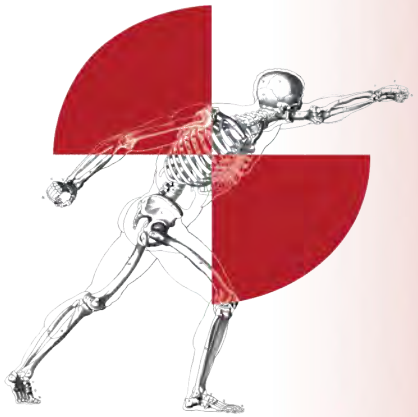
PMHS Biomechanical Responses and Injury Mechanisms in Rear-Facing Rigid Seat Tests

Presenter: Yun-Seok Kang

Injury Biomechanics Research Center, The Ohio State University

RCCADS Public Workshop

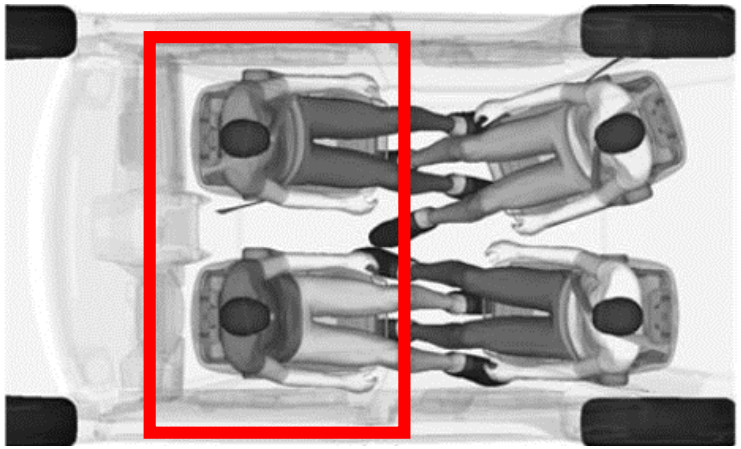


INJURY BIOMECHANICS RESEARCH CENTER

THE OHIO STATE UNIVERSITY

Introduction

- 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 rear-facing in a frontal collision [Jorlov et al., 2017; Koppel et al., 2019; Ostling and Larsson, 2019]
  - Studies using computational models and ATDs [Kitagawa et al., 2017; Jin et al., 2018; Zeller and Manneck, 2019]
    - FE models: validated in low-speeds (< 17 km/h)
    - ATDs: not validated for rear impacts

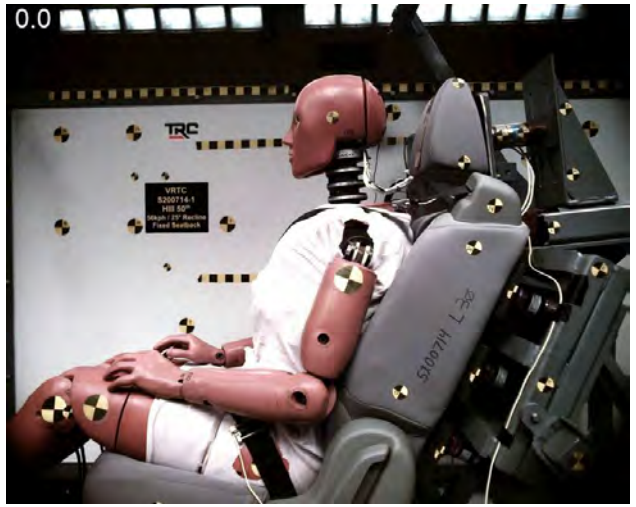


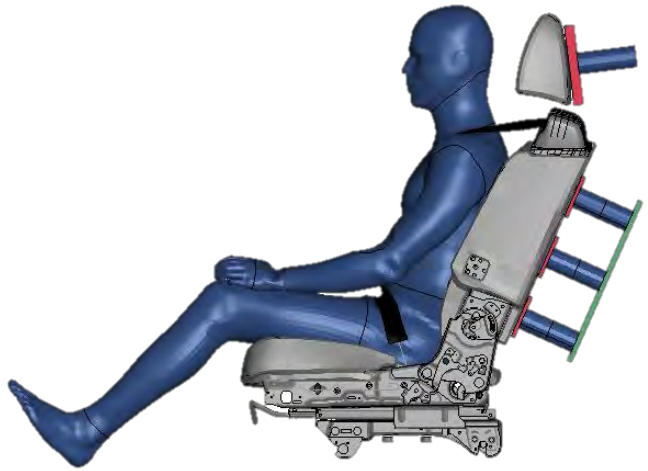
Kitagawa et al., 2017

Zellmer and Manneck, 2019

Objective

- To investigate biomechanical responses and injuries from Post Mortem Human Subjects (PMHS) in multiple scenarios in a rear-facing seating configuration at frontal impacts
  - Effect of Seat Back Recline (25 deg vs. 45 deg)
  - Effect of Belt Restraint/Seat Type (Integrated vs. Fixed D-ring)
  - Effect of Speed (24 km/h vs. 56 km/h)

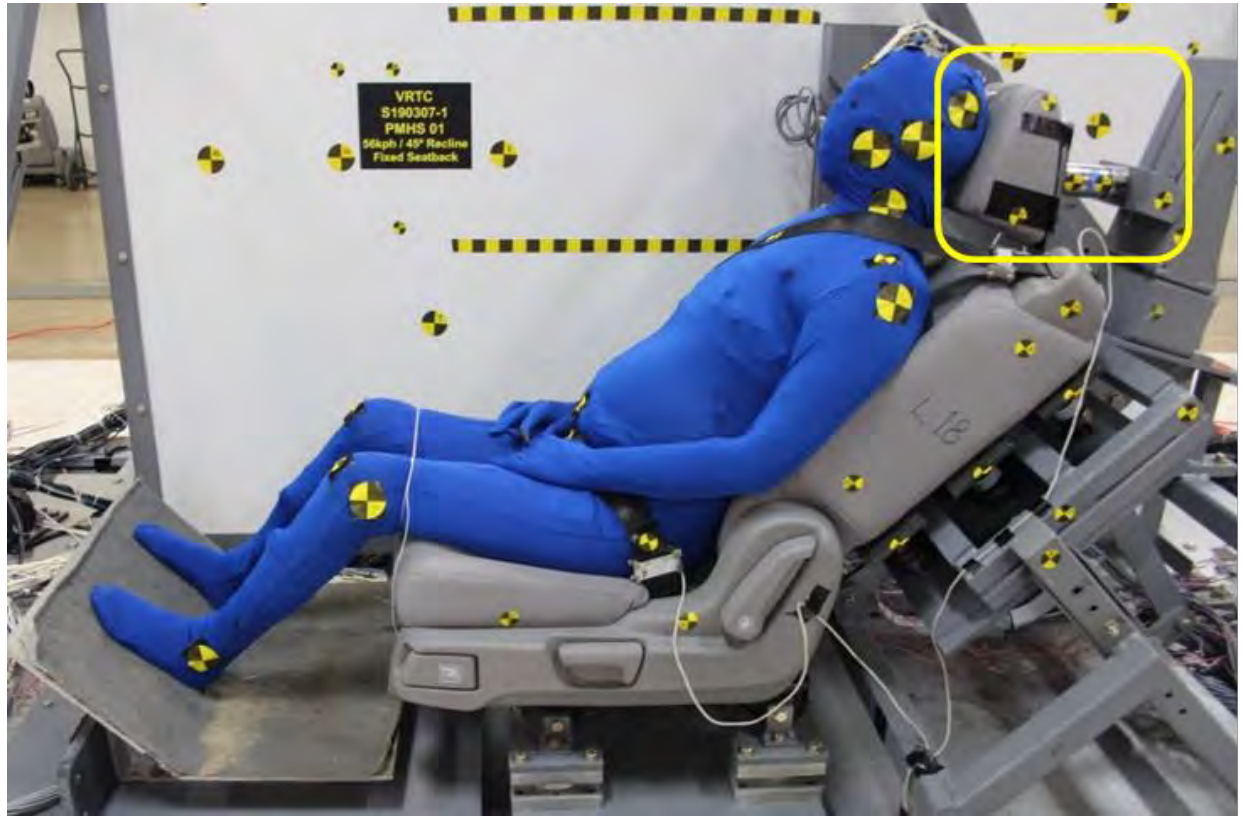




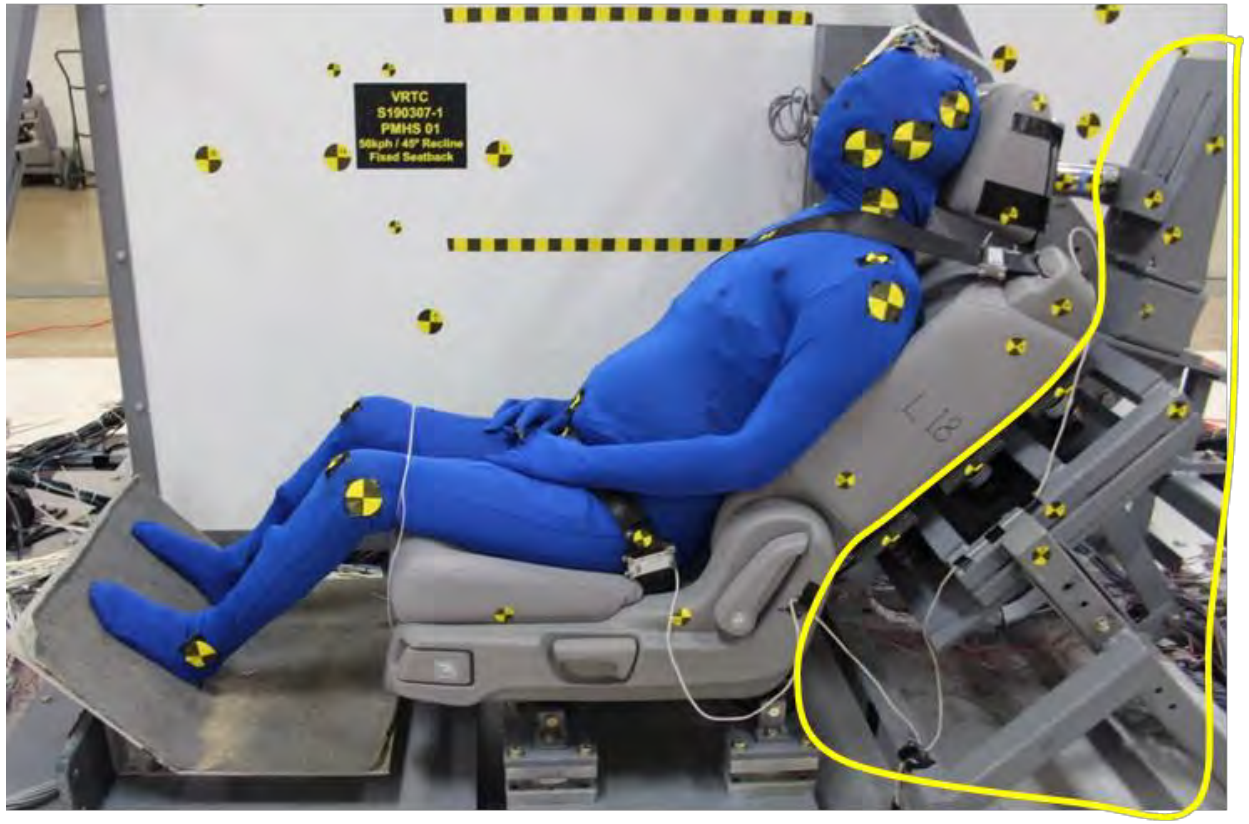
Content Warning

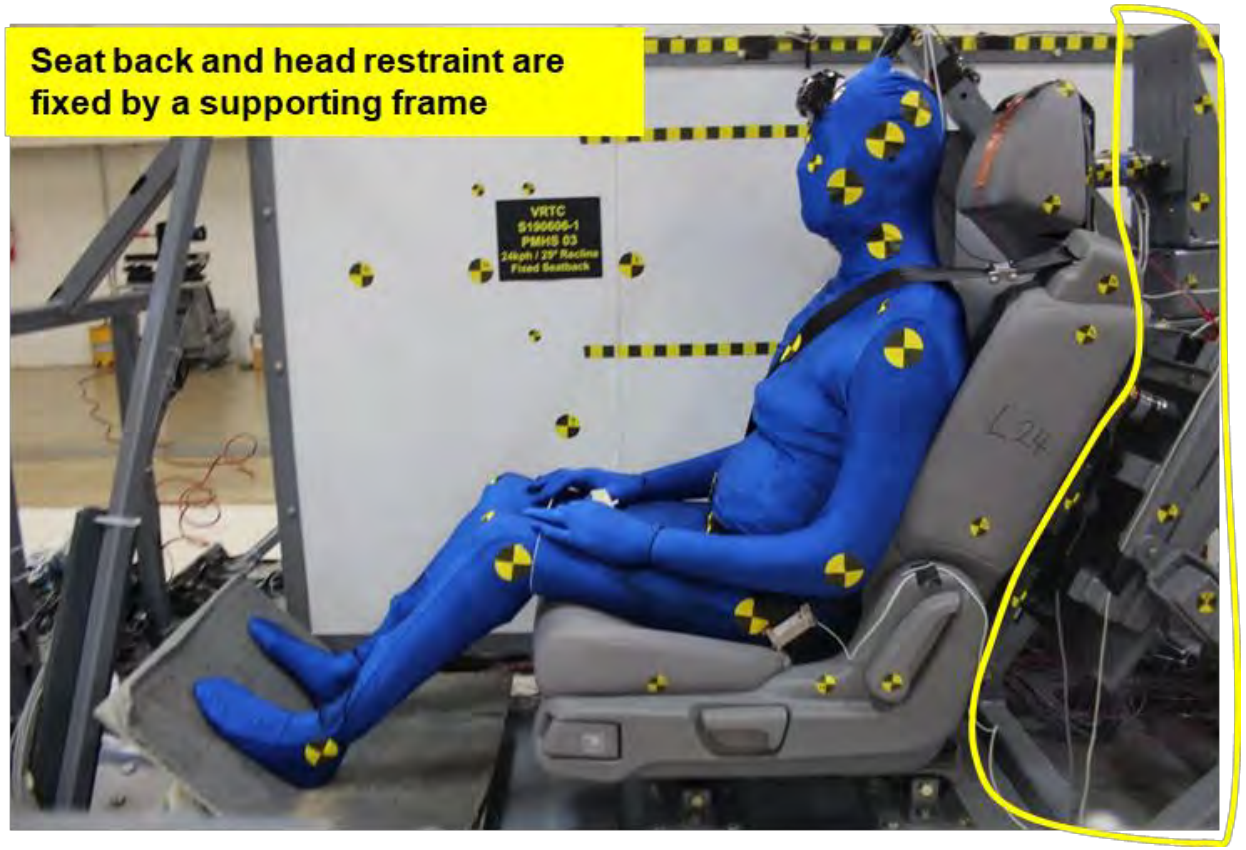
The following slides include cadaveric images that may be considered disturbing to some viewers!

