中国汽车工程研究院股份有限公司
China Automotive Engineering Research Institute Co., Ltd.

Research on Reclined Occupant Safety in Frotal Impact and Draft Test and Assessment Protocol

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2025/05/21

Organization and Team

Central Enterprise

Research Institute

Listed Company

China Automotive Engineering Research Institute Co., Ltd (CAERI)

Testing Engineering Business Unit

Automotive Safety Technology Center

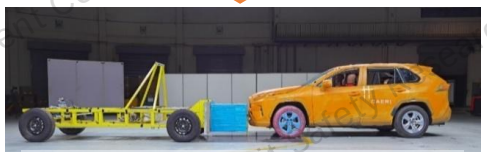
- Traffic Accident
- New Car Assessment
- Components Test
- Safety Equipment
- Virtual SImulation
- Advanced Technology Research
- Crash Test
- VRU Protection
- Performanc e R&D

Research | **Test** | **Simulation**

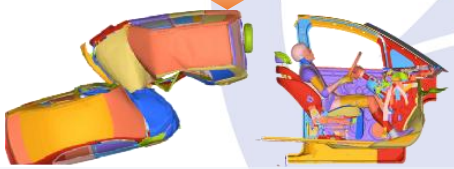
C-IASI

中国保险汽车安全指数

CHINA INSURANCE AUTOMOTIVE SAFETY INDEX



Professional and Advanced Technical Services



Technological Support for High-quality and Sustainable Development

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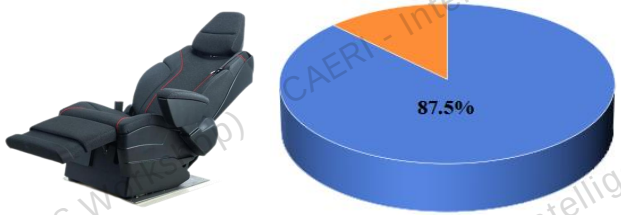
Research Background

High Market Penetration Rate and Popular with Consumer



➢ 87.5% Penetration Rate (28/32 OEMs)

**Source：CAERI Investigation 2023-2024*

Higher mortality Risk and Injury Severity in Accidents

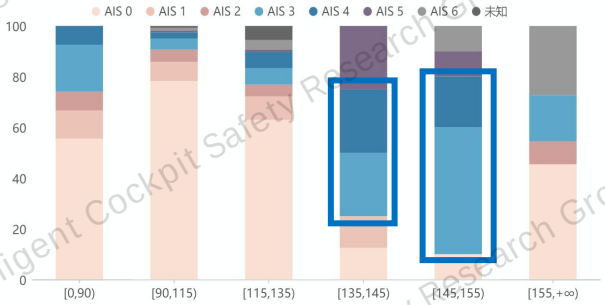
Table 4 Mortality Risk With Full or Partial Recline, Compared With Occupants in the Upright Position

Seat Position	Adjusted Odds Ratio for Mortality	95% CI
Partial reclined	1.15	1.05–1.26
Fully reclined	1.77	1.09–2.88

Adjusted for age, sex, height, weight, seatbelt use.

➢ Higher mortality of reclined occupants

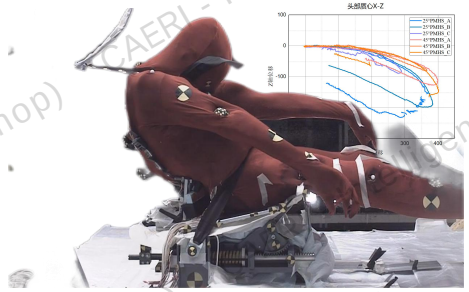
**Source：NASS/CDS N=90412 [1]*

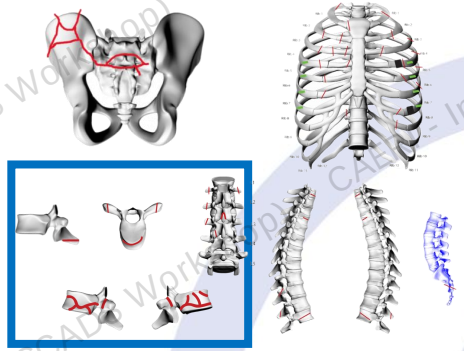


➢ Higher proportion of AIS 3+ injuries

**Source：FASS N=3270*

New Injuries and Higher Injury Severity in Tests





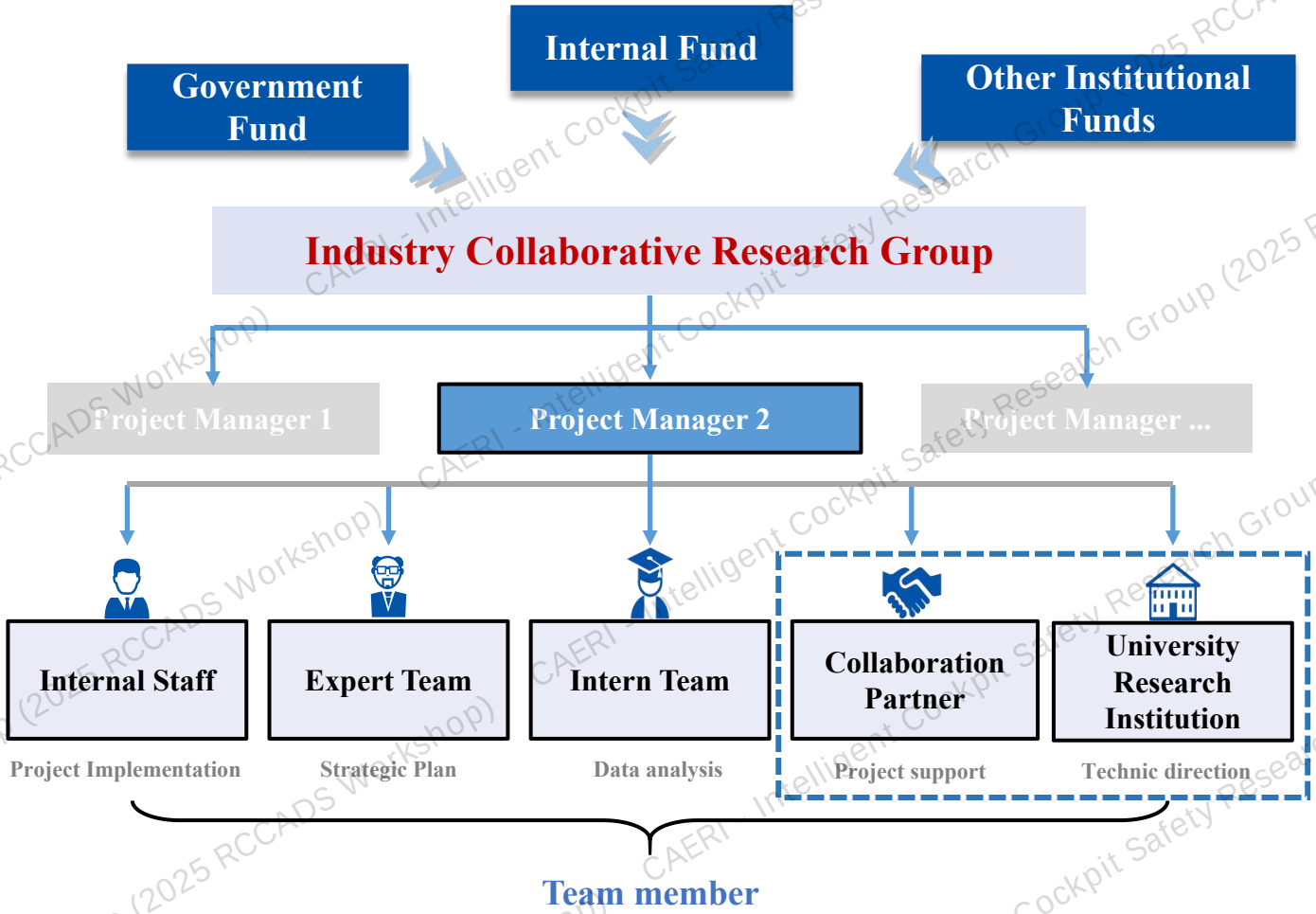
➢ Submarining, Iliac wing, sternum, ribs and spine fractures

