

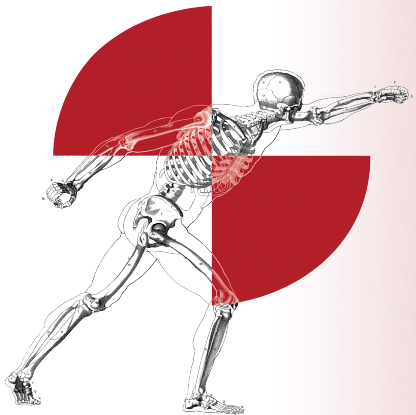
Pelvic Responses and Injuries to Male Post-Mortem Human Subjects (PMHS) in Rear-facing Seat Configurations in High-speed Frontal Impacts

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RCCADS Public Workshop

5/25/2023



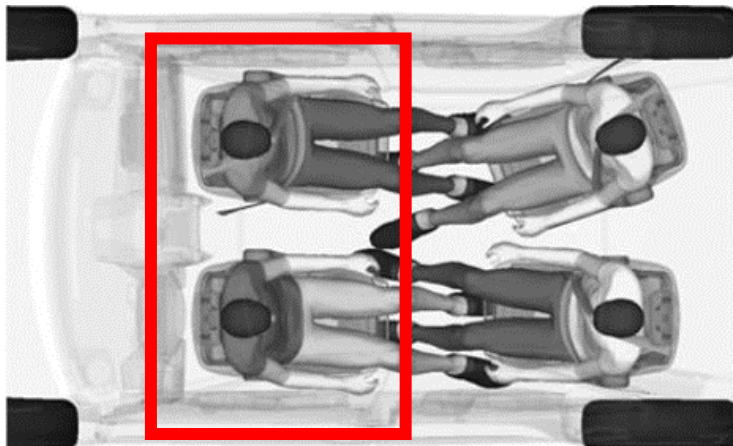
INJURY BIOMECHANICS
R E S E A R C H C E N T E R



THE OHIO STATE UNIVERSITY

Introduction

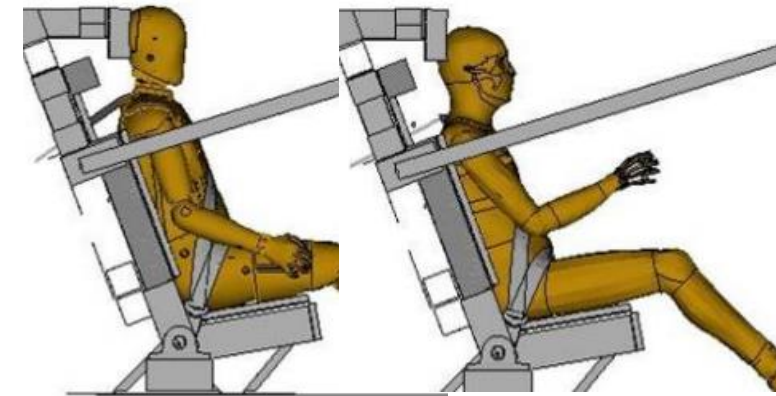
- Future vehicle interior cabin designs may incorporate non-standard seating configurations for vehicles with Automated Driving Systems (ADS)
 - One potential configuration is a reclined seat that is rear-facing in a frontal collision [Jorlov et al., 2017; Koppel et al., 2019; Ostling and Larsson, 2019]
 - 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; Soni et al., 2020



Introduction

- Recent rear-facing studies [Kang et al., 2020 & 2022]
 - PMHS responses and injuries at ΔV of 56km/h
 - Two recline conditions (25deg & 45deg)
 - Original equipment manufacture (OEM) seats with rigid reinforcement
 - ABTS (Kang et al., 2020)
 - FDR (Kang et al., 2022)
- PMHS injuries
 - Cervical spine laxity
 - Upper extremity injuries
 - Lower extremity injuries
 - **Rib fractures**
 - **Pelvis fractures**



ABTS/Odyssey



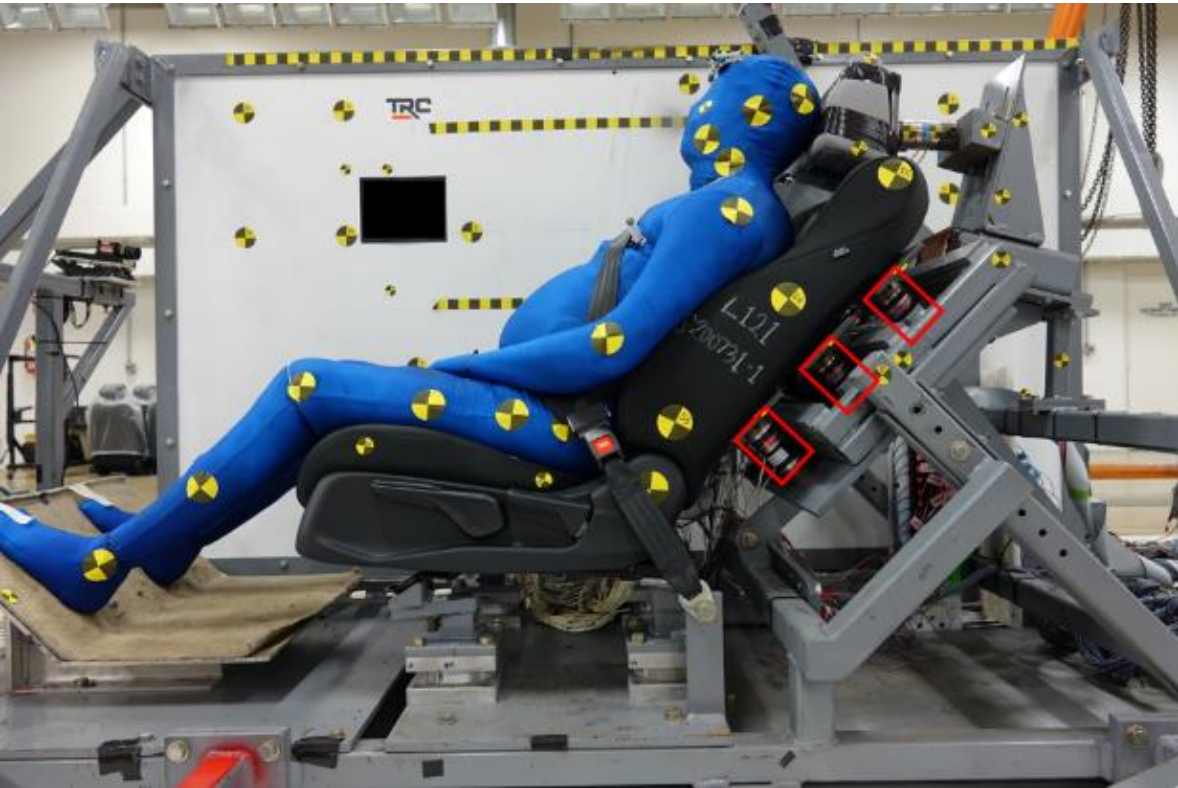
FDR/accord

Objectives

- To investigate pelvis injury and responses in rear-facing seat configurations in high-speed frontal impacts



Sled Buck Description



PMHS14



PMHS21

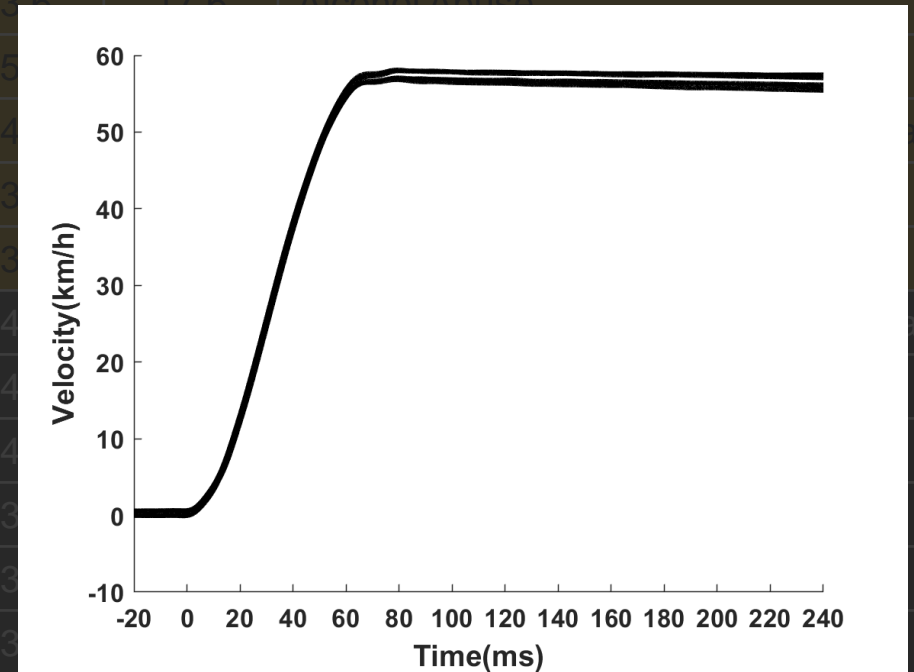
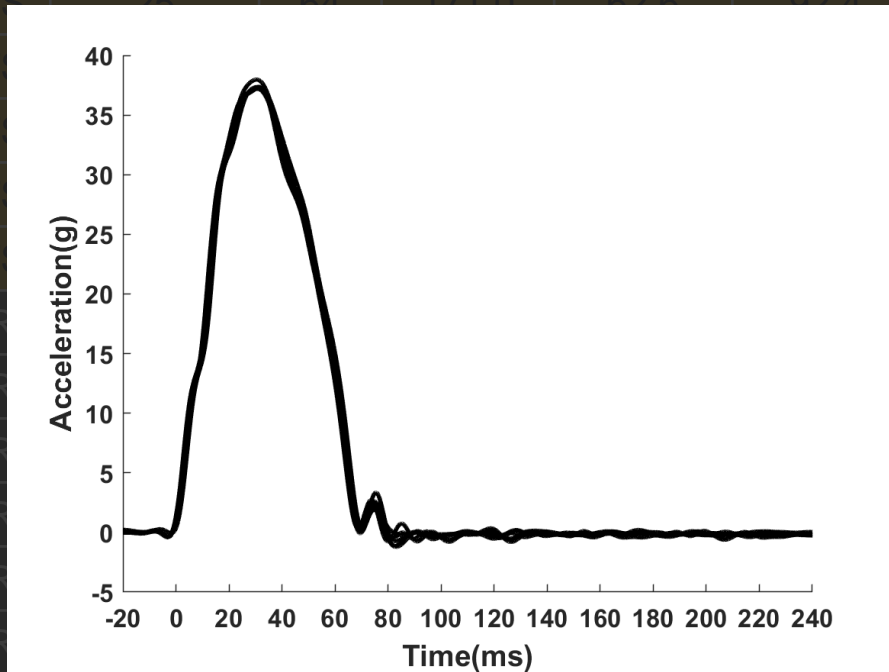