Sled Buck Description



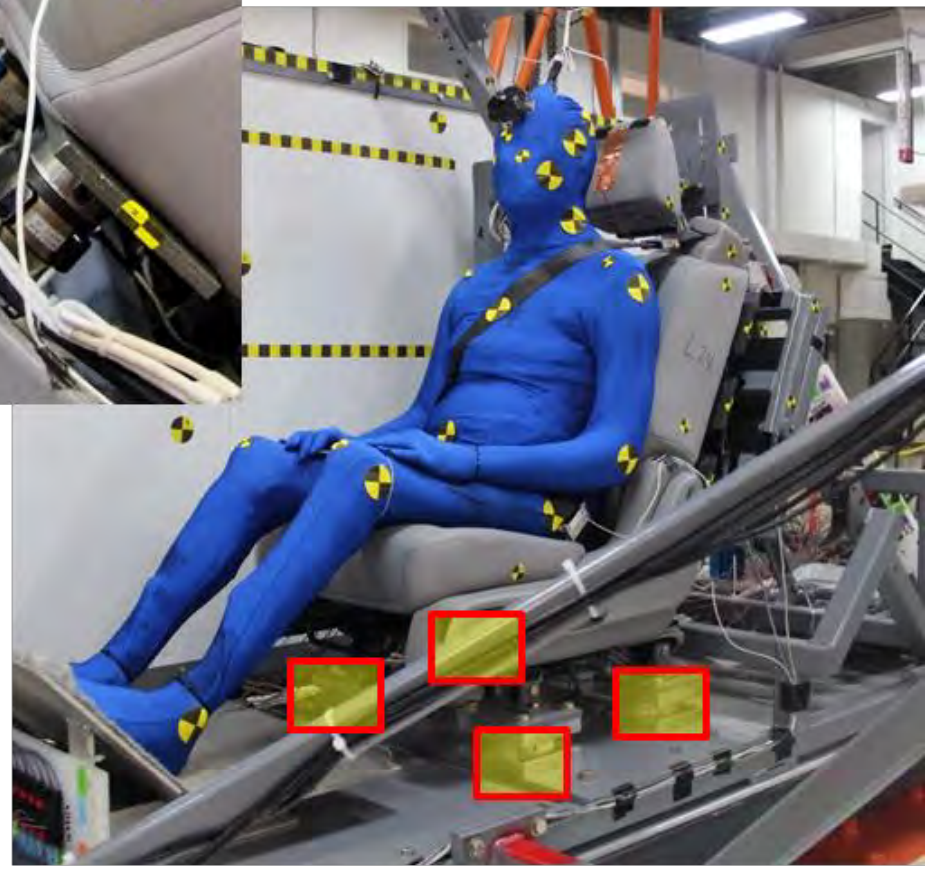
Sled Buck Description





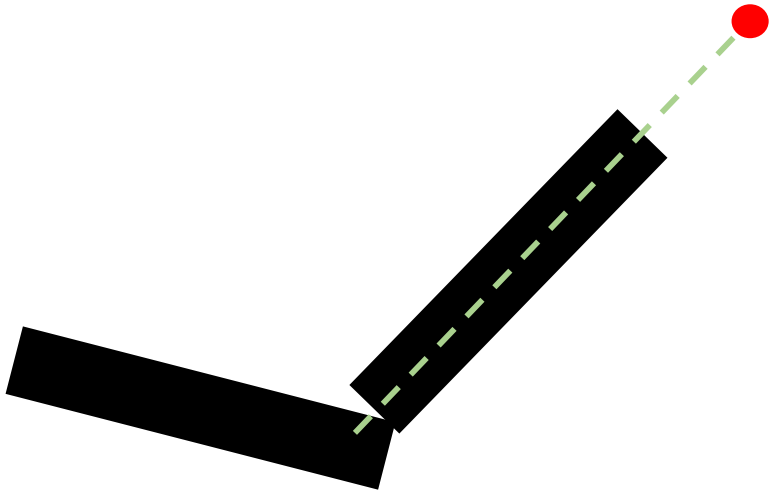
Sled Buck Description

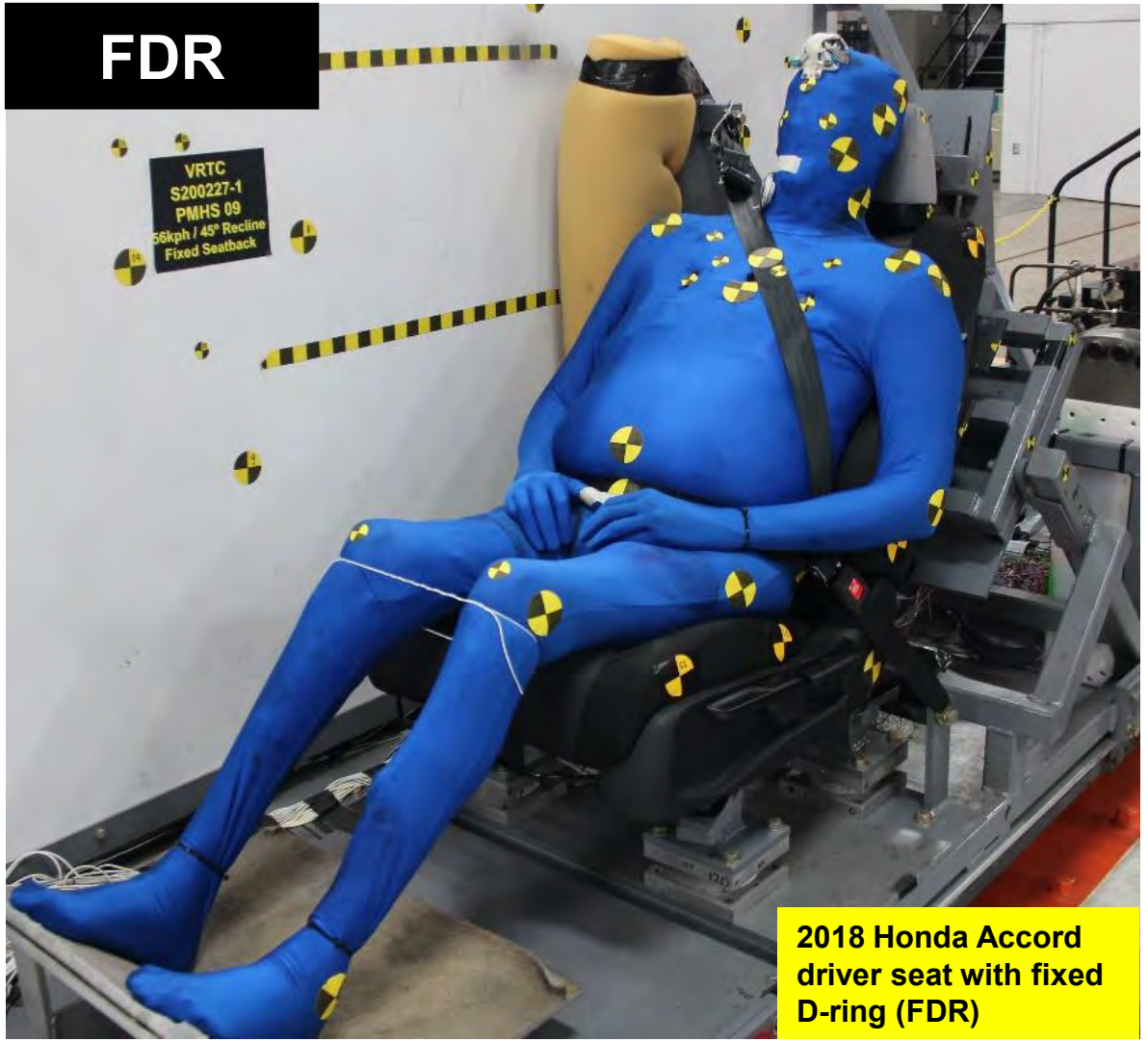
Load cells at head restraint (1), seat back (6), and seat anchors (4) to measure reaction loads



Sled Buck Description

D ring location
45 deg





2018 Honda Accord driver seat with fixed D-ring (FDR)

PMHS Characteristics – 56 km/h

N=14	Speed	Seat	Recline	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)	Cause of Death
PMHS01	56	ABTS	45	57	167.0	62.6	90.0	3.8	20.6	Chronic Obstructive Pulmonary Disease
PMHS02	56	ABTS	25	64	171.0	62.6	92.4	3.6	17.6	Alcohol Abuse
PMHS03	56	ABTS	25	54	174.0	93.9	97.0	5.0	20.6	Choking and asphyxiation
PMHS04	56	ABTS	45	59	178.0	96.2	96.5	4.4	23.2	Chronic Obstructive Pulmonary Disease
PMHS05	56	ABTS	45	62	176.0	77.1	95.7	3.5	21.2	Pancreatic CA
PMHS06	56	ABTS	25	61	176.5	72.6	94.0	3.9	20.2	Ischemic stroke, heart failure
PMHS09	56	FDR	45	71	187.5	89.4	96.5	4.3	17.1	Chronic Obstructive Pulmonary Disease
PMHS10	56	FDR	25	62	177.8	100.7	94.5	4.4	20.1	Cardiac Arrest
PMHS11	56	FDR	25	65	181.0	92.1	96.5	4.3	21.7	Stroke
PMHS12	56	FDR	25	58	177.8	71.7	94.2	3.9	21.1	Lung CA with mets
PMHS13	56	FDR	45	53	176.3	76.2	95.7	3.7	19.7	Melanoma with mets
PMHS14	56	FDR	45	63	172.3	85.3	93.0	3.8	23.4	Heart failure
PMHS21	56	FDR	25	62	172.7	68.5	89.7	3.8	20.2	Lung CA with mets
PMHS22	56	FDR	45	61	176.6	71.7	94.1	3.6	19.3	Metastatic squamous cell carcinoma
Mean (SD)	N/A	N/A	N/A	61 (5)	176.0 (4.8)	80.0 (12.7)	94.3 (2.3)	4.0 (0.4)	20.4 (1.8)	N/A
50th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A

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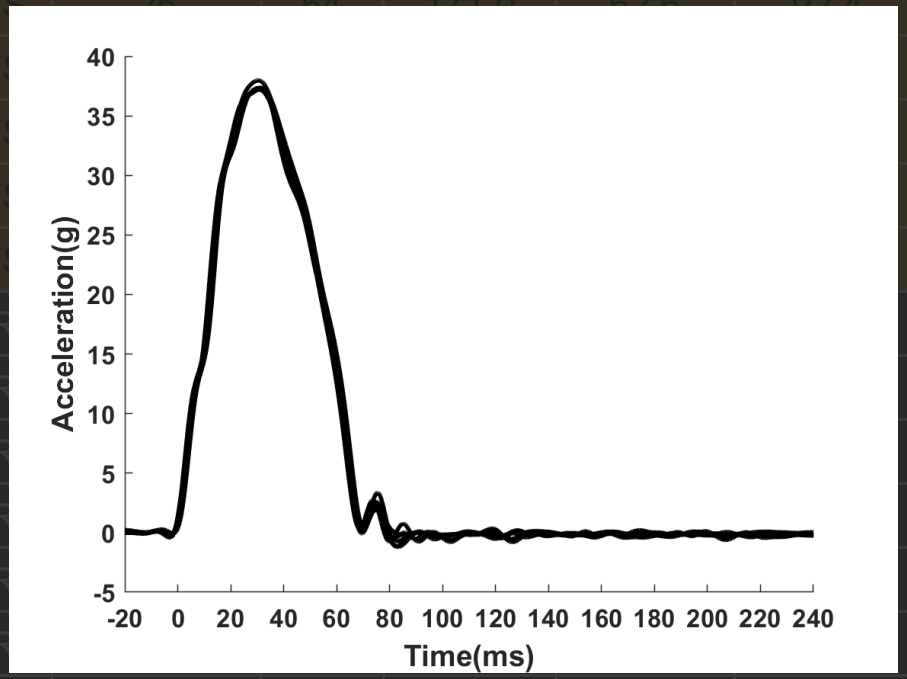
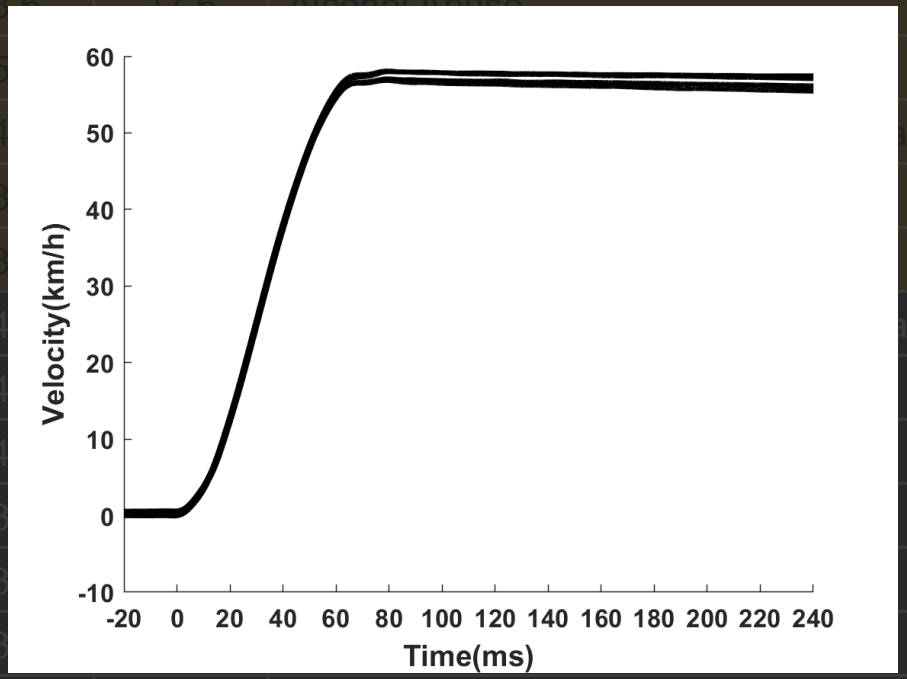
50th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A





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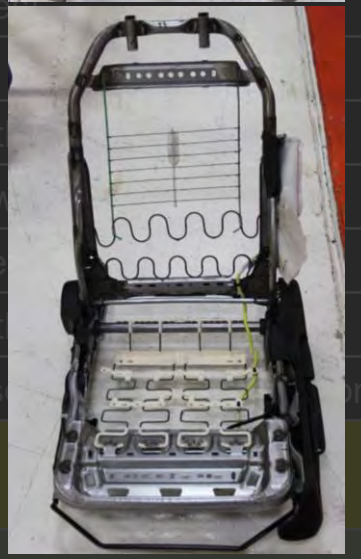
PMHS02	56	ABTS	25				92.4			hol Abu
PMHS03	56	ABTS	25				97.0			king and
PMHS04	56	ABTS	45				96.5			onic Obs Disease
PMHS05	56	ABTS	45				95.7			creatic C
PMHS06	56	ABTS	25				94.0			emic str
PMHS09	56	FDR	45				96.5			onic Obs Disease
PMHS10	56	FDR	25				94.5			diac Arre
PMHS11	56	FDR	25				96.5			ke
PMHS12	56	FDR	25				94.2			g CA wit
PMHS13	56	FDR	45				95.7			anoma w
PMHS14	56	FDR	45				93.0			rt failure
PMHS21	56	FDR	25				89.7			g CA wit
PMHS22	56	FDR	45				94.1			astatic s oma
Mean (SD)	N/A	N/A	N/A				94.3 (2.3)			
50th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A



