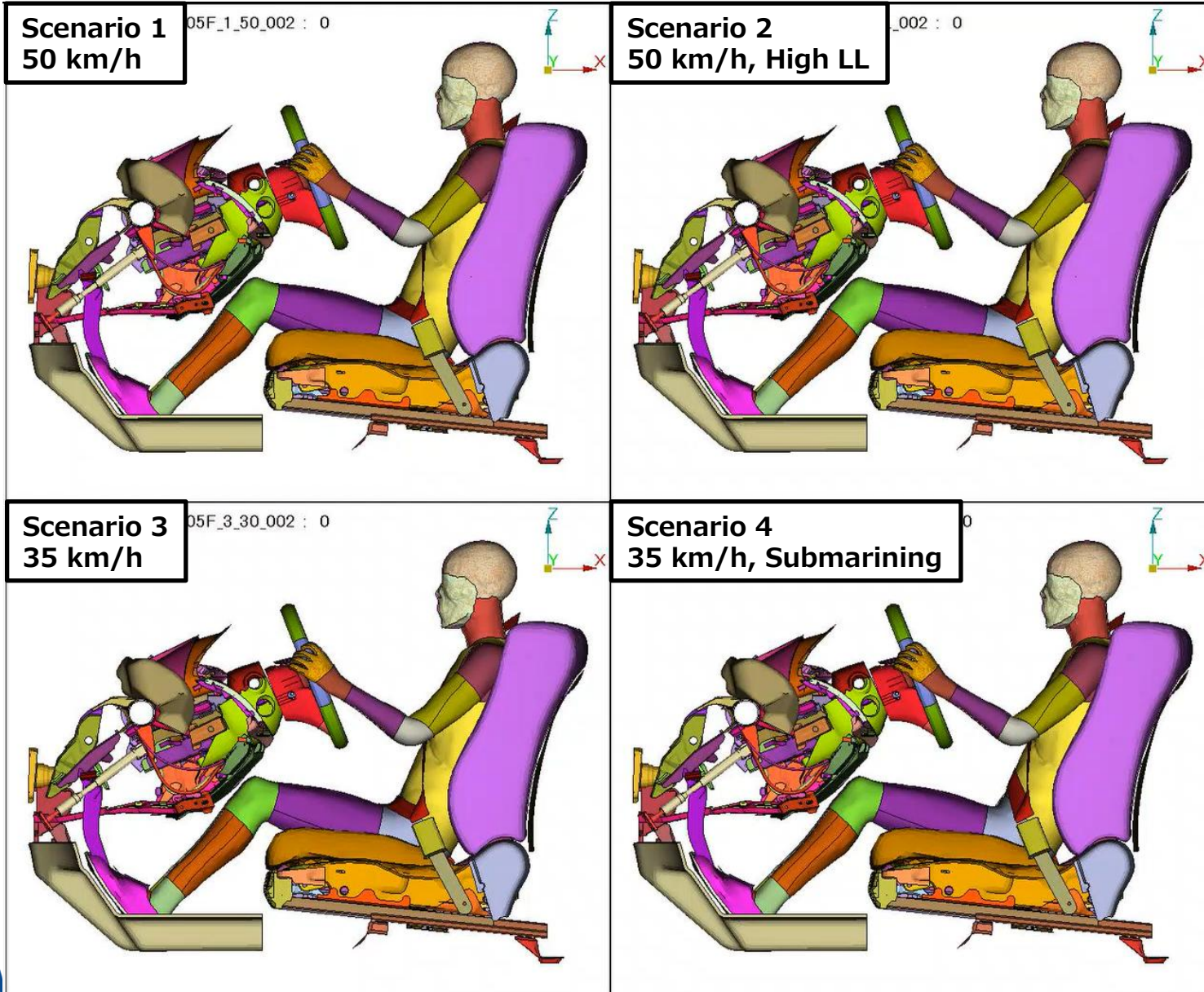
Higher than standard



	Impact speed, test config	Lap belt path	Knee-dashboard panel contact	Load limiter
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Scenario 1 (50 km/h)

The abdominal soft tissue appears to bulge out between the shoulder belt and the lap belt.

Scenario 2 (50 km/h, high load limiter)

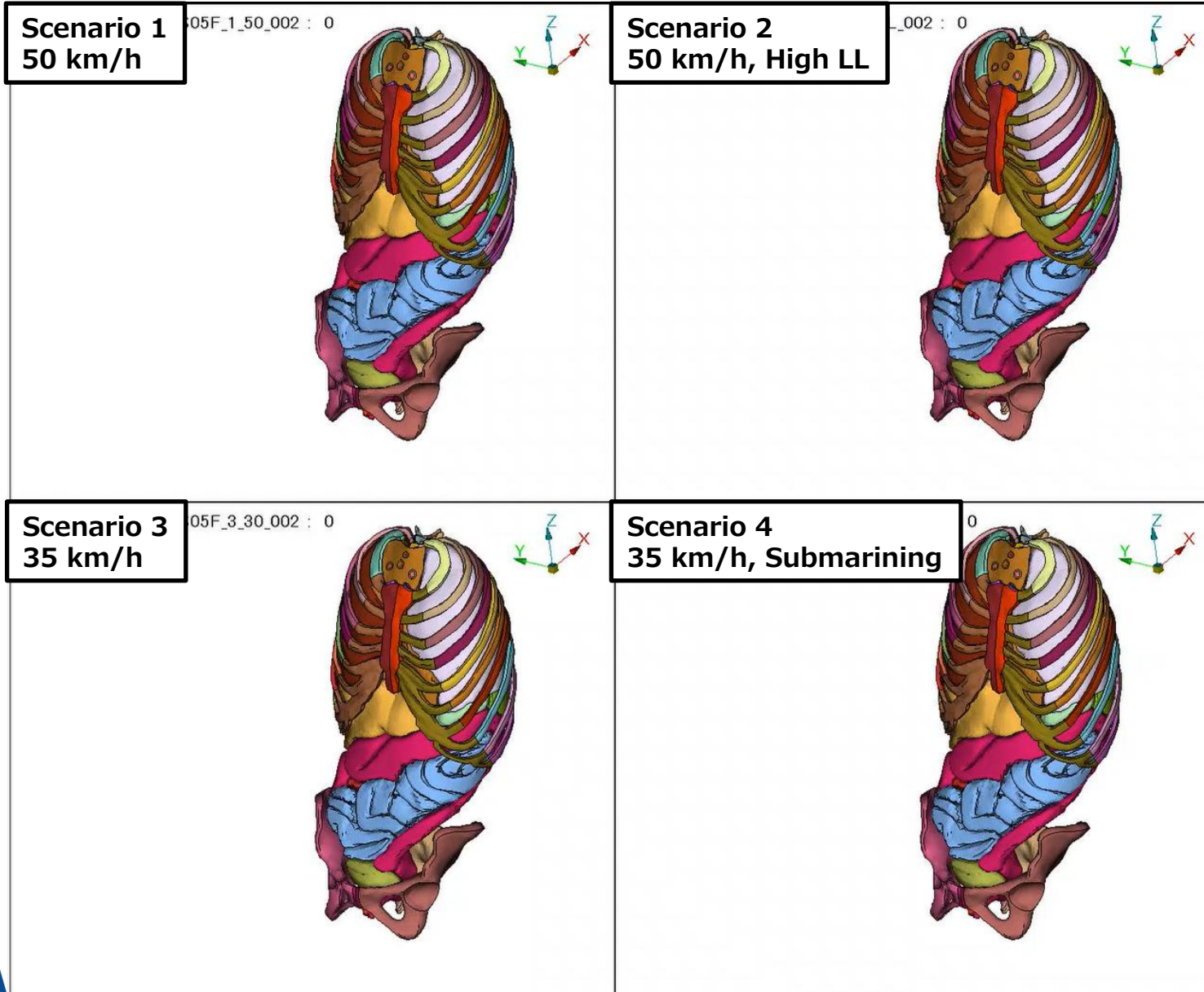
Compared with Scenario 1, the change in whole-body kinematics is small, with slightly earlier rebound.