Male PMHS Characteristics – 56 km/h

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

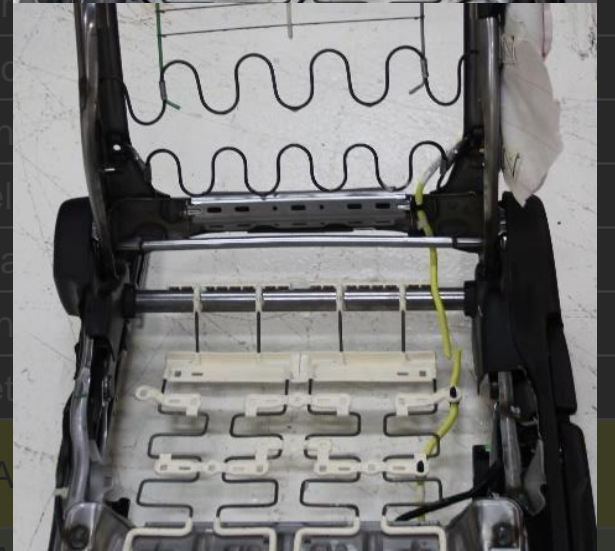
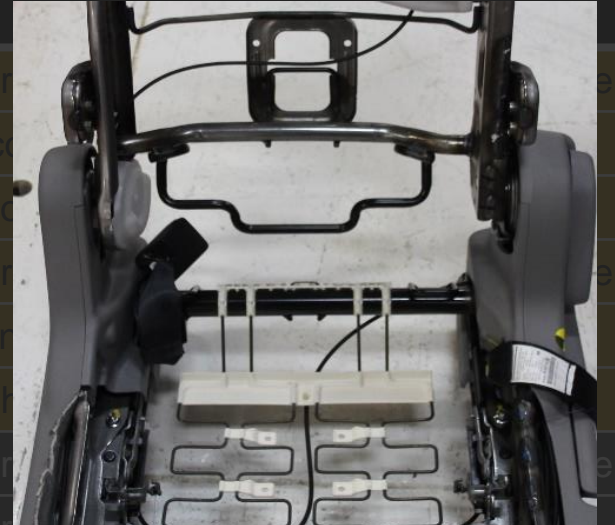
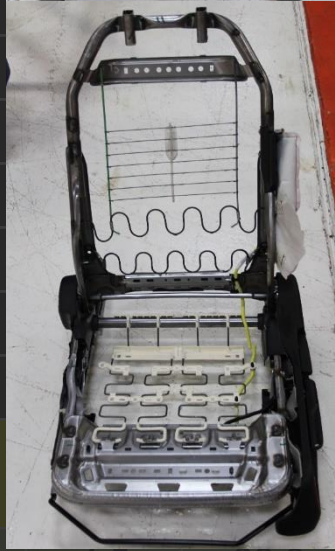
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PMHS02	56	ABTS	25	64	171.0	62.6	92.4	3.6	17.6	Alcohol Abuse
PMHS03	56	ABT								
PMHS04	56	ABT								
PMHS05	56	ABT								
PMHS06	56	ABT								
PMHS09	56	FDR								
PMHS10	56	FDR								
PMHS11	56	FDR								
PMHS12	56	FDR								
PMHS13	56	FDR								
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PMHS21	56	FDR	25	62	172.7	68.5	89.7	3.8	20.2	Lung CA with mets
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50 th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A



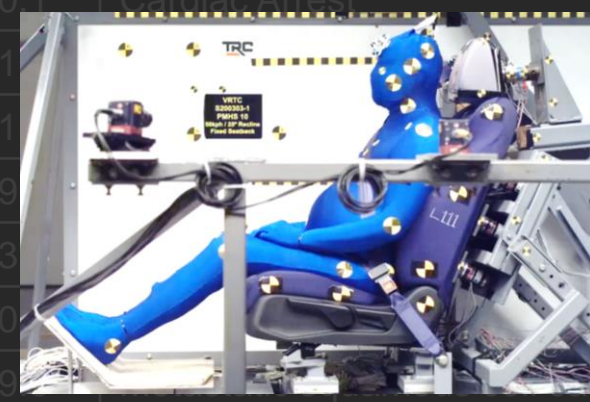
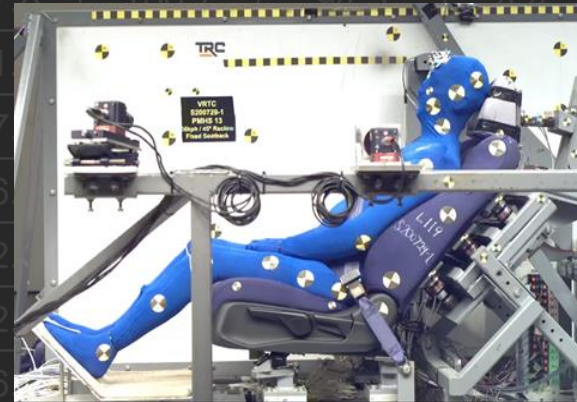
Male PMHS Characteristics – 56 km/h

N=14	Speed	Seat	Recline	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass	Chest Depth	Cause of Death
PMHS01	56	ABTS	45		170.0	70.0	90.0			Chr
PMHS02	56	ABTS	25		172.4	72.4	92.4			Alc
PMHS03	56	ABTS	25		177.0	77.0	97.0			Chr
PMHS04	56	ABTS	45		176.5	76.5	96.5			Chr
PMHS05	56	ABTS	45		175.7	75.7	95.7			Par
PMHS06	56	ABTS	25		174.0	74.0	94.0			Isl
PMHS09	56	FDR	45		176.5	76.5	96.5			Chr
PMHS10	56	FDR	25		174.5	74.5	94.5			Car
PMHS11	56	FDR	25		176.5	76.5	96.5			Str
PMHS12	56	FDR	25		174.2	74.2	94.2			Lun
PMHS13	56	FDR	45		175.7	75.7	95.7			Mel
PMHS14	56	FDR	45		173.0	73.0	93.0			Hea
PMHS21	56	FDR	25		179.7	79.7	99.7			Lun
PMHS22	56	FDR	45		174.1	74.1	94.1			Met
Mean (SD)	N/A	N/A	N/A		174.3 (2.3)	74.3 (2.3)	94.3 (2.3)			N/A
50 th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A

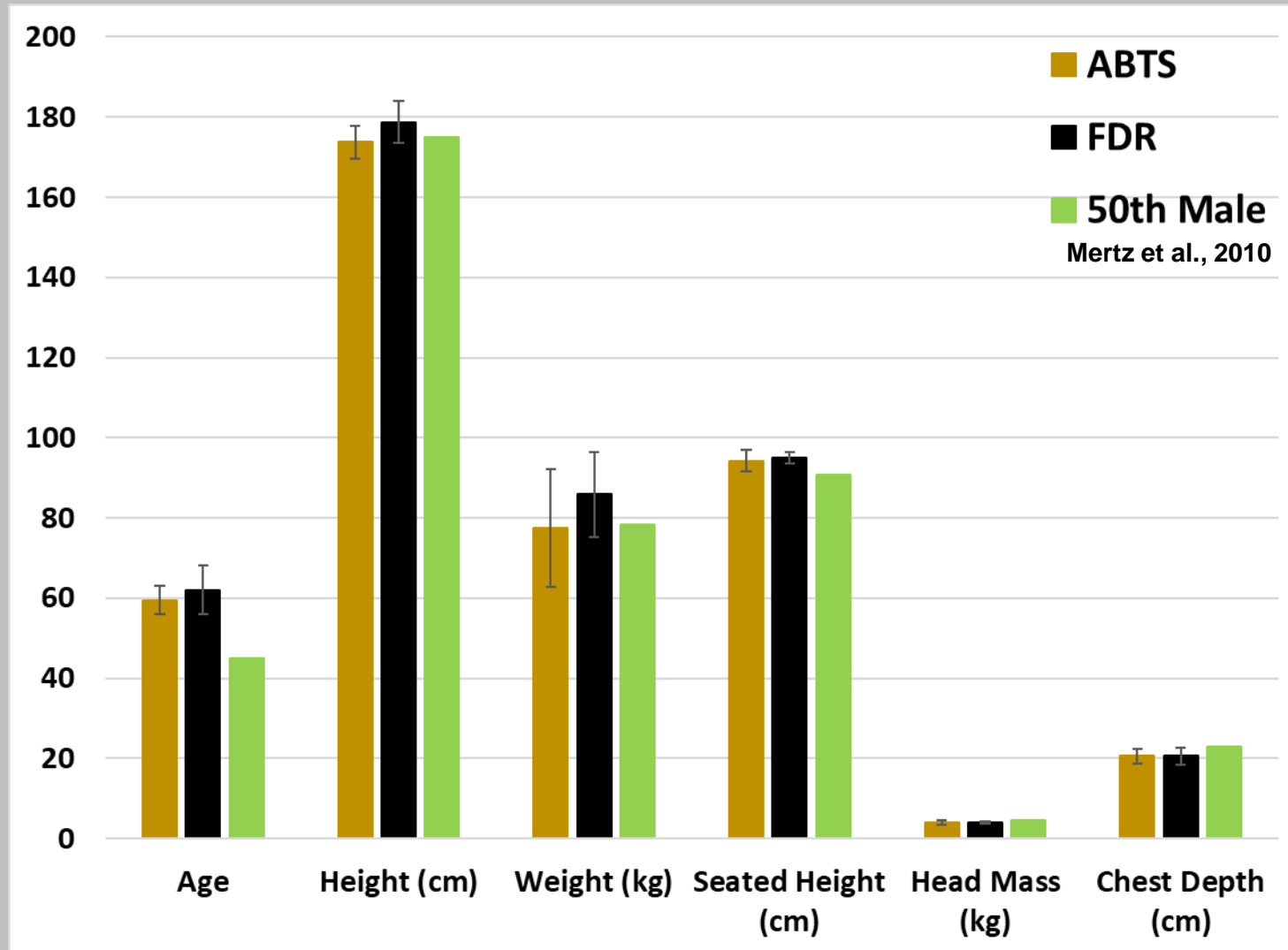


Male PMHS Characteristics – 56 km/h

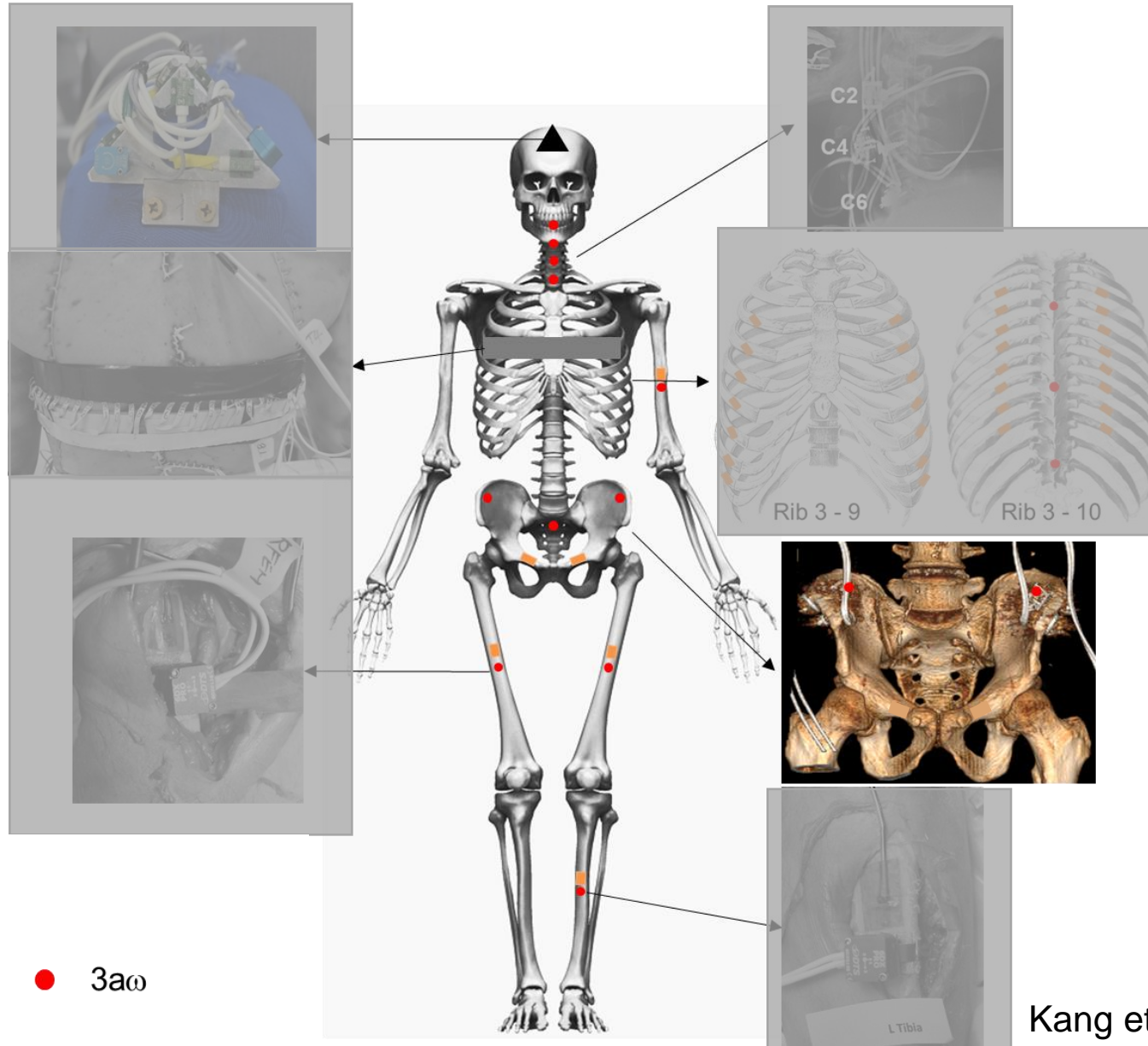
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PMHS05	56	ABTS	45	62	176.0	62.6	92.4	3.6	21.0	Alcohol Abuse
PMHS06	56	ABTS	25	61	176.0	62.6	92.4	3.6	20.0	Alcohol Abuse
PMHS09	56	FDR	45	71	187.0	100.7	94.5	4.4	17.0	Alcohol Abuse
PMHS10	56	FDR	25	62	177.0	100.7	94.5	4.4	20.1	Cardiac Arrest
PMHS11	56	FDR	25	65	181.0	100.7	94.5	4.4	21.0	Alcohol Abuse
PMHS12	56	FDR	25	58	177.0	100.7	94.5	4.4	21.0	Alcohol Abuse
PMHS13	56	FDR	45	53	176.0	100.7	94.5	4.4	19.0	Alcohol Abuse
PMHS14	56	FDR	45	63	172.0	100.7	94.5	4.4	23.0	Alcohol Abuse
PMHS21	56	FDR	25	62	172.0	100.7	94.5	4.4	20.0	Alcohol Abuse
PMHS22	56	FDR	45	61	176.0	100.7	94.5	4.4	19.0	Alcohol Abuse
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
50 th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9	N/A