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PMHS04	56	ABTS	45	59	178				23	ary Disease
PMHS05	56	ABTS	45	62	176				21	
PMHS06	56	ABTS	25	61	176				20	
PMHS09	56	FDR	45	71	187				17	ary Disease
PMHS10	56	FDR	25	62	177.8	100.7	94.5	4.4	20.1	Cardiac Arrest
PMHS11	56	FDR	25	65	181				21	
PMHS12	56	FDR	25	58	177				21	
PMHS13	56	FDR	45	53	176				19	
PMHS14	56	FDR	45	63	172				23	
PMHS21	56	FDR	25	62	172				20	
PMHS22	56	FDR	45	61	176				19	cinoma
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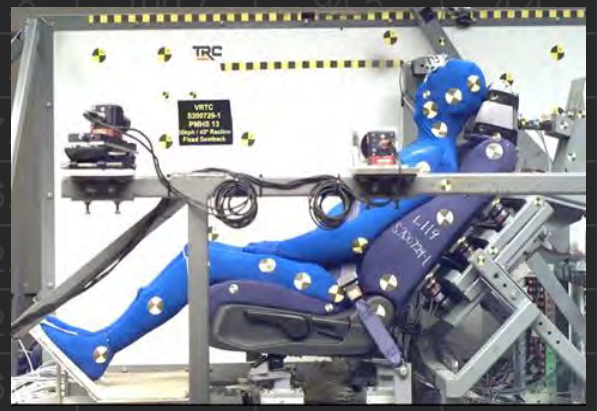
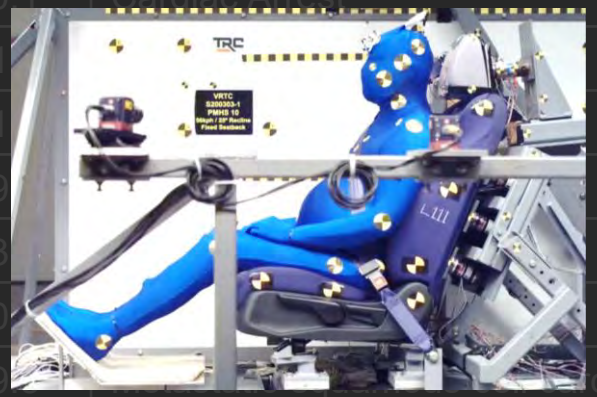
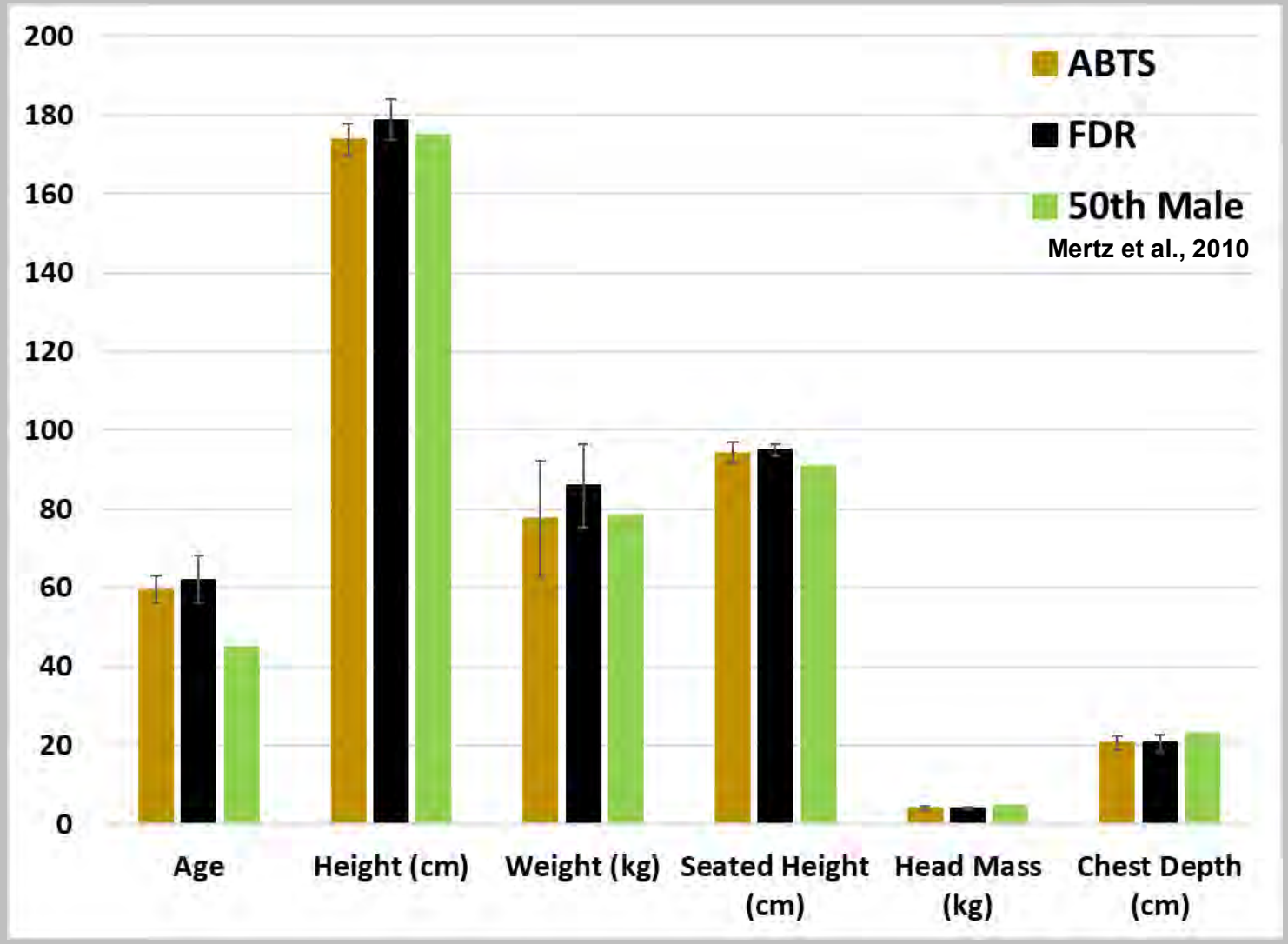




PMHS Characteristics – **56 km/h**

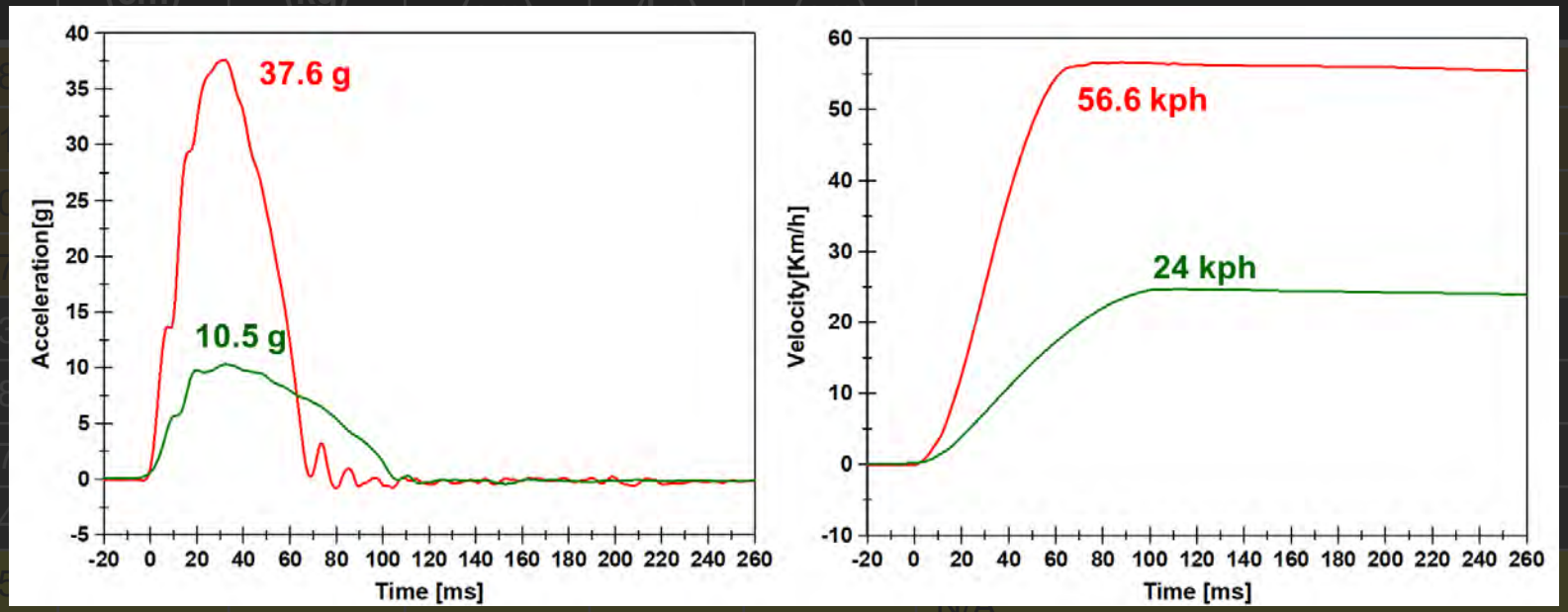


PMHS Characteristics – 24 km/h

N=8	Speed	Seat	Recline	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)	Cause of Death
PMHS07	24	ABTS	25	68	174.3	71.7	91.6	3.9	20.4	Coronary artery disease
PMHS08	24	ABTS	45	71	178.0	72.1	95.0	3.6	21.6	Throat & lung CA
PMHS19	24	ABTS	45	60	184.7	87.1	97.4	4.6	20.4	Glioblastoma
PMHS20	24	ABTS	25	67	167.2	68.0	92.2	3.3	20.5	Bladder CA
PMHS15	24	FDR	45	83	173.0	81.6	93.0	3.9	20.7	Respiratory failure
PMHS16	24	FDR	25	58	169.1	63.5	94.7	4.3	22.2	Lung CA
PMHS17	24	FDR	25	57	169.1	55.3	93.8	3.6	18.9	Lung CA
PMHS18	24	FDR	45	54	173.0	59.0	91.3	3.6	19.1	Lung CA
Mean (SD)	N/A	N/A	N/A	65 (10)	173.6 (5.7)	69.8 (10.8)	93.6 (2.0)	3.9 (0.4)	20.5 (1.1)	N/A
50th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A

PMHS Characteristics – 24 km/h

N=8	Speed	Seat	Recline	Age	Height (cm)	Weight (kg)	Seated Height	Head Mass	Chest Depth	Cause of Death
PMHS07	24	ABTS	25	68						
PMHS08	24	ABTS	45	71						
PMHS19	24	ABTS	45	60						
PMHS20	24	ABTS	25	67						
PMHS15	24	FDR	45	83						
PMHS16	24	FDR	25	58						
PMHS17	24	FDR	25	57						
PMHS18	24	FDR	45	54						
Mean (SD)	N/A	N/A	N/A	65 (10)	(5.7)	(10.8)	(2.0)	(0.4)	(1.1)	N/A
50th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A



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PMHS19	24	ABTS	45	60	184.7	87.1	97.4	4.6	20.4	Glioblastoma
PMHS20	24	ABTS	25	67	167.2	68.0	92.2	3.3	20.5	Bladder CA
PMHS15	24	FDR	45	83	173.0	81.6	93.0	3.9	20.7	Respiratory failure
PMHS16	24	FDR	25	58	169.1	63.5	94.7	4.3	22.2	Lung CA
PMHS17	24	FDR	25	57	169.1	55.3	93.8	3.6	18.9	Lung CA
PMHS18	24	FDR	45	54	173.0	59.0	91.3	3.6	19.1	Lung CA
Mean (SD)	N/A	N/A	N/A	65 (10)	173.6 (5.7)	69.8 (10.8)	93.6 (2.0)	3.9 (0.4)	20.5 (1.1)	N/A
50th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A

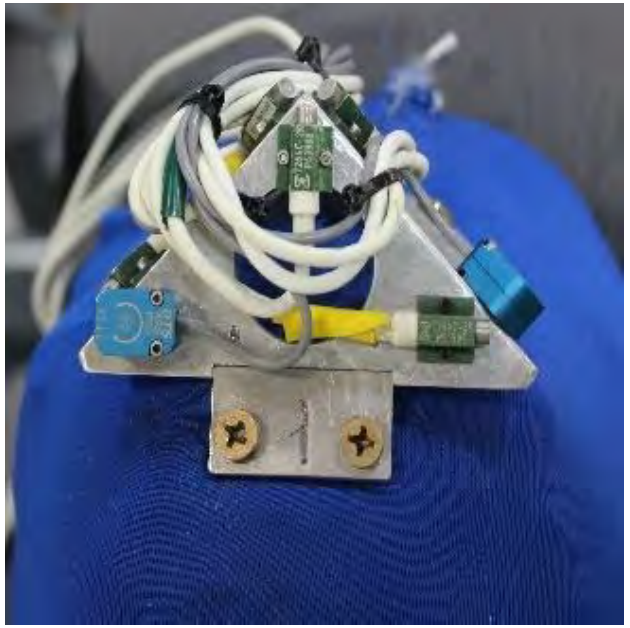
Total: 22 PMHS tests (2 speeds, 2 reclines, 2 seat/restraint systems)

56 km/h: 14 PMHS tests & 24 km/h: 8 PMHS tests

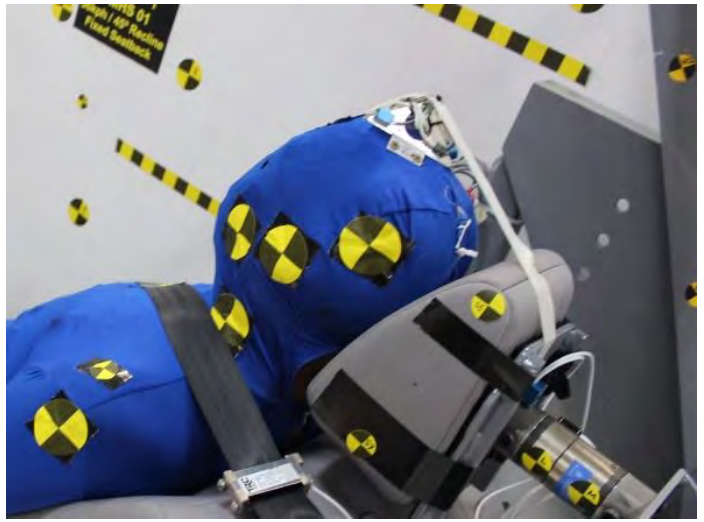
PMHS Instrumentation

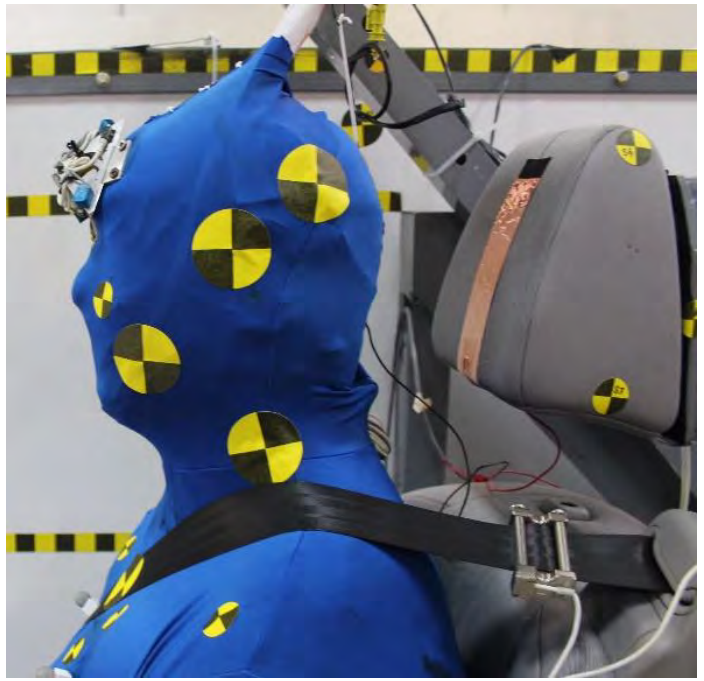
6aω

Head	
Chest	
C2/C4/C6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	
L Humerus	



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





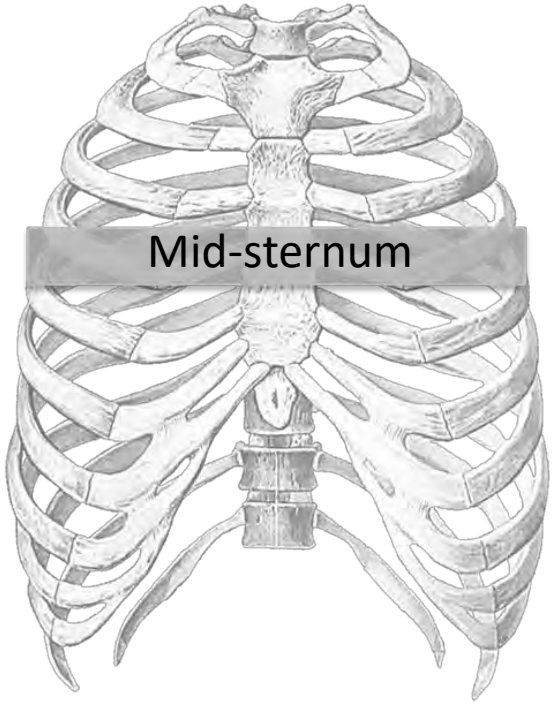
PMHS Instrumentation

6aω

Chestband

Strain Gauges

Head	
Chest	
C2/C4/C6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	
L Humerus	



