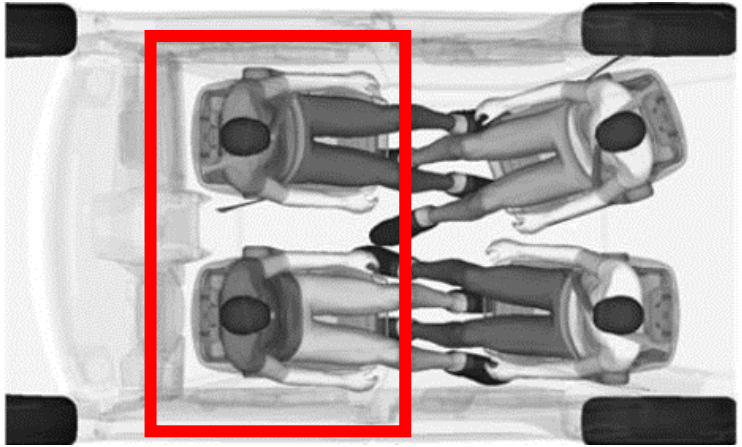
Biomechanical Responses and Injuries of PMHS in Rear Facing Alternative Seating Configurations

Yun-Seok Kang[1], Jason Stammen[2], Alena Hagedorn[3], Rakshit Ramachandra[1], Colton Thomas[3], Amanda Agnew[1], Hyun Jung Kwon[3], Kevin Moorhouse[2], John H. Bolte IV[1]

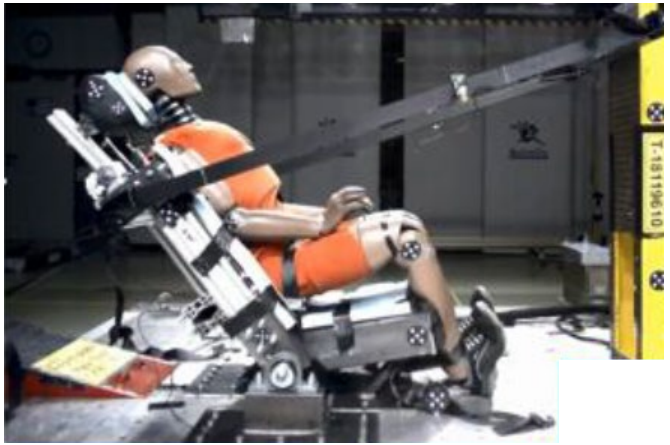
[1]Injury Biomechanics Research Center, The Ohio State University
[2]National Highway Traffic Safety Administration, Vehicle Research and Test Center
[3]Transportation Research Center, Inc.

Motivation

- Future vehicle interior cabin designs may incorporate non-standard seating configurations for vehicles with Automated Driving Systems (ADS)
  - One potential configuration is a reclined seat that is either rear-facing in a frontal collision or forward-facing in a rear collision
  - Studies using computational models and ATDs [Kitagawa et al., 2017; Jin et al., 2018; Zeller and Manneck, 2019]



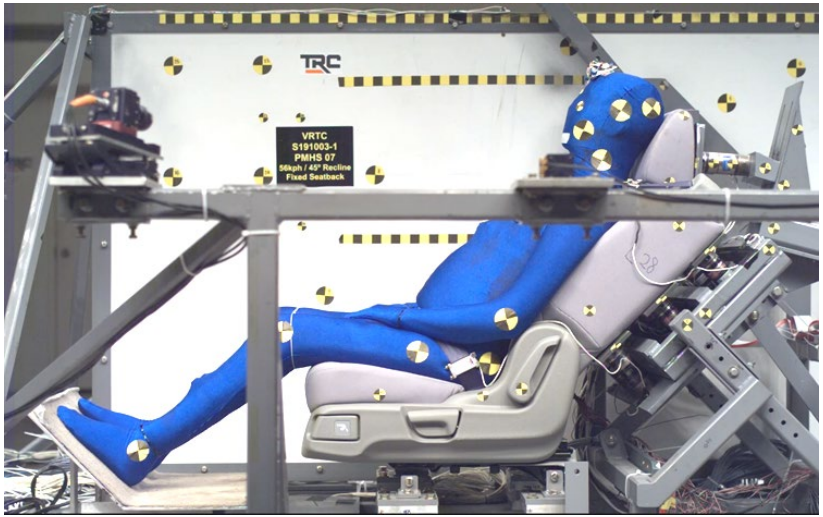
Kitagawa et al., 2017



Zeller and Manneck, 2019

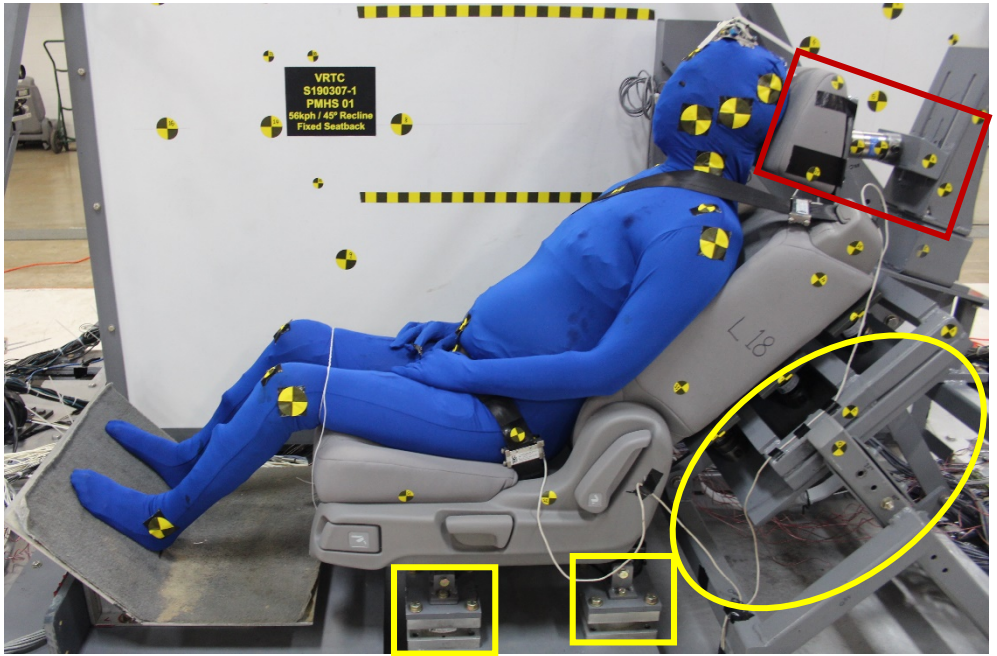
Objective

- To investigate biomechanical responses and injuries from Post Mortem Human Subjects (PMHS) in two recline angle scenarios in a rear-facing seating configuration at high speed impacts



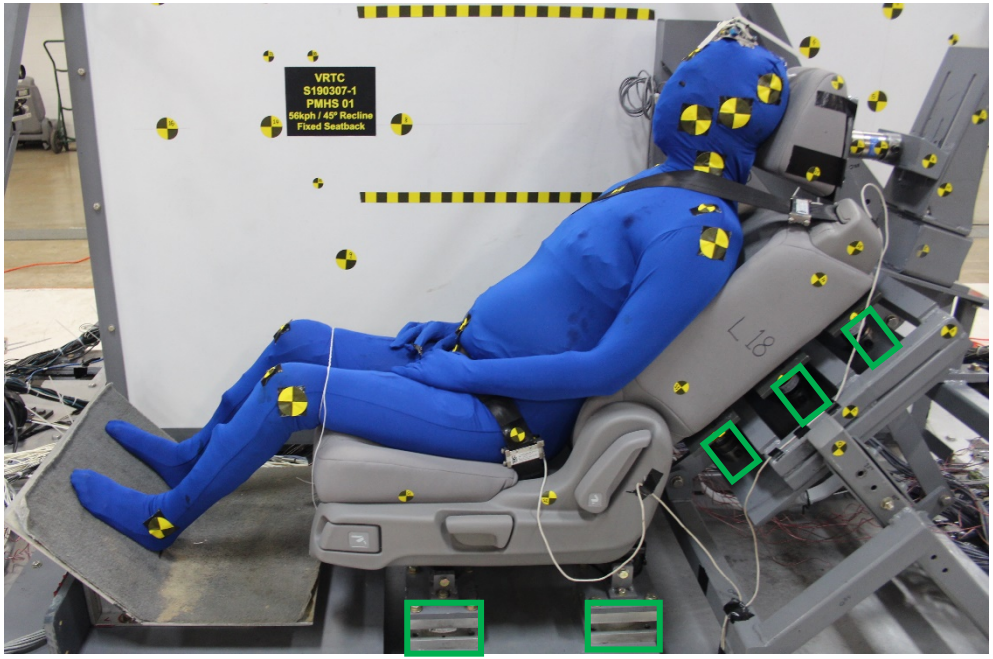
Methods

Sled Buck Design



- Adjustable head restraint (HR)
- Rigidized seat back (SB), seat anchor (SA), and HR supporting frame

Sled Buck Design



- Adjustable head restraint (HR)
- Rigidized seat back (SB), seat anchor (SA), and HR supporting frame
- Load cell at HR (1), SB (6), and SA (4)
- 2017 Honda Odyssey with integrated seat belt

PMHS Information

	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	57	167.0	62.6	91.7	3.8	20.6
PMHS02	64	171.0	62.6	92.4	3.6	17.6
PMHS03	54	177.8	93.9	97.0	5.0	20.6
PMHS04	59	177.8	96.2	96.5	4.4	23.2
PMHS05	62	177.8	77.1	95.7	3.5	21.2
PMHS06	61	176.5	72.6	96.2	3.9	20.2
Mean (SD)	60 (4)	174.7 (4.6)	77.5 (14.7)	94.9 (2.3)	4.0 (0.6)	20.6 (1.8)
50th Male	45	175	78.2	90.7	4.5	22.9

PMHS Information

	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	57	167.0	62.6	91.7	3.8	20.6
PMHS02	64	171.0	62.6	92.4	3.6	17.6
PMHS03	54	177.8	93.9	97.0	5.0	20.6
PMHS04	59	177.8	96.2	96.5	4.4	23.2
PMHS05	62	177.8	77.1	95.7	3.5	21.2
PMHS06	61	176.5	72.6	96.2	3.9	20.2
Mean (SD)	60 (4)	174.7 (4.6)	77.5 (14.7)	94.9 (2.3)	4.0 (0.6)	20.6 (1.8)
50th Male	45	175	78.2	90.7	4.5	22.9

PMHS Information

	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	57	167.0	62.6	91.7	3.8	20.6
PMHS02	64	171.0	62.6	92.4	3.6	17.6
PMHS03	54	177.8	93.9	97.0	5.0	20.6
PMHS04	59	177.8	96.2	96.5	4.4	23.2
PMHS05	62	177.8	77.1	95.7	3.5	21.2
PMHS06	61	176.5	72.6	96.2	3.9	20.2
Mean (SD)	60 (4)	174.7 (4.6)	77.5 (14.7)	94.9 (2.3)	4.0 (0.6)	20.6 (1.8)
50th Male	45	175	78.2	90.7	4.5	22.9

PMHS Information

	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	57	167.0	62.6	91.7	3.8	20.6
PMHS02	64	171.0	62.6	92.4	3.6	17.6
PMHS03	54	177.8	93.9	97.0	5.0	20.6
PMHS04	59	177.8	96.2	96.5	4.4	23.2
PMHS05	62	177.8	77.1	95.7	3.5	21.2
PMHS06	61	176.5	72.6	96.2	3.9	20.2
Mean (SD)	60 (4)	174.7 (4.6)	77.5 (14.7)	94.9 (2.3)	4.0 (0.6)	20.6 (1.8)
50th Male	45	175	78.2	90.7	4.5	22.9

PMHS Information

	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	57	167.0	62.6	91.7	3.8	20.6
PMHS02	64	171.0	62.6	92.4	3.6	17.6
PMHS03	54	177.8	93.9	97.0	5.0	20.6
PMHS04	59	177.8	96.2	96.5	4.4	23.2
PMHS05	62	177.8	77.1	95.7	3.5	21.2
PMHS06	61	176.5	72.6	96.2	3.9	20.2
Mean (SD)	60 (4)	174.7 (4.6)	77.5 (14.7)	94.9 (2.3)	4.0 (0.6)	20.6 (1.8)
50th Male	45	175	78.2	90.7	4.5	22.9