Male PMHS Characteristics – 56 km/h



PMHS Instrumentation



● 3aω

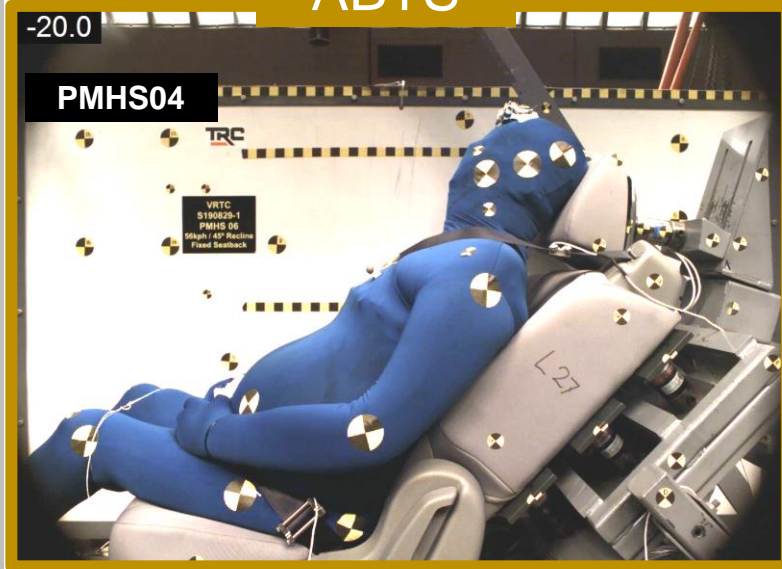
Kang et al., 2020 & 2022



High Speed Videos

ABTS

45 deg



FDR

-20.0

PMHS09

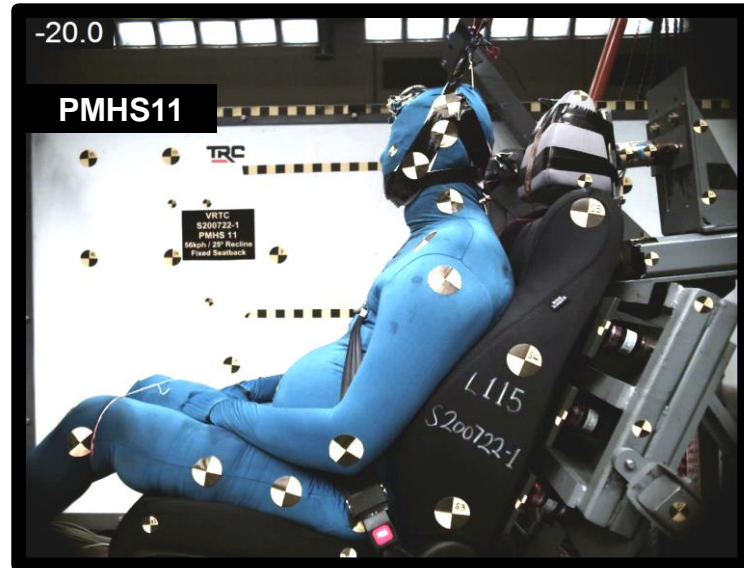


25 deg

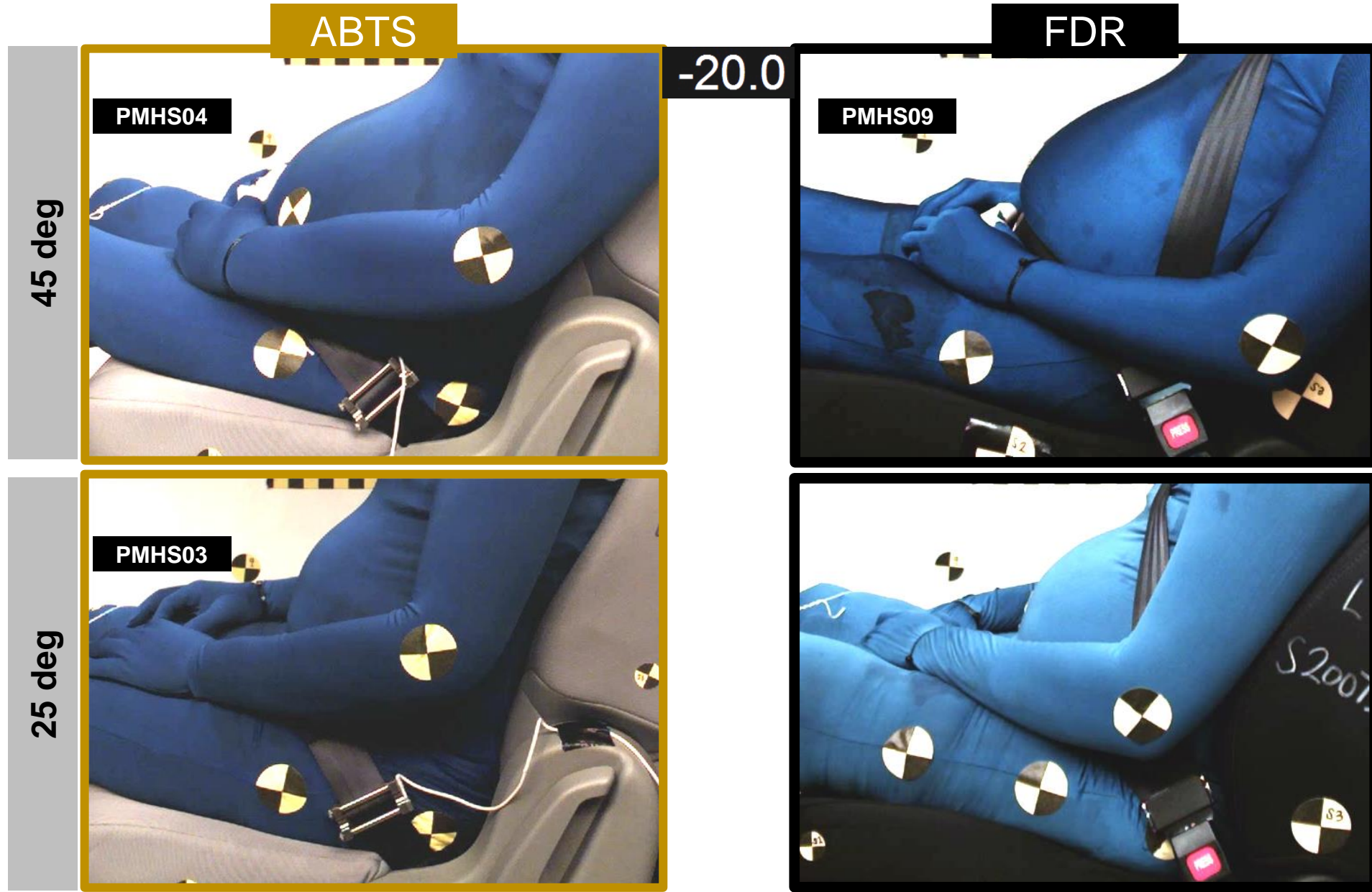


-20.0

PMHS11



High Speed Videos



56 kph, 45 deg

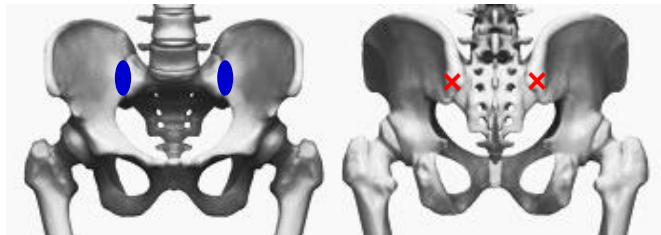
✗ Fracture
● SI Joint damage

ABTS

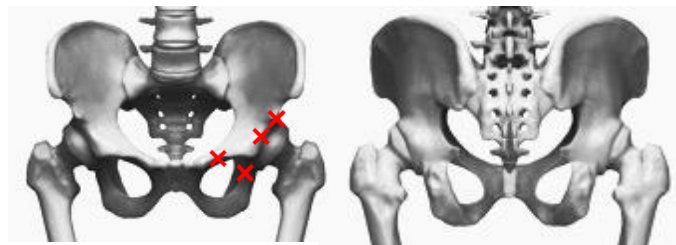


No Injury

PMHS01

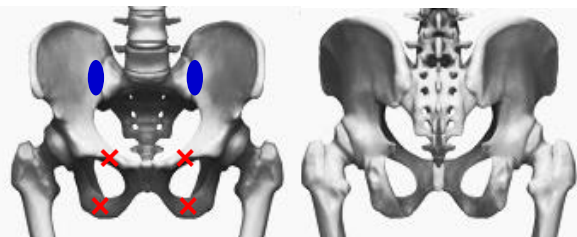


PMHS04

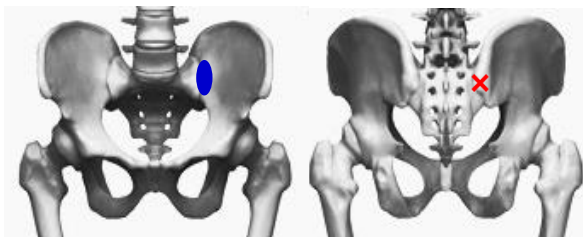


PMHS05

FDR



PMHS09



PMHS13



No Injury

PMHS14



PMHS22

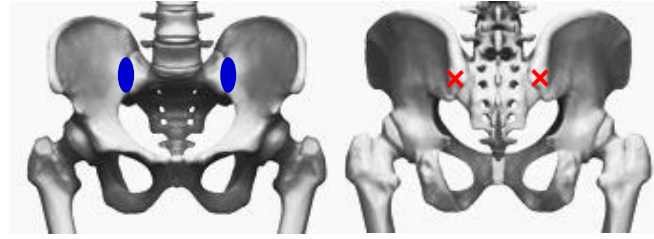
56 kph, 45 deg

✗ Fracture
● SI Joint damage

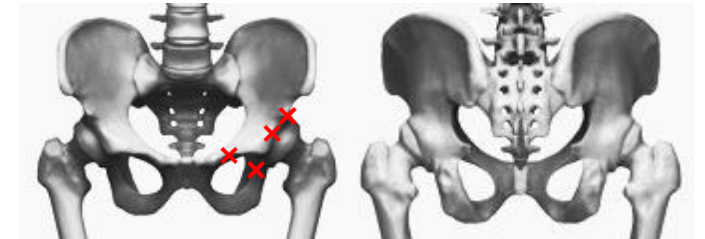


No Injury

PMHS01



PMHS04



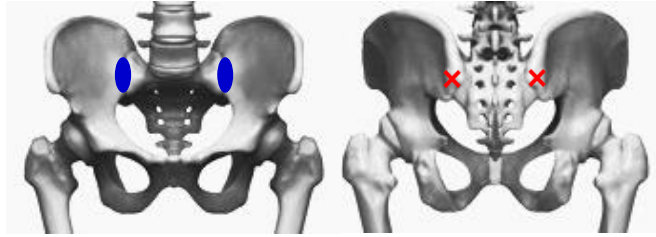
PMHS05

56 kph, 45 deg