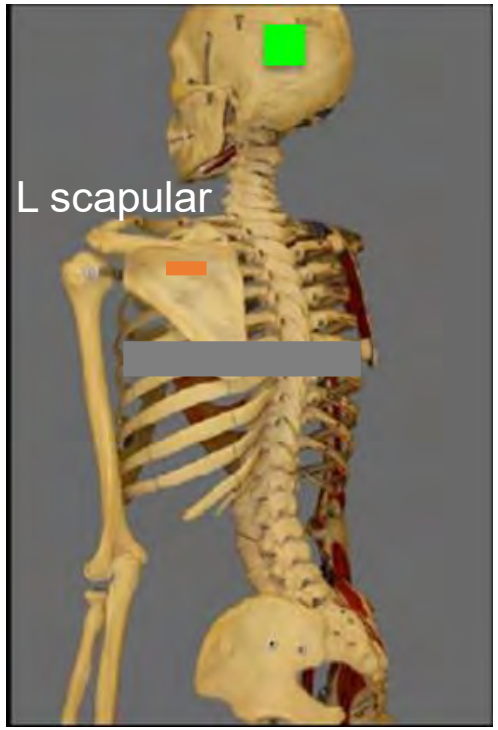
PMHS Instrumentation

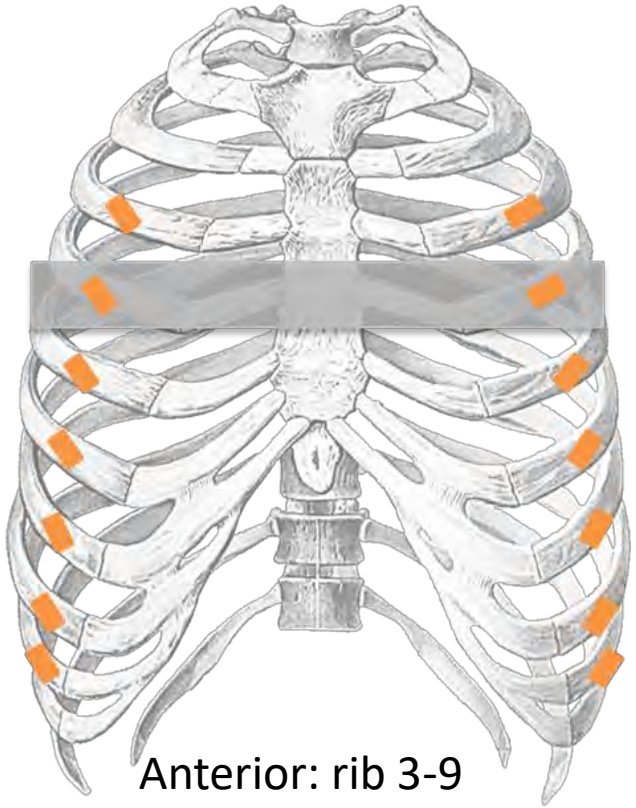
6aω

Chestband

Strain Gauges

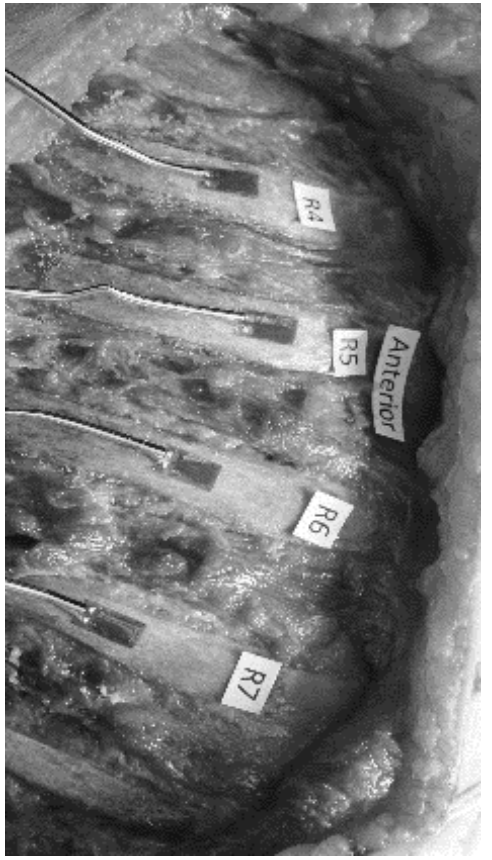
Head	
Chest	
C2/C4/C6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	
L Humerus	





Anterior: rib 3-9

Posterior: rib 3-10



PMHS Instrumentation

6aω
Chestband
Strain Gauges
3aω

Head	
Chest	
C2/C4/C6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
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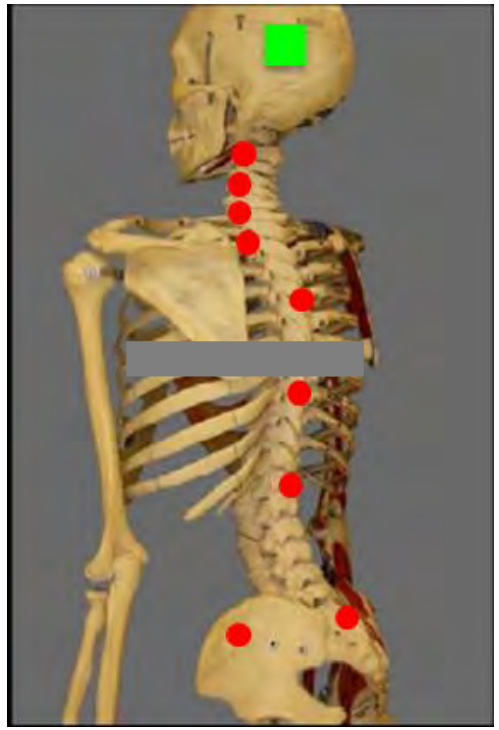
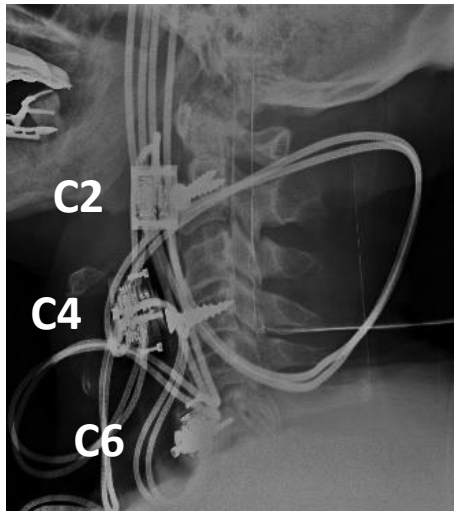
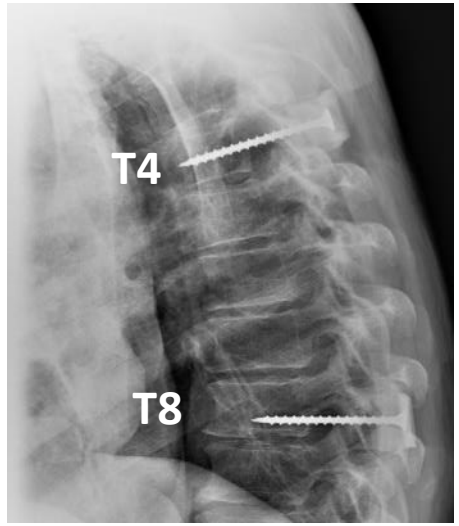
L Humerus	







PMHS Instrumentation

6aω
Chestband
Strain Gauges
3aω

Head	
Chest	
C2/C4/C6	
T1	
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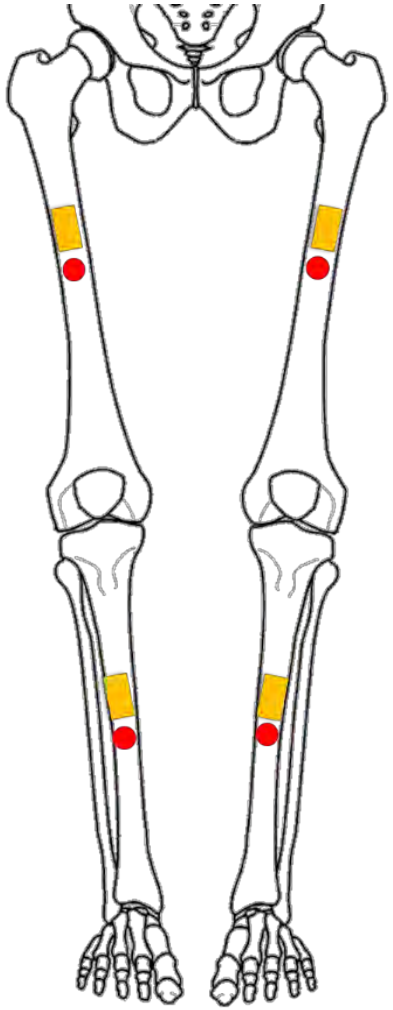
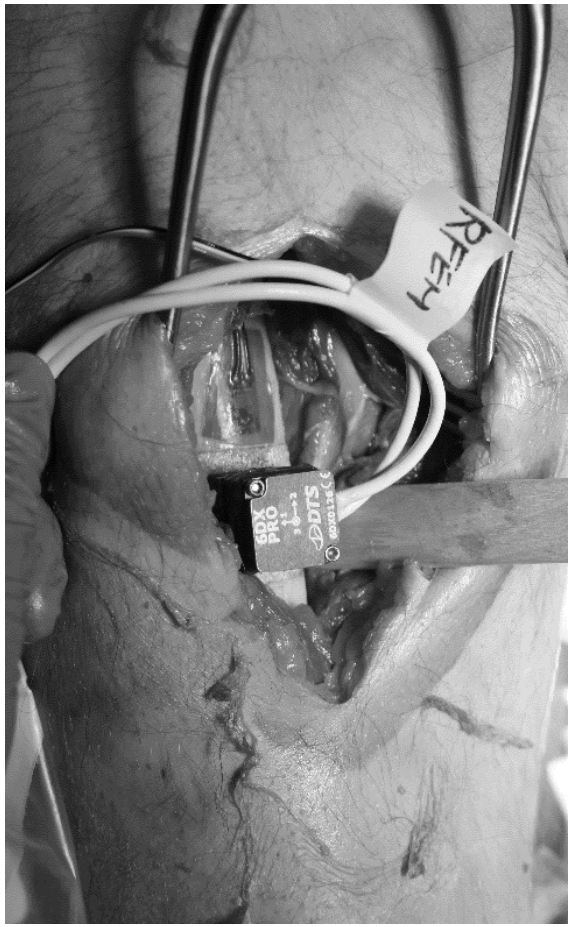
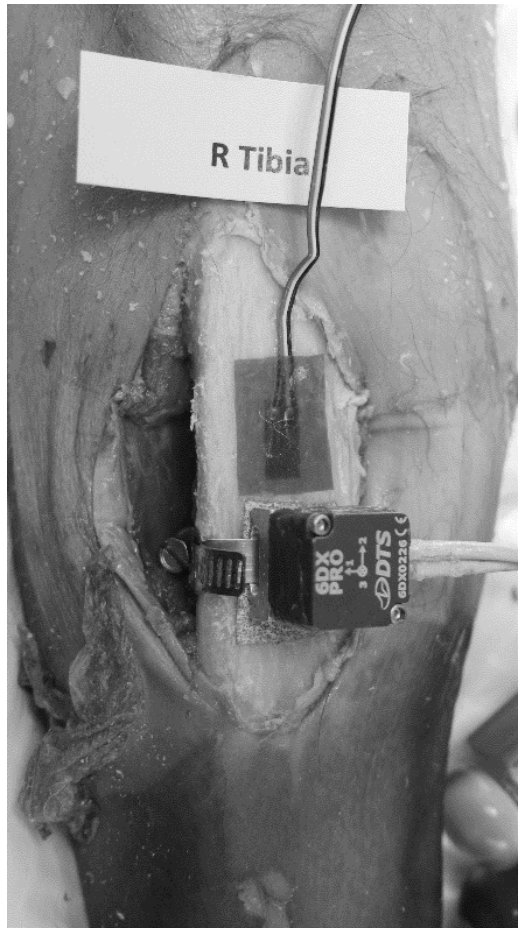






PMHS Instrumentation

Revised instrumentation for a new series in 2021

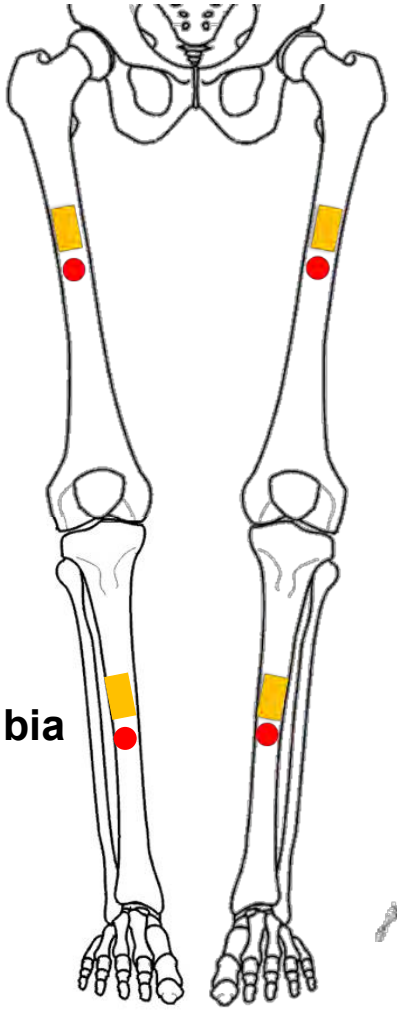
6aω

Chestband

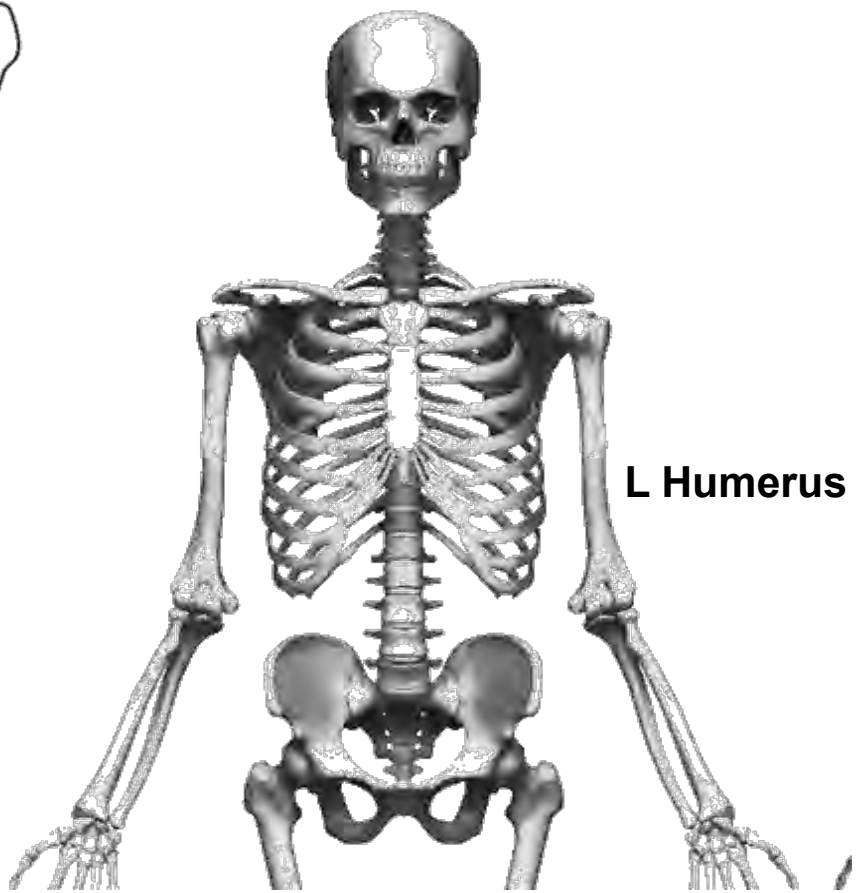
Strain Gauges

3aω

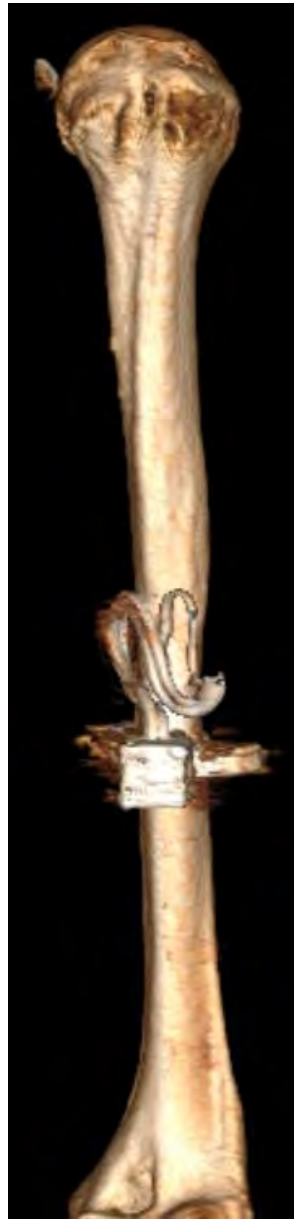
Head	
Chest	
C2/C4/C6	
T1	
T4	
T8	
T12	
S1	
Pelvis	
Femur	
Tibia	
L Humerus	