PMHS Information

	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	57	167.0	62.6	91.7	3.8	20.6
PMHS02	64	171.0	62.6	92.4	3.6	17.6
PMHS03	54	177.8	93.9	97.0	5.0	20.6
PMHS04	59	177.8	96.2	96.5	4.4	23.2
PMHS05	62	177.8	77.1	95.7	3.5	21.2
PMHS06	61	176.5	72.6	96.2	3.9	20.2
Mean (SD)	60 (4)	174.7 (4.6)	77.5 (14.7)	94.9 (2.3)	4.0 (0.6)	20.6 (1.8)
50th Male	45	175	78.2	90.7	4.5	22.9

PMHS Information

	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	57	167.0	62.6	91.7	3.8	20.6
PMHS02	64	171.0	62.6	92.4	3.6	17.6
PMHS03	54	177.8	93.9	97.0	5.0	20.6
PMHS04	59	177.8	96.2	96.5	4.4	23.2
PMHS05	62	177.8	77.1	95.7	3.5	21.2
PMHS06	61	176.5	72.6	96.2	3.9	20.2
Mean (SD)	60 (4)	174.7 (4.6)	77.5 (14.7)	94.9 (2.3)	4.0 (0.6)	20.6 (1.8)
50th Male	45	175	78.2	90.7	4.5	22.9

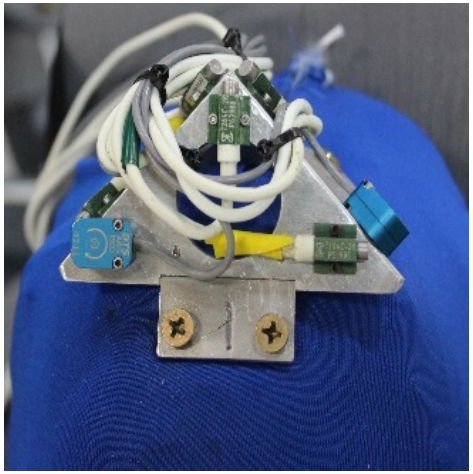
Text Matrix

	Sled pulse (km/h)	Seat back recline (deg)
PMHS01	56	45
PMHS02	56	25
PMHS03	56	25
PMHS04	56	45
PMHS05	56	45
PMHS06	56	25

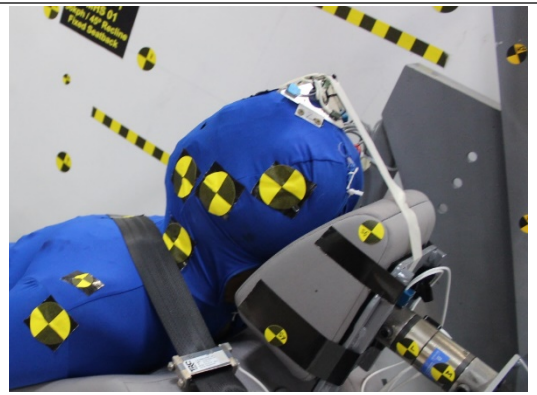
PMHS Instrumentation

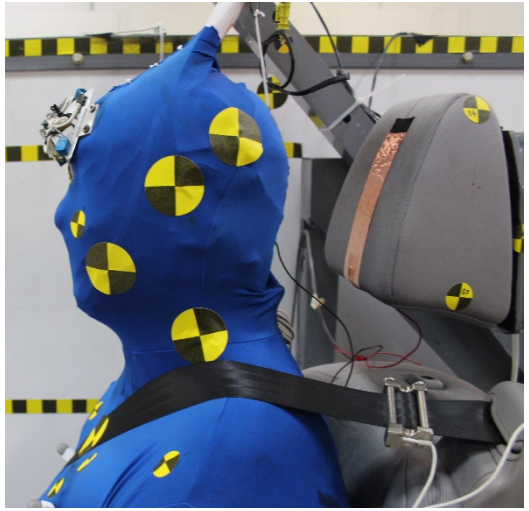
6aω

	PMHS
Head	■
Chest	■
C2/4/6	●
T1	●
T4	●
T8	●
T12	●
S1	●
Pelvis	● ●
Femur	■ ●
Tibia	■ ●



Kang et al., 2011 & 2015; Yoganandan et al., 2006

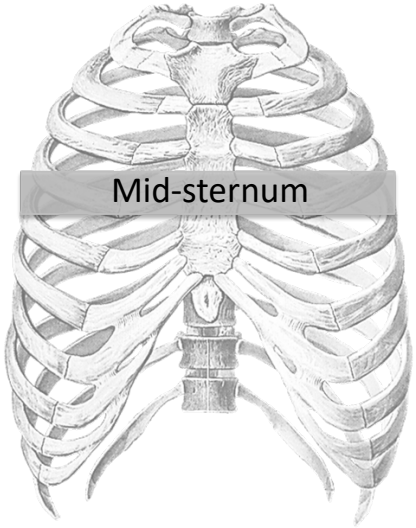




PMHS Instrumentation

6aω
Chestband
Strain Gauges

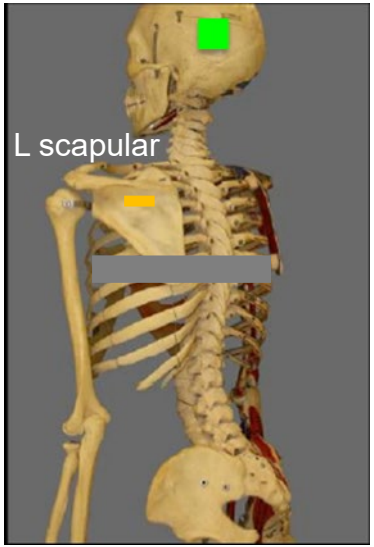
	PMHS
Head	
Chest	
C2/4/6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	

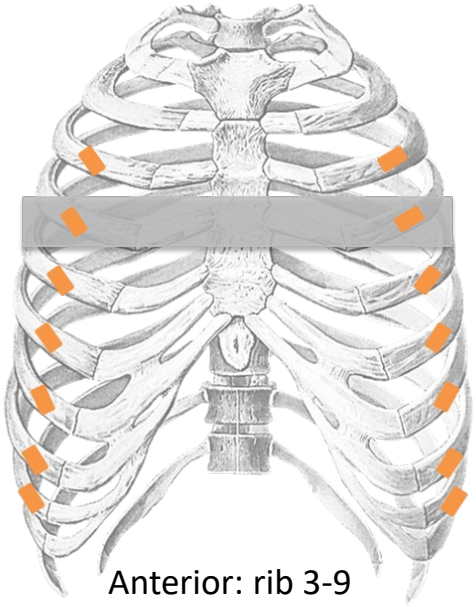


PMHS Instrumentation

6aω
Chestband
Strain Gauges

	PMHS
Head	
Chest	
C2/4/6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	



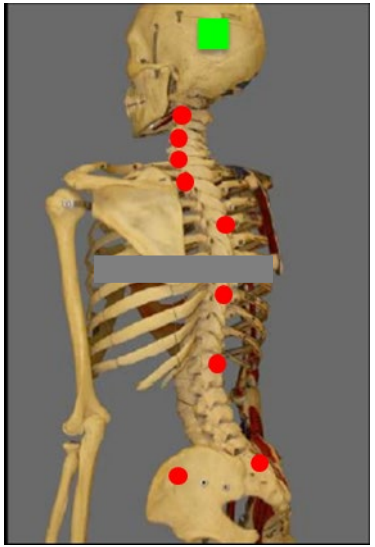


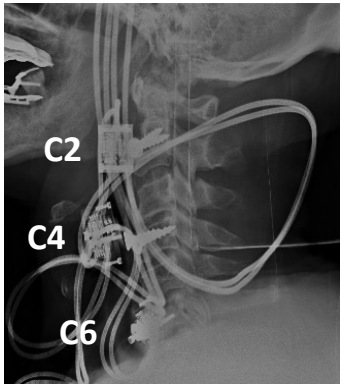
Anterior: rib 3-9
Posterior: rib 3-10

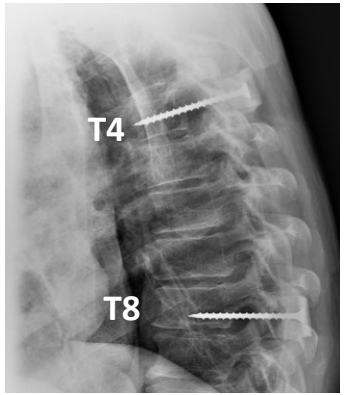
PMHS Instrumentation

6aω
Chestband
Strain Gauges
3aω

	PMHS
Head	
Chest	
C2/4/6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	



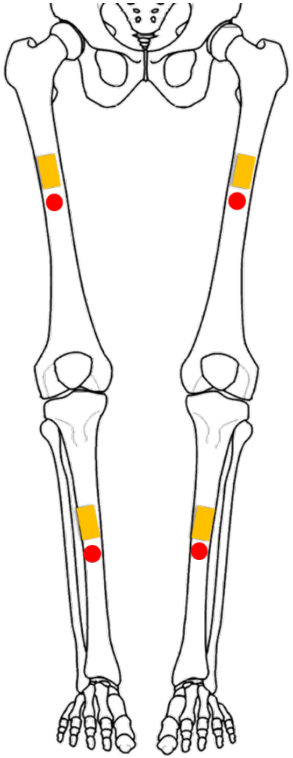


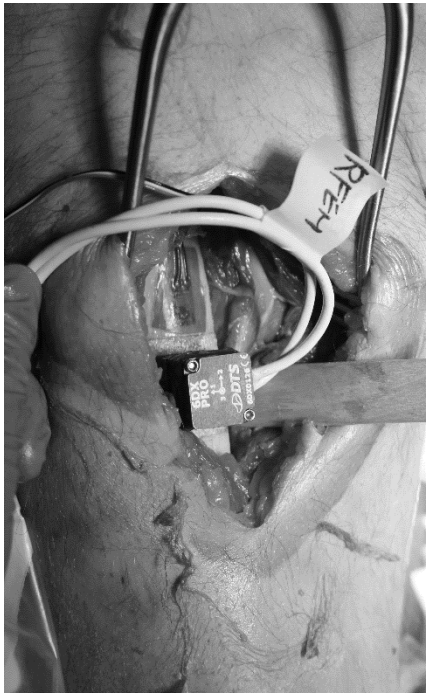


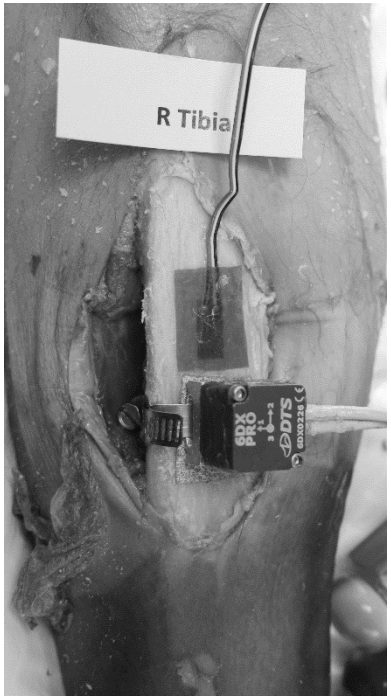
PMHS Instrumentation

6aω
Chestband
Strain Gauges
3aω

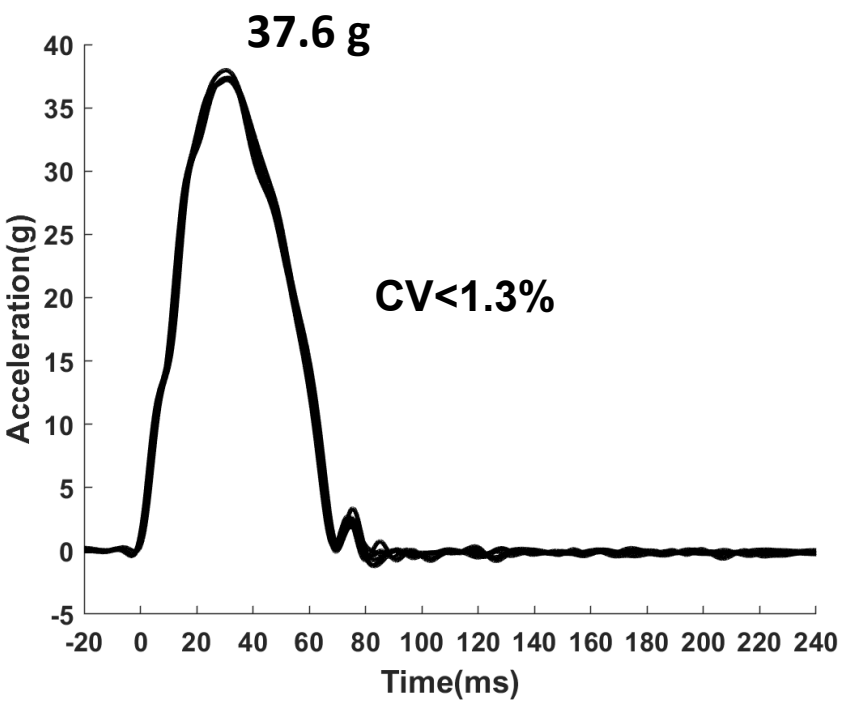
	PMHS
Head	
Chest	
C2/4/6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	