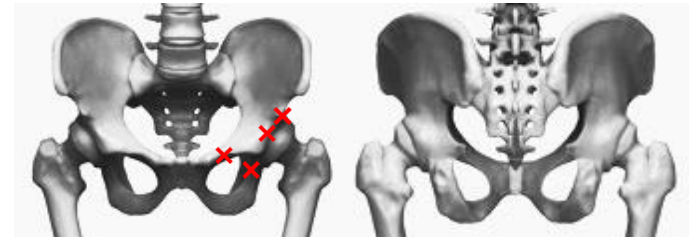
✗ Fracture
● Joint damage



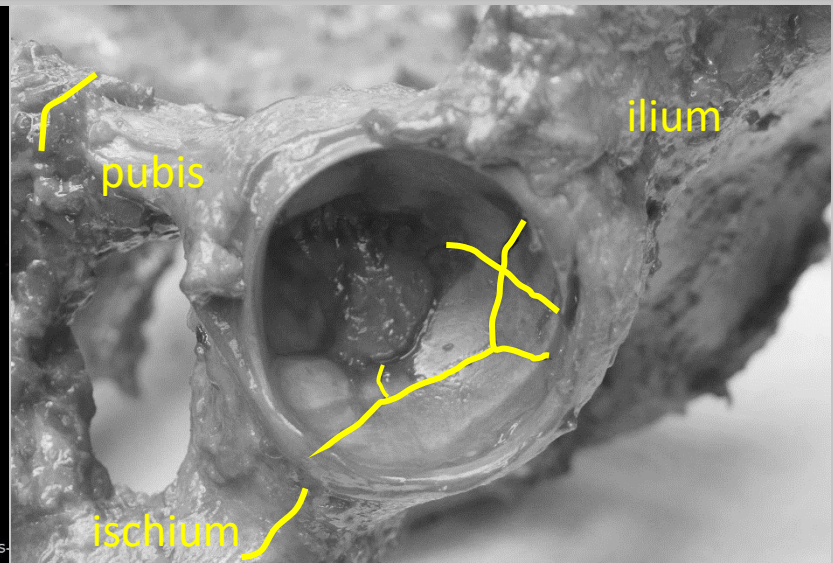
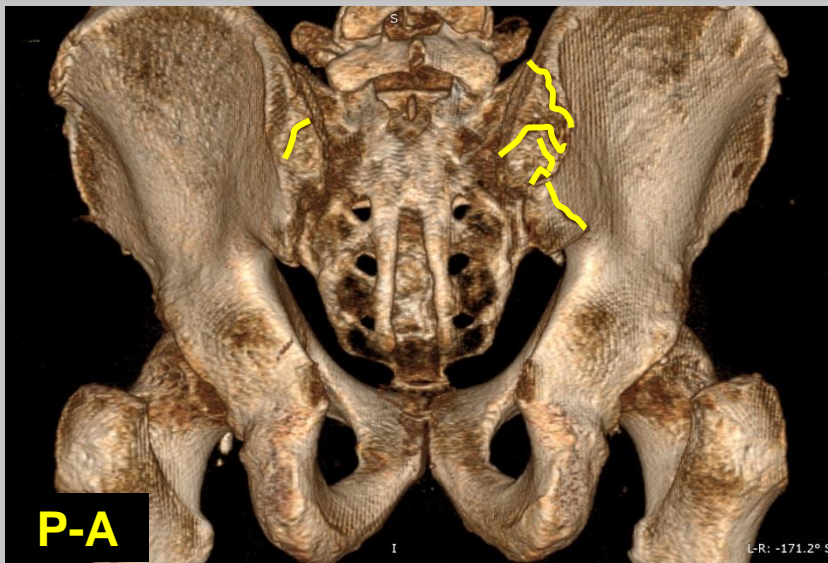
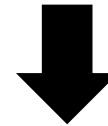
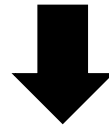
PMHS01



PMHS04



PMHS05



56 kph, 45 deg

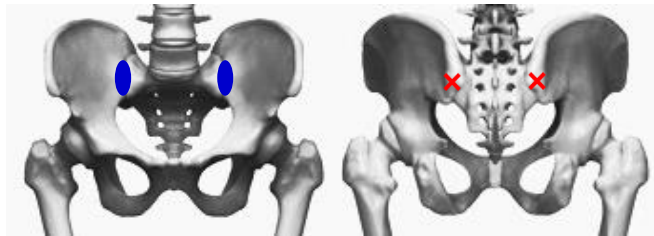
✗ Fracture
● Joint damage

ABTS

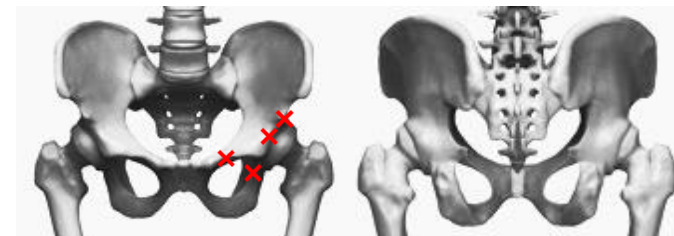


No Injury

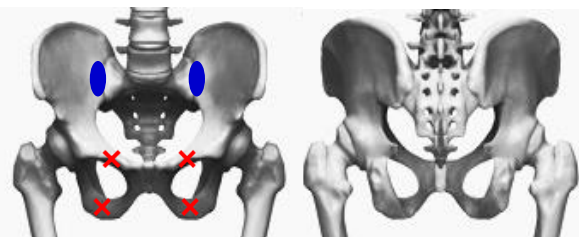
PMHS01



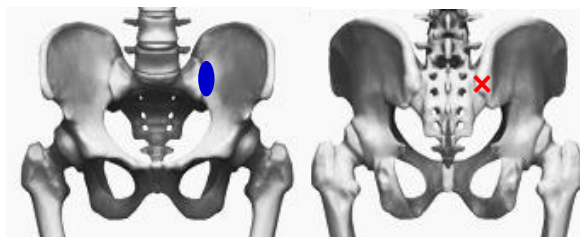
PMHS04



PMHS05



PMHS09



PMHS13



No Injury

PMHS14

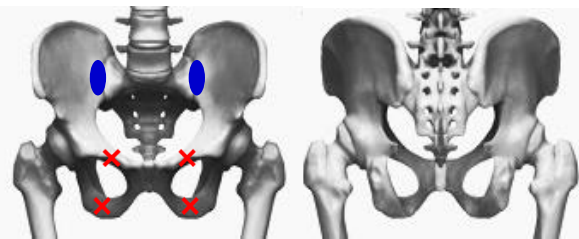


PMHS22

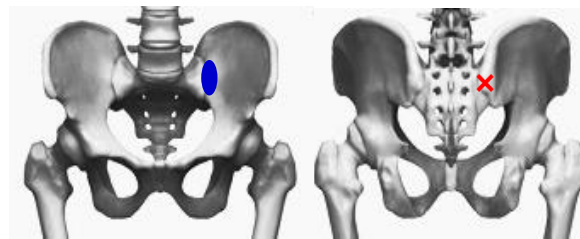
FDR

56 kph, 45 deg

FDR



PMHS09



PMHS13

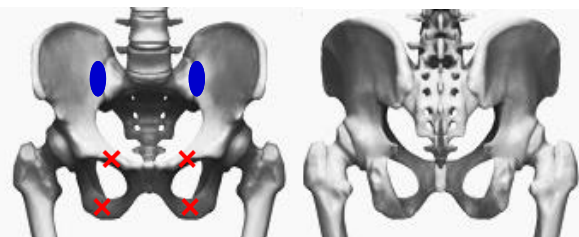
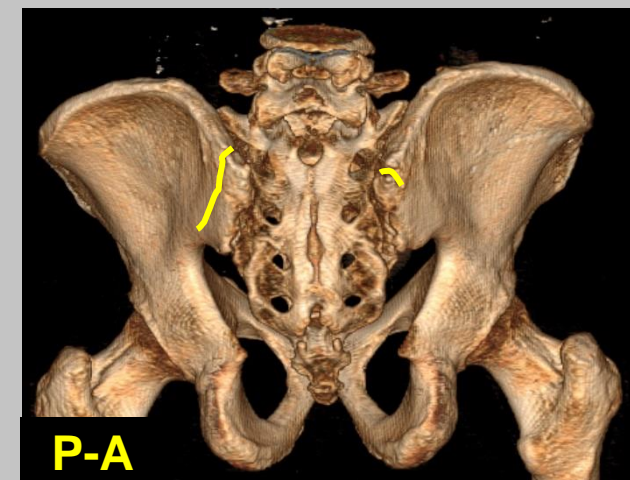
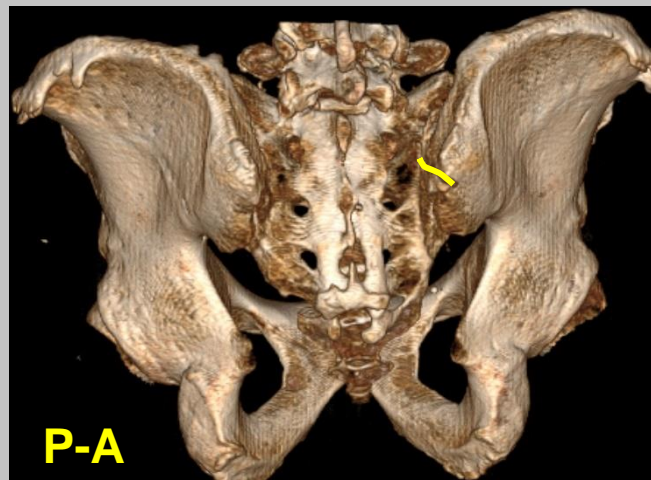
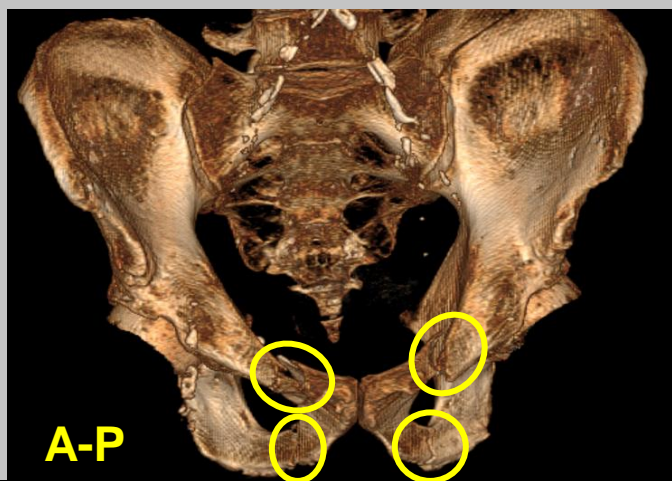