R Tibia



L Humerus



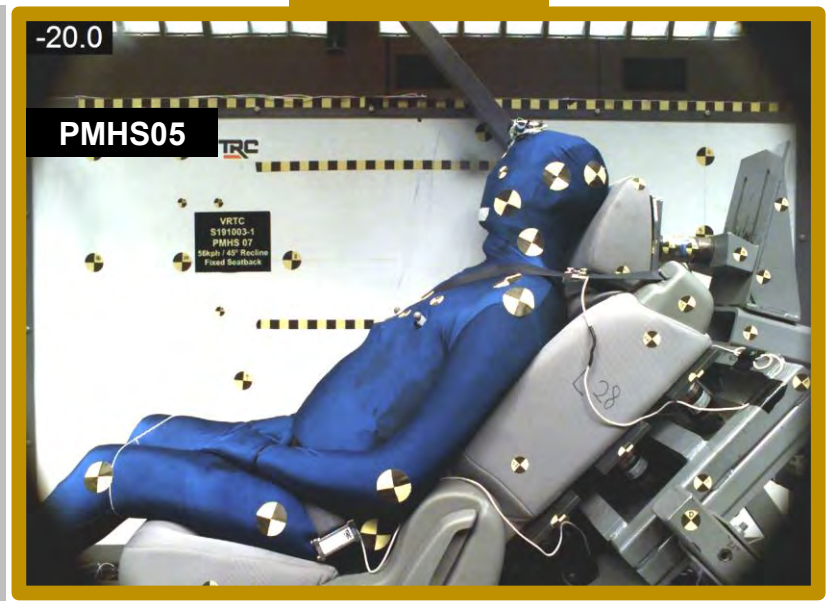
Moved right tibia instrumentation to left humerus

Results
(Preliminary Results)

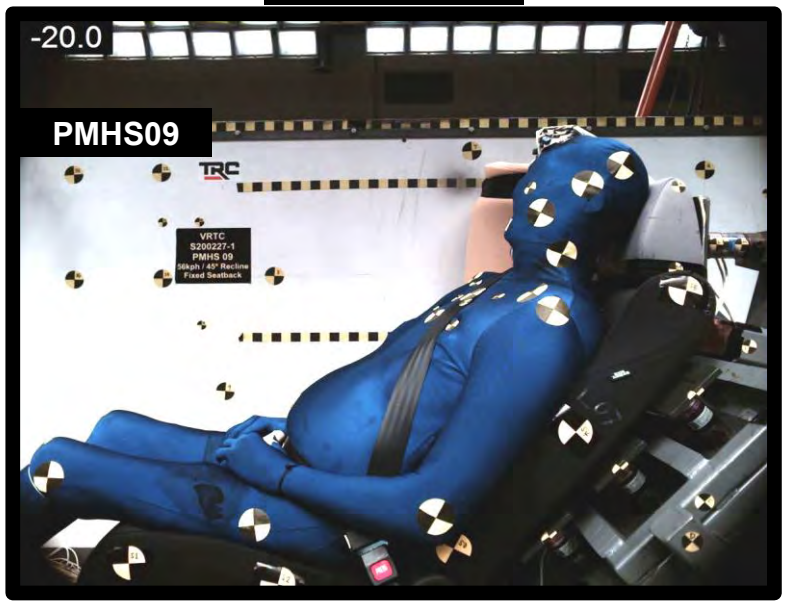
High Speed Videos – 56 km/h ABTS vs. FDR

45 deg

ABTS



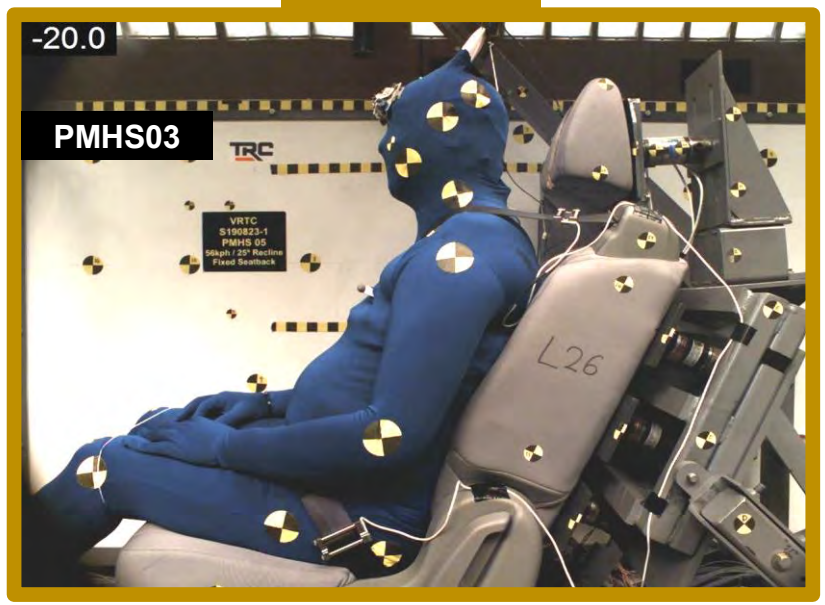
FDR



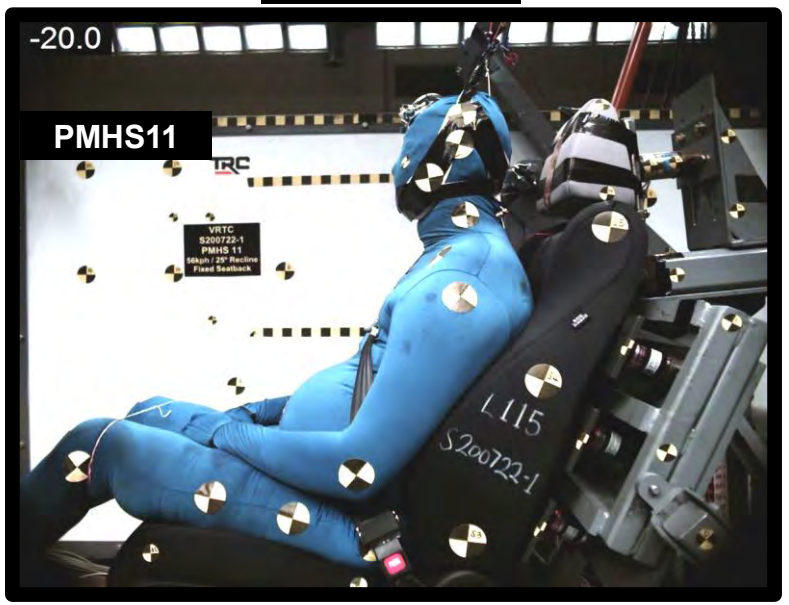
High Speed Videos – 56 km/h ABTS vs. FDR

25 deg

ABTS

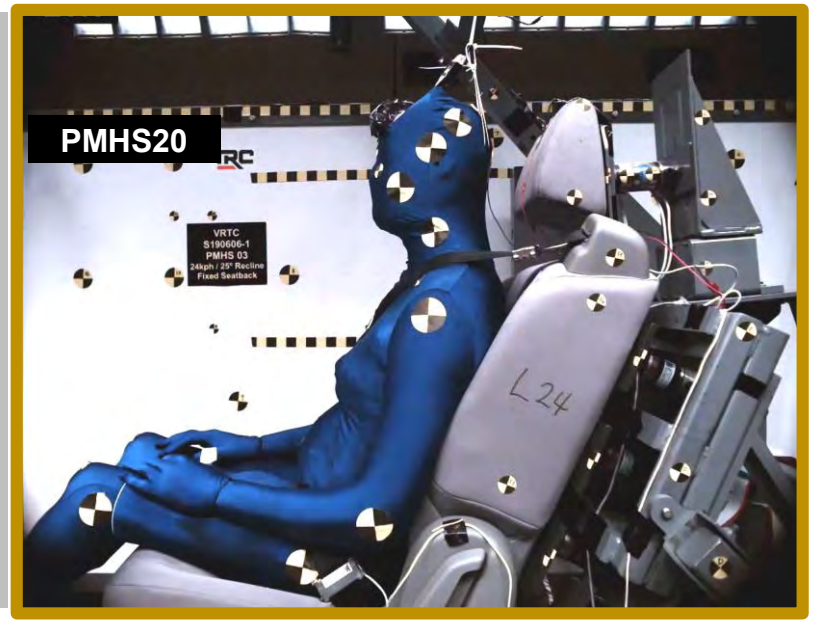


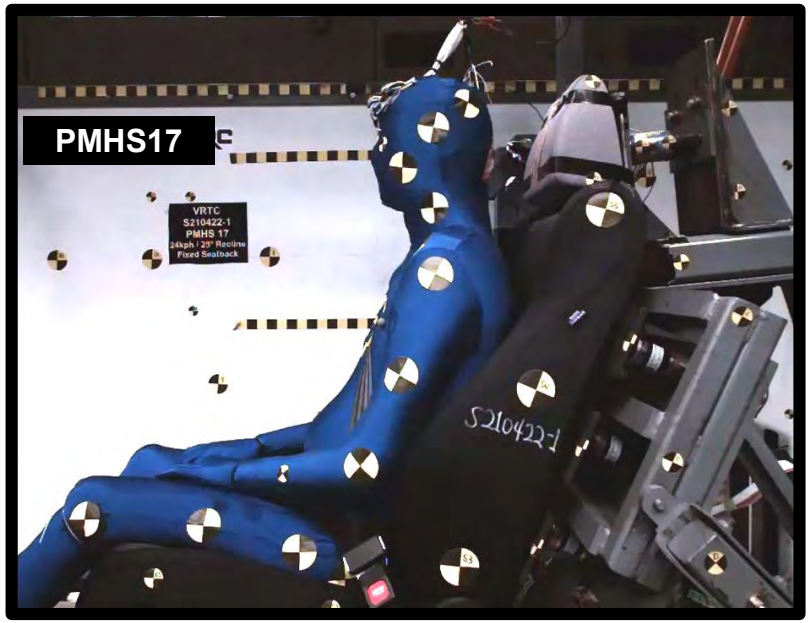
FDR



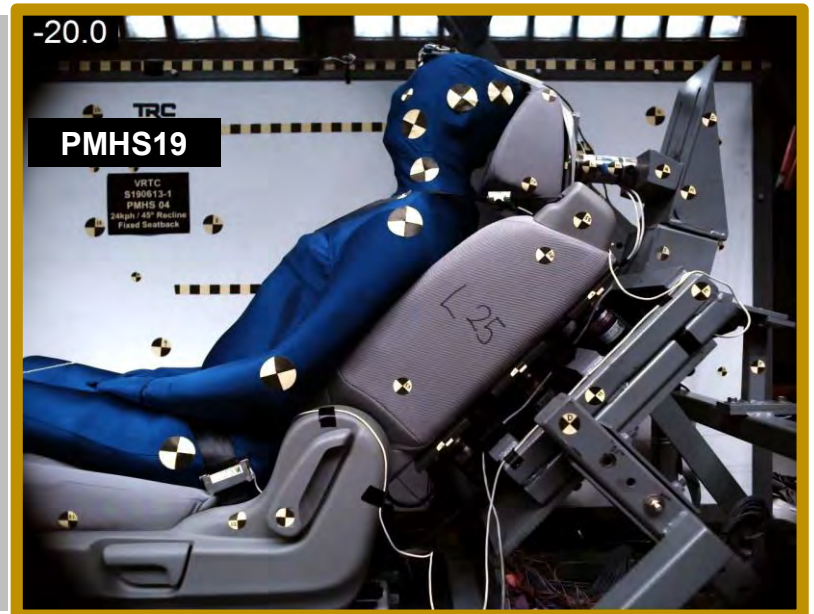
High Speed Videos – 24 km/h ABTS vs. FDR