Scenario 3 (35 km/h)

Compared with Scenario 1, the timing of head-to-airbag contact and knee-to-dashboard contact is delayed.

Scenario 4 (35 km/h, pseudo-submarining)

Because the knees are not restrained by the dashboard panel, forward displacement of the knees and pelvis is larger. At around 78 ms, the belt completely slips off the left ASIS (submarining). Immediately after submarining, the upper body above the thorax moves rearward, while the body below the pelvis moves forward.



Scenario 1 (50 km/h)

The liver and the large intestine (right side of the transverse colon), among other areas not restrained by the shoulder belt, move markedly forward. The liver is initially mostly hidden inside the rib cage, but moves forward relative to the rib cage and appears to protrude from it. Forward displacement peaks at around 60 ms. Most of the small intestine is restrained by the shoulder and lap belts, so forward displacement is small.

Scenario 2 (50 km/h, high load limiter)

Compared with Scenario 1, changes in kinematics are small.

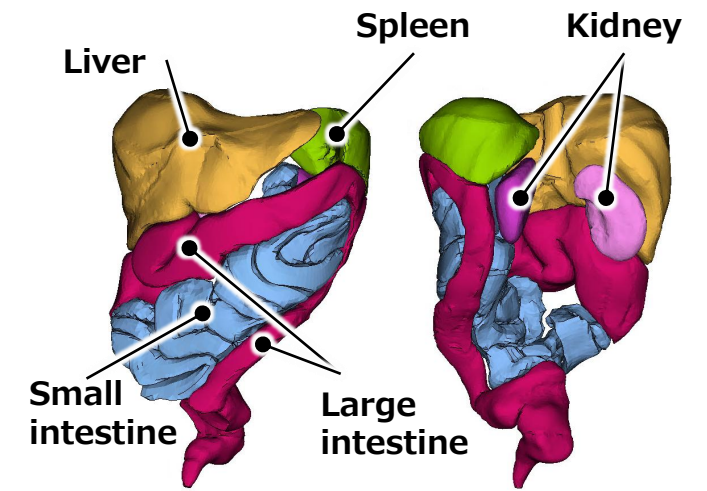
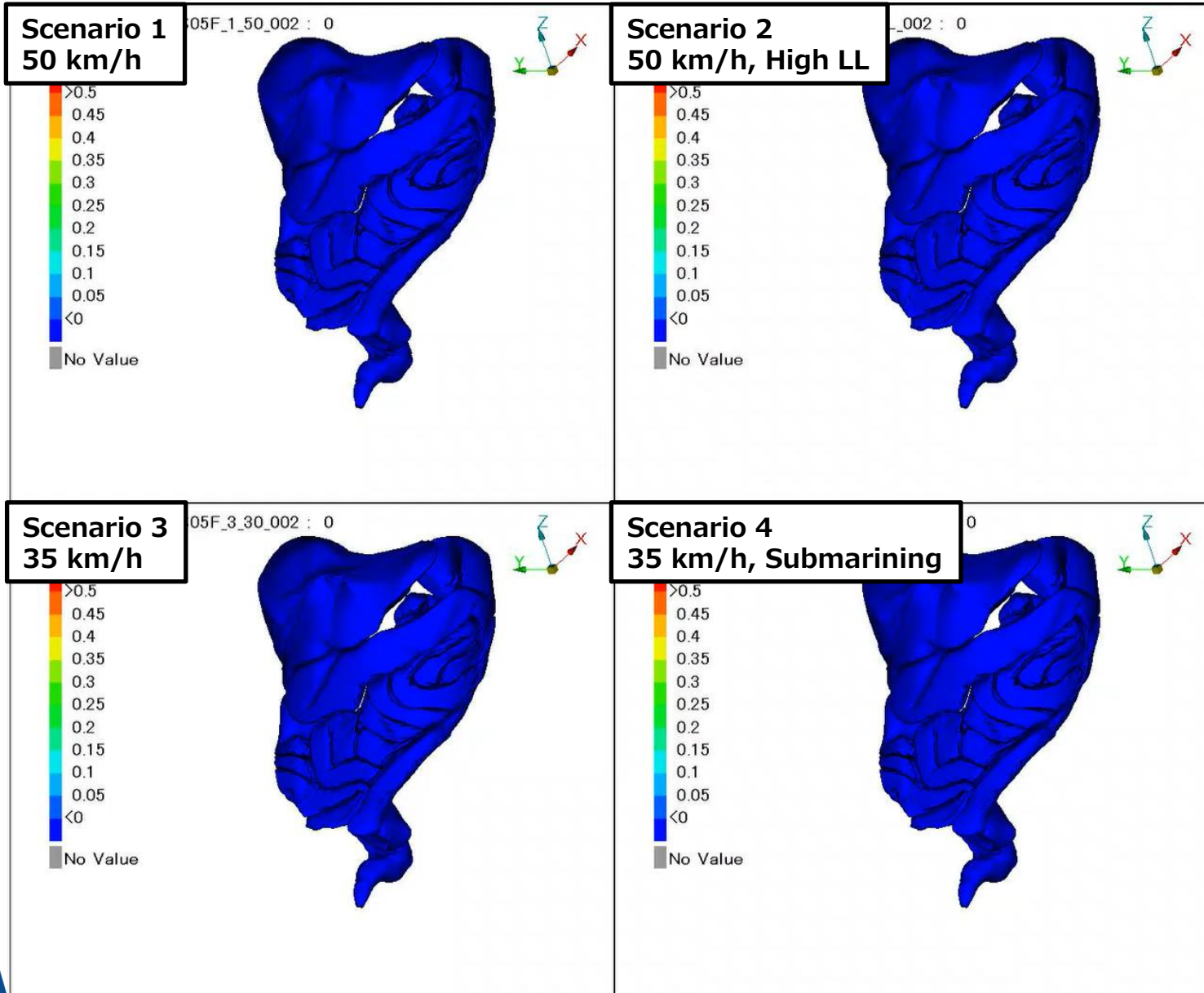
Scenario 3 (35 km/h)

Compared with Scenario 1, forward displacement of the organs is smaller.