**Source：UMTRI & UVA PMHS Tests Reports*

There is no test and assessment protocol to ensure **reclined occupants safety** in collisions.

[1] Letarte, Peter B. , et al. "The effect of reclined seats on mortality in motor vehicle collisions - Discussion." The Journal of trauma 64.3(2008):627-628.

Research Group



1. Object → 2. Tool → 3. Method → 4. Rating → 5. Protocol

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Frame

- **1. Object**
  - Definition of Reclined Seat
  - Selection of T&A Objects
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  - Dummy
- **3. Method**
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  - Positioning Procedures of Seat and Dummy
- **4. Rating**
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  - ATD Injury
  - Overall
- **5. Protocol**
  - Protocol Location

1. Object

Definition of Reclined Seat

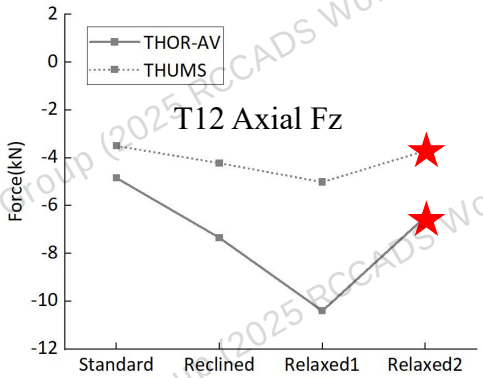
- Automotive reclined seats refer to automotive seats that **can adjust the angle** of components including the **seat cushion**, **seat back**, and **leg/foot suppot** to make the occupantts' posture different from the traditional sitting posture.
- After adjustment, the seat cushion angle is greater than **10°** and the torso angle is greater than **35°** （measured by HPM-II）.

Selection of T&A Objects

- Reclined seatst which are forbidden during driving are not within the scope of the protocol, but **reports** must be provided.

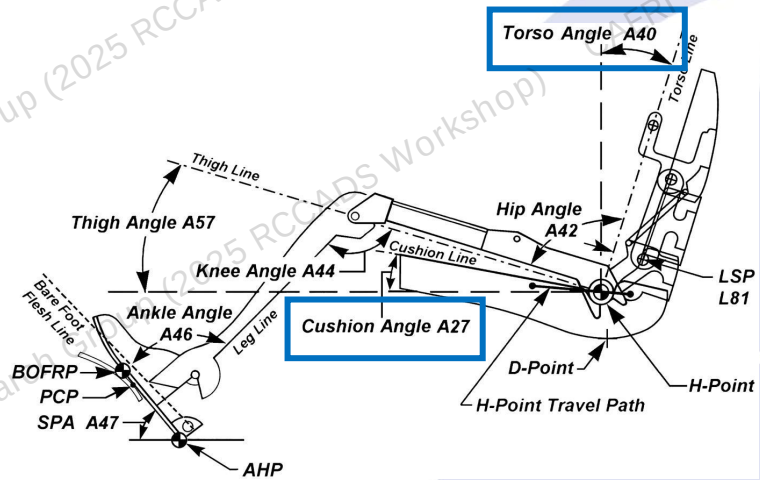
Test Angle of Reclined Seat

- Prioritize testing according to the **OEM-recommended reclining angles**. If not available, test according to the **maximum** seat back reclining angle.



Posture	Torso Angle	Cushion Angle	Leg Support Angle
Upright	25°	15°	\
Partial Reclined	45°	25°	\
Fully Reclined 1	56°	15°	40°
Fully Reclined 2 ★	65°	30°	30°

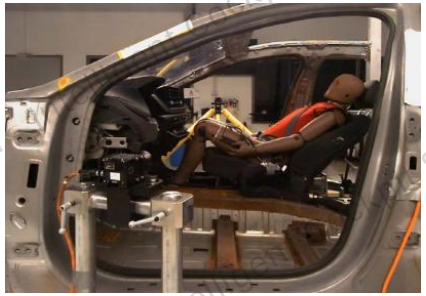
★ submarining



HPM-II, SAE J4002 2022

Selection of Environment Samples and BIW

- If the reclined seat is in the front row, BIW and interior components such as the IP panel need to be configured. If it is in the rear row, the front-row seats are required, and the others are optional.