25 deg





45 deg



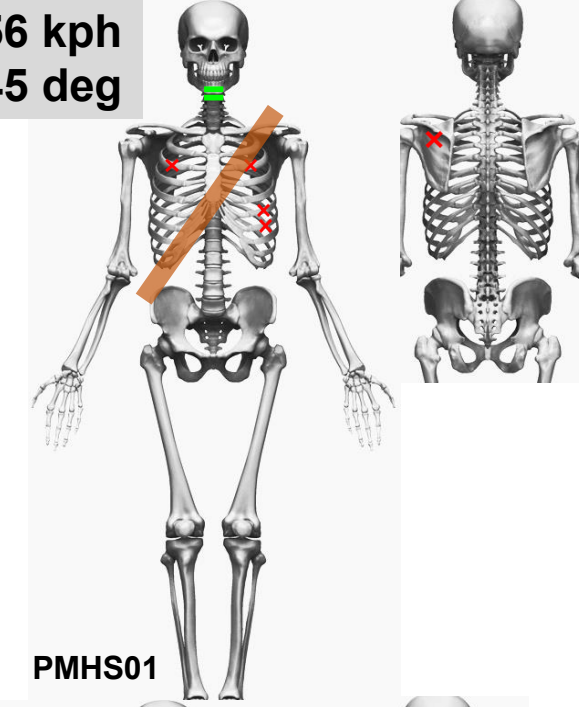
PMHS Injury – 56 km/h

ABTS

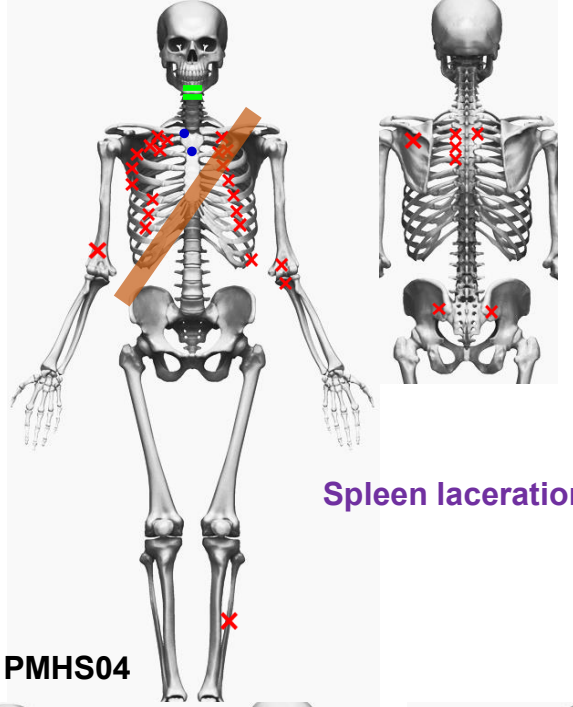
FDR

56 kph
45 deg

laxity
Fracture
Joint damage

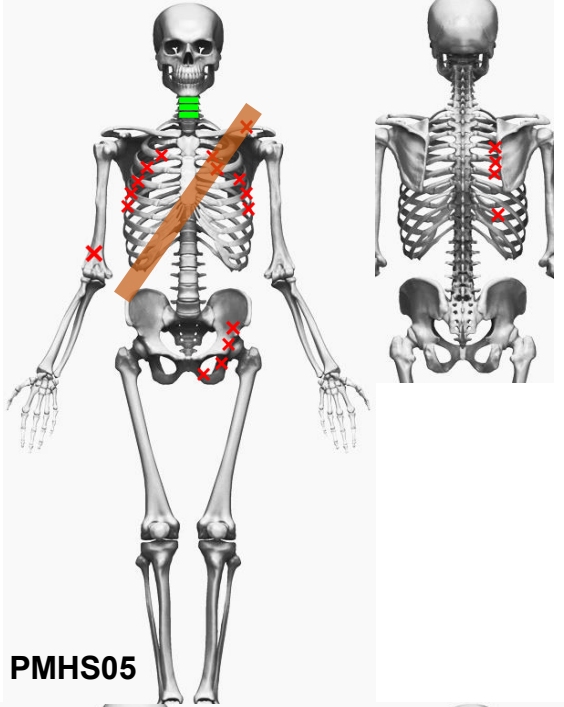


PMHS01

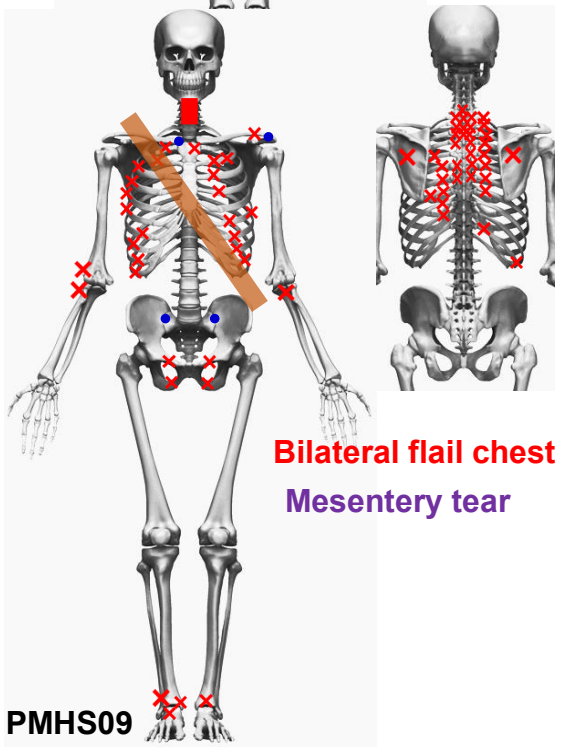


Spleen laceration

PMHS04

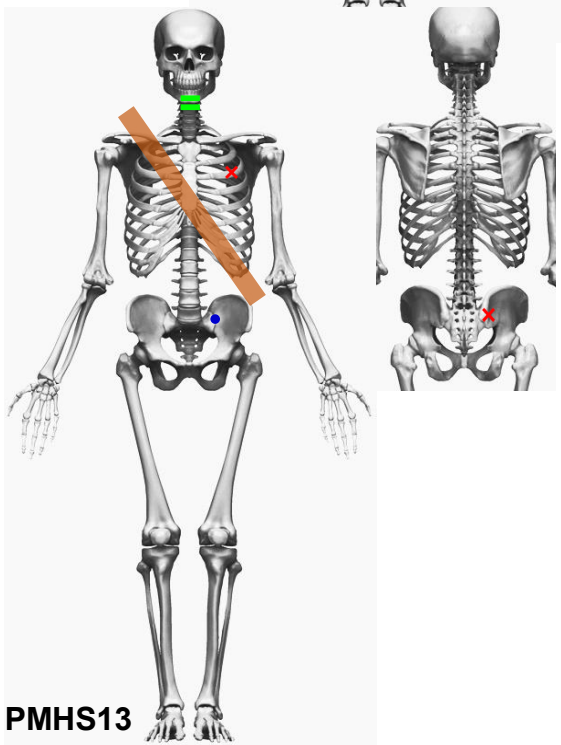


PMHS05

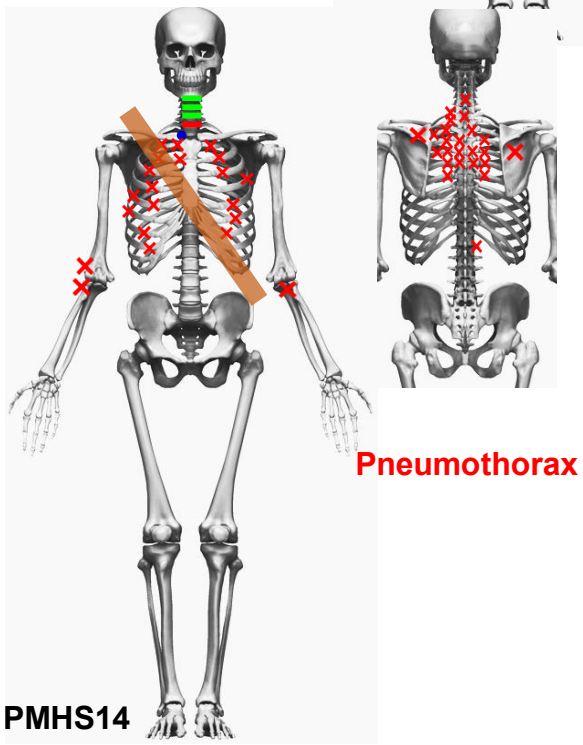


Bilateral flail chest
Mesentery tear

PMHS09

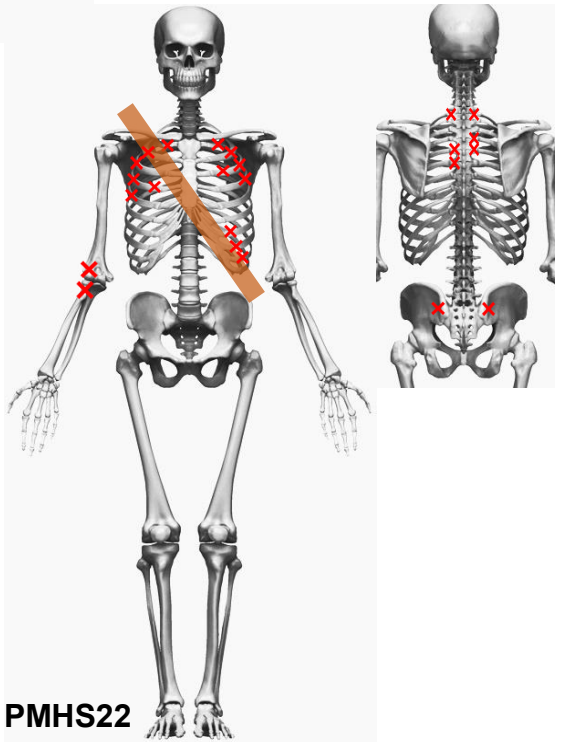


PMHS13



Pneumothorax

PMHS14



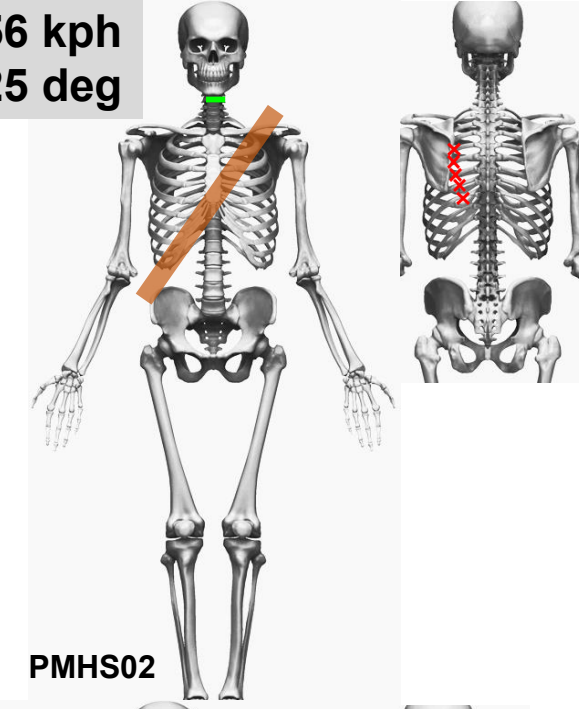
PMHS22

ABTS

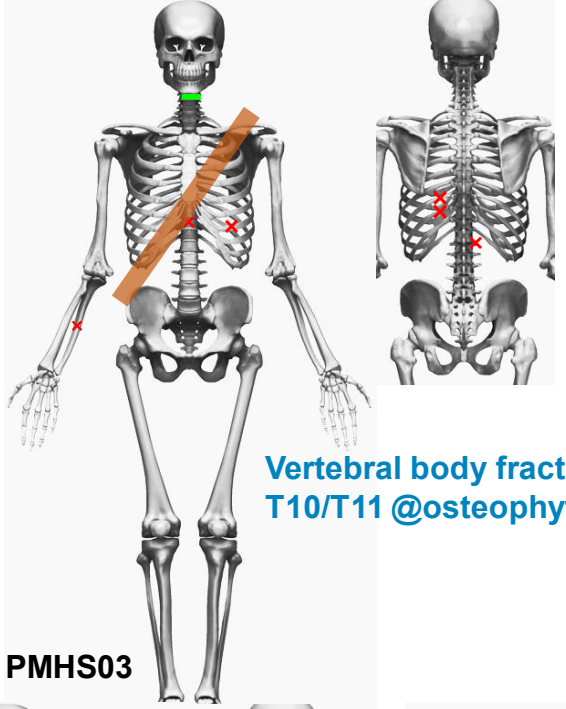
FDR

56 kph
25 deg

laxity
Fracture
Joint damage

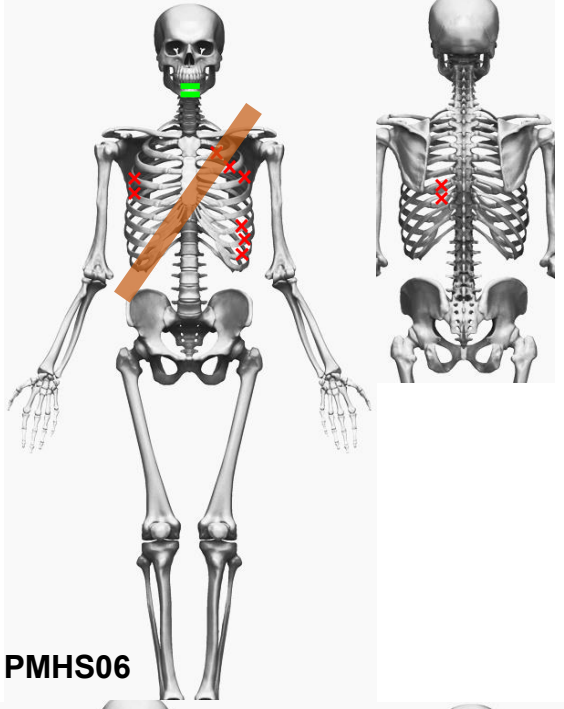


PMHS02

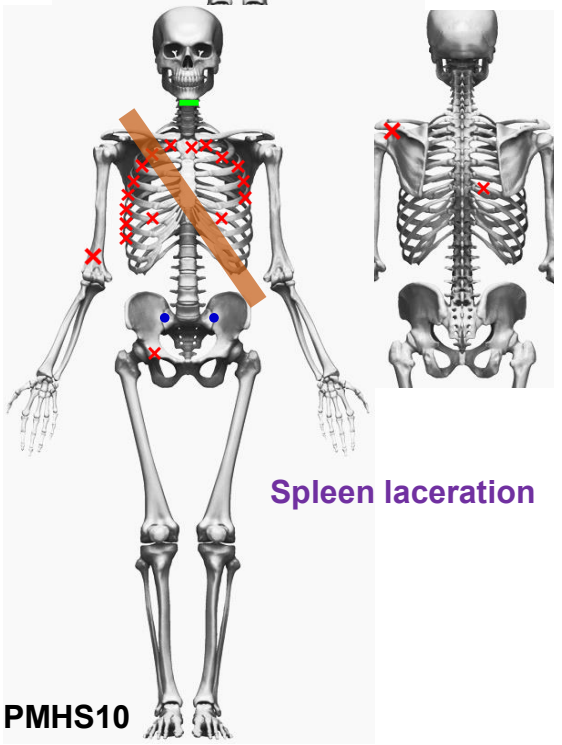


Vertebral body fracture at
T10/T11 @osteophyte

PMHS03

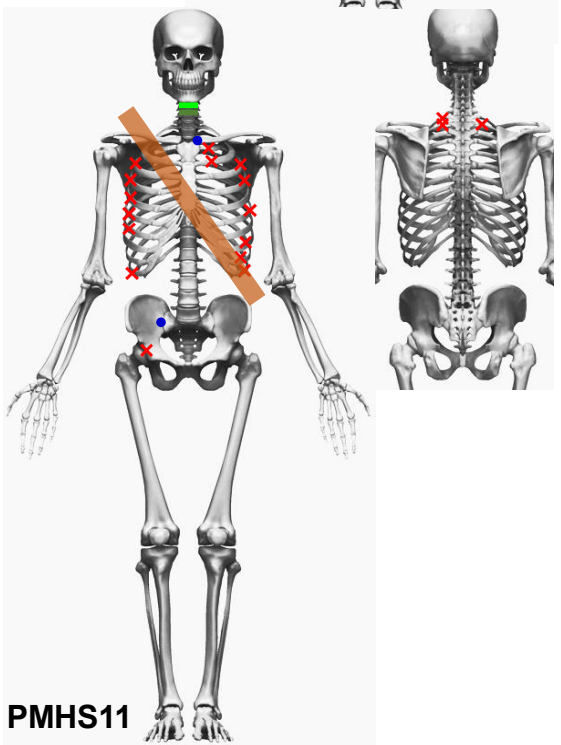


PMHS06

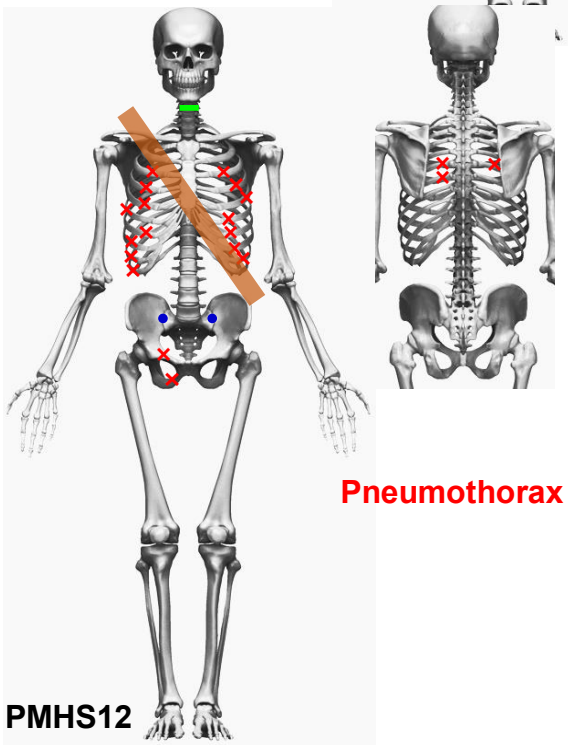


Spleen laceration

PMHS10

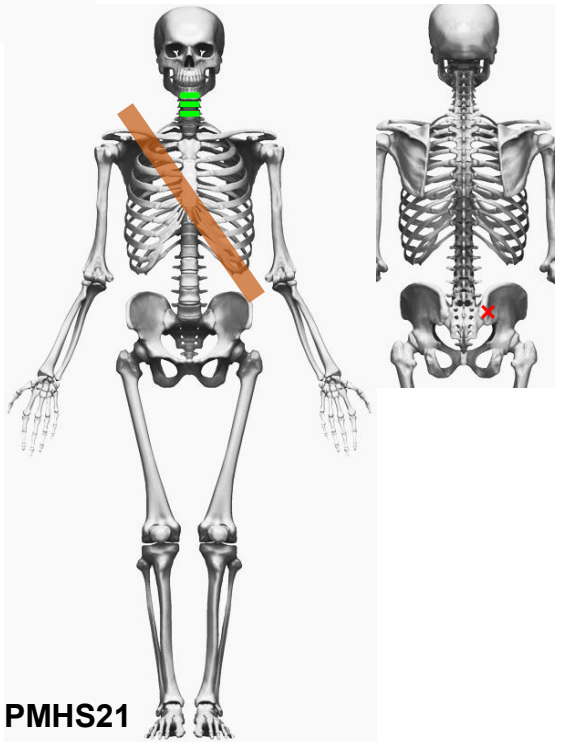


PMHS11



Pneumothorax

PMHS12



PMHS21

PMHS Injury – 24 km/h

No major injuries

-No rib fractures

-No pelvis fractures

Only injury: minor cervical spine laxity (4 out of 8 PMHS)