Scenario 4 (35 km/h, pseudo-submarining)

After submarining (after 78 ms), the lap belt shifts further upward, loading the upper small intestine, the large intestine (transverse colon), and the lower part of the liver. The liver behaves as if it is loaded upward from below by the lap belt.

Maximum principal strain in abdominal organs



Scenario 1 (50 km/h)

Due to the effects of attachments, strain is high in the anterosuperior part of the liver (strain > 0.5). Strain is also high in the liver, large intestine, and small intestine at locations loaded by the shoulder belt. Due to loading from the lap belt, strain becomes large in the small intestine. In the large intestine, strain only rises slightly and transiently around 40 ms.

Scenario 2 (50 km/h, high load limiter)

Compared with Scenario 1, the increase in strain caused by the shoulder belt is larger.

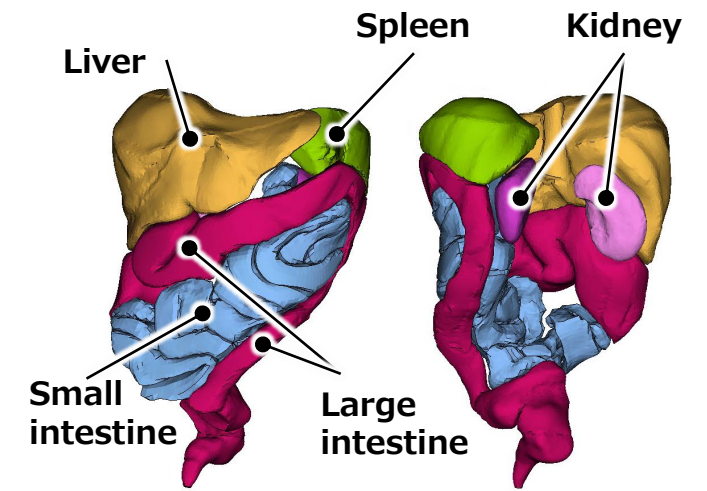
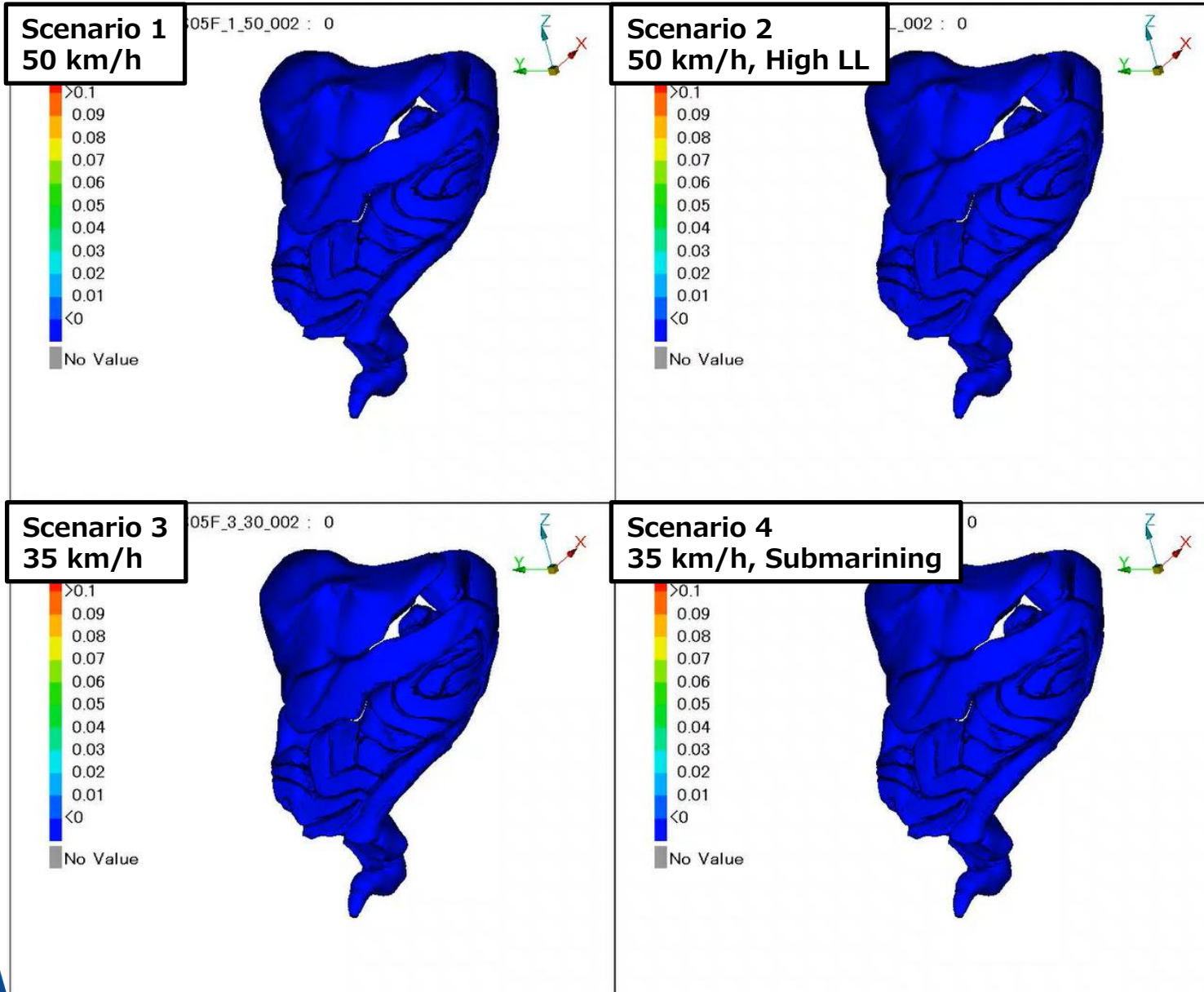
Scenario 3 (35 km/h)

Compared with Scenario 1, overall strain is smaller.

Scenario 4 (35 km/h, pseudo-submarining)

No marked increase in strain was observed after submarining.

Pressure in abdominal organs [MPa]



Scenario 1 (50 km/h)

In the liver, spleen, and large intestine, pressure becomes high at the anterior edge after deformation. In the liver, pressure also becomes high at the location loaded by the shoulder belt. In the small intestine, high-pressure regions are observed mainly at locations loaded by the shoulder and lap belts; however, many of these are localized and transient (pressure above 0.1 MPa lasting only a few ms).

Scenario 2 (50 km/h, high load limiter)

Compared with Scenario 1, the area of high pressure in the liver is slightly larger.

Scenario 3 (35 km/h)

Compared with Scenario 1, the overall response is smaller.

Scenario 4 (35 km/h, pseudo-submarining)

After submarining, pressure becomes high at the small-intestine region loaded by the lap belt.