PMHS14

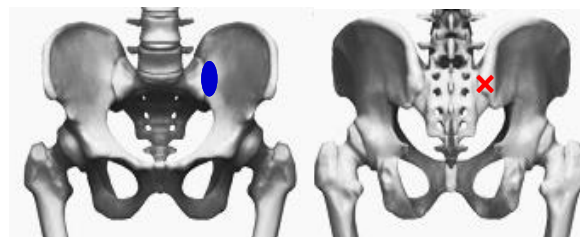


PMHS22

56 kph, 45 deg



PMHS09



PMHS13



No Injury

PMHS14



PMHS22

FDR

✗ Fracture
● Joint damage

56 kph, 25 deg

ABTS



PMHS02

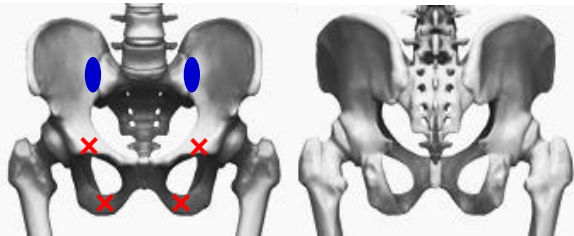


PMHS03



PMHS06

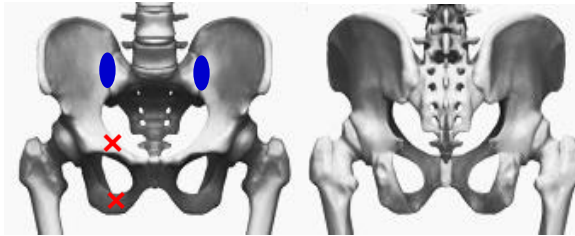
FDR



PMHS10



PMHS11



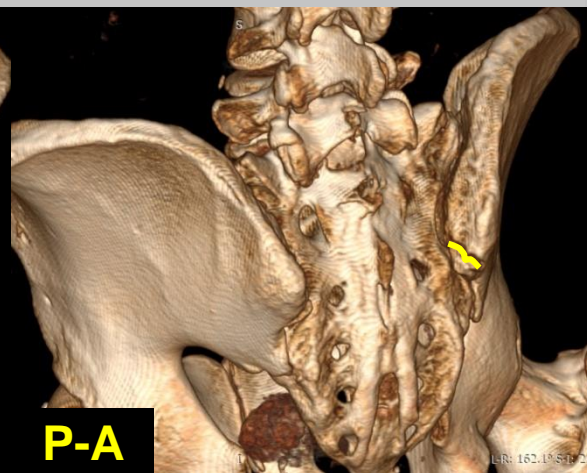
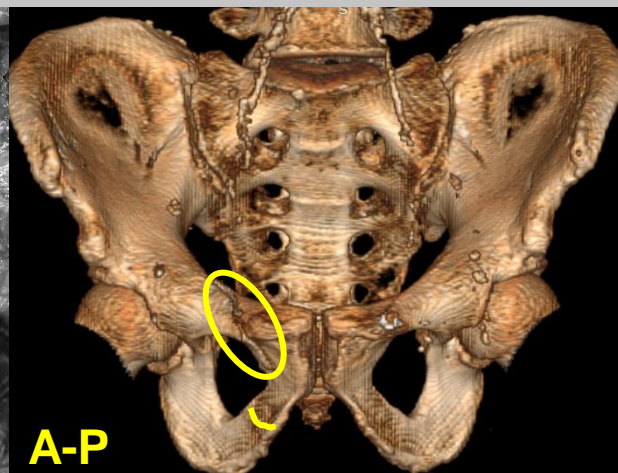
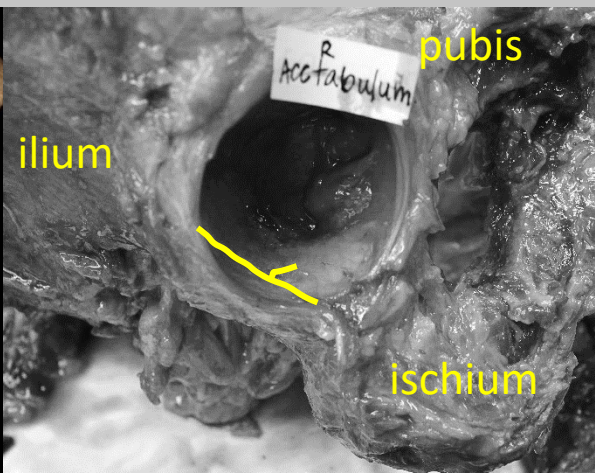
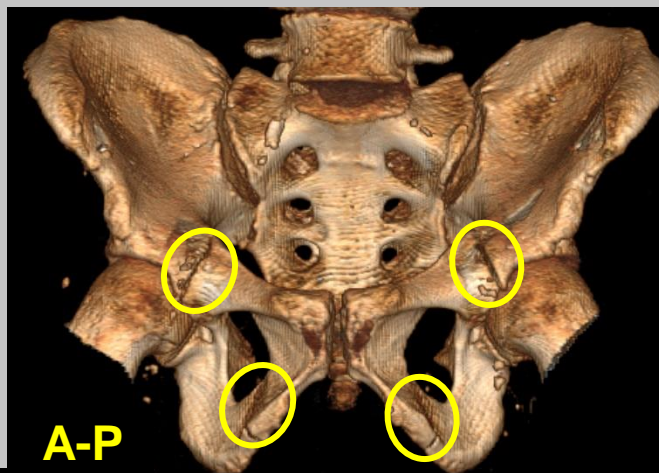
PMHS12



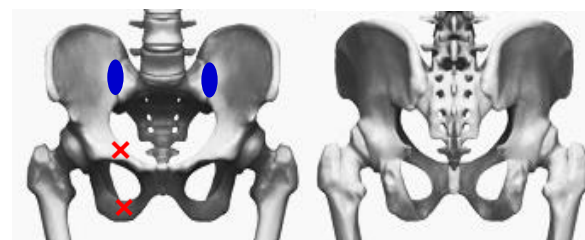
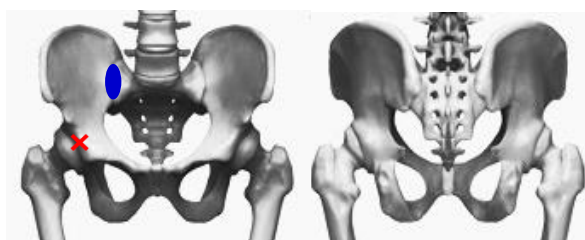
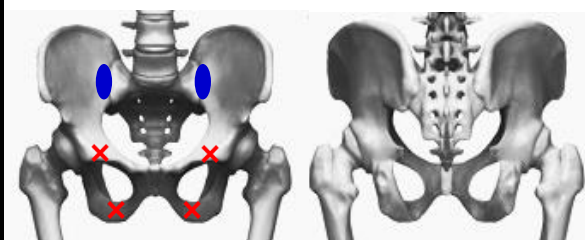
PMHS21

56 kph, 25 deg

✗ Fracture
● Joint damage



FDR



56 kph, 25 deg

✗ Fracture
● Joint damage



PMHS02

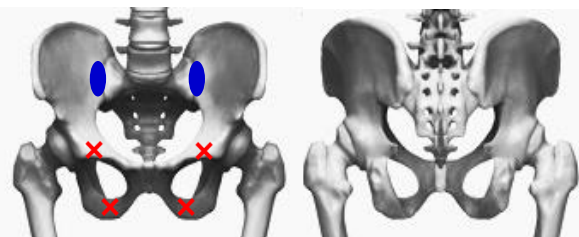


PMHS03

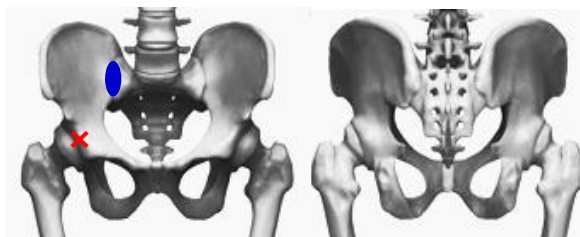


PMHS06

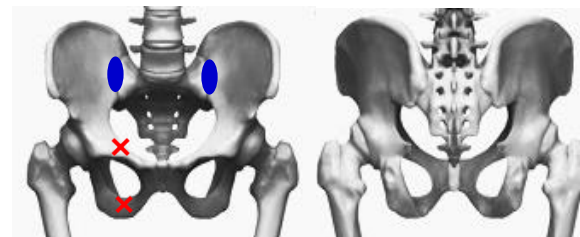
Why?



PMHS10



PMHS11

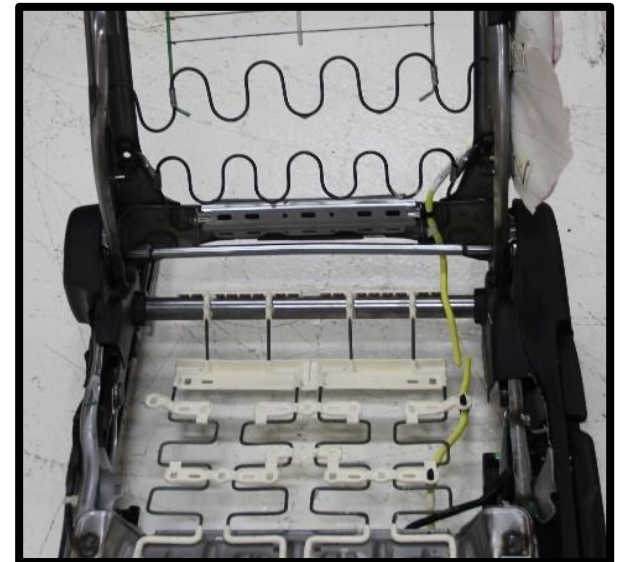
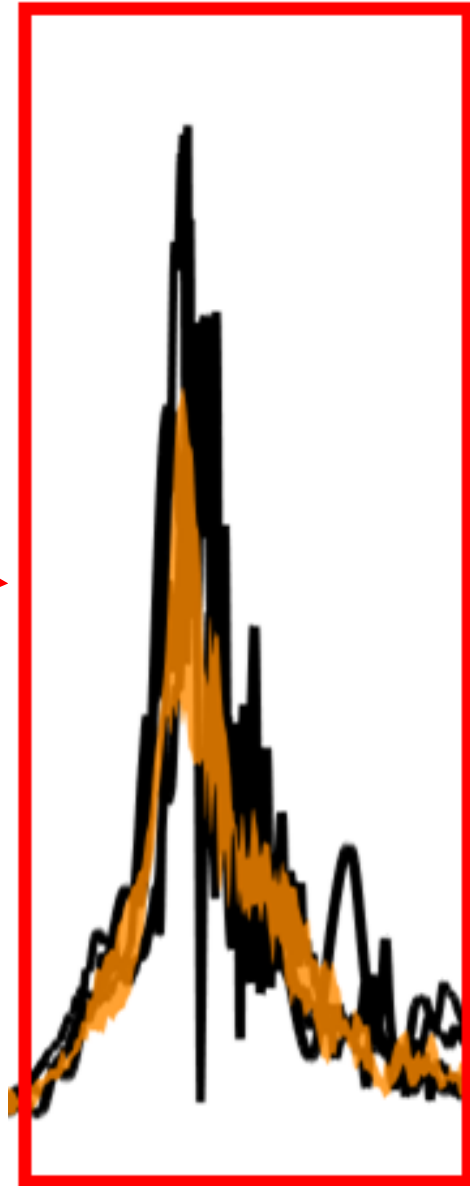
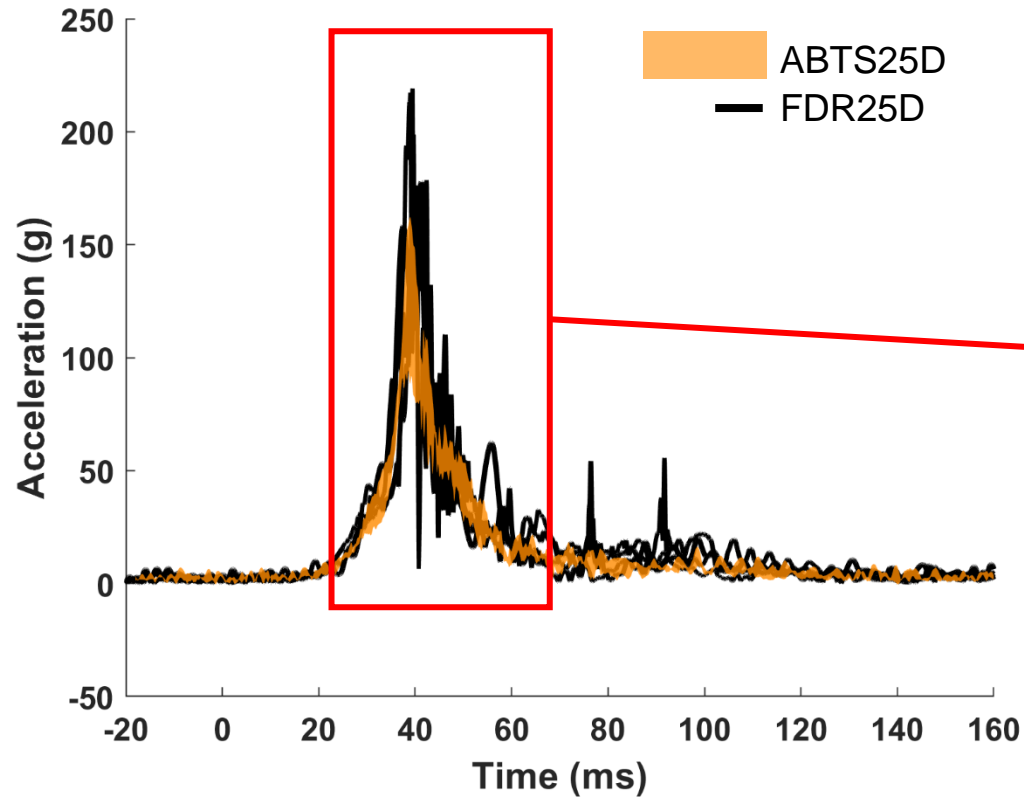