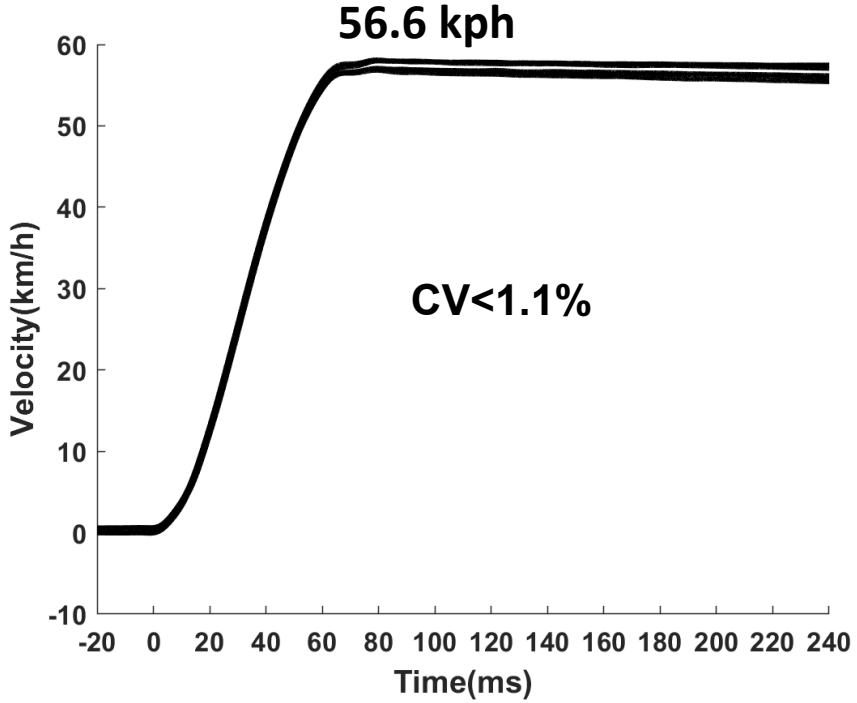




Sled Input



Sled Acceleration

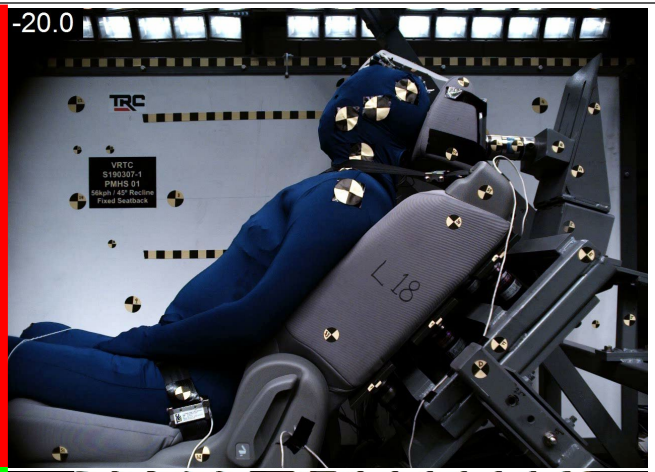


Sled Velocity

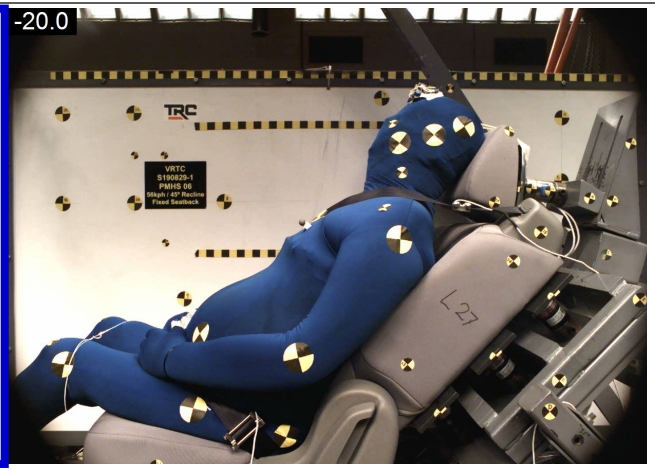
Results
(Preliminary Results)

High Speed Video - 45 deg (n=3)

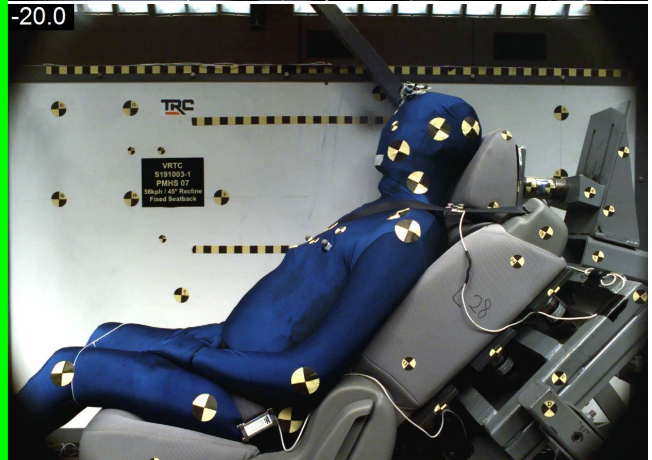
PMHS01



PMHS04

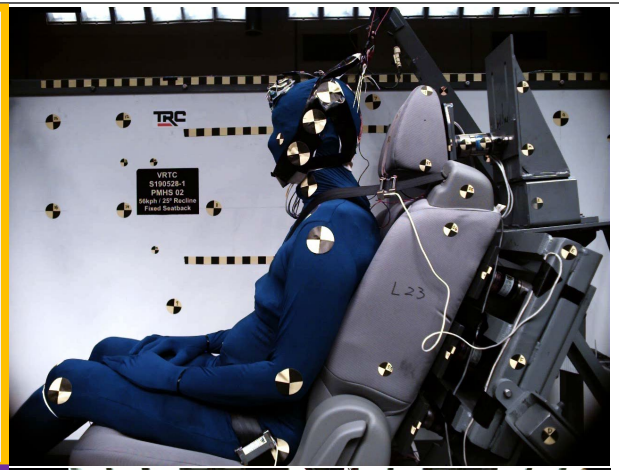


PMHS05

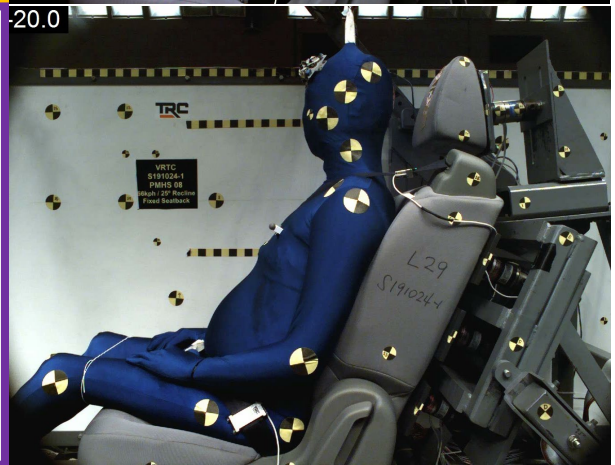


High Speed Video - 25 deg (n=3)