Injury metrics and injury risk

Injury risk functions used (THUMS AM50 v7.1)

- ◆ Injury risk functions (IRFs) developed based on **THUMS AM50 v7.1** were used.

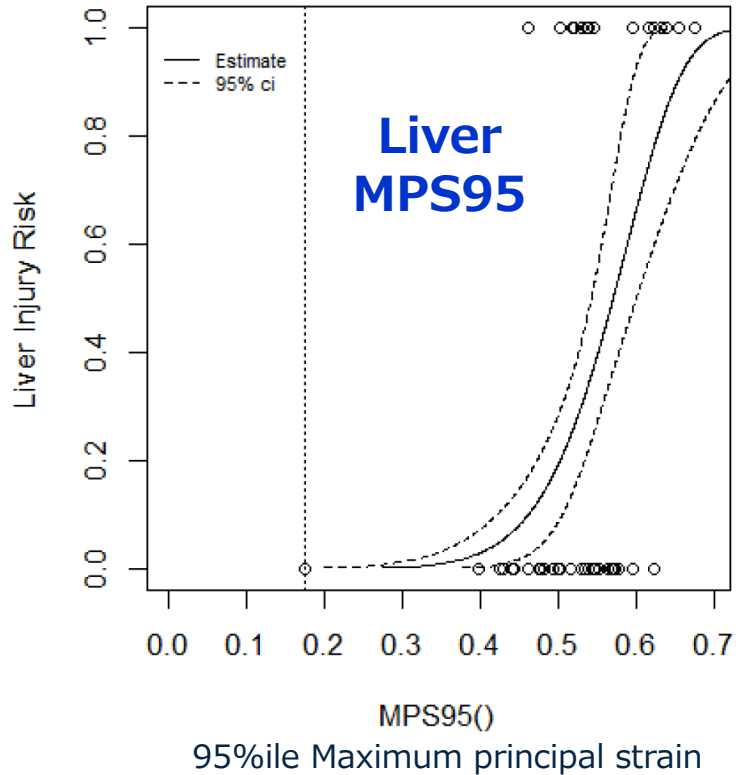
Auriault et al., IRCOBI 2025

Probabilistic Injury Risk Function Development for the liver, spleen, and small intestine of the 50th percentile male THUMS version 7 finite element model

Upper Abdomen

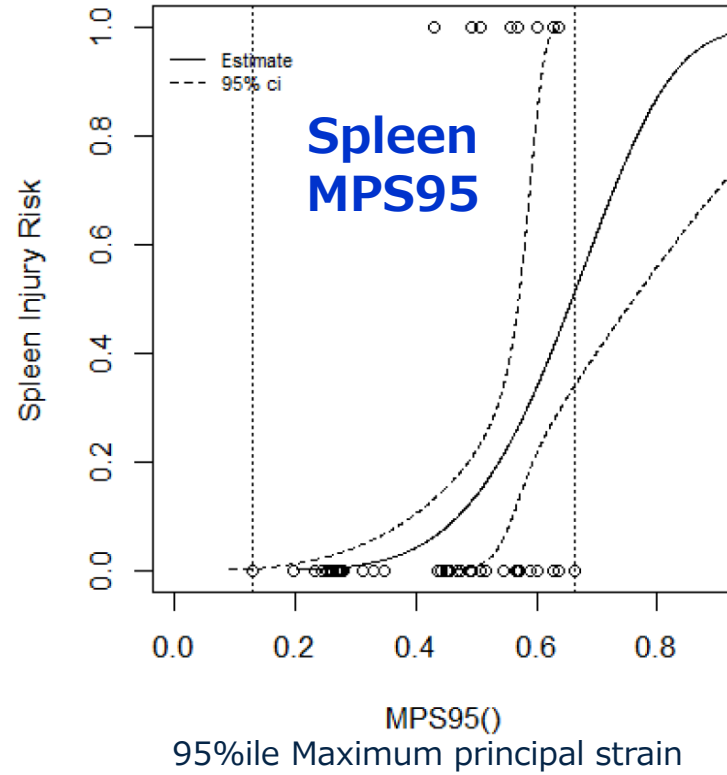
Survival Weibull

scale: 0.595 shape: 8.912 sample size: 84



Survival Weibull

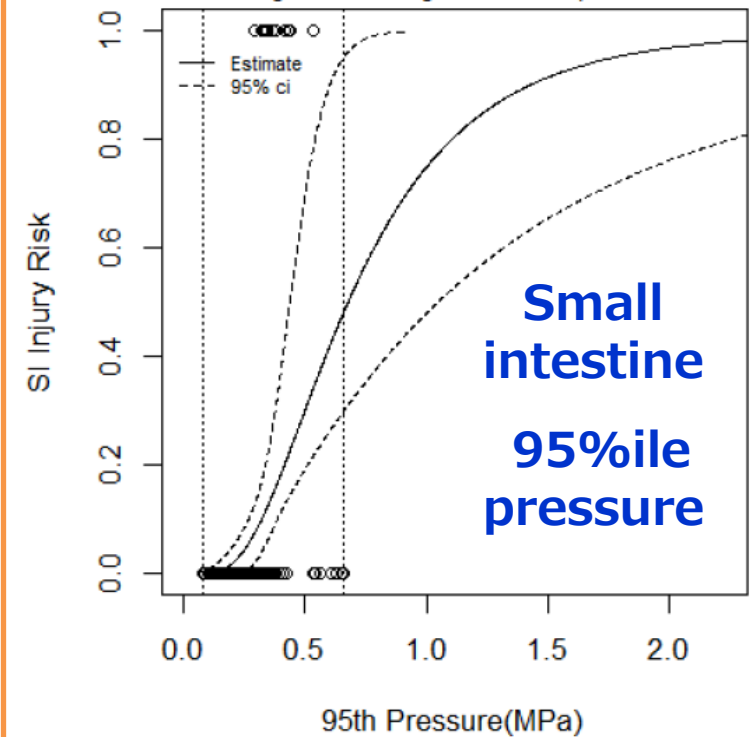
scale: 0.703 shape: 5.584 sample size: 84