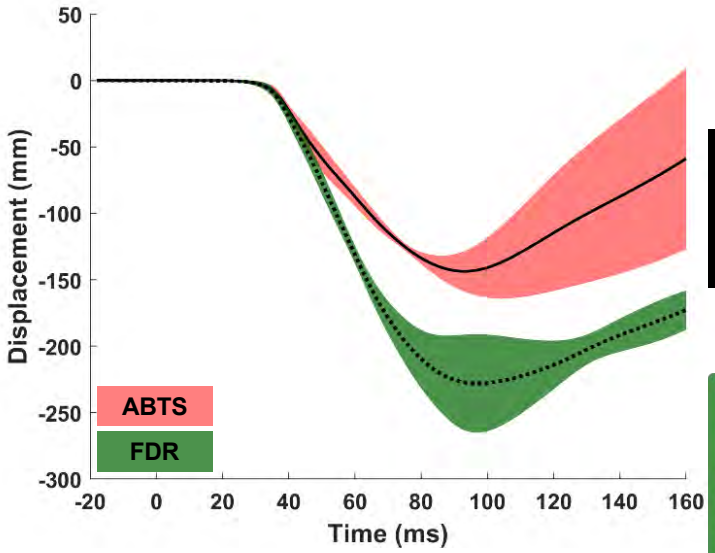
Ramping Behavior – 56 km/h

PMHS21 and 22 were not included in the corridors

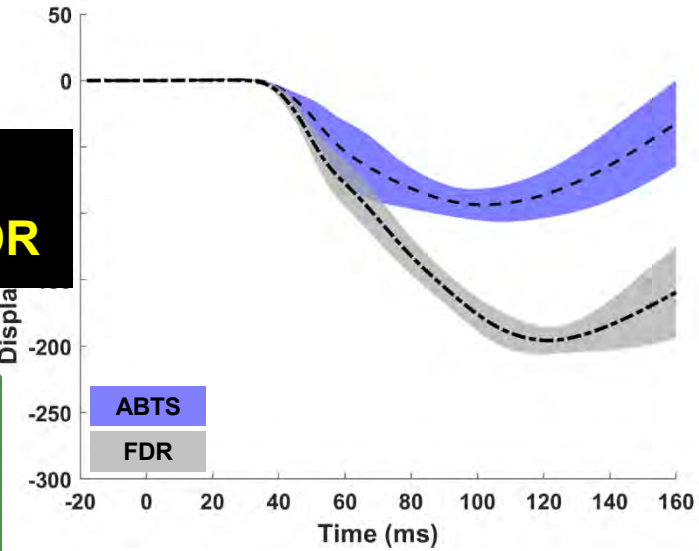
45 deg

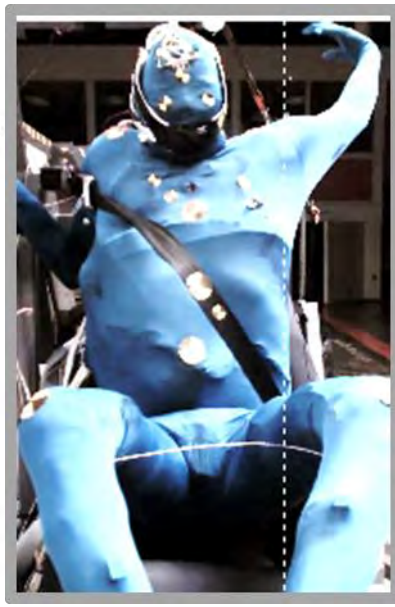
25 deg

Head

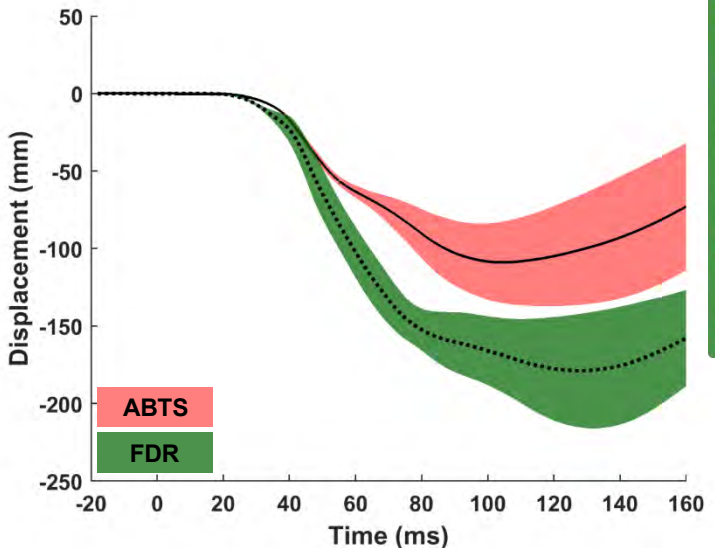


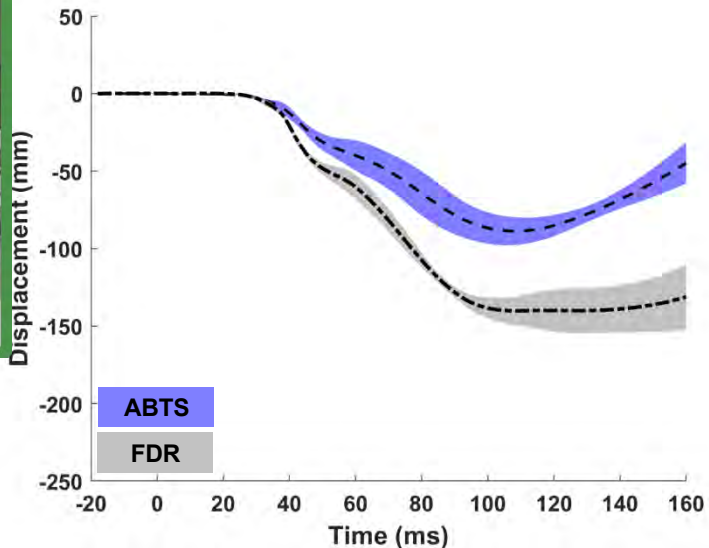
More ramping in 45deg and FDR





Pelvis

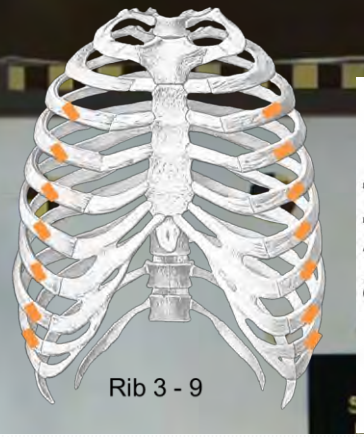


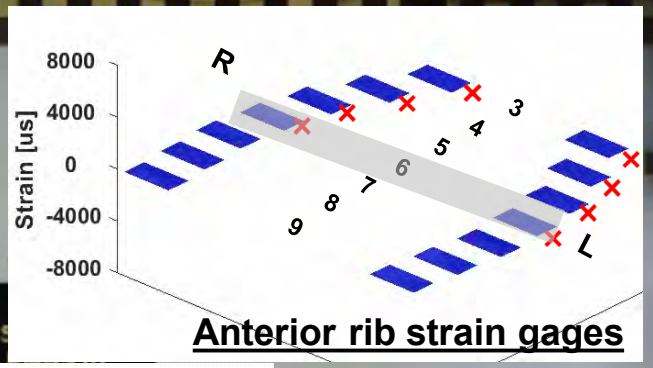


Rib Fractures – 56 km/h

ABTS 45 Deg

0.0

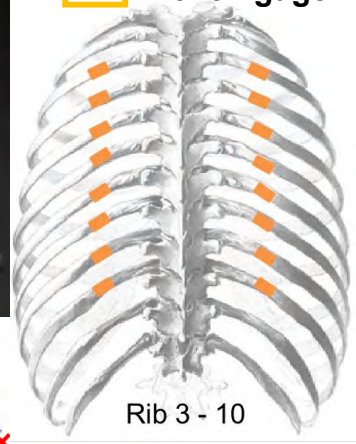




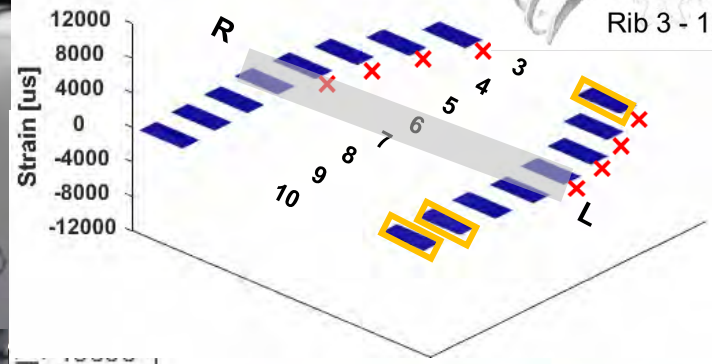
Anterior rib strain gages

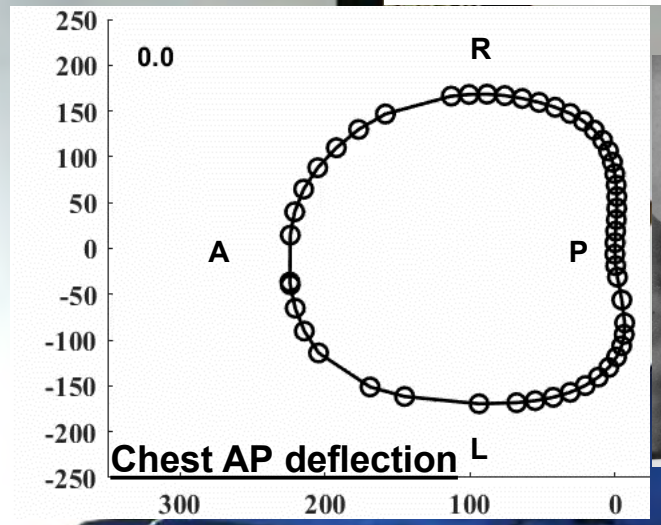
Fracture

Broken gage

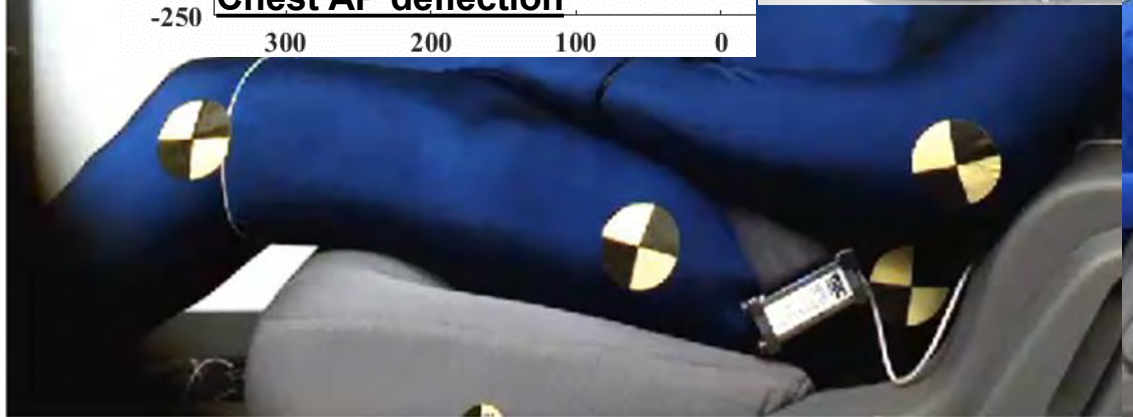


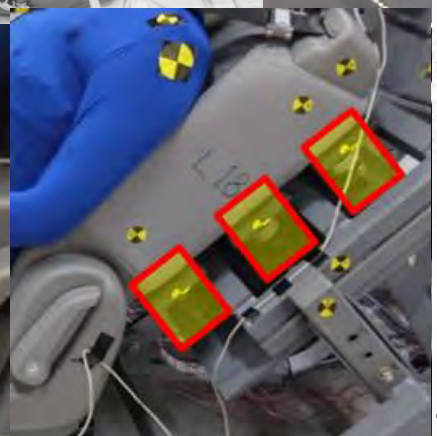
Posterior rib strain gages

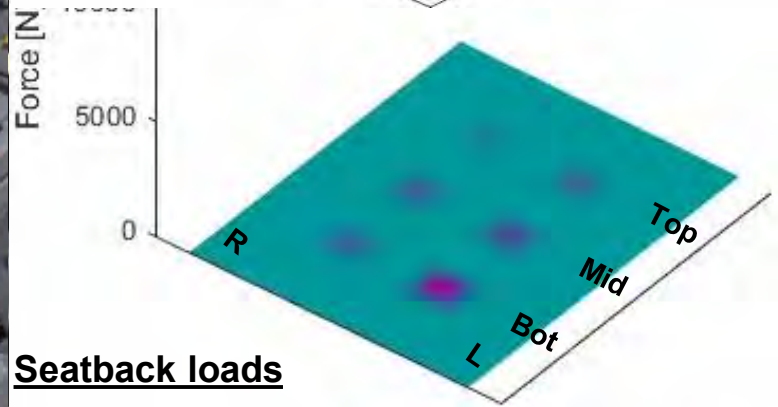




Chest AP deflection







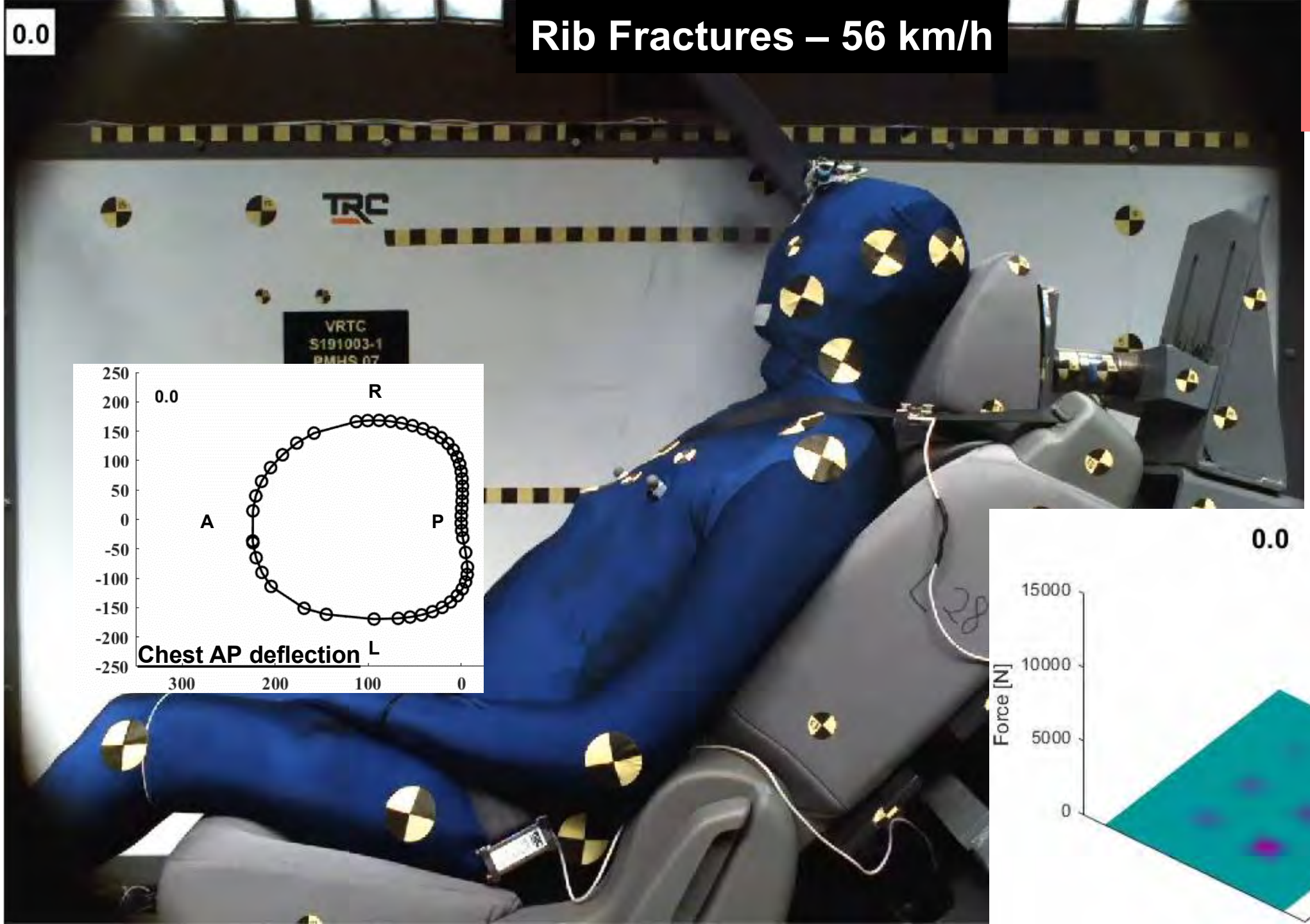
Seatback loads

Rib Fractures – 56 km/h

ABTS 45 Deg

✕ Fracture

▭ Broken gage

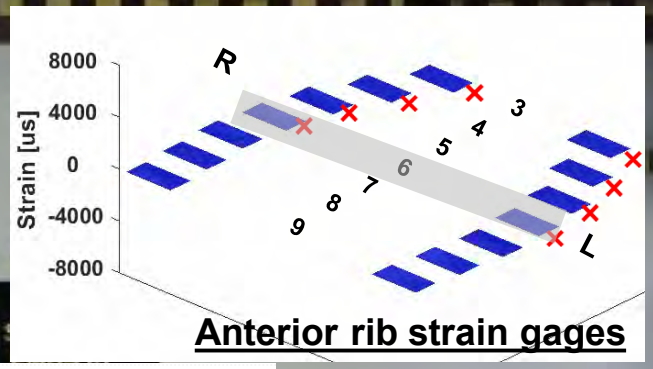


Rib Fractures – 56 km/h

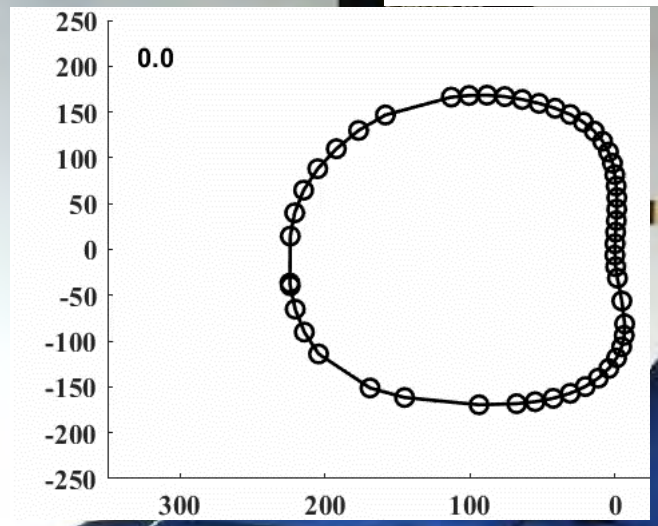
ABTS 45 Deg

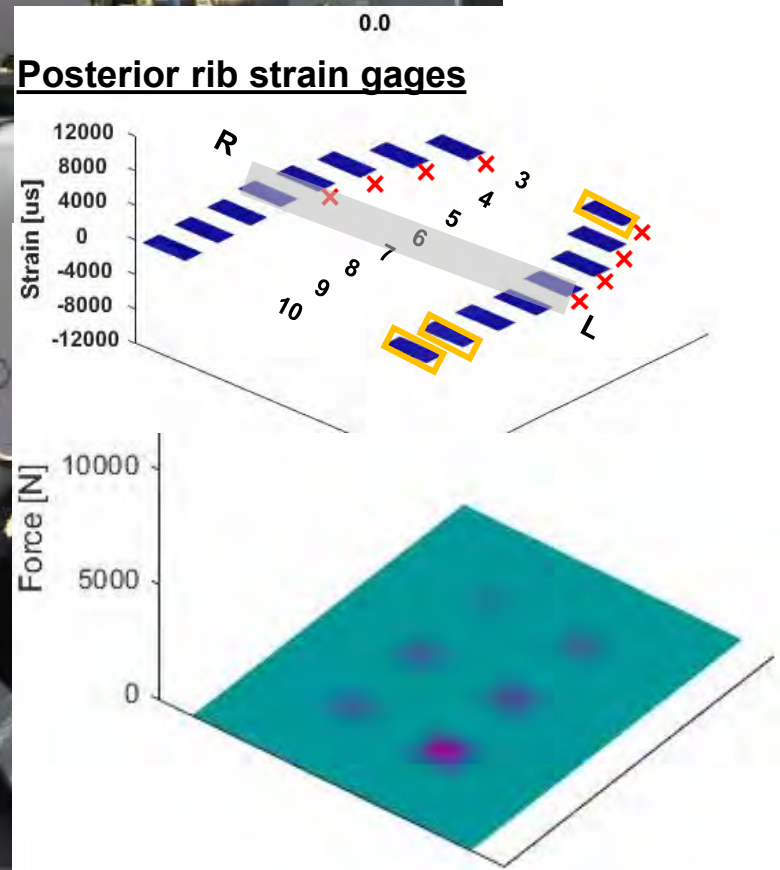
Fracture

Broken gage



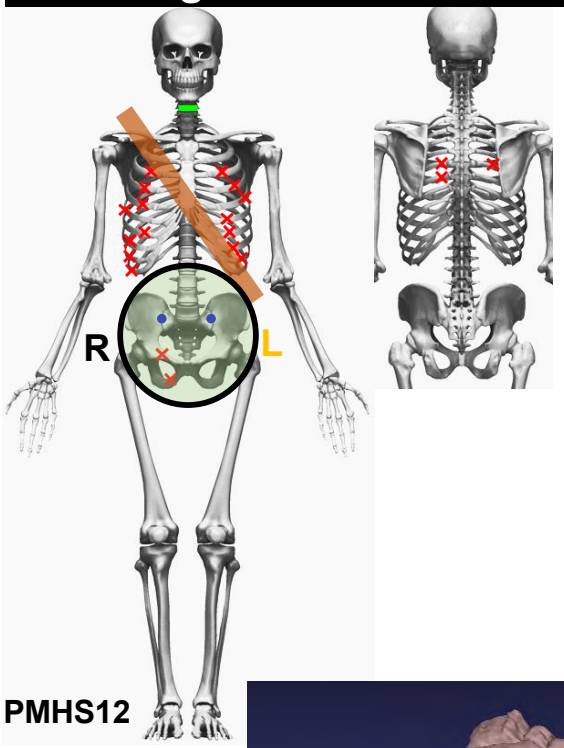
Anterior rib strain gages



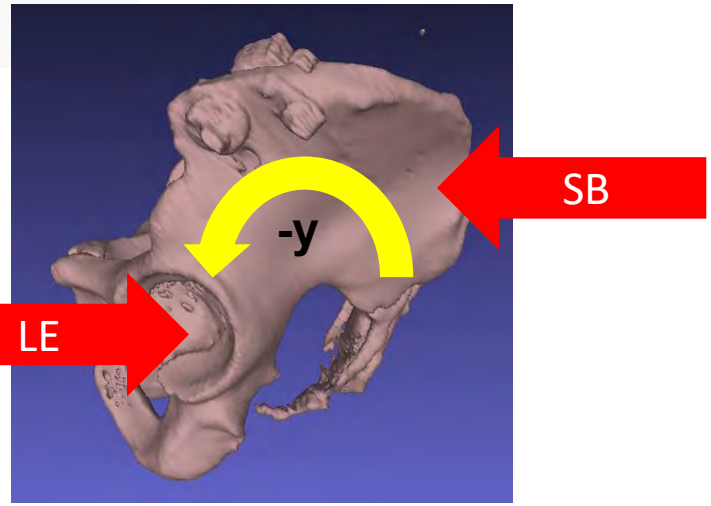


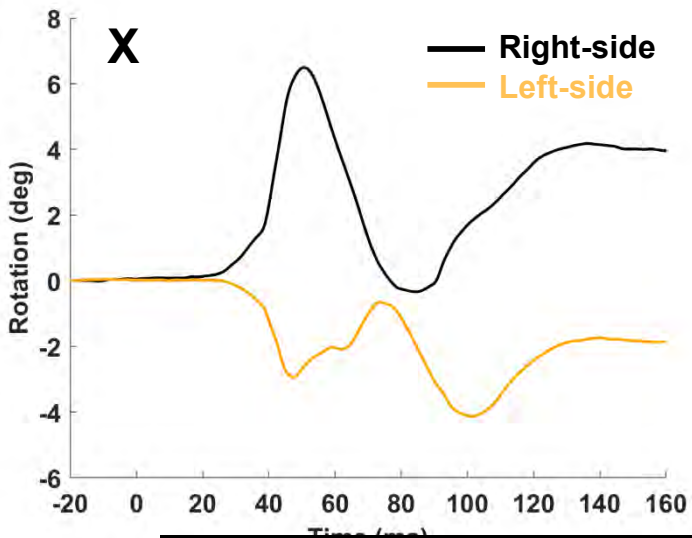
Pelvis Fractures – 56 km/h

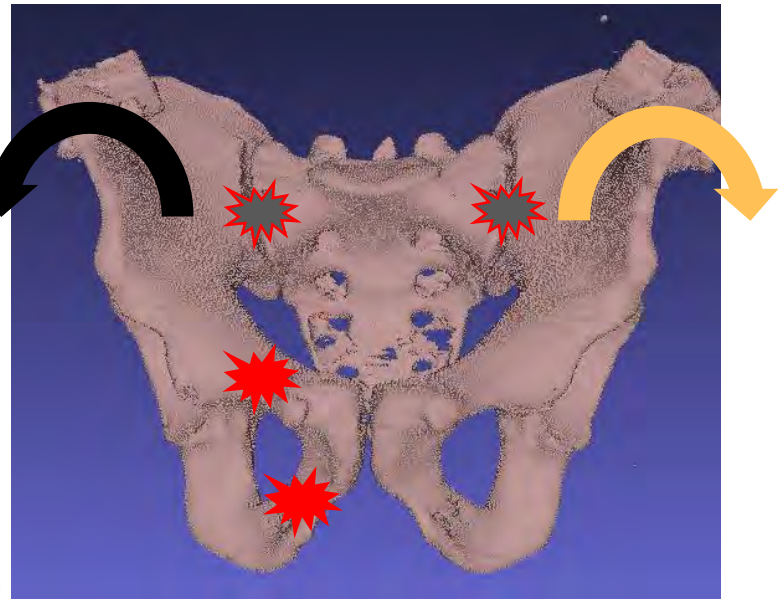
25 deg & 56km/h in FDR



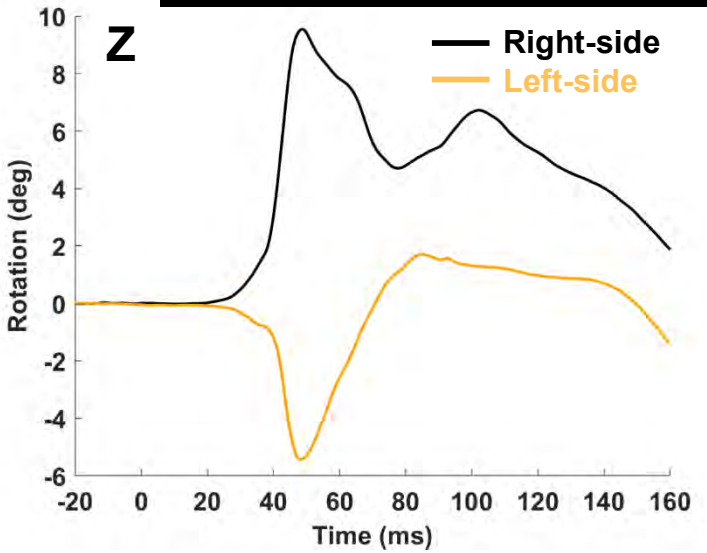
PMHS12





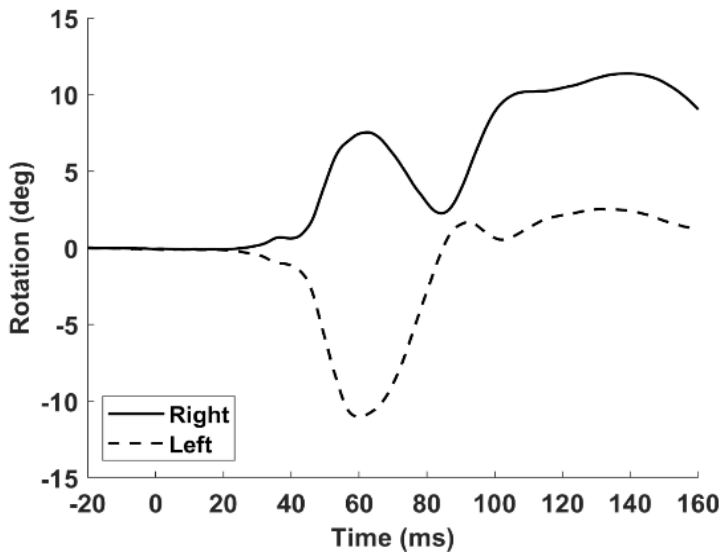