PMHS02



PMHS06

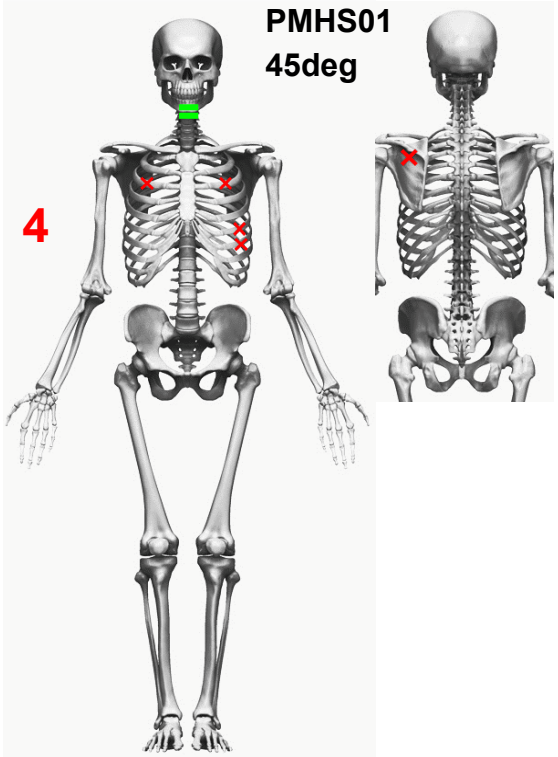


PMHS03

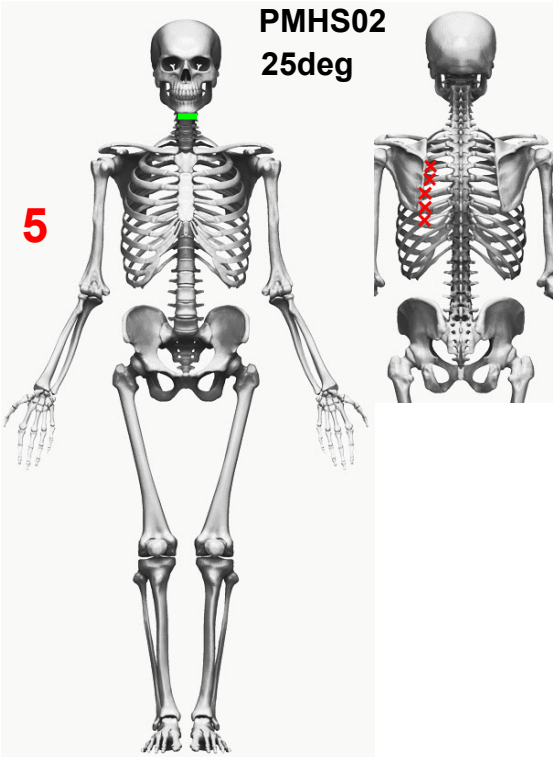
Injuries

laxity
Fracture

SAE GI 2019 meeting



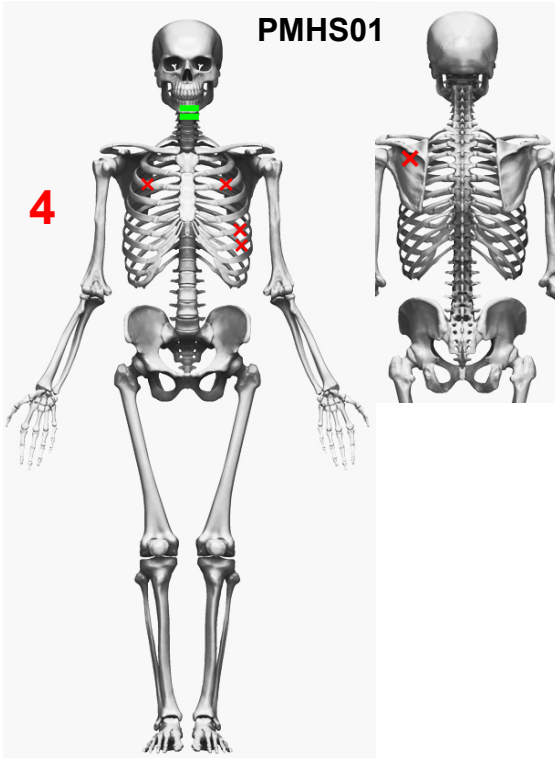
TRC / RCCADS* meeting

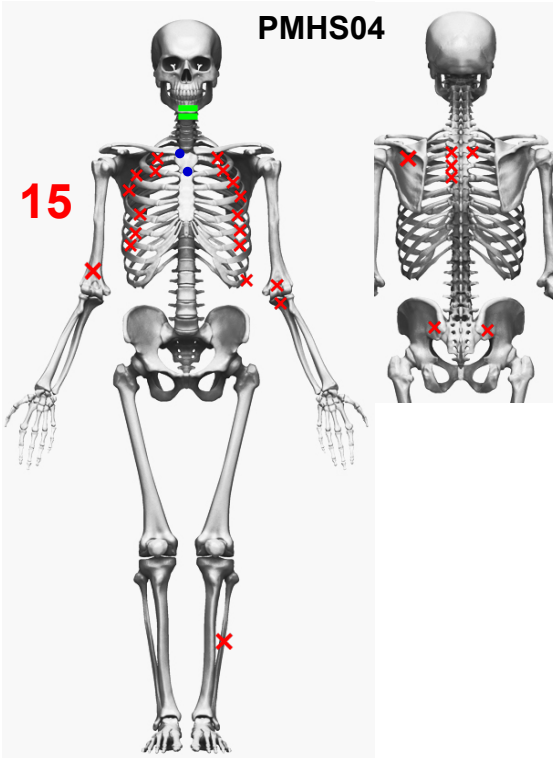


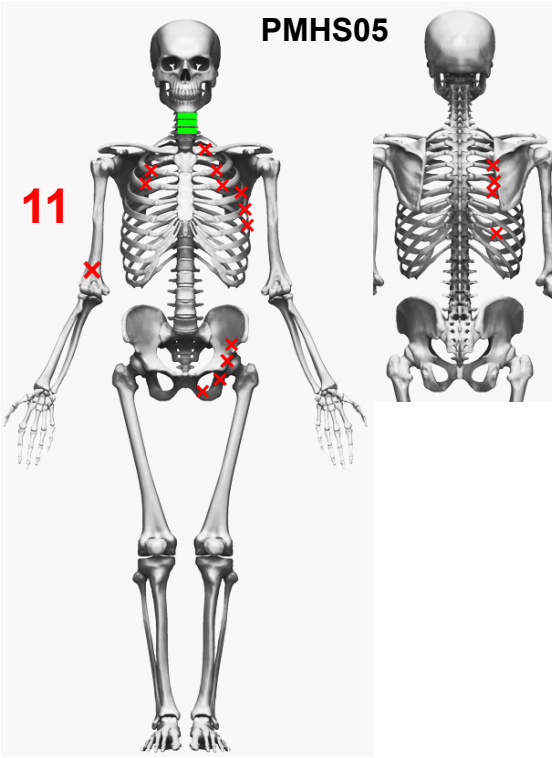
*Transportation Research Center Inc. / Research Consortium for Crashworthiness in Automated Driving Systems

Injuries – 45deg (n=3)

laxity
Fracture
Joint damage

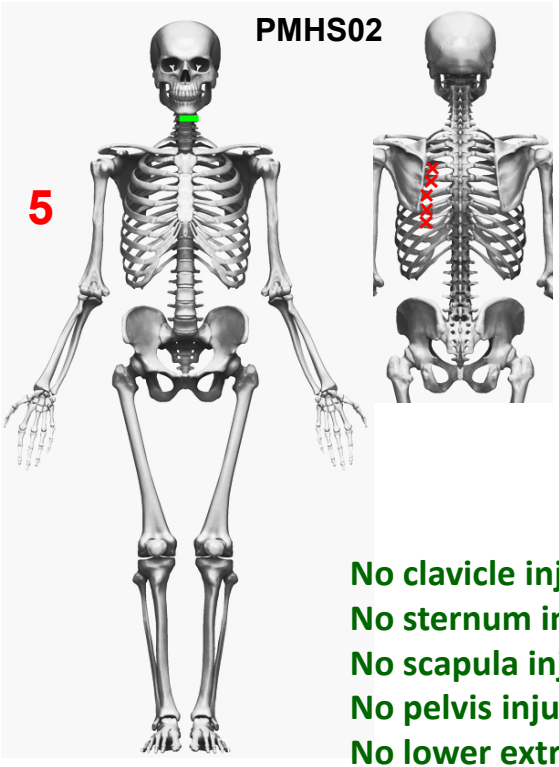


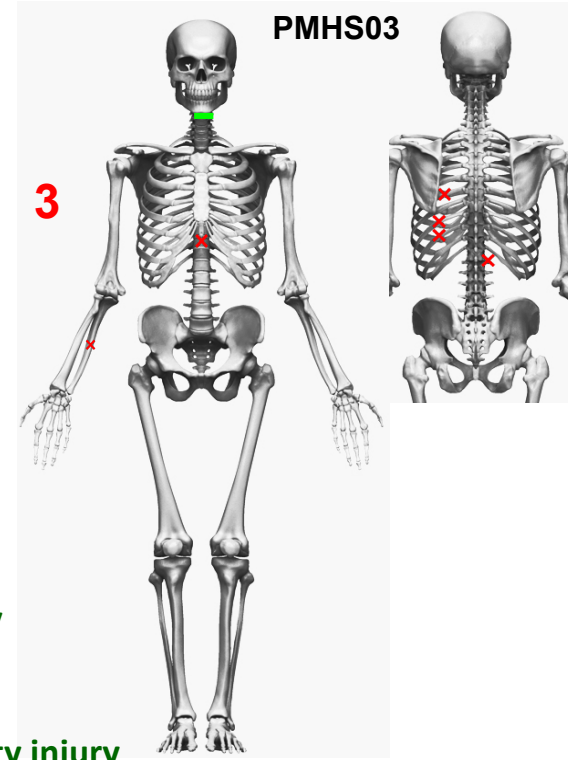


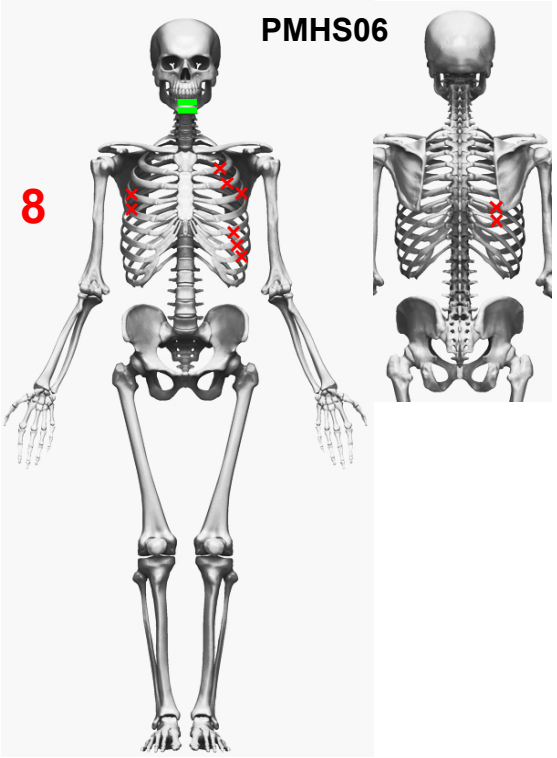


Injuries – 25deg (n=3)

laxity
Fracture

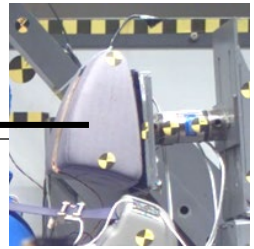


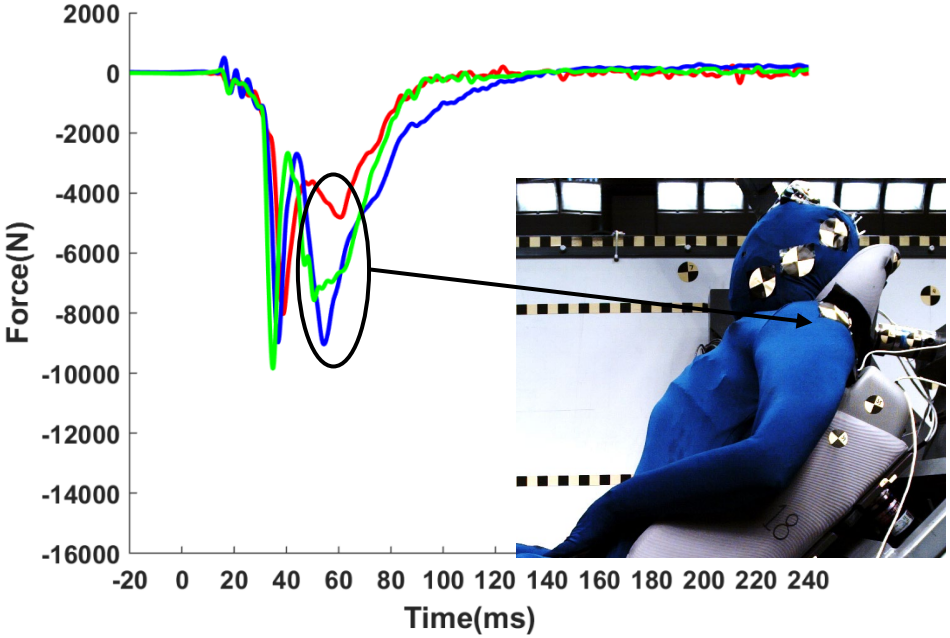




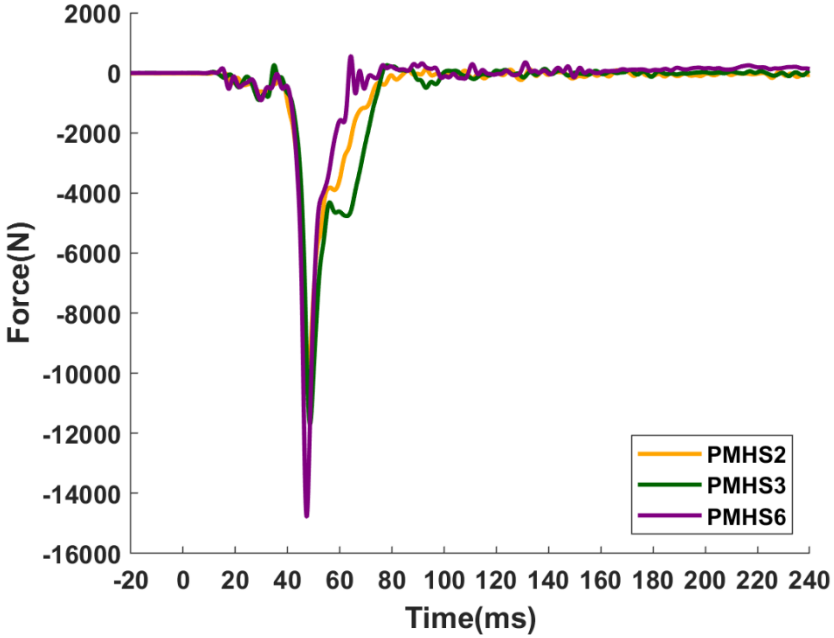
No clavicle injury
No sternum injury
No scapula injury
No pelvis injury
No lower extremity injury
Less rib fractures
One vertebral body fracture at T11 but @osteophyte