Lower Abdomen

Survival Log-Normal

meanlog: -0.39 sdlog: 0.581 sample size: 145

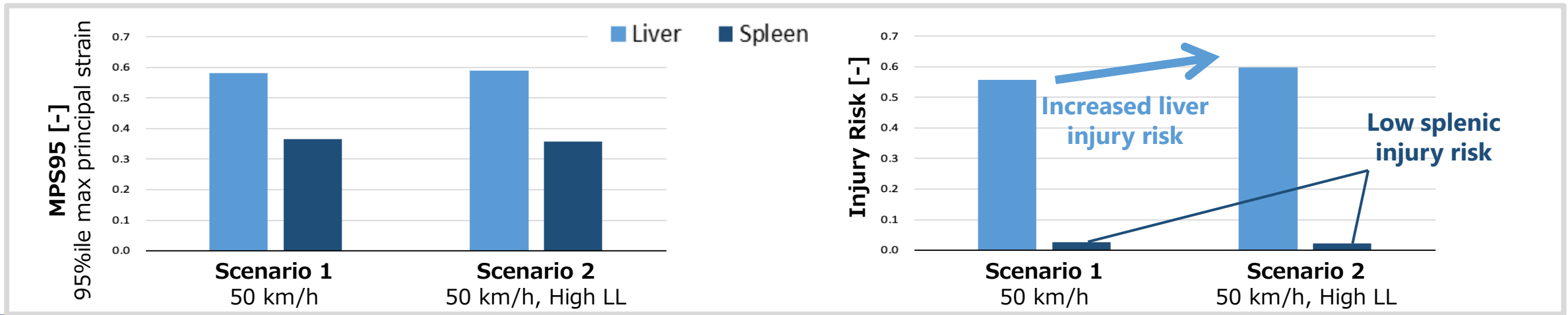
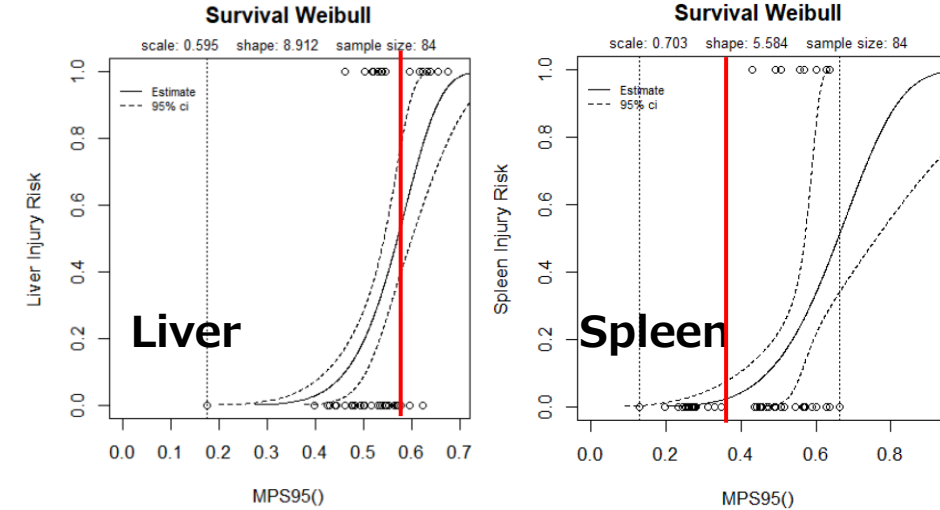


Upper abdomen (liver and spleen): MPS95 and injury risk

Scenario 1 (50 km/h) vs. Scenario 2 (50 km/h, high load limiter)

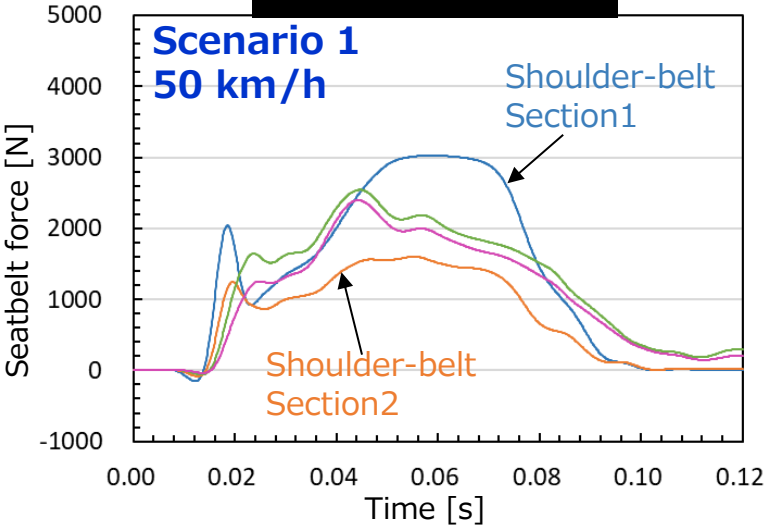
- Expectation: Higher liver injury metric and risk in Scenario 2
- ◆ **MPS95:** Similar for Scenario 1 and 2.
- ◆ **Injury risk**
 - Spleen:** Similar for Scenario 1 and 2 (low risk)
 - Liver:** Slightly higher in Scenario 2
 - ✓ Although MPS95 values were similar, the values lay in a region of the risk curve where the risk changes rapidly, resulting in a difference.

➔ **This is consistent with the expectation. However, the difference in liver MPS95 and injury risk is small.**

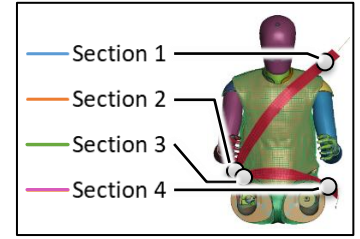
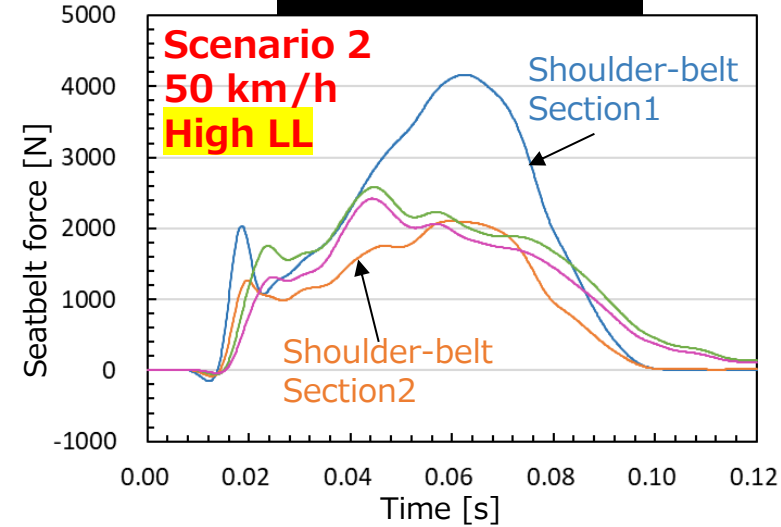