Off-axis rotations may be an indicator of fractures

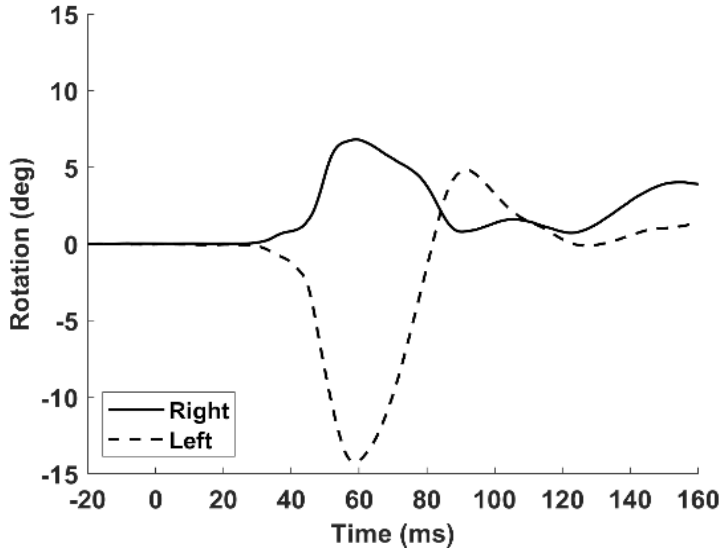


Pelvis Off-axis Rotations – 56 km/h

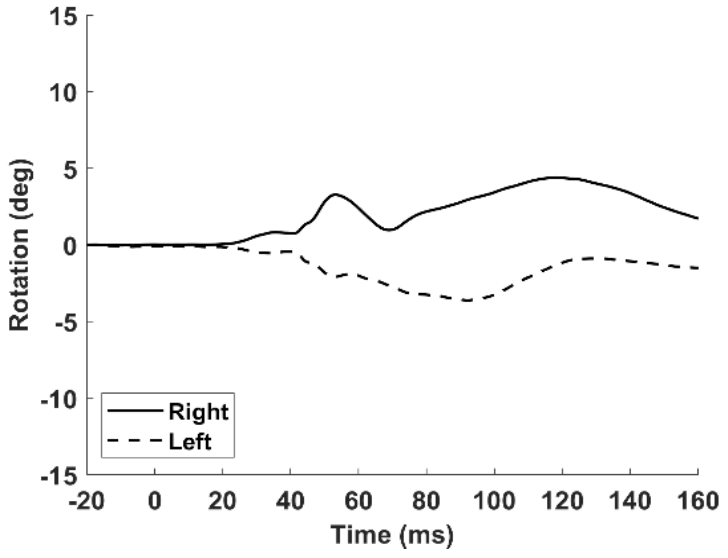
Rotation about X axis

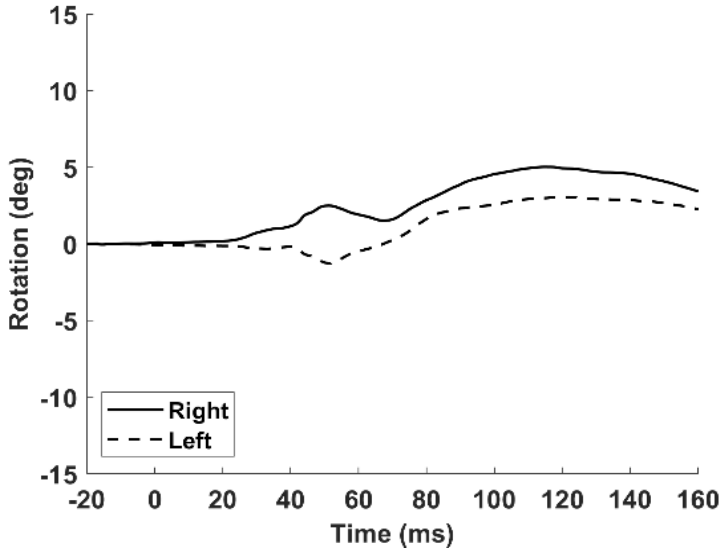


Rotation about Z axis



PMHS with pubic ramus fractures





PMHS with no pubic ramus fractures

Summary

- Injury
  - More injuries were observed in the FDR (especially 25 deg) in 56 km/h
    - Pelvis and rib fractures
      - No pelvis fractures in 25-deg ABTS
  - No major injuries in 24 km/h even with the rigidized seatback
    - Only c-spine minor laxity
- Ramping
  - Higher ramping was observed in the FDR
    - Standard 3-point belt in the FDR was not able to hold the PMHS in place
      - 45 deg: hyperextension of the neck
- Thorax responses
  - Chestband, strain gage, and seatback load data were analyzed to understand rib fractures
- Pelvis responses
  - Off-axis rotations may be an indicator of the pubic ramus fractures

Acknowledgements

Anatomical Donors of… THE OHIO STATE UNIVERSITY

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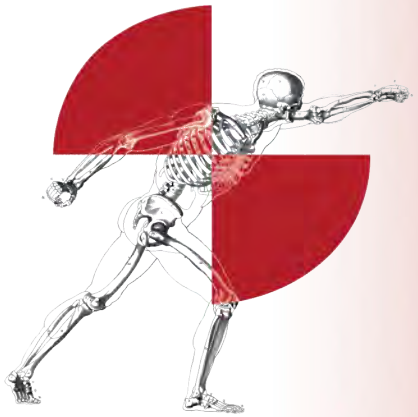
Akshara Sreedhar, Molly Tillis, Myeongkwan Kang,
Angela Tesny, Zac Haverfield, Tim DeWitt, Angela Harden, Randee Hunter

PMHS Biomechanical Responses and Injury Mechanisms in Rear-Facing Rigid Seat Tests

Presenter: Yun-Seok Kang

Injury Biomechanics Research Center, The Ohio State University

RCCADS Public Workshop



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