PMHS12

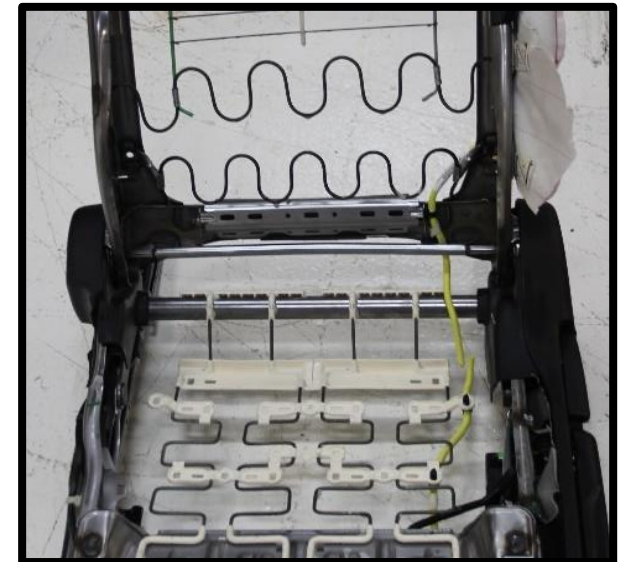
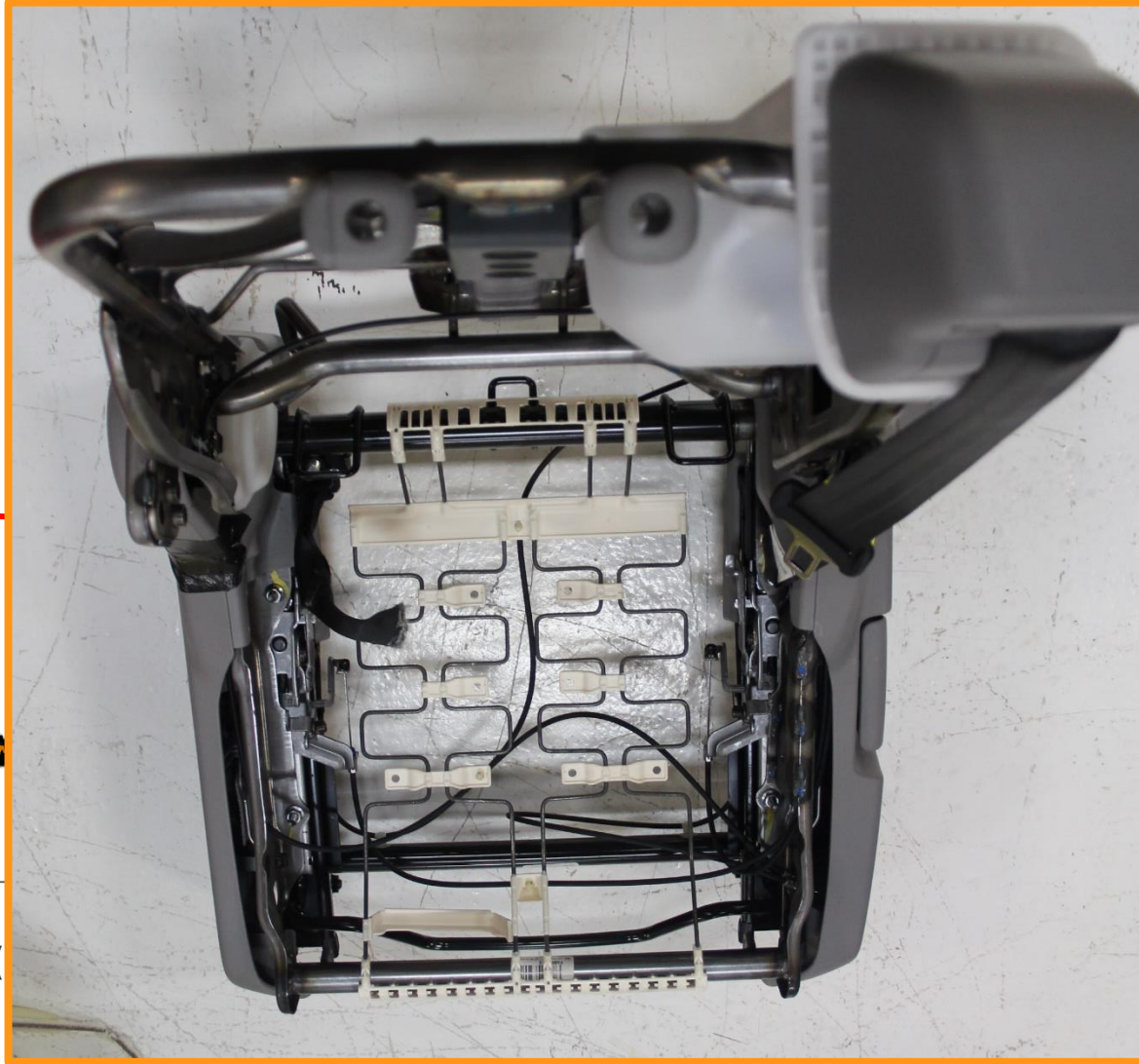
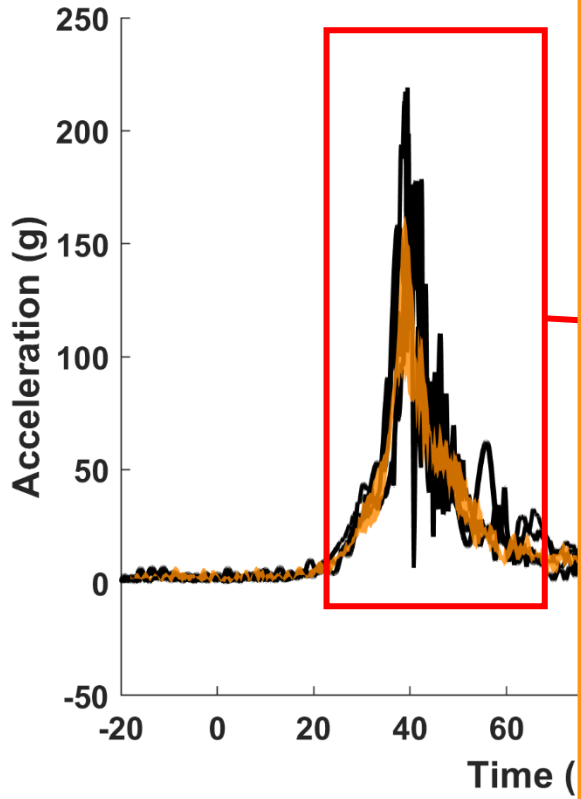


PMHS21

Pelvis Resultant Acceleration

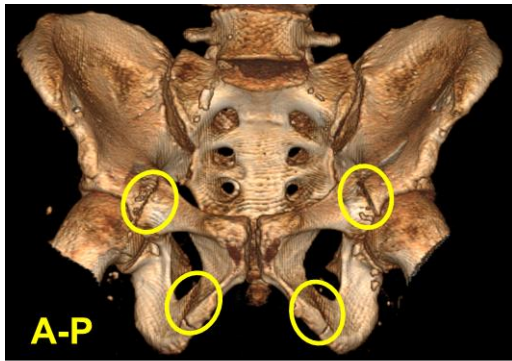


Pelvis Resultant Acceleration

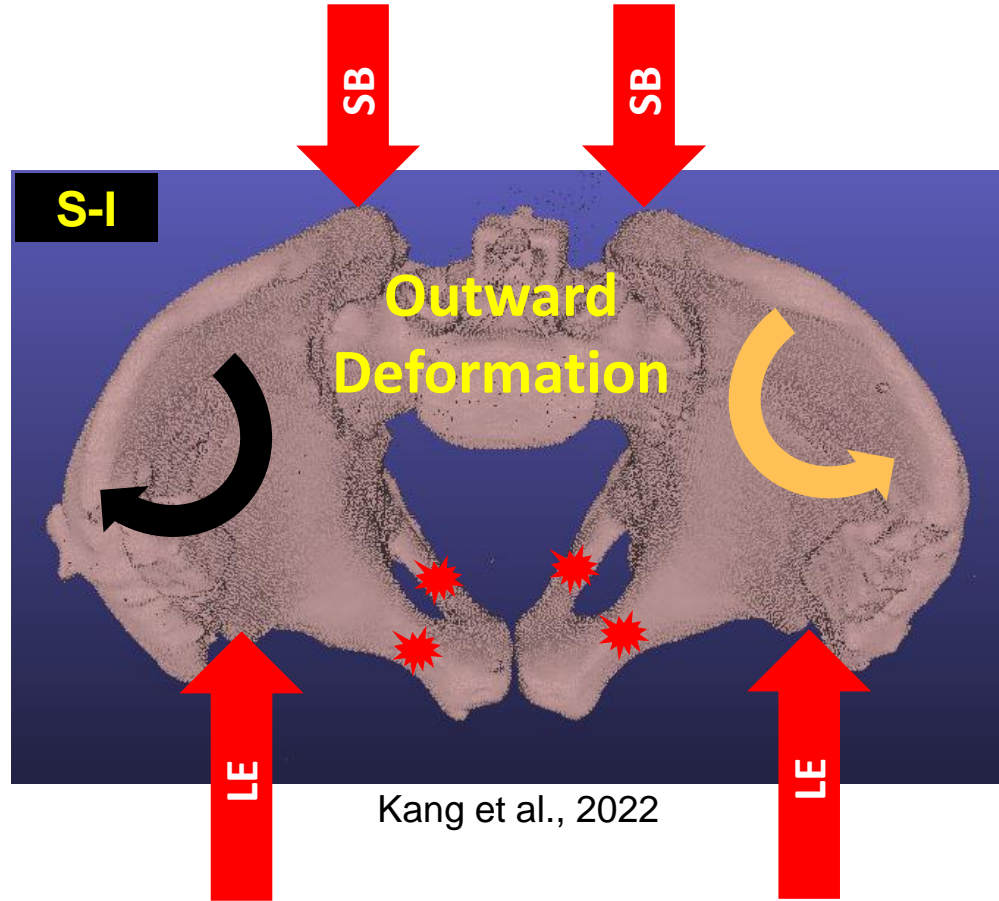
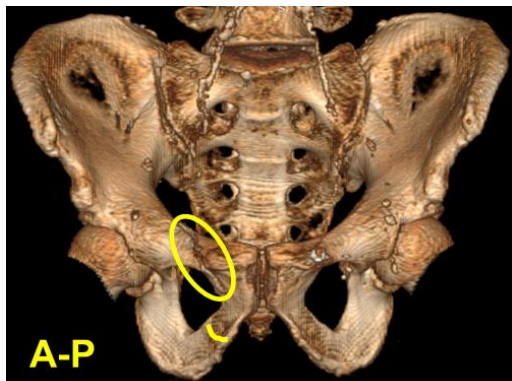


Pubic Ramus Fracture

PMHS10
FDR25D



PMHS12
FDR25D



- Thigh: ~7kg
- Leg: ~3kg

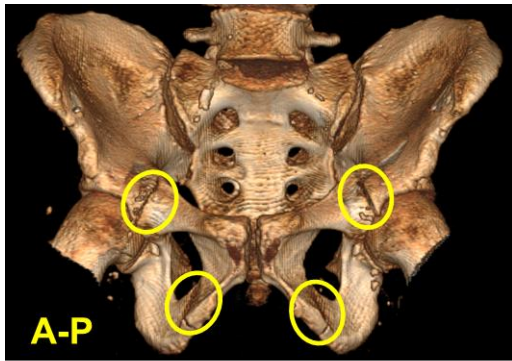
$$(7+3)\text{kg} \times 90\text{g} \times 9.81 = 8.8\text{kN}$$