Shoulder-belt force and liver maximum principal strain

Seatbelt force



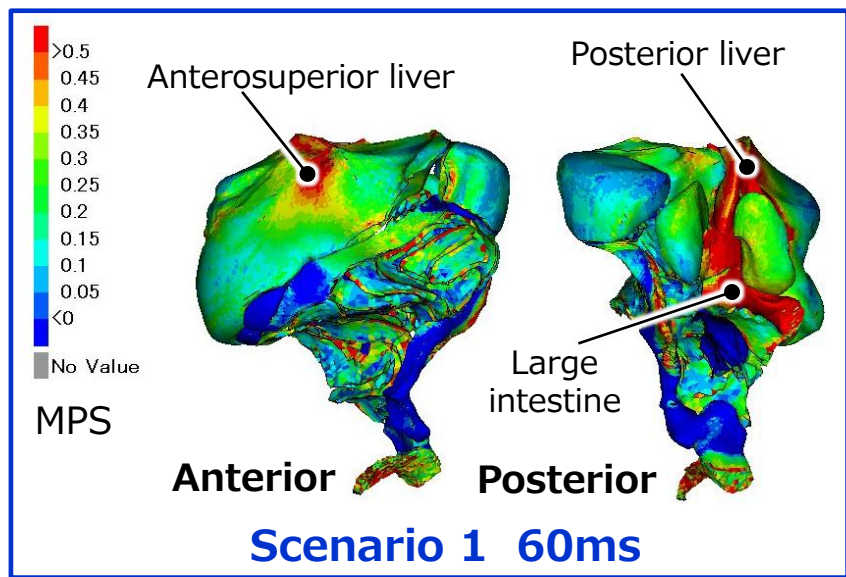
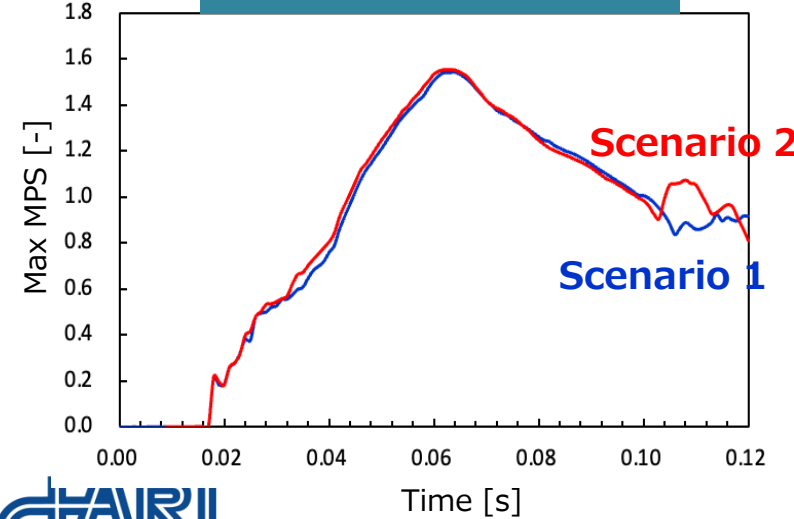
Seatbelt force



The shoulder-belt load was successfully increased as intended, but the peak strain appears to be driven by a different mechanism.

- Shoulder-belt force: Scenario 1 < Scenario 2
- Liver max MPS: Similar between the two scenarios
- In both scenarios, the organs show a protruding behavior (see next slide), and excessive strain occurs at the liver attachments.
 - This issue was also noted by experts.
 - Anterosuperior liver: attachment to the diaphragm
 - Posterior liver: attachments to the diaphragm and the inferior vena cava

Liver Max MPS



Remaining issue

- ✓ Biofidelity of organ response in the HBM

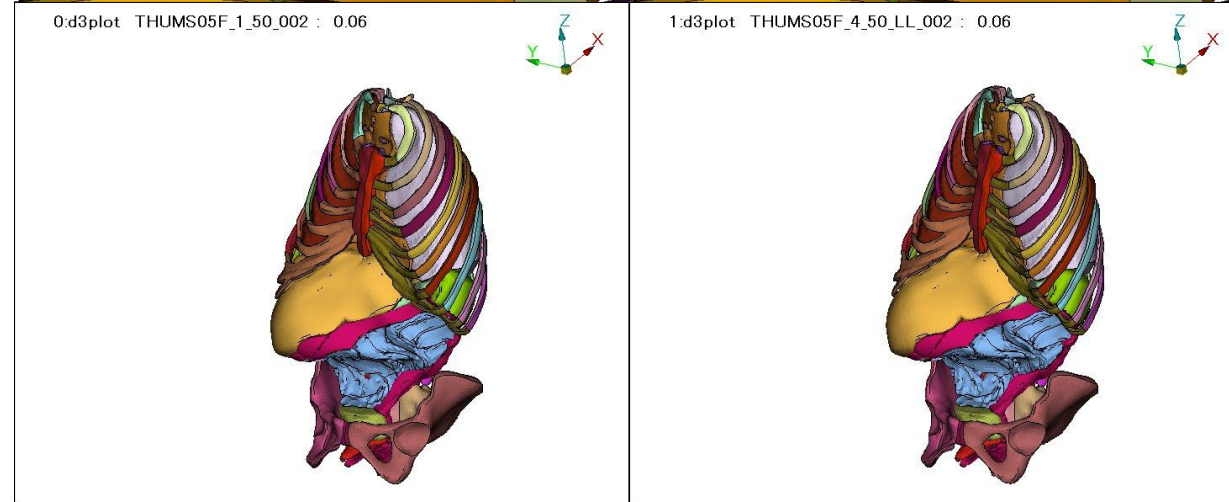
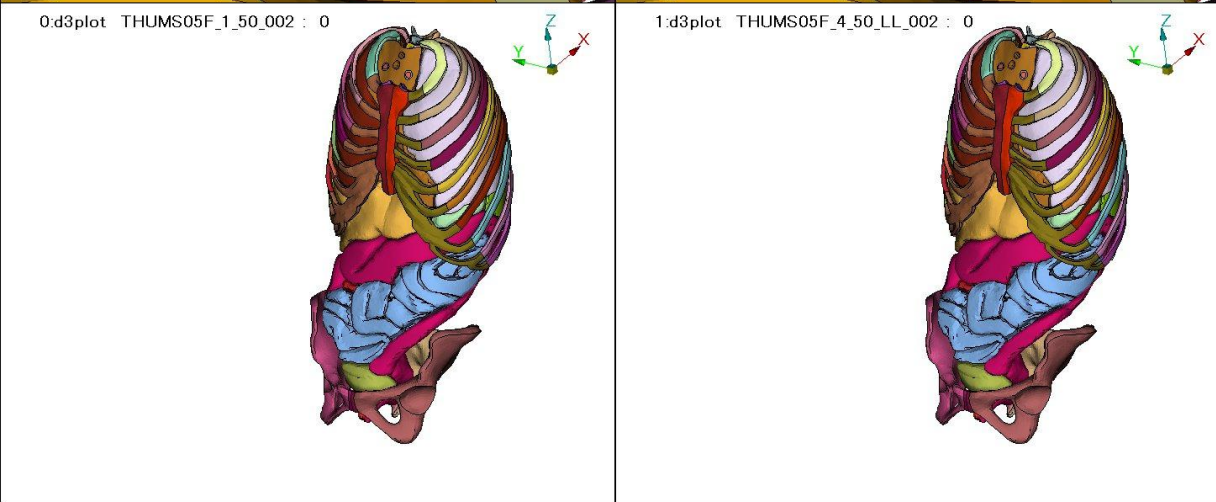
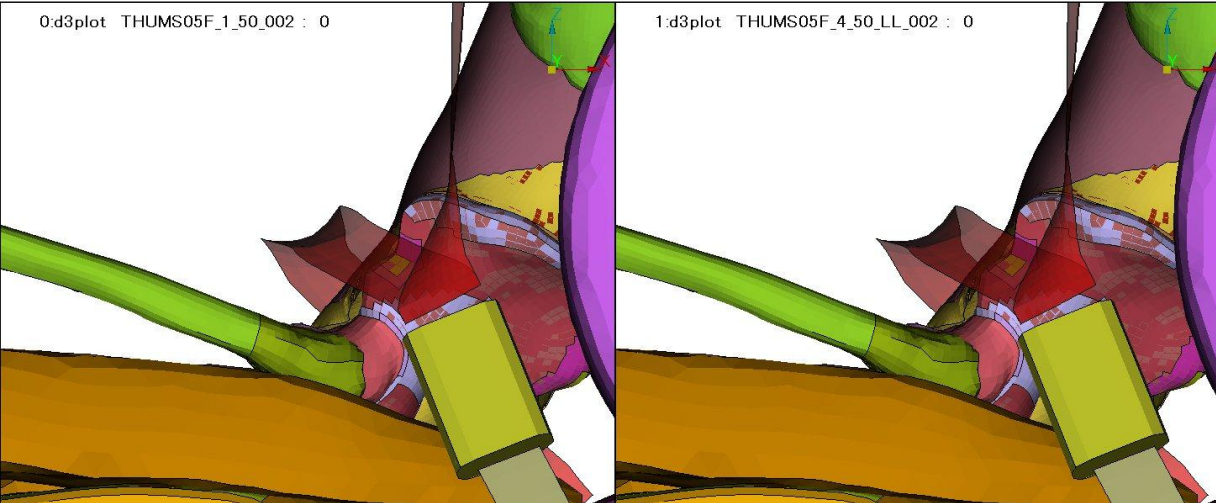
Shoulder-belt force and liver maximum principal strain