Head Restraint Force x



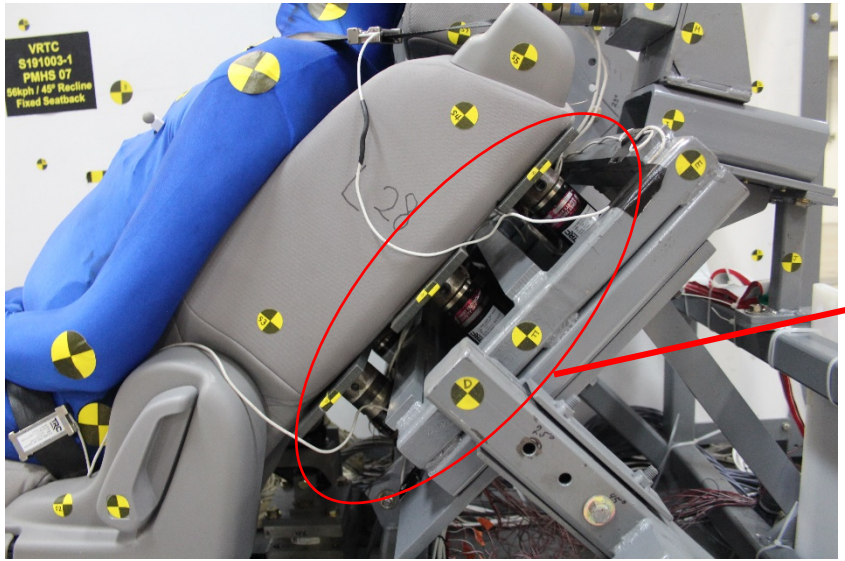


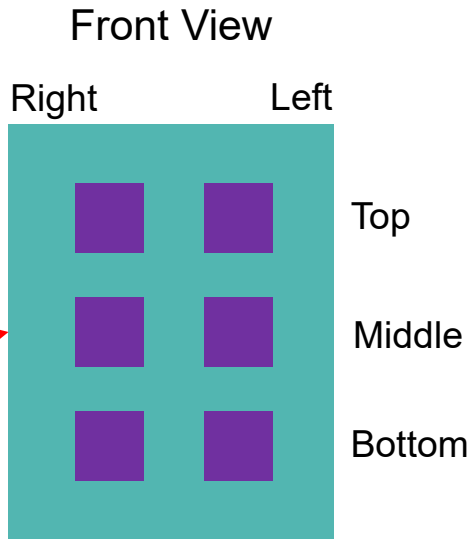
<56kph/45deg>

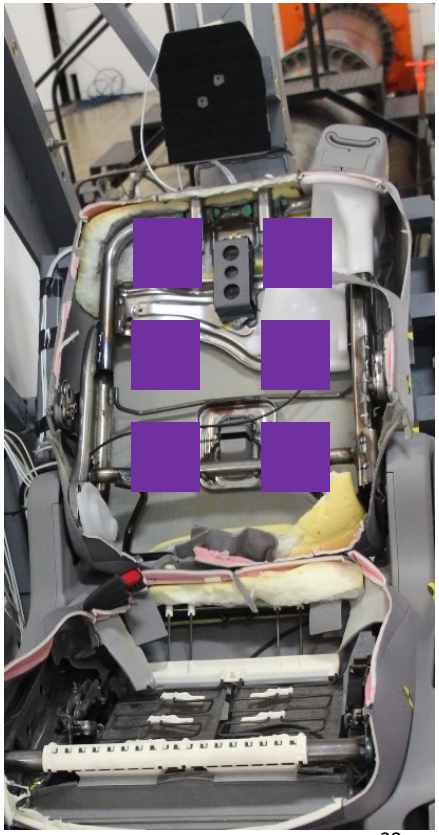


<56kph/25deg>

Seat Back Load Cell

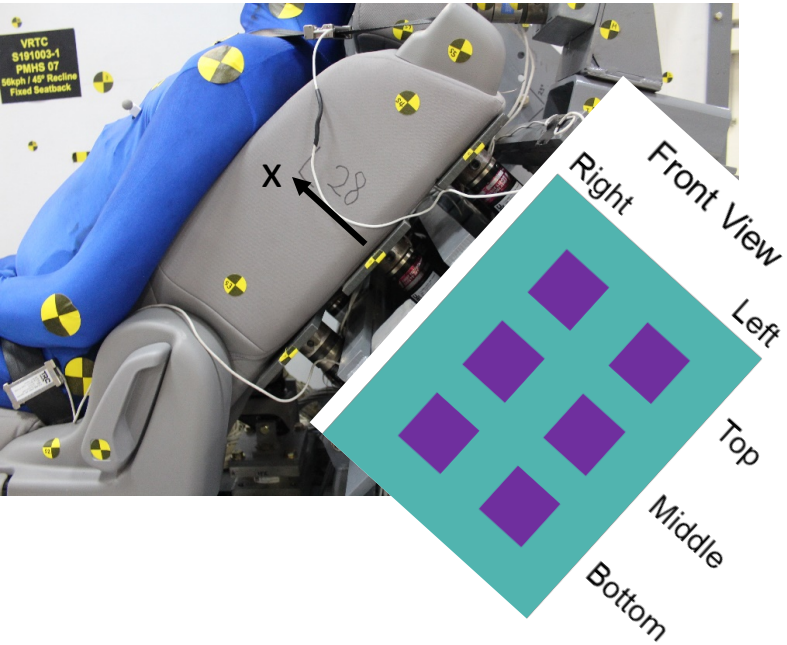


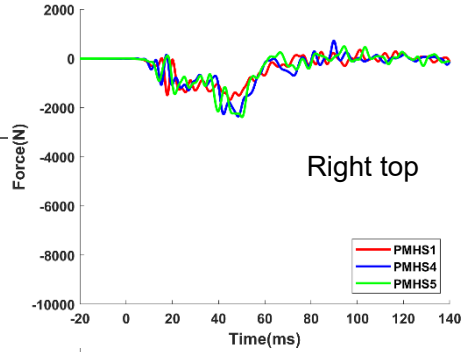


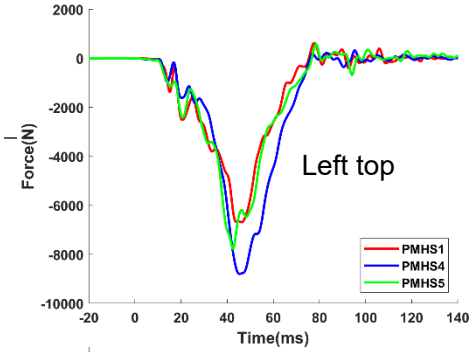


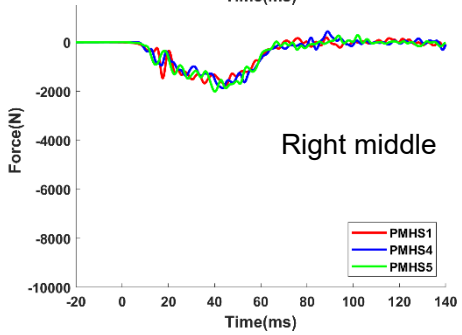
Seat Back Force x

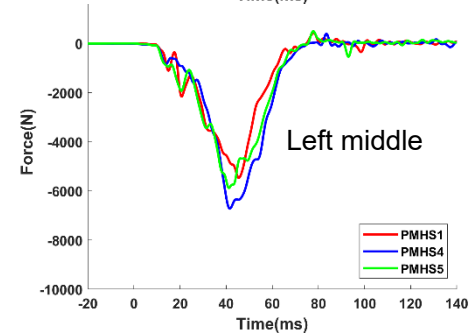
56kph/45deg (n=3)

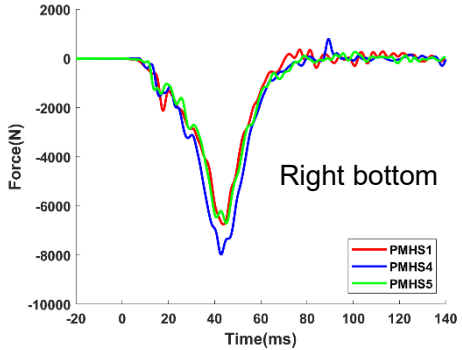


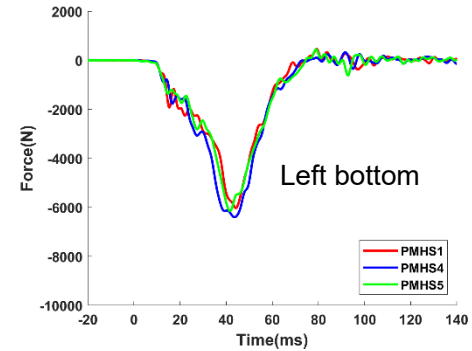






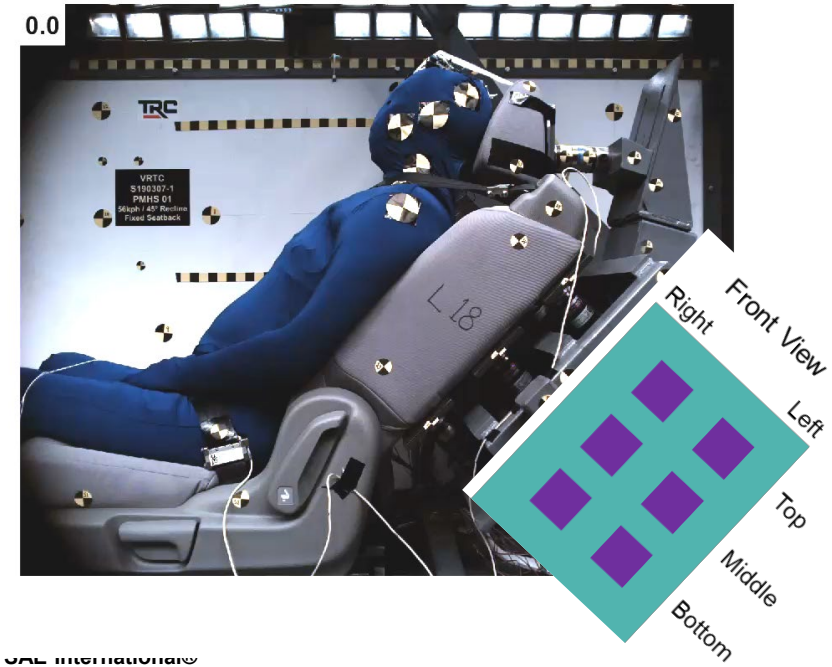


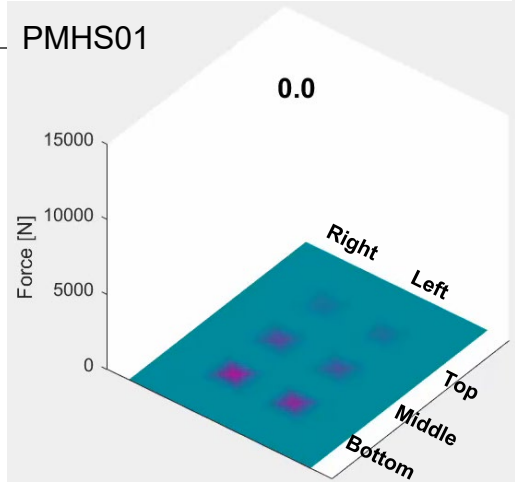


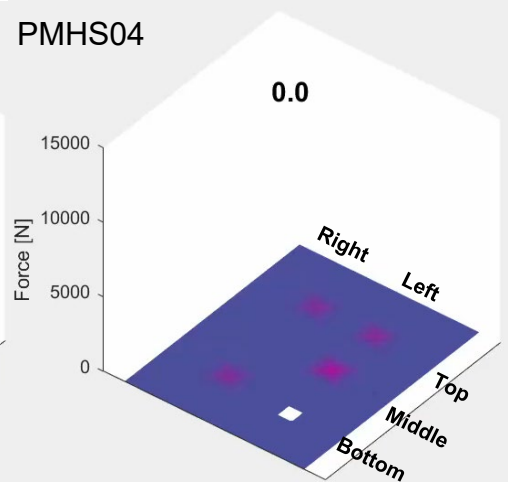


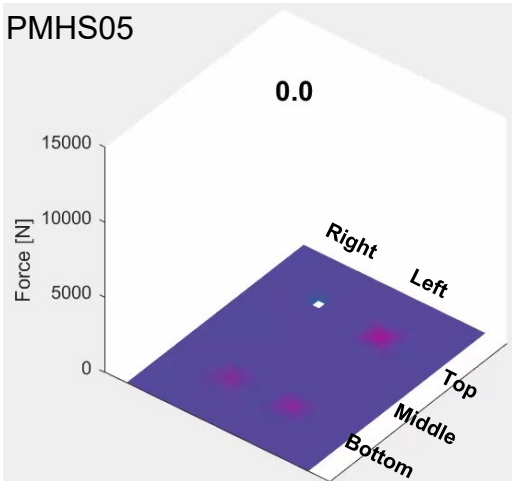
Seat Back Force x

56kph/45deg (n=3)