Dummy

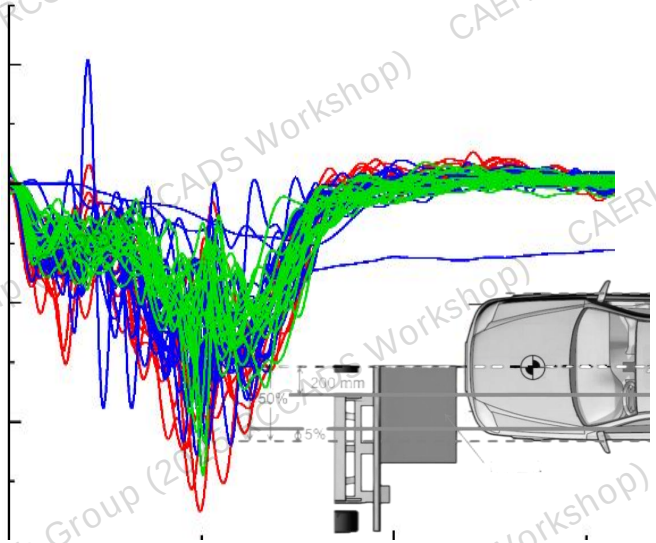
Selection Principles

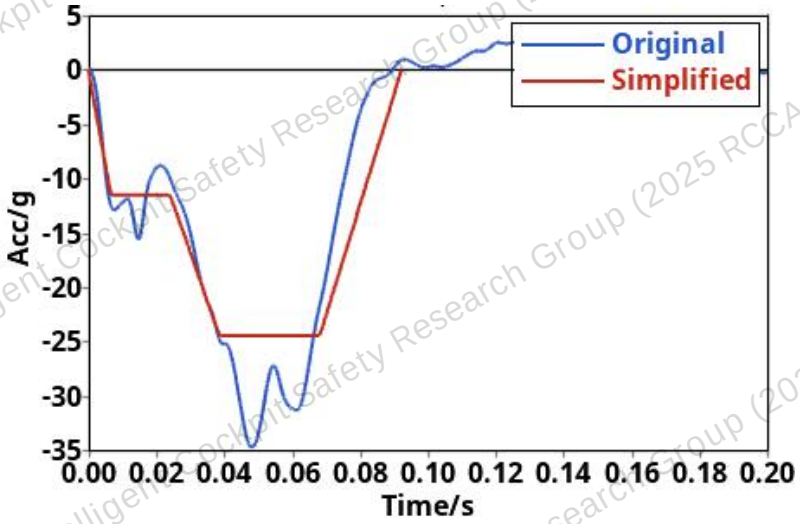
- Biofidelity
  - Published paper, presentations and other reports or public materials
  - PMHS corridor and ATD responses
- Test Execution
  - Repeatability
  - Durability
- Price
  - Price and Service
- Consistent with Global Protocols
  - Consistent with EuroNCAP, IIHS, etc.
- Others (IRCs, FE model, etc.)
  - Available injury risk curves
  - Available and validated FE model

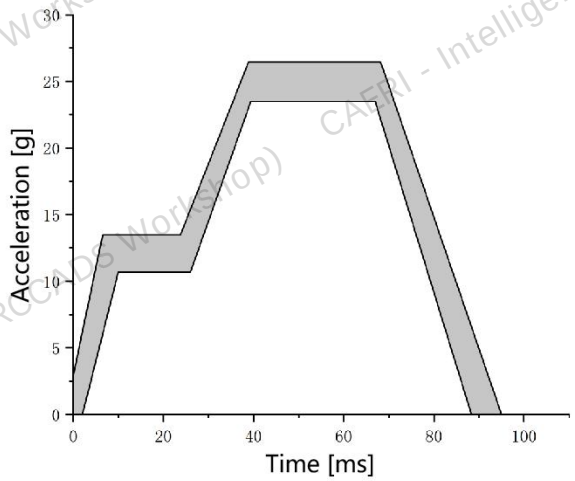
3. Method

Test Pulse

- Extract the characteristics of the vehicle acceleration curves from over 50 tests of **moderate-offset frontal collisions between two vehicles with equal mass and stiffness**. Simplify them into a double - trapezoidal pulse to serve as the standard input and corridor for testing.







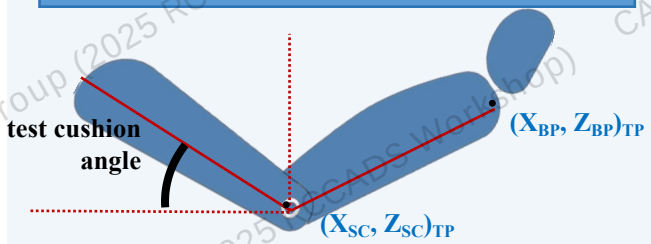
3. Method

■ Adjustment and Positioning Procedures of Seat and Dummy

- × The adjustment procedures from current protocol are **not applicable** to seats with **larger angles**.
- × **H-point and posture like pelvis angle** of reclined dummy is quite **different** from the current upright dummy.
- × The reclined posture prediction function is only applicable when the **seat cushion angle is 14.5°**. (Reed et al. 2019 TIP)

STEP 1
Target Position

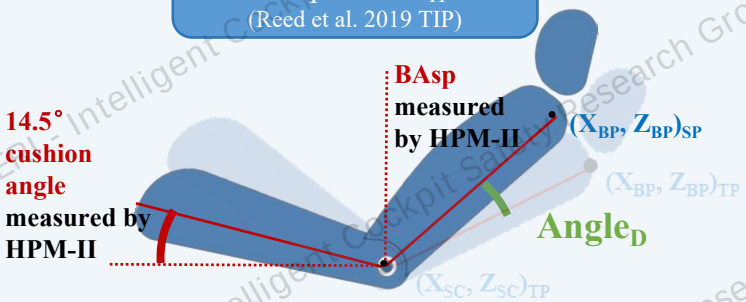
Adjust to target position (test condition), record H-point by HPM-II



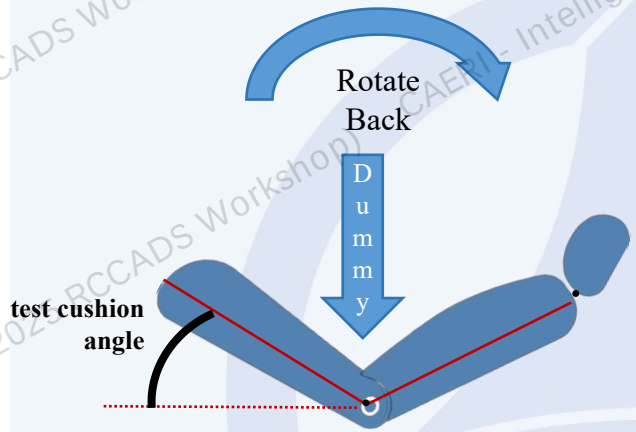
STEP 2
Standard Position

Rotation

Calculate Pelvis angle PAsp and PA_{TP} (Reed et al. 2019 TIP)