$$(7+3)\text{kg} \times 90\text{g} \times 9.81 = 8.8\text{kN}$$

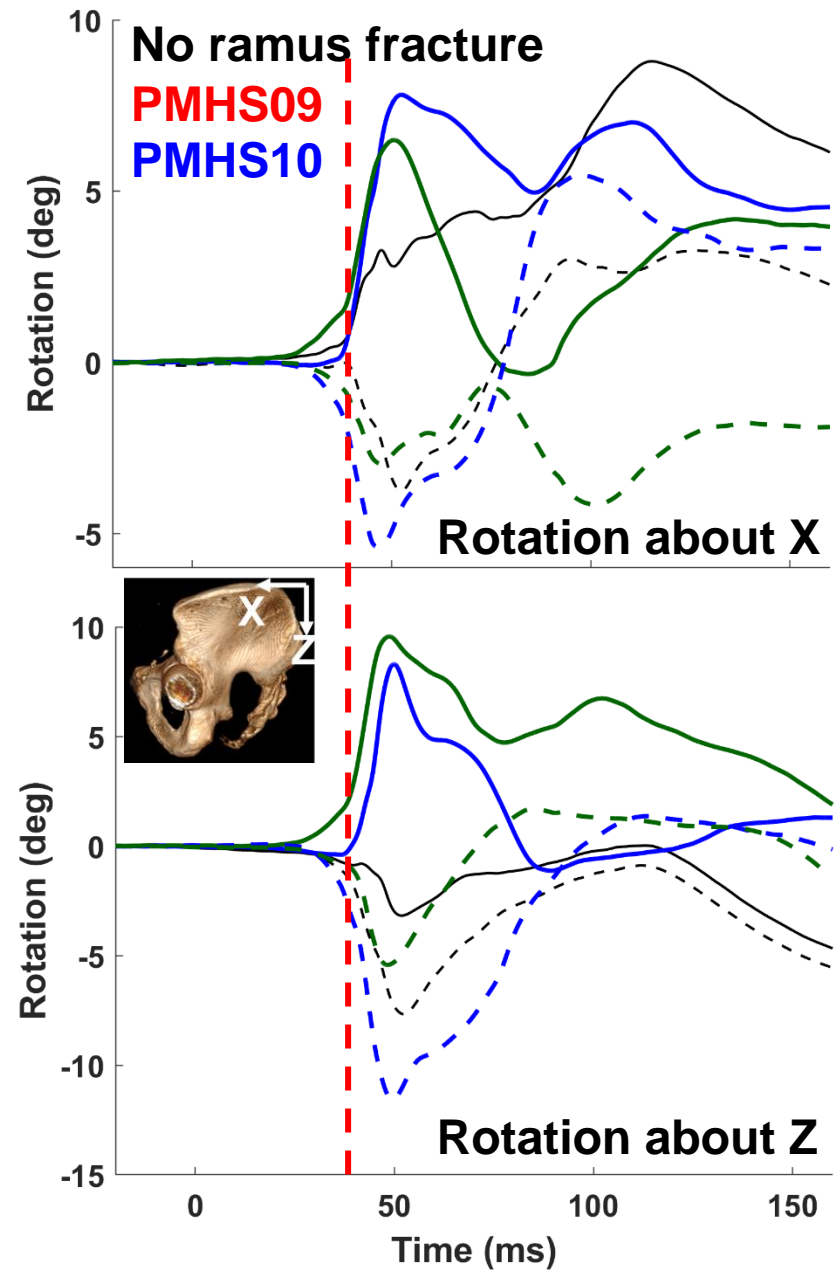
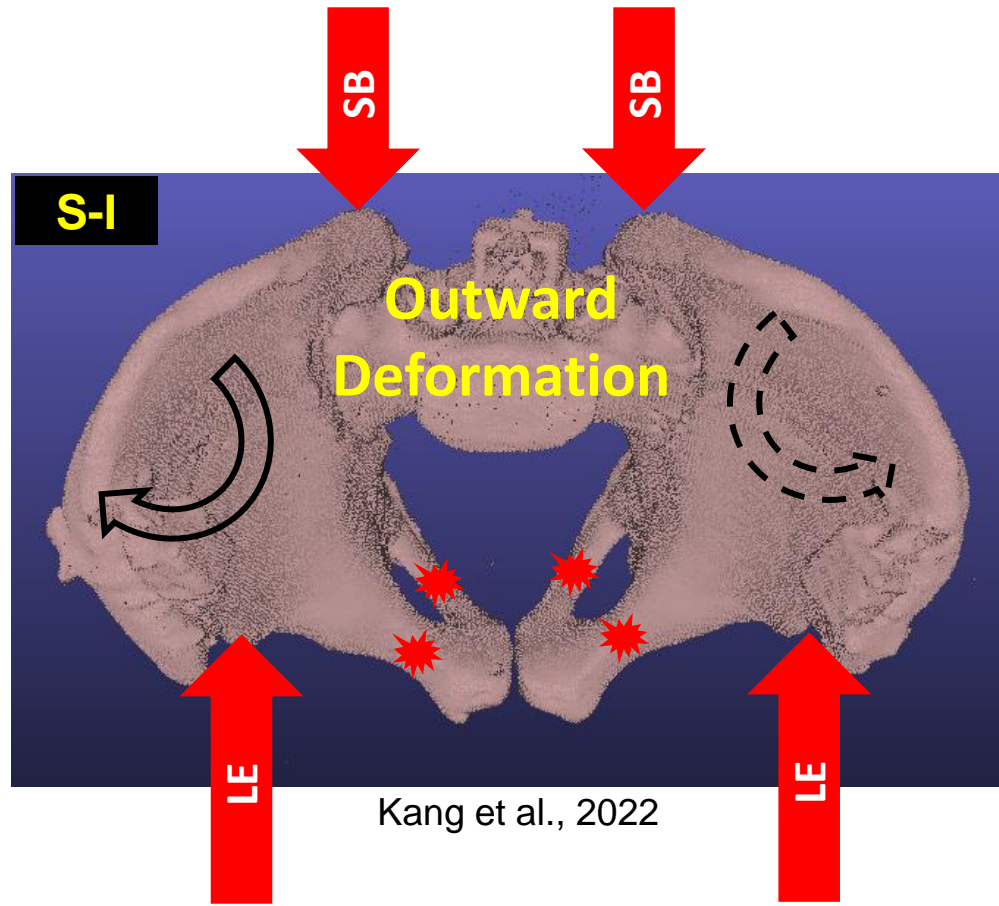
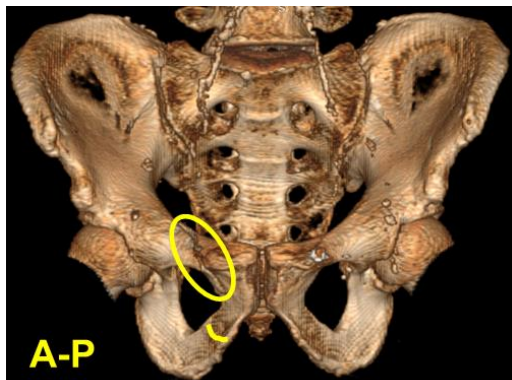


Pelvis Outward Deformation

PMHS10
FDR25D

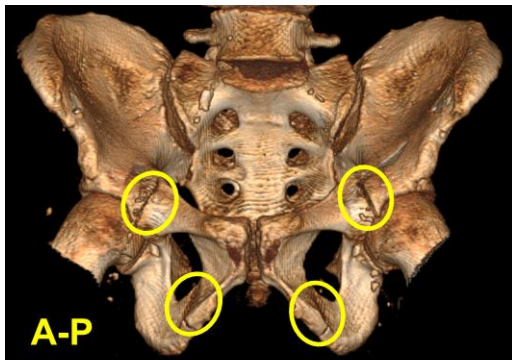


PMHS12
FDR25D

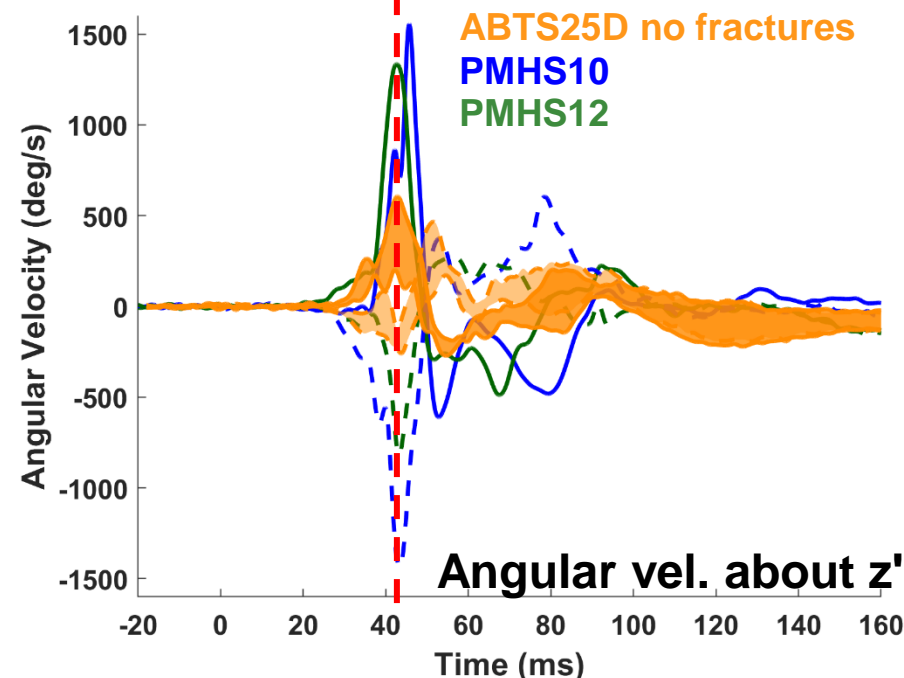
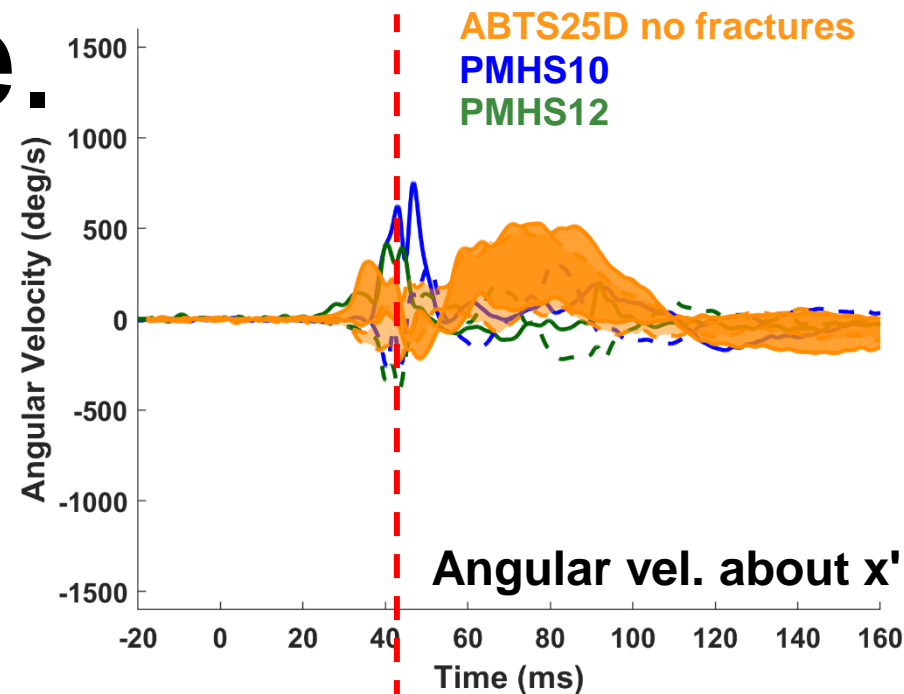
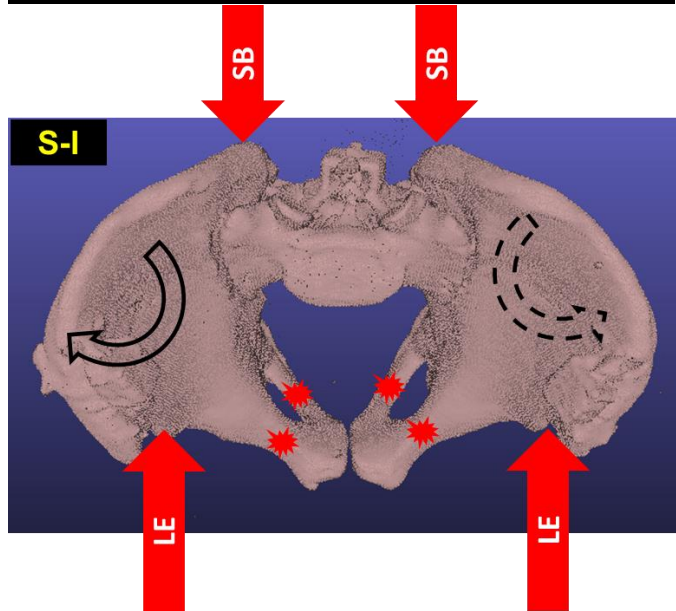
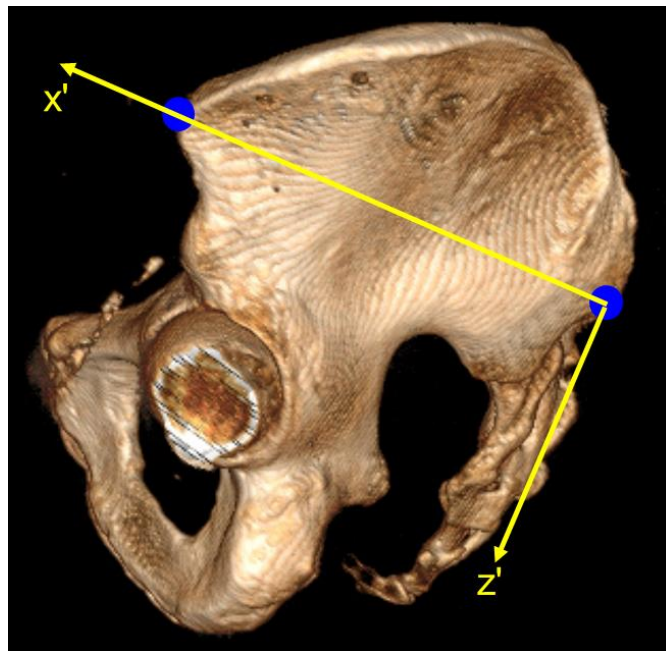
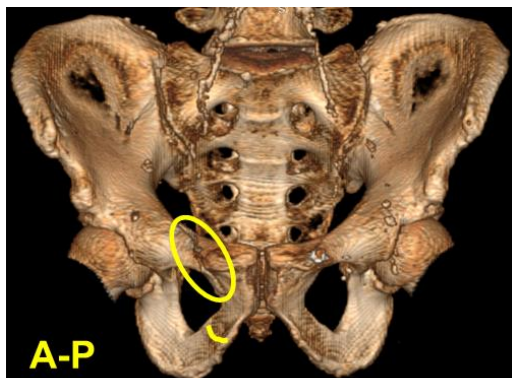


Pelvis Off-axis Local Kine.