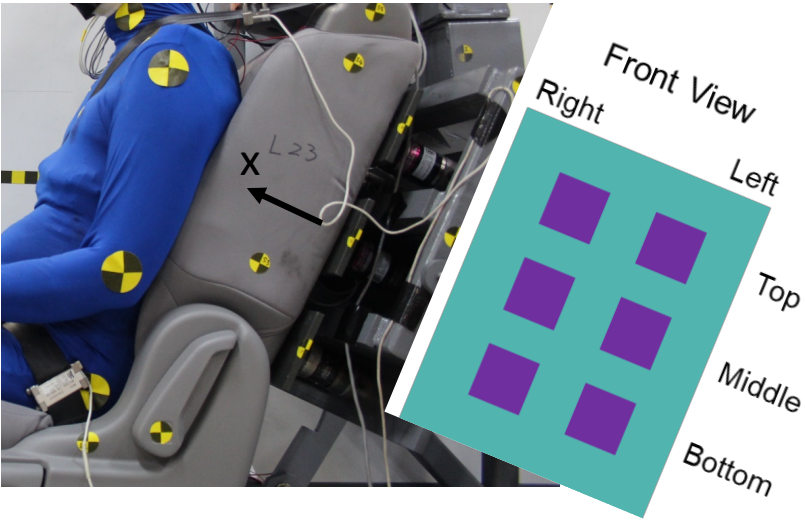


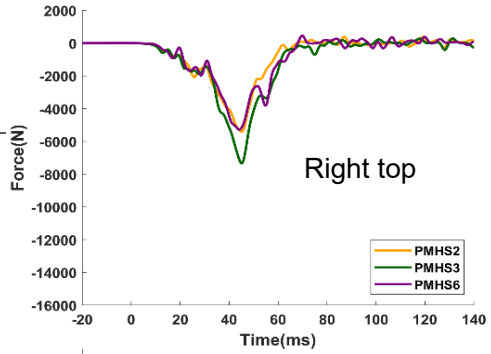


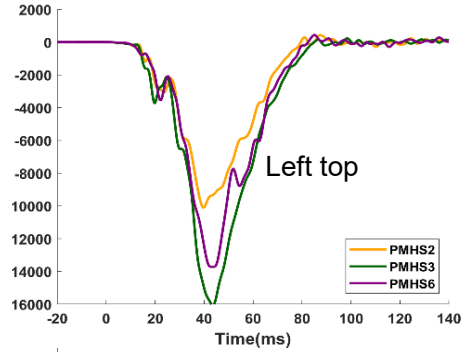


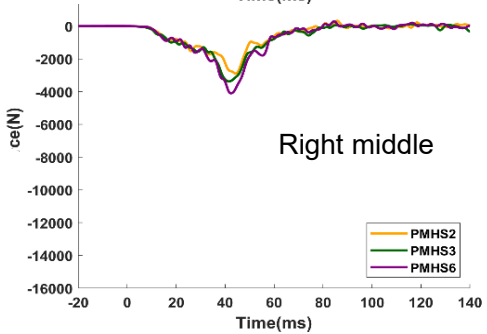
Seat Back Force x

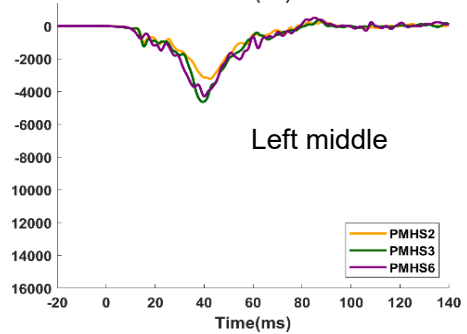
56kph/25deg (n=3)

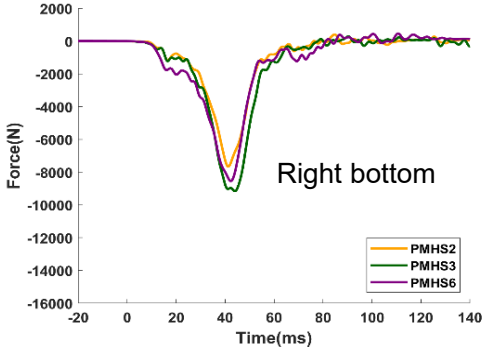


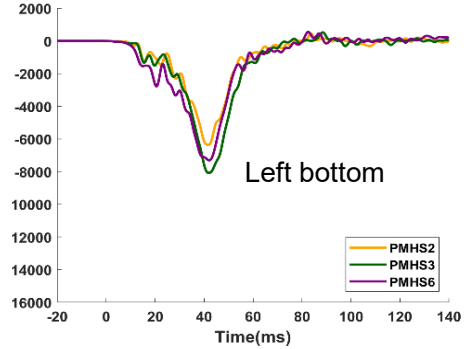






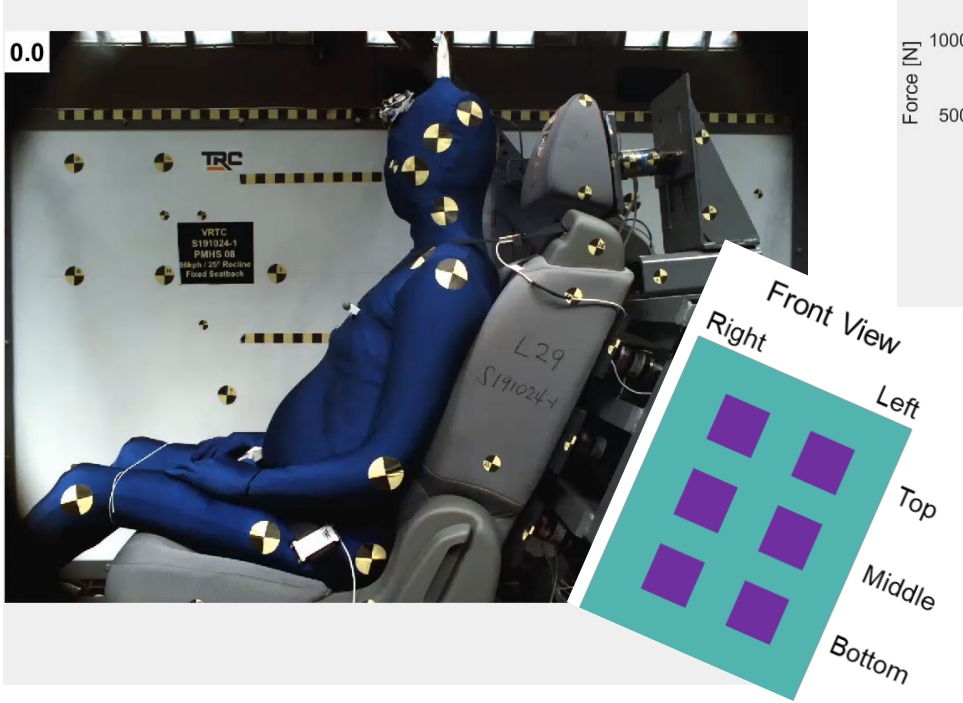


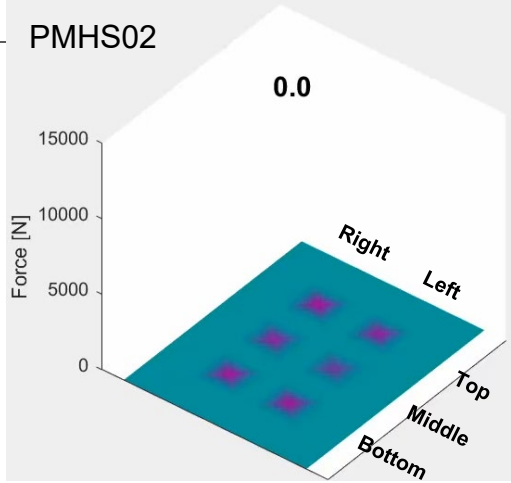


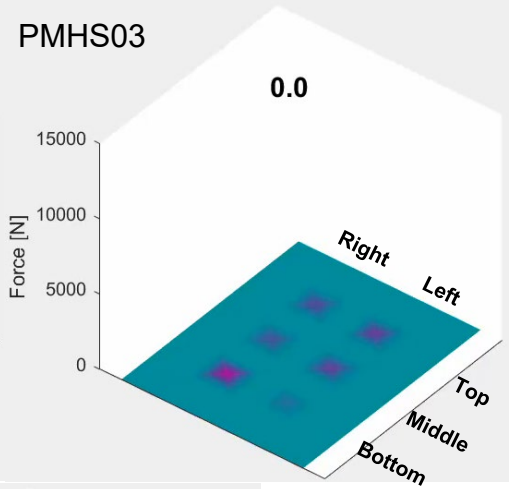


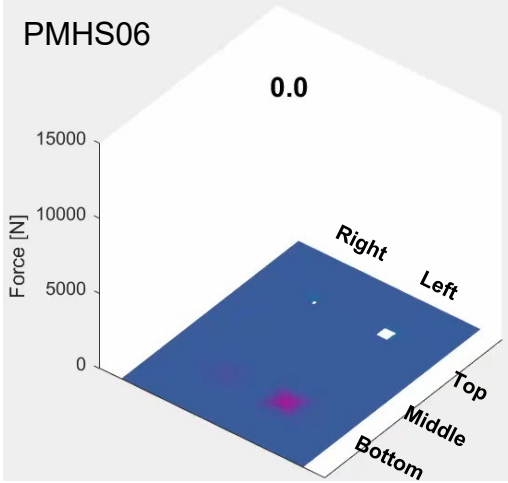
Seat Back Force x

56kph/25deg (n=3)