Scenario 1
50 km/h

Scenario 2
50 km/h, High LL

Scenario 1
50 km/h

Scenario 2
50 km/h, High LL



0 ms

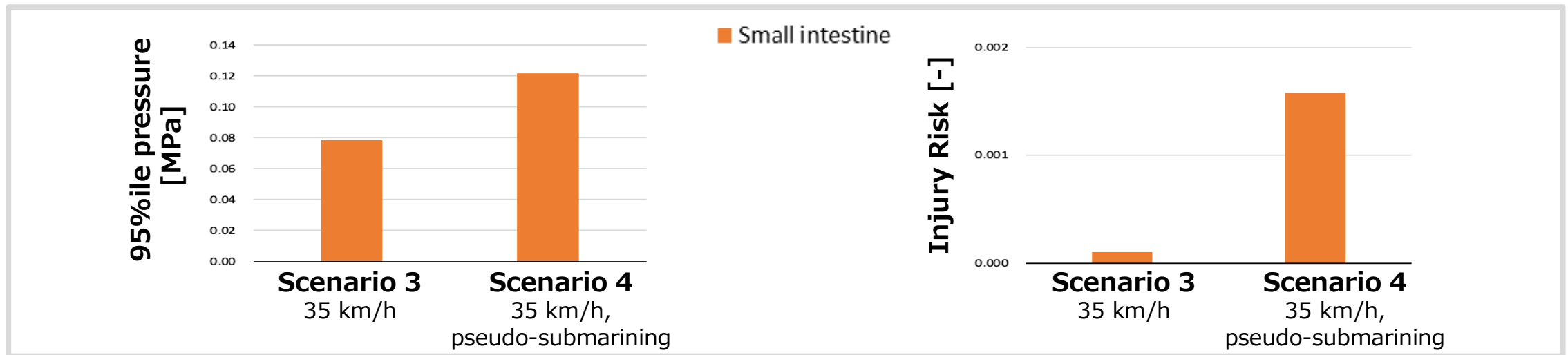
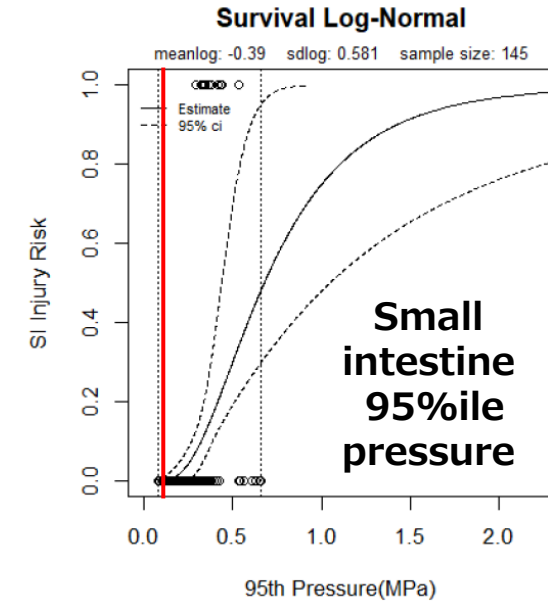
60 ms