PMHS10
FDR25D



PMHS12
FDR25D



56 kph, 25 deg

✖ Fracture
● Joint damage



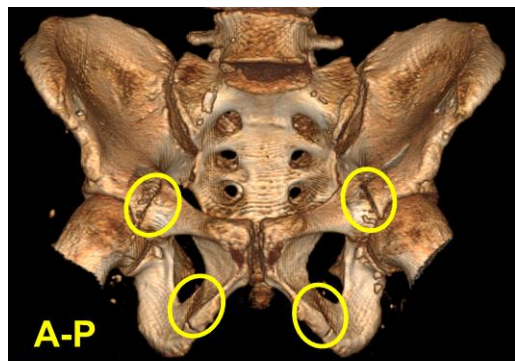
PMHS02



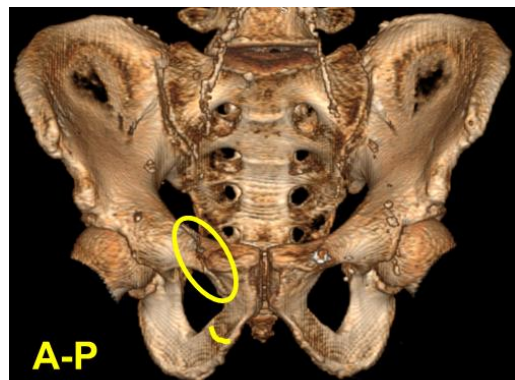
PMHS03



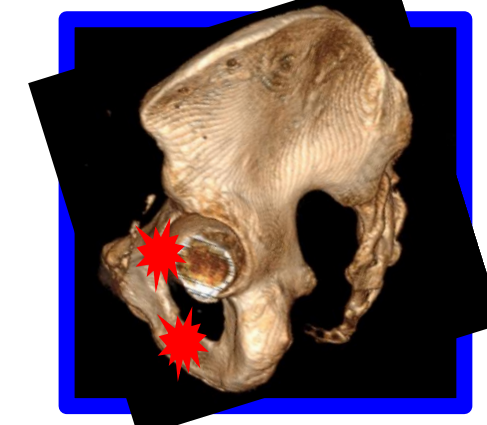
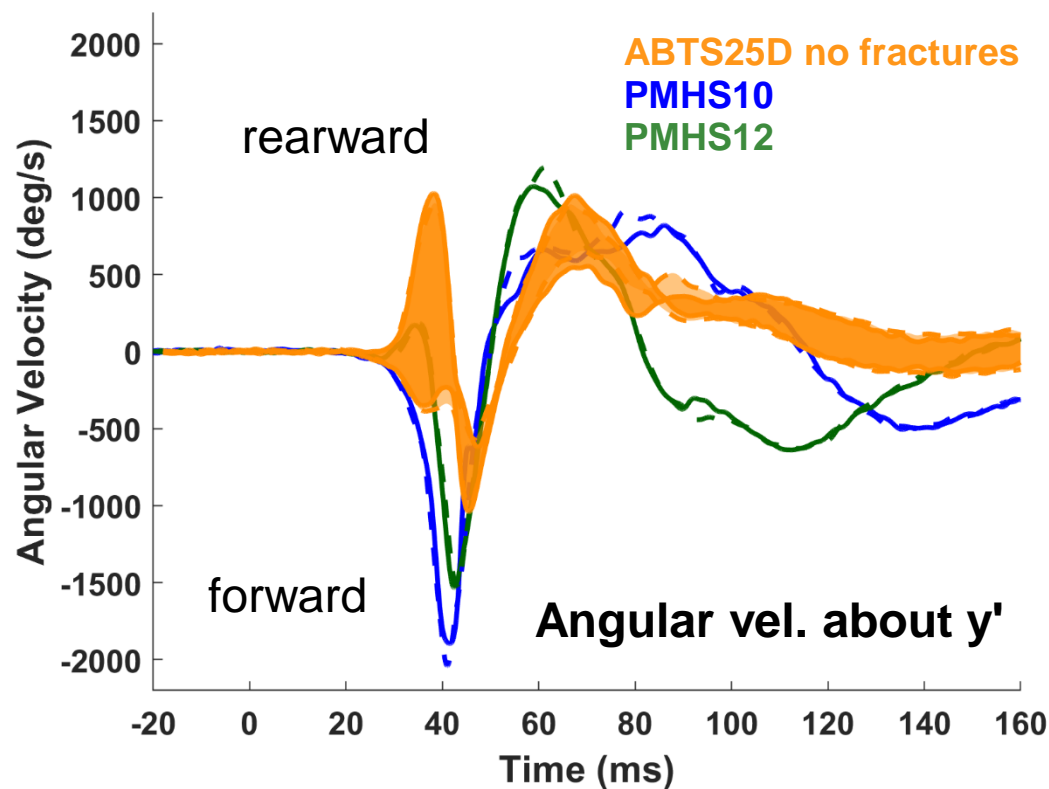
PMHS06



PMHS10
FDR25D

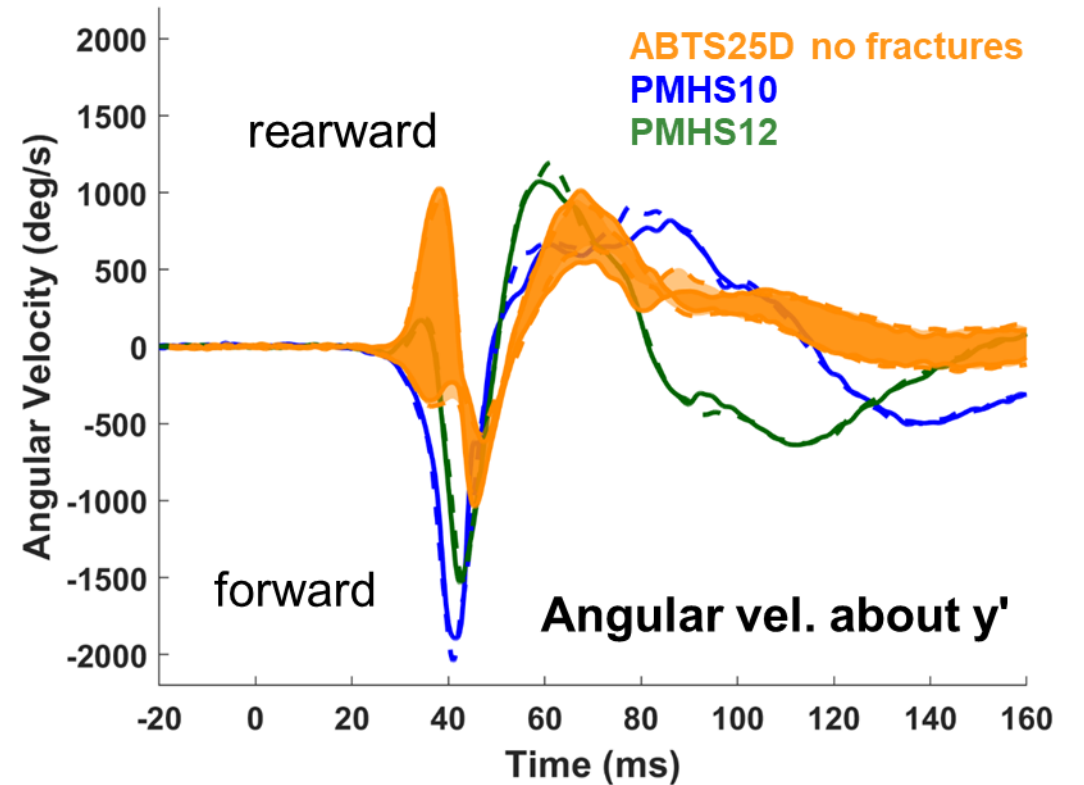
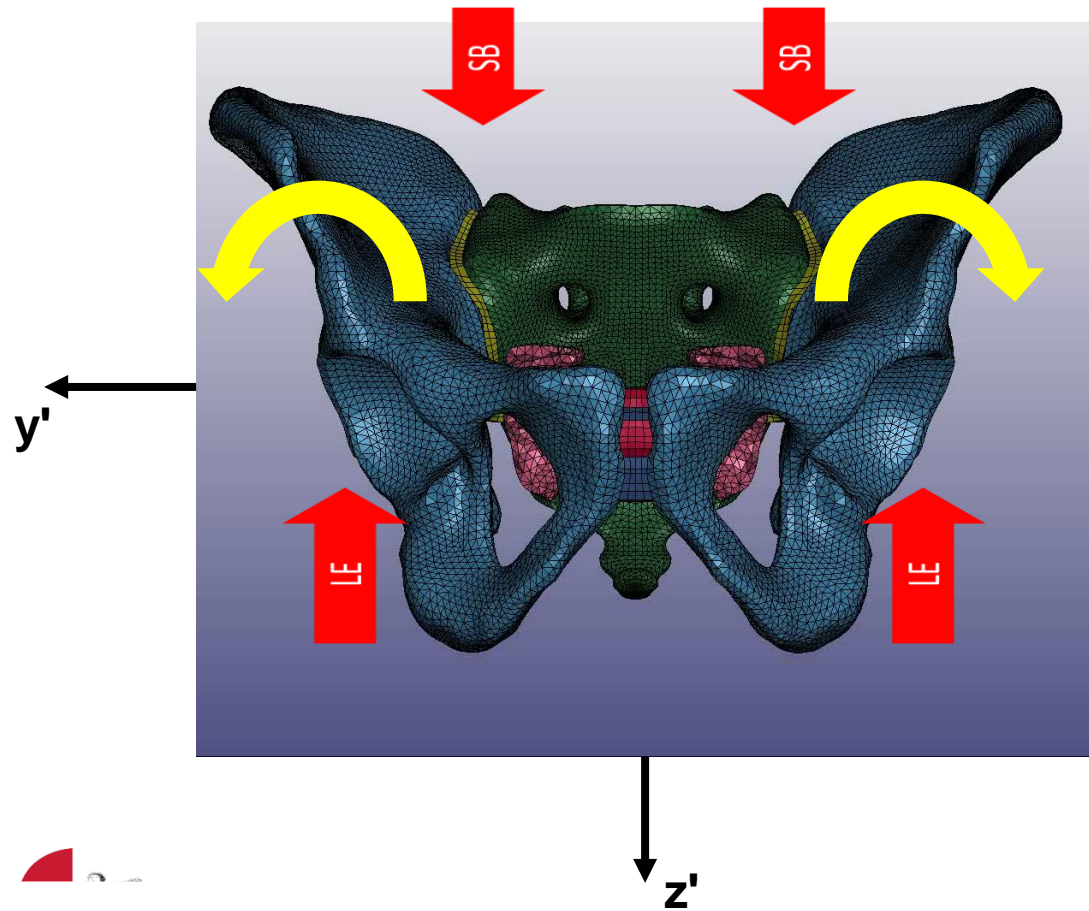


PMHS12
FDR25D



Pelvis Outward Deformation

- Pubic ramus fractures in GHBMC
 - Large forward angular velocity about y' axis



56 kph, 25 deg

✗ Fracture
● Joint damage