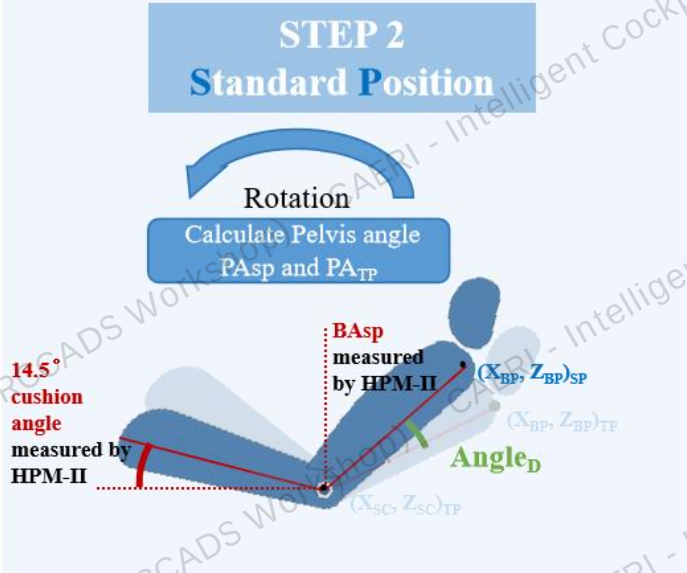
STEP 3
Target Position



- Adjustment procedures of other parts of the dummy are basically consistent with that of the THOR-50M dummy in MPDB test protocol of C-IASI.

3. Method

■ Pelvis Angle and H-point of Dummy



To calculate **pelvis angle**, rotate the seat **until the seat cushion angle is 14.5°**:

- Based on the torso angle BA_{SP} measured by HPM-II, PA_{SP} is

$$PA_{SP} = 0.33BA_{SP} + 50.6°$$

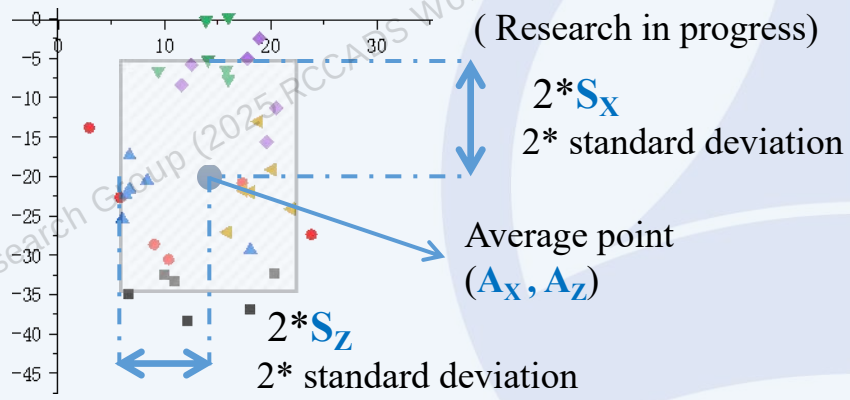
(Reference: Reed et al. 2019 TIP)

- Based on the seat rotation angle $Angle_D$ and the difference **X** between pelvis angle sensor values and human pelvic angles caused by different dummy structures, the target pelvic angle of dummy $PA_{dummyTP}$ is

$$PA_{TP} = PA_{SP} + Angle_D,\ PA_{dummyTP} = PA_{TP} + X$$

- To obtain **H-point** of the dummy, HPM-II is used for H-point, and the method of using the HPM-II refers to SAE J4002.
- The coordinate relationship between the H-point measured by the HPM-II and the H-point of the dummy should meet the following ranges:
  - $X_{Dummy} = X_{HPM-II} + A_X \pm 2*S_X$ mm
  - $Z_{Dummy} = Z_{HPM-II} + A_Z \pm 2*S_Z$ mm

X / Z coordinate differences between HPM-II and Dummy
(Research in progress)

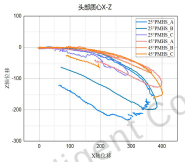


■ Main Risks of Reclined Occupants

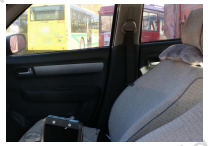
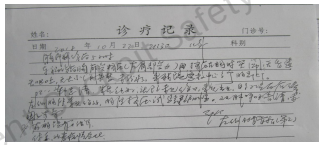
☐ What are the main injury risks for reclined occupants in frontal impacts?

Real Human Injuries

- Summary of **PMHS test** reports

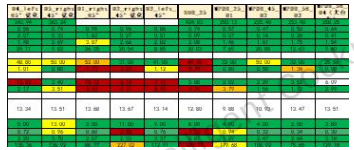




- Analysis of **accident** occupants' injury reports

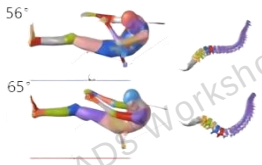




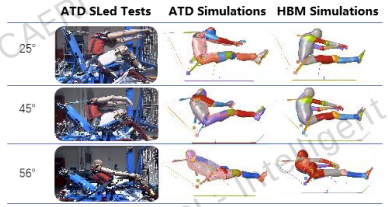
Dummy-Predicted injuries

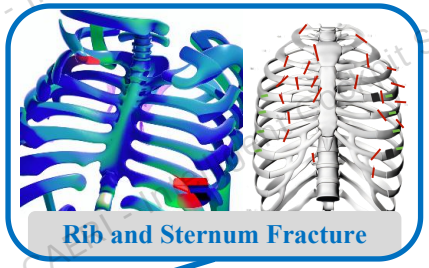
- 80+ **sled tests** and analyses

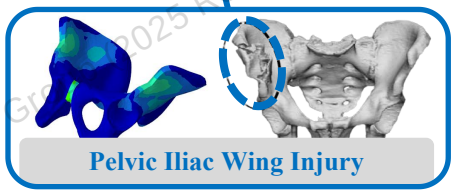



- Corresponding **HBM simulation** analysis







✓ **Risks are concentrated in the thorax, pelvis, and lumbar spine, with kinematic risks of submarining and belt rubbing neck.**

4. Rating

Lumbar Spine

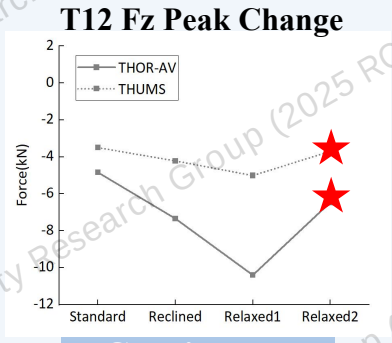
- In **9 out of 11** frontal impact reclined cadaver tests, **AIS2+** injuries were observed in the T12 - L5 vertebrae, among which **7 of the 9** cases were **AIS3**.

1. *https://www.nhtsa.gov/research/biomechanics*
2. *Baudrit, P., et al., Stapp Car Crash J, 2022.*
3. *Richardson, R., et al., Stapp Car Crash J, 2020.*

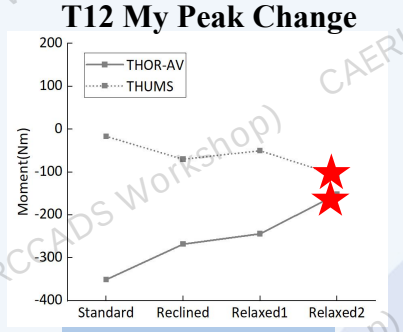
How to assess lumbar spine injury in dummy?

Posture	Torso Angle	Cushion Angle	Leg Support Angle
Upright	25°	15°	\
Partial Reclined	45°	25°	\
Fully Reclined 1	56°	15°	40°
Fully Reclined 2 ★	65°	30°	30°

★ submarining



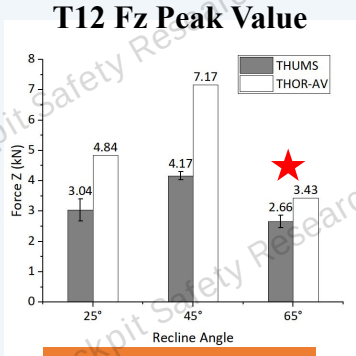
Consistency



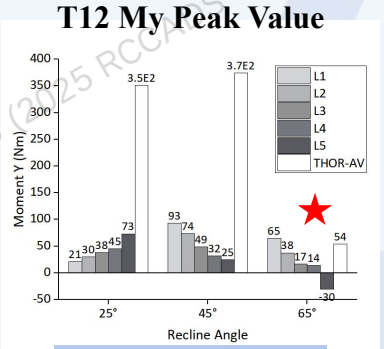
Inconsistency

Posture	Torso Angle	Cushion Angle
Standard	25°	15°
Reclined	45°	15°
Relaxed1 ★	65°	15°

★ submarining



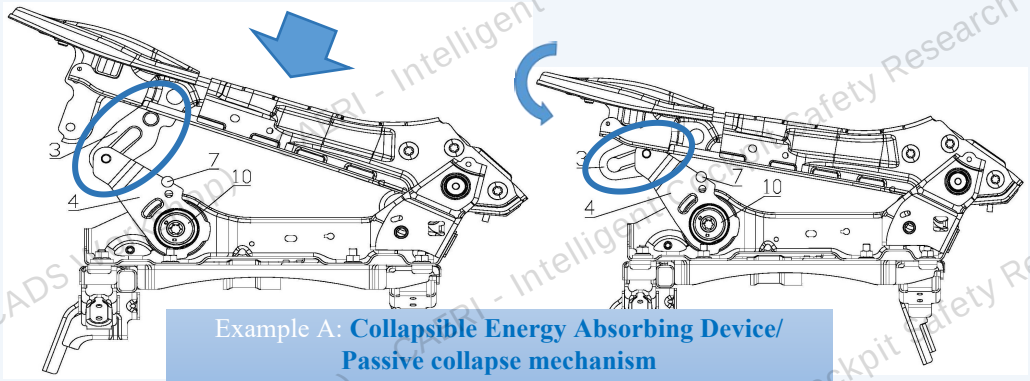
Ratio 1.6 / 1.7



Inconsistency

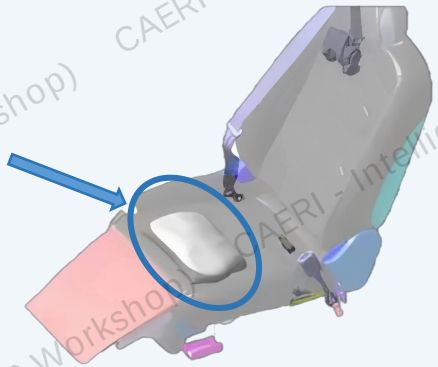
4. Rating

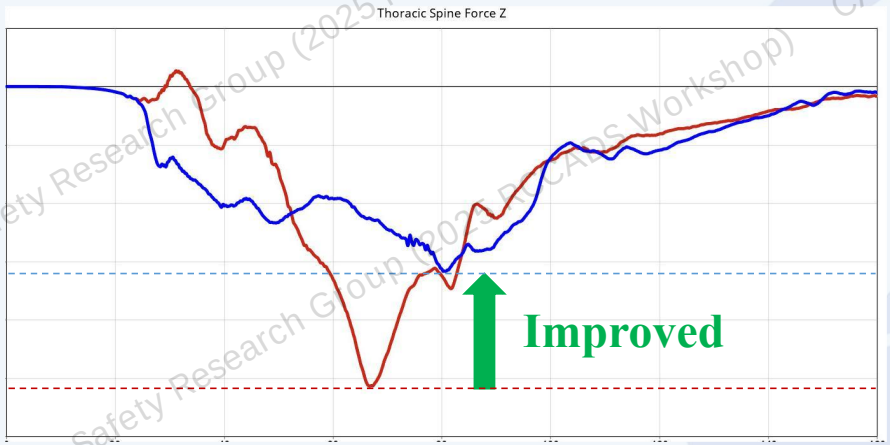
■ Examples of solutions for excessive lumbar axial compression force



Example A: **Collapsible Energy Absorbing Device/ Passive collapse mechanism**
Patent: CN221137781U

Example B:
Cushion Airbag





4. Rating

Pelvic Iliac

- In **7 out of 11** frontal impact reclined cadaver tests, **AIS2+** injuries were observed.

1. *https://www.nhtsa.gov/research/biomechanics*
2. *Baudrit, P., et al., Stapp Car Crash J, 2022.*
3. *Richardson, R., et al., Stapp Car Crash J, 2020.*
4. *Moreau, D., et al., Ann Biomed Eng, 2023.*
5. *Richardson, R., et al.,Traffic Inj Prev, 2024.*

Annals of Biomedical Engineering (2023) 51:1942–1949
https://doi.org/10.1007/s10439-023-03244-8

BMES BIOMEDICAL ENGINEERING SOCIETY

ORIGINAL ARTICLE

Development of an Injury Risk Function for the Anterior Pelvis Under Frontal Lap Belt Loading Conditions

David Moreau[1] · Pavel Chernyavskiy[2] · Sara Sochor[1] · Bronislaw Gepner[1] · Jason Forman[1] · Martin Östling[3] · Jason R. Kerrigan[1]

Received: 9 February 2023 / Accepted: 15 May 2023 / Published online: 5 July 2023

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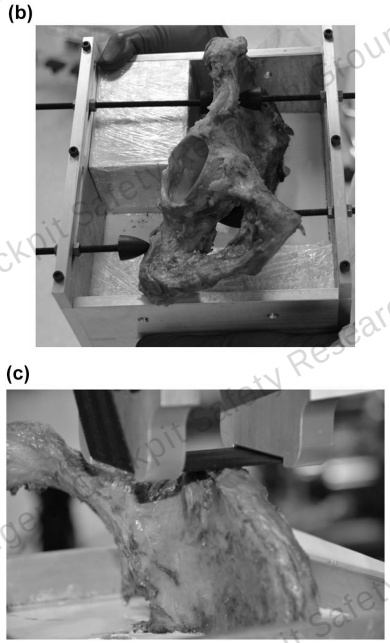


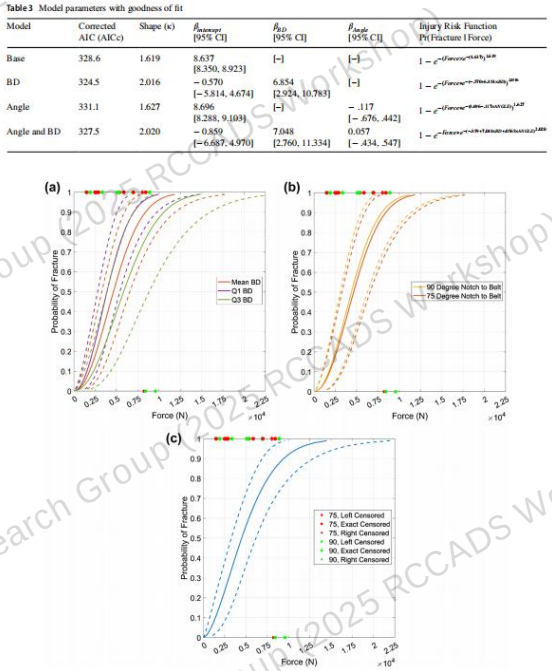


Table 3 Model parameters with goodness of fit

Model	Corrected AIC (AICc)	Shape (c)	$\beta_{Intercept}$ [95% CI]	β_{BD} [95% CI]	β_{Angle} [95% CI]	Injury Risk Function Pr(Fracture | Force)
Base	328.6	1.619	8.637 [8.350, 8.923]	[–]	[–]	$1-e^{-(Force/e^{-8.637})^{1.619}}$
BD	324.5	2.016	−0.570 [−5.814, 4.674]	6.854 [2.924, 10.783]	[–]	$1-e^{-(Force/e^{-(-0.570+6.854\cdot BD)})^{2.016}}$
Angle	331.1	1.627	8.696 [8.288, 9.103]	[–]	−.117 [−.676, .442]	$1-e^{-(Force/e^{-(8.696-0.117\cdot Angle)})^{1.627}}$
Angle and BD	327.5	2.020	−0.859 [−6.687, 4.970]	7.048 [2.760, 11.334]	0.057 [−.434, .547]	$1-e^{-(Force/e^{-(-0.859+7.048\cdot BD+0.057\cdot Angle)})^{2.020}}$

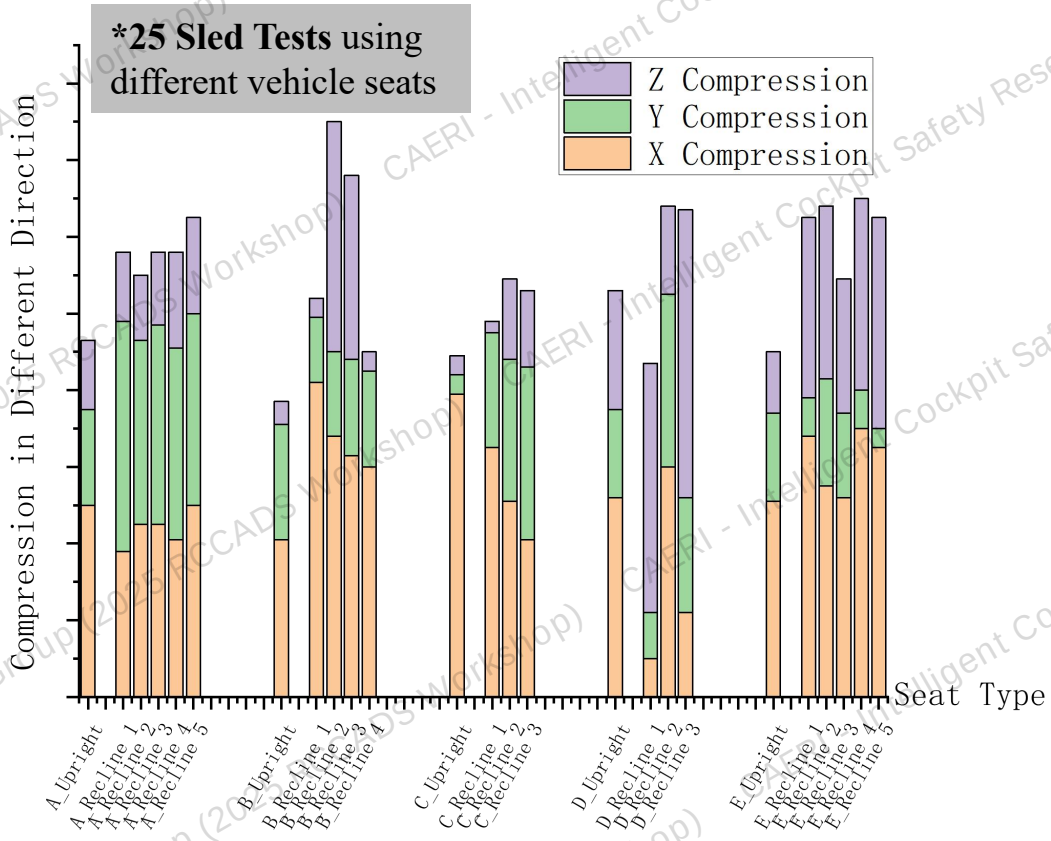
Pelvic Iliac Wing Injury Risk Function

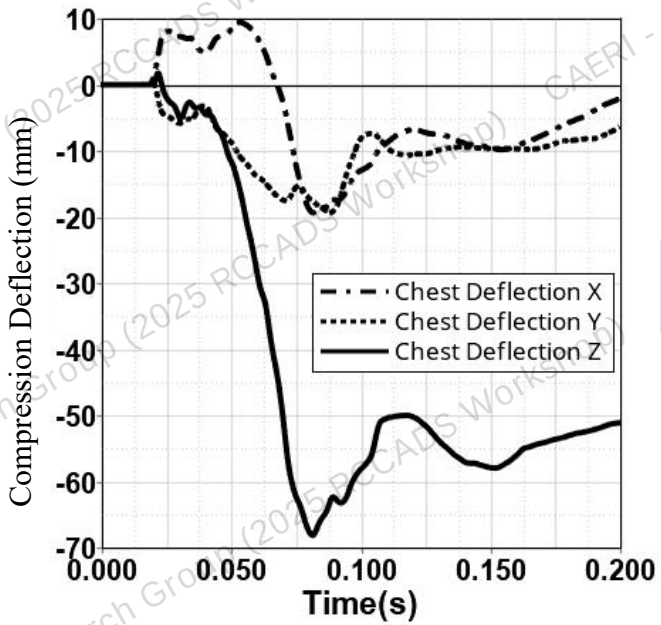
- **A dummy only has force sensors in X direction Fx for iliac wing now.**
- **How to assess pelvic iliac injury in dummy?**

4. Rating

Thorax Injury

- In reclined posture, almost every cadaver test resulted in rib or sternum fractures.
- In reclined posture, ATD tests and simulations indicate that the chest compression deformation will be higher and the Z direction of chest compression may contribute more.





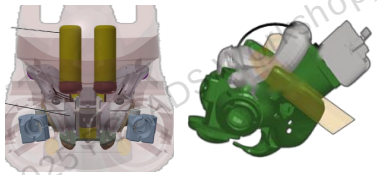
Rating	Good	Acceptable	Marginal	Poor
Chest Compression Deformation（mm）	Monitor (X/Y/Z and Resultant)			

4. Rating

■ Abdomen Injury

☐ **If the occupant submarines, the belt force acting directly on the abdomen may cause organ damage.**

Dummy Abdominal Pressure



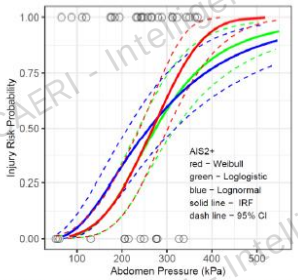


Figure 14. Abdomen MAIS2+ injury risk curves

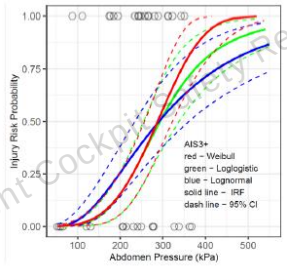
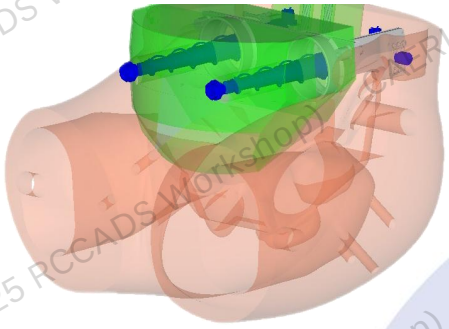


Figure 15. Abdomen MAIS3+ injury risk curves

Table 8. Abdomen pressure injury risk function scale and shape parameters and injury risk values

AIS	Fit	Shape	Scale	AIC	GKG	AUROC	Qual. Index	Injury Risk Values (kPa)		
								5%	25%	50%
MAIS2+	Weibull	3.5054	298.5578	312.8	0.19	0.597	0.23	128	209	269
	Loglogistic	3.9430	275.2554	322.6	0.11	0.557	0.30	130	208	275
	Lognormal	1.7177	260.3630	344.1	0.07	0.536	0.40	100	176	260
MAIS3+	Weibull	3.8799	316.2339	255.6	0.16	0.579	0.23	147	229	288
	Loglogistic	4.4597	293.2402	261.3	0.10	0.550	0.28	152	229	293
	Lognormal	1.7547	290.5577	285.0	0.05	0.524	0.43	114	198	291

Dummy Abdominal Compression Deformation



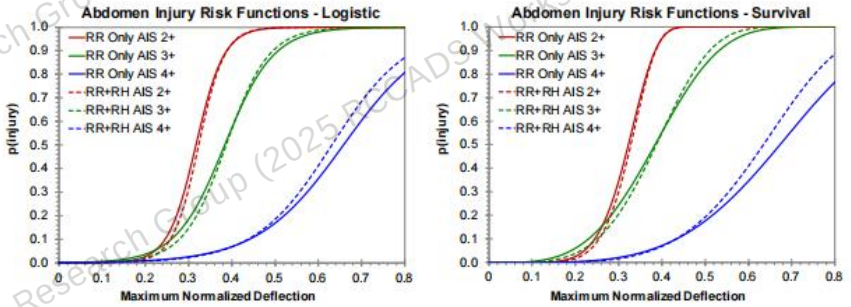


Figure 6.8. Abdomen injury risk functions calculated using AIS 2+, 3+, and 4+ as the injury definition.

Matthew Craig et al., Injury Criteria for the THOR 50th Male ATD, September 2020

Restraint System and ATD Kinematic Rating

Restraint System and ATD Kinematic					
Derived from restraint system and ATD kinematic demerits					Demerits
1.1.1	**Head and Neck Protection**				
1.1.1.1	Dangerous deployment of frontal airbag[1]				1
1.1.1.2	Diagonal belt slippage (obvious rubbing with ATD's neck)				1
1.1.1.3	Two or more hard contacts on the head[2]				1
1.1.2	**Chest and Abdomen Protection**				
1.1.2.1	Excessive shoulder belt load（6kN）				2
1.1.3	**Knee and Pelvis Protection**				
1.1.3.1	**ATD submarining**				**4**
1.1.4	**Other Protection**				
1.1.4.1	Failure to unlock the seat belt or excessive unlocking force[3]				1
1.1.4.2	Seat Failure（Do NOT include seat failures resulting from design for the purpose of achieving occupant protection）				6
Restraint System and ATD Kinematics Rating		Good	Acceptable	Marginal	Poor
Demerits		≤1	≤3	≤5	≥6

1. Dangerous deployment of the frontal airbag means that during the airbag deployment process, in the head evaluation area, it sweeps across the dummy's face in the horizontal or vertical direction, posing a potential risk to the dummy's face or eyes, or its deployment speed is greater than 90 m/s. The head evaluation area refers to the rearward area perpendicular to the longitudinal plane of the vehicle, 150 mm in front of the dummy's face under the test condition.
2. Two or more hard contacts on the head (1 defect) means that there are two or more hard contacts that cause the resultant head acceleration to exceed 70g.
3. Failure to unlock the seat belt or excessive unlocking force (1 defect) means that when the dummy is released from the restraint system after a collision, the seat belt cannot be unlocked or the unlocking force of the seat belt buckle is greater than 60N.

4. Rating

■ ATD Injury Rating

ATD Injury					
2.1	**ATD Injury Rating**				
2.1.1	**Head/Neck**	Good	Acceptable	Marginal	Poor
2.1.1.1	HIC15	≤560	≤700	≤840	＞840
2.1.1.2	Shear Force Fx（kN）※	≤1.9	≤2.5	≤3.1	＞3.1
2.1.1.3	Tensile Force Fz（kN）※	≤2.7	≤3.0	≤3.3	＞3.3
2.1.1.4	Tensile Bending Moment Mocy（Nm）※	≤42	≤49.5	≤57	＞57
If there is one hard contact resulting in the resultant head acceleration exceeding 70 g, the head and neck injury rating will be degraded by one level, but the defects in the restraint system and ATD kinematics rating will not be counted					
2.1.2	**Chest/Abdomen**	Good	Acceptable	Marginal	Poor
2.1.2.1	Chest Compression Deformation（mm）	Monitoring(X/Y/Z and Resultant)			
2.1.2.2 (Depends on dummy)	Abdomen Pressure（bar）	≤1.28	≤2.09	≤2.69	＞2.69
	Abdomen Compression Deformation（mm）	Monitoring(X/Y/Z and Resultant)			

2.1.3	**Thigh/Hip**	Good	Acceptable	Marginal	Poor
2.1.3.1	Compression Force on Thigh Fz（kN）	≤3.8@0ms ≤3.8@10ms	≤6.44@0ms ≤5.68@10ms	≤9.07@0ms ≤7.56@10ms	>9.07@0ms >7.56@10ms
2.1.3.2	Compression Force on Acetabulum F_{AR}（kN）	≤3.28	≤3.69	≤4.1	＞4.1
2.1.3.3	Iliac Force Fx（kN）	≤2.5	≤3.5	≤4.5	＞4.5
2.1.3.4	Lap Belt Force（kN）	Monitoring			
2.1.4	**Spine**	Good	Acceptable	Marginal	Poor
2.1.4.1	Lumbar Spine Compression Force T12 Fz（kN）	≤4.5	≤5.5	≤6.5	＞6.5
2.1.4.2	Lumbar Spine Bending Moment T12 My (Nm)	Monitoring			
2.1.5	**Tibia/Foot**	Good	Acceptable	Marginal	Poor
2.1.5.1	Knee joint sliding displacement D (mm)	≤12	≤15	≤18	＞18
2.1.5.2	Tibia index (upper and lower) TI	≤0.8	≤1.0	≤1.2	＞1.2
2.1.5.3	Tibia axial force Fz (kN）	≤4.0	≤6.0	≤8.0	＞8.0
2.2.5.4	Maximum resultant foot acceleration A(g)	≤150	≤200	≤260	＞260

Neck※ -- The current neck criteria and thresholds are derived from the THOR dummy in the current C-IASI protocols, and may be updated based on research.

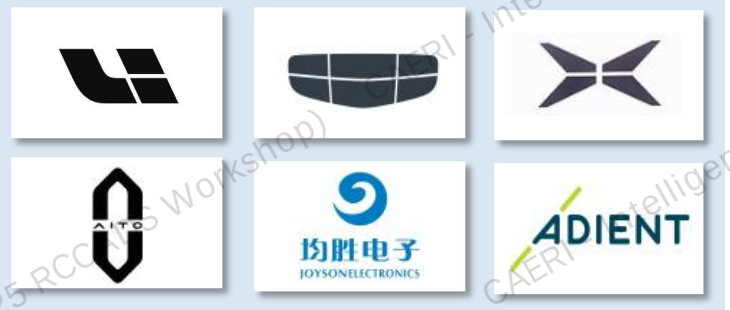
Overall Rating and Protocol Location

- Physical tests. C-IASI → Vehicle Occupant Safety Index → Additional Protocols（TBD）；
- Select the lowest-configured vehicle equipped with reclined seats for testing. Each position with a reclined seat (eg. the front-passenger seat, second-row seats) needs to be tested separately. Then, pick the worst result among all.

Rating Object	Overall Rating			
	GOOD（G）	ACCEPTABLE（A）	MARGINAL（M）	POOR（P）
Driver/front-passenger/second-row, etc.	Pick the worst rating			
Head and Neck	0	2	10	20
Chest and Abdomen	0	2	10	20
Thigh and Hip	0	2	10	20
Spine	0	2	10	20
Leg and Foot	0	1	2	4
Restraint System and ATD Kinematic	0	2	6	10
Overall Rating Cutoffs	0-3	4-9	10-19	20+

Acknowledgment

Sample Provision



Comparative Analysis of HBMs vs ATDs & Laboratory Test Implementation

Protocol Feedback

Simulation and Analysis

Injury Criteria and Thresholds Research

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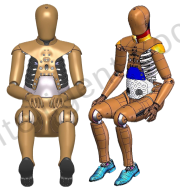
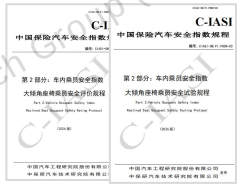
3.1 Protocol Plan



December 2024
Validation test,
Test and assessment protocol draft release

C-IASI 2026 version Project Research（2022-2024）



January 2025 - Q3 2025
Protocol editing and internal comment collection

C-IASI 2026 version Protocol Editing（2025）

2025 Q4
Comment collection

2026 Q1
Protocol Release

C-IASI 2026 version protocol Implementation（2026-2027）

2027 Q1
Protocol Implementation

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