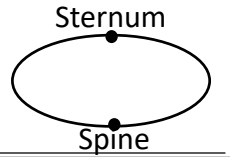




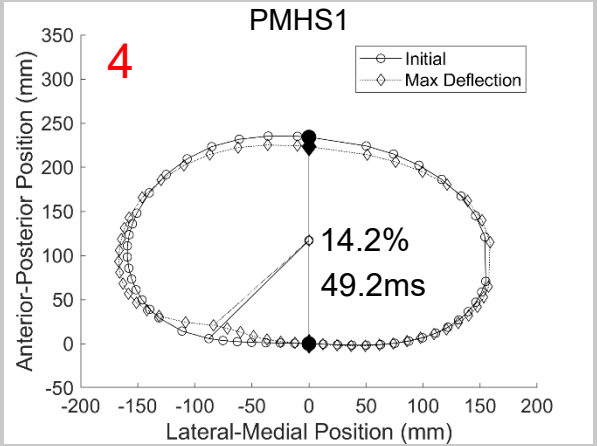


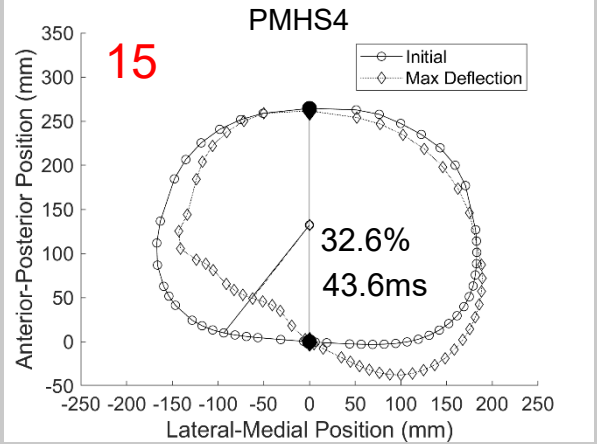


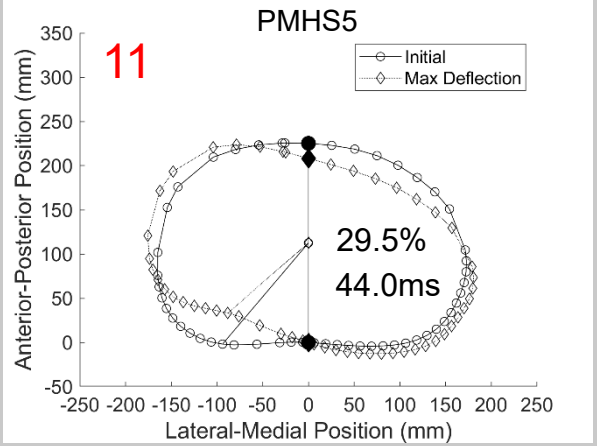
Posterior Chest Deflection



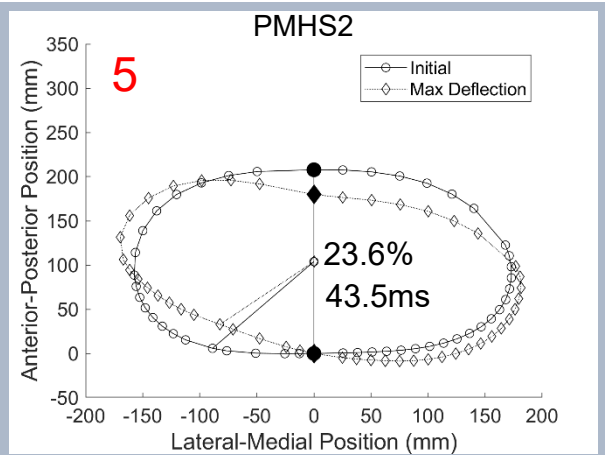
45deg

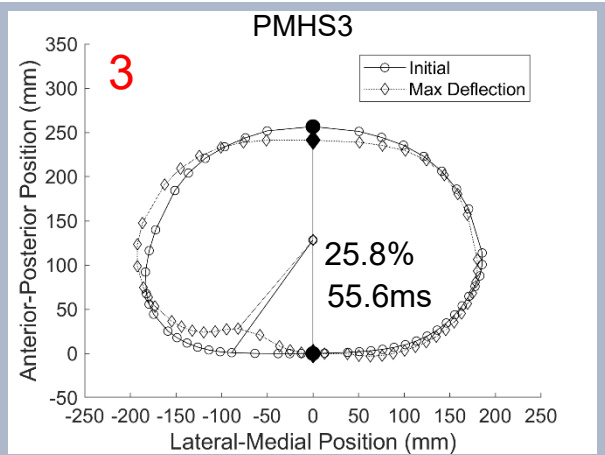


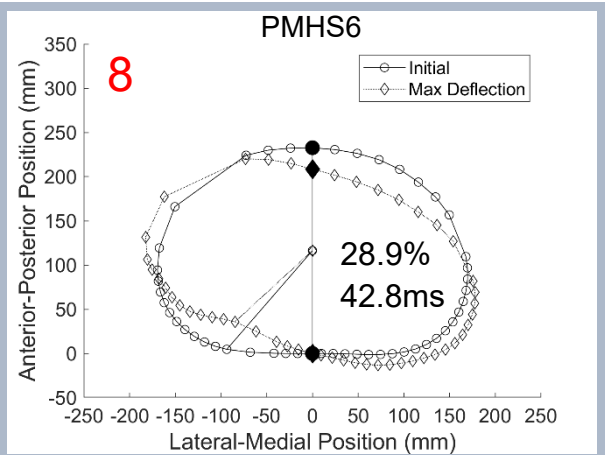




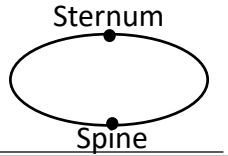
25deg



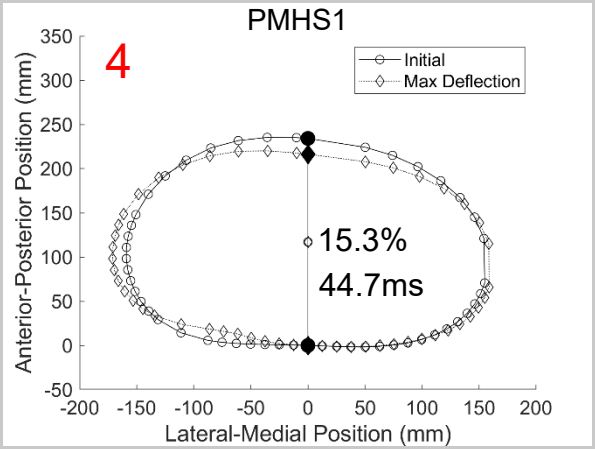


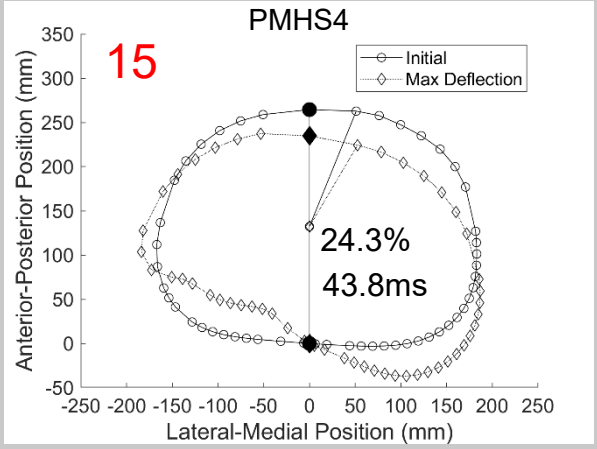


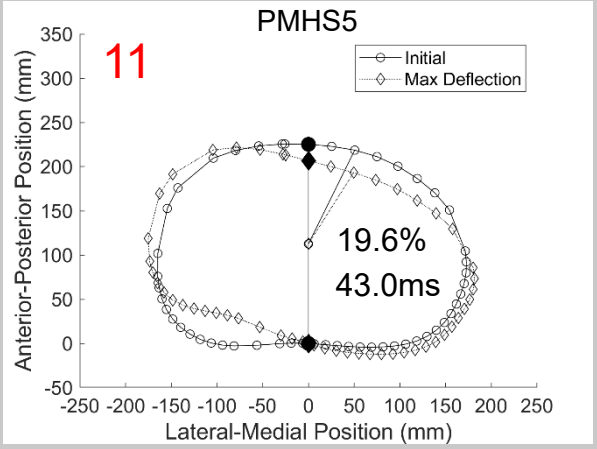
Anterior Chest Deflection



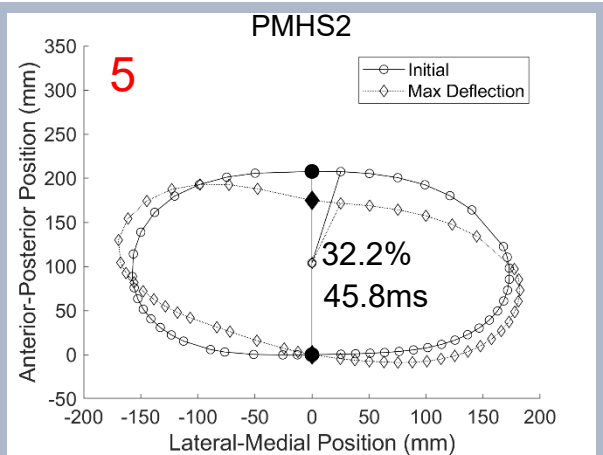
45deg

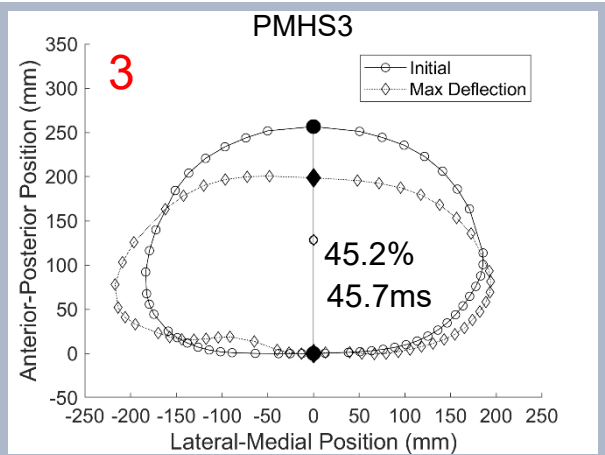


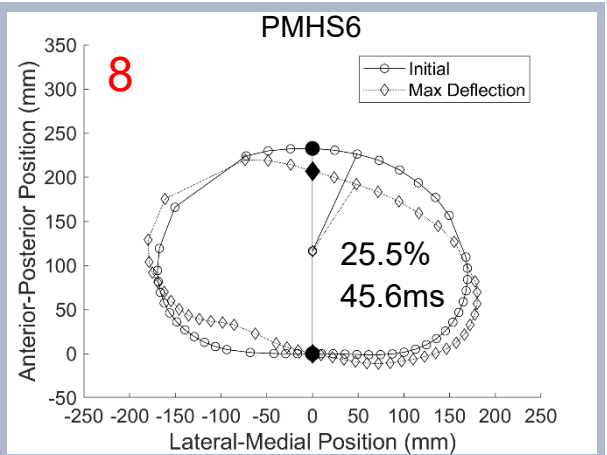




25deg

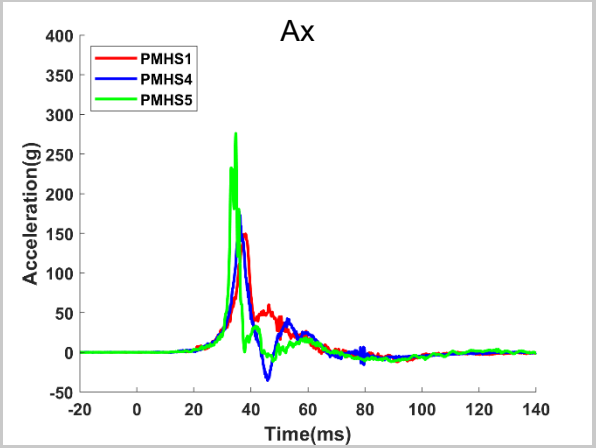


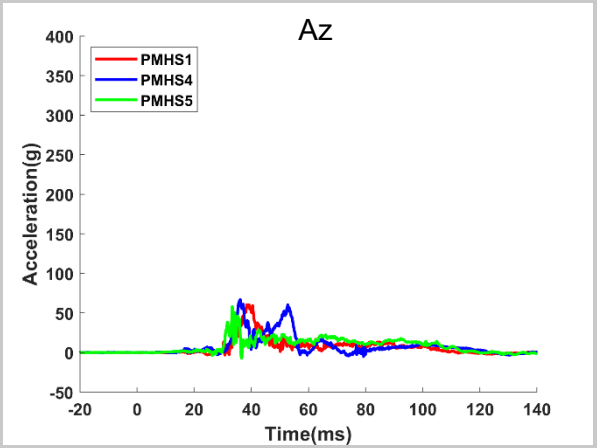


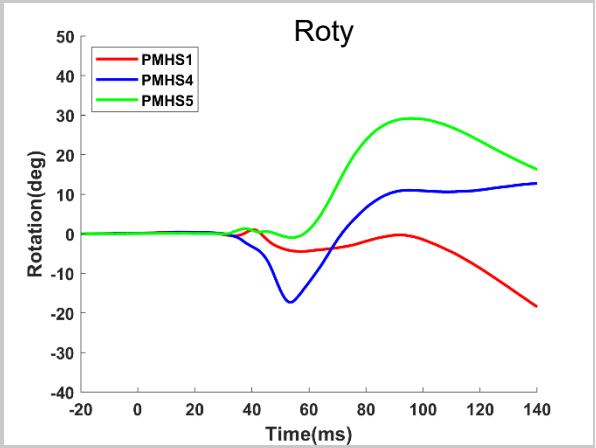


Kinematics – Head

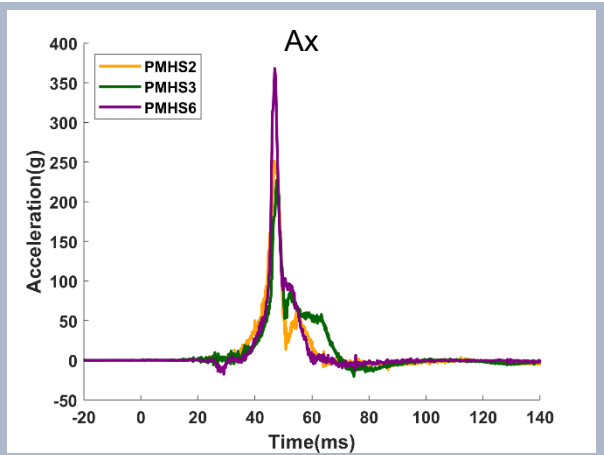
45deg

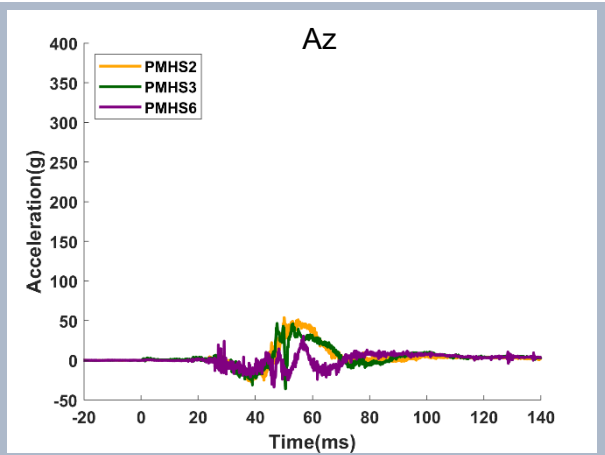


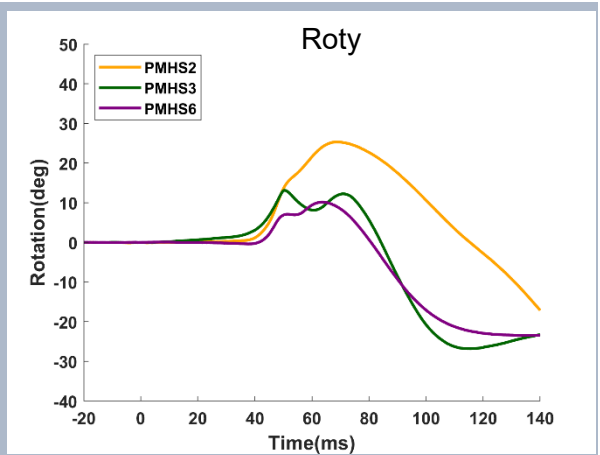




25deg

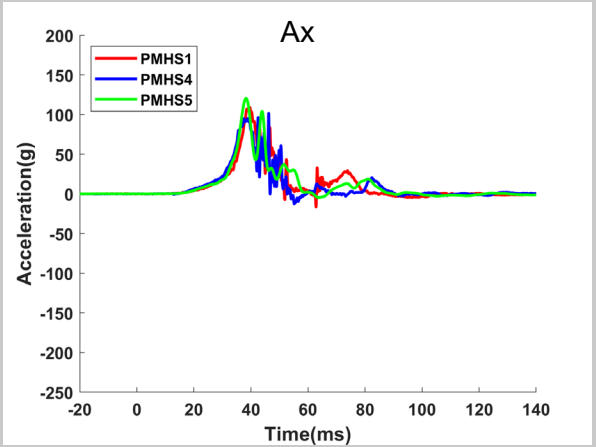


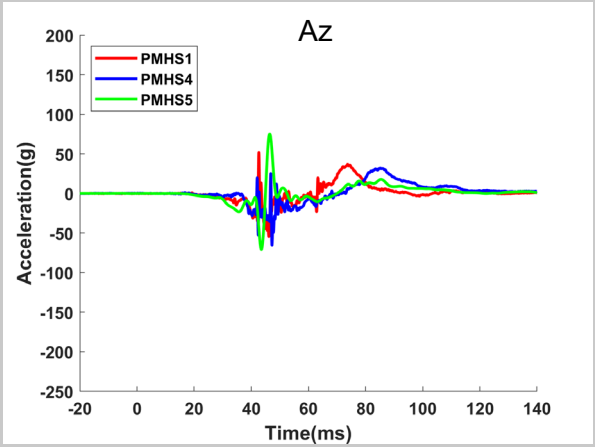


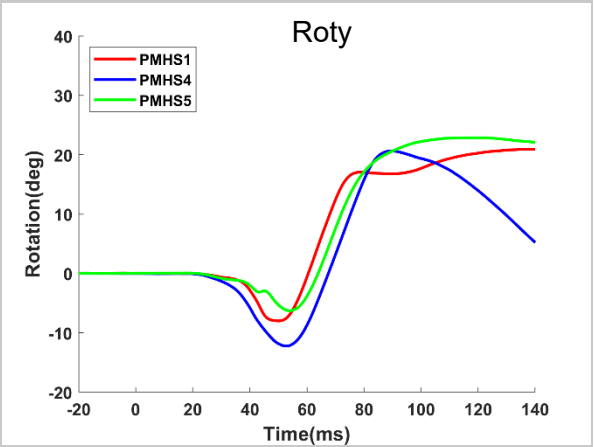


Kinematics – Pelvis

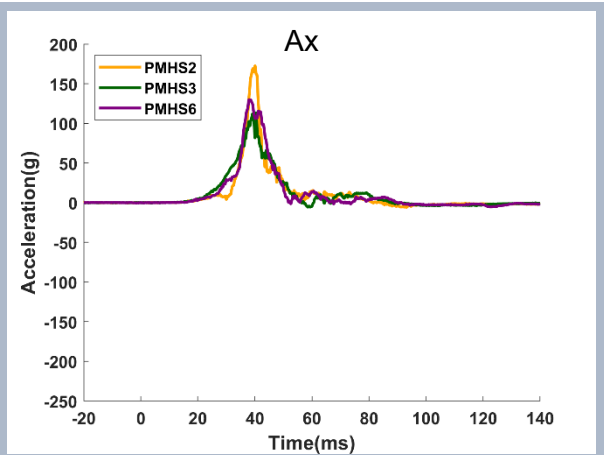
45deg

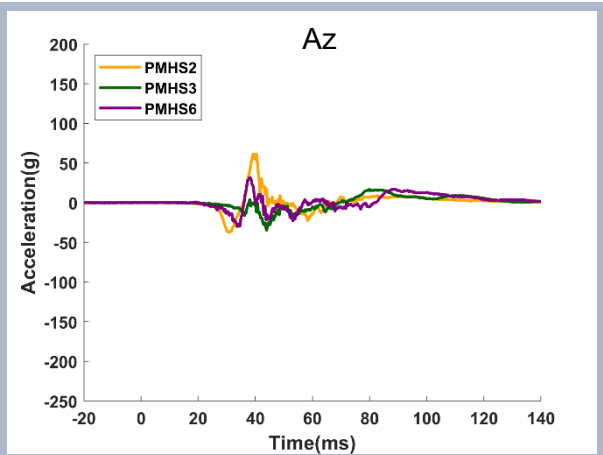


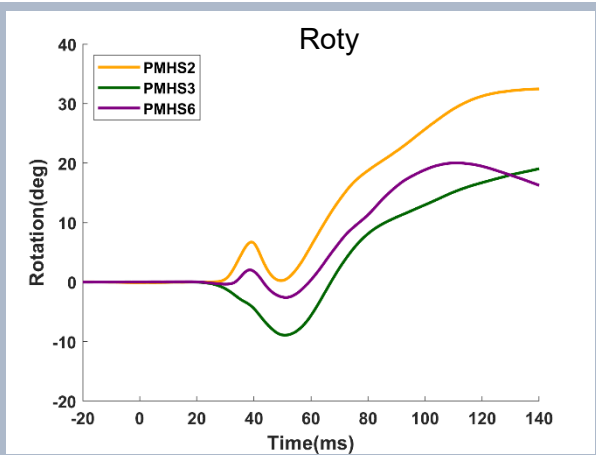




25deg







Summary

- Rear-facing sled tests using 6 PMHS were conducted at 56km/h
  - Head and pelvis kinematics
  - Head restraint and seat back reaction forces
  - Injuries
    - Minor c-spine injuries and transverse process fractures
    - Rib fractures from all 6 PMHS
      - # of ribs fractured: 3 – 15
    - Clavicle, scapula, and pelvis fractures only in the 45 deg reclined condition
    - Humerus and ulna fractures
      - Flailing of the arms
    - More injuries in the 45 deg reclined condition

Thank you for your attention!!!

Speaker Information

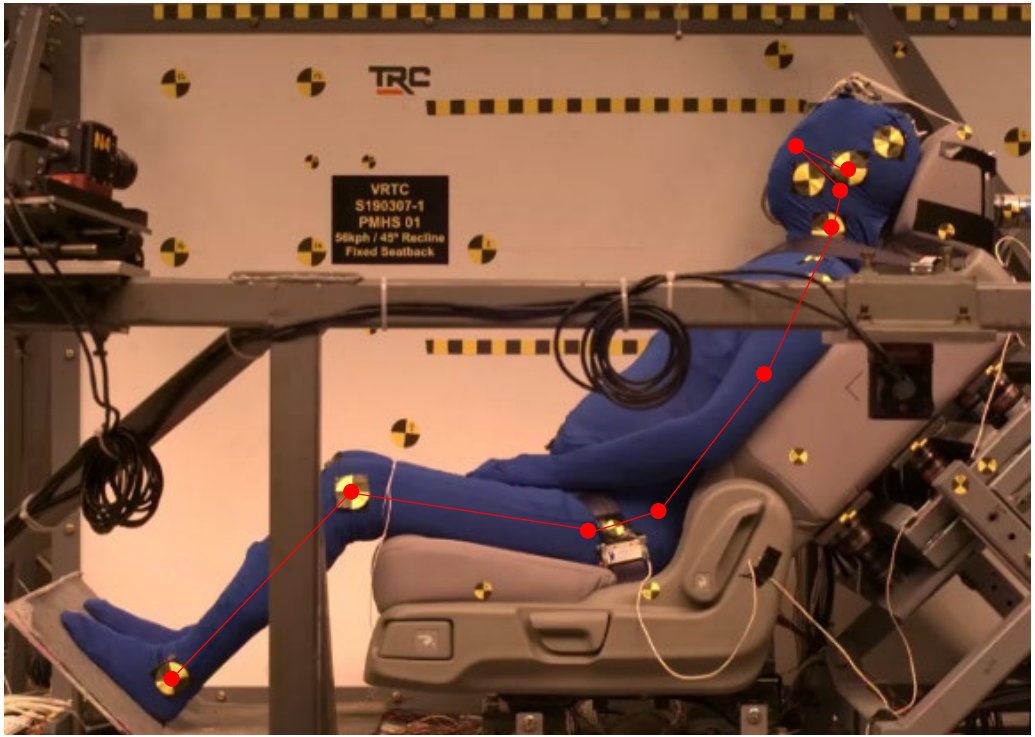
- Yun-Seok Kang, PhD
- Injury Biomechanics Research Center, The Ohio State University
- 333 West 10th Ave, Columbus, Ohio, 43210
- 614-366-7584
- yunseok.kang@osumc.edu

Biomechanical Responses and Injuries of PMHS in Rear Facing Alternative Seating Configurations