Lower abdomen (small intestine): 95%ile pressure and injury risk

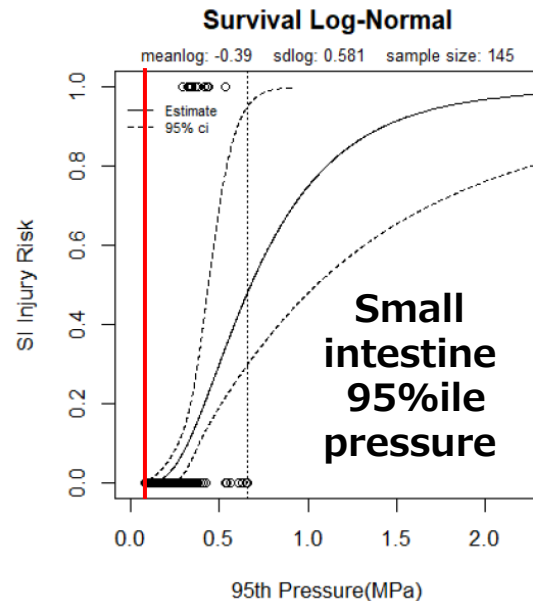
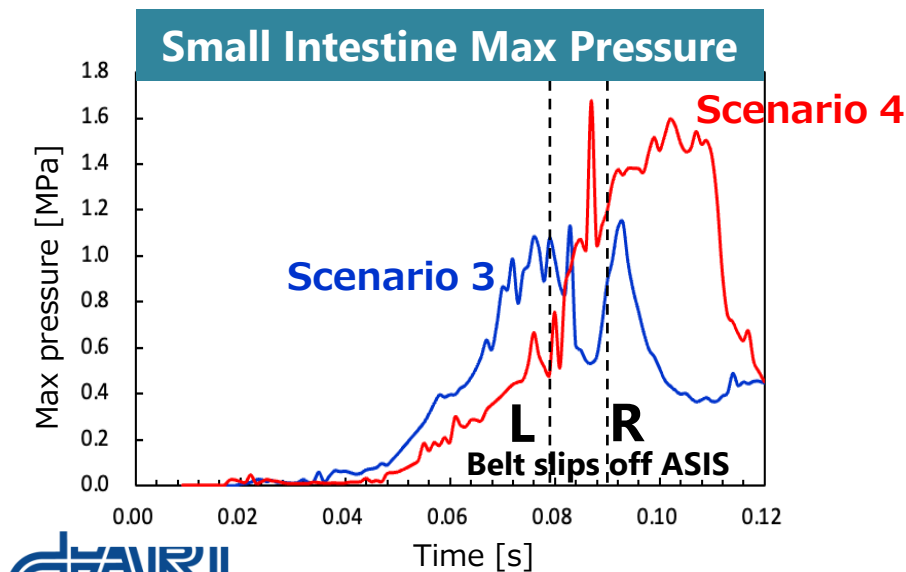
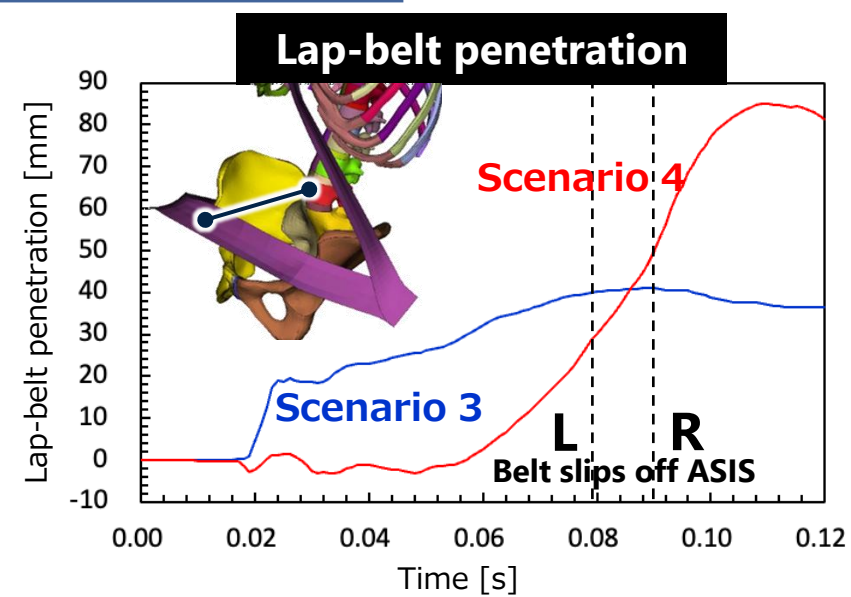
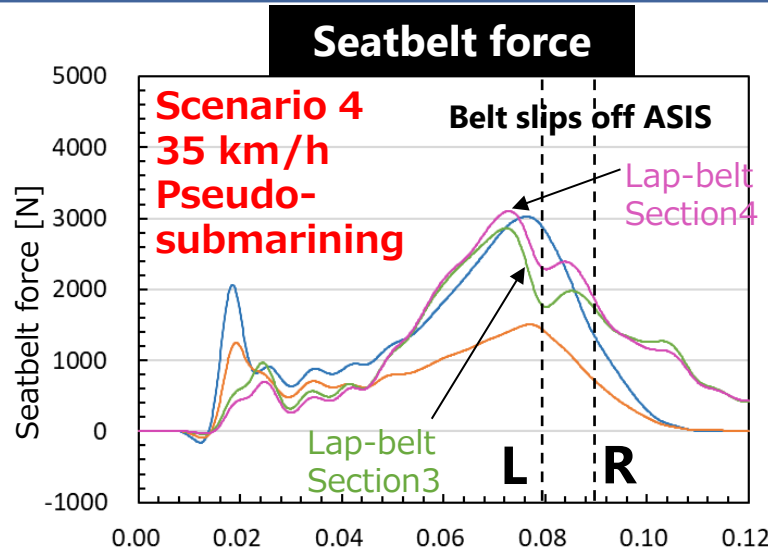
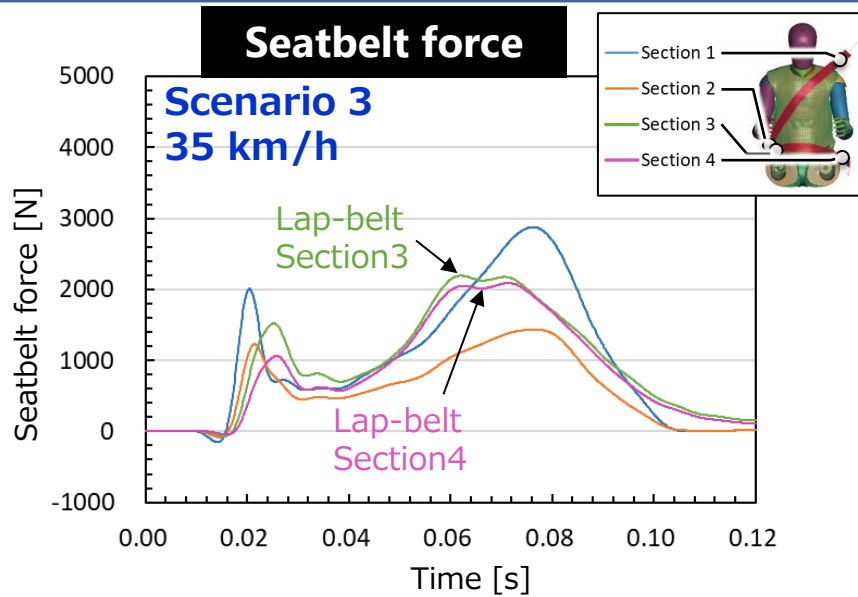
Scenario 3 (35 km/h) vs Scenario 4 (35 km/h, pseudo-submarining)

- Expectation: Scenario 4 would produce a higher small-intestine injury metric and injury risk
- ◆ 95%ile Pressure: Higher in Scenario 4
- ◆ Small intestine injury risk: Higher in Scenario 4

➔ This is consistent with the expectation.
However, the estimated risk is extremely low.



Lap-belt force, belt penetration, and small-intestine pressure



The lap belt successfully increased small-intestine pressure as intended, suggesting that small-intestine injury risk may be assessable using pressure. However, the estimated injury risk remained extremely low.

- Lap belt force: Scenario 3 < Scenario 4
- Lap belt penetration: Scenario 3 < Scenario 4
- Small intestine max pressure: Scenario 3 < Scenario 4
- 95%ile pressure : Scenario 3 < Scenario 4
Scenario 3: 0.079 MPa, Scenario4: 0.122 MPa

Remaining issue
✓ Accuracy of the IRF

- Simulation conditions likely to cause abdominal injuries were defined from Japanese frontal crash data.
- Frontal sled simulations were conducted using THUMS AF05 v7.1.
- Organ response metrics and injury risks were evaluated for the liver, spleen, and small intestine.

- The HBM enabled organ-specific response assessment.

- The simulation results were generally consistent with the hypotheses derived from accident data:
 - ✓ Higher load limiter increased liver injury risk.
 - ✓ Submarining increased small-intestine pressure and injury risk.

- Further validation is needed for:
 - ✓ Biofidelity of the HBM liver response
 - ✓ Small-intestine injury risk function