Yun-Seok Kang[1], Jason Stammen[2], Alena Hagedorn[3], Rakshit Ramachandra[1], Colton Thomas[3], Amanda Agnew[1], Hyun Jung Kwon[3], Kevin Moorhouse[2], John H. Bolte IV[1]

[1]Injury Biomechanics Research Center, The Ohio State University
[2]National Highway Traffic Safety Administration, Vehicle Research and Test Center
[3]Transportation Research Center, Inc.

PMHS Positioning



	UMTRI Target[1]	PMHS
Head Angle	22.3 ± 2º	**22.0º**
Pelvic Angle	**21.1 ± 5º**	**25.0º**
Thigh Angle	**11.1 ± 2º**	**10.0º**
Leg Angle	**45.9 ± 2º**	**46.0º**
Hip-to-Eye Angle	**31.6± 5º**	**26.0º**
Back set	0 mm	0 mm
Top set	---	46 mm
Hip X	+55 ± **10** mm	+60.4 mm
Hip Z	-375 ± **10** mm	-366 mm

[1]Reed MP, Ebert SM, Jones ML. Posture and belt fit in reclined passenger seats. Traffic injury prevention. 2019 Jun 12;20(sup1):S38-42.

Injuries – 56kph/45deg

Body Region	PMHS01	PMHS04	PMHS05
Spine	C3/C4, C4/C5 laxity	C3/C4, C4/C5 laxity Right T4 TP fx Left T4/T5/T6 TP fxs	C4/C5, C5/C6, C6/C7 laxity Right T11 TP fx
Scapula	Left fx	Left fx	No Injury
Ribs	R3A L3A, L6A, L7A	R1A, R2A, R4L, R5M, R6A, R7A L1A, L2M, L3M, L4M, L5A, L6A L7A, L10L	R2A, R3A, R5P, R6P, R9P R4P L2A, L3A, L4L, L5L, L6L
Sternal Area	No Injury	Manubriosternal jt Right sternoclavicular jt	Left Clavicle fx
Pelvis	No Injury	Right posterior ilium fx Left posterior ilium fx	Left acetabulum fx (extended to ilium, ischium, and pubis)
Extremities	No Injury	Left fibula fx Left humerus, ulna fx Right humerus fx	Right humerus fx

fx: fracture, A: anterior, L: lateral, P: posterior,
TP: transverse process, M: multi-fragmentary, jt: joint

Injuries – 56kph/25deg

Body Region	PMHS02	PMHS03	PMHS06
Spine	C4/C5 laxity	C4/C5 laxity T11 VB fx Right L1 TP fx	C3/C4, C4/C5 laxity
Scapula	No Injury	No Injury	No Injury
Ribs	L5P, L6P, L7P, L8P, L9P	L7A, L9P, L10P	R4L, R5L L2A, L3A, L4L, L7A L8A&P, L9A&P
Sternal Area	No Injury	No Injury	No Injury
Pelvis	No Injury	No Injury	No Injury
Extremities	No Injury	No Injury	No Injury

fx: fracture, A: anterior, L: lateral, P: posterior,
TP: transverse process, M: multi-fragmentary, jt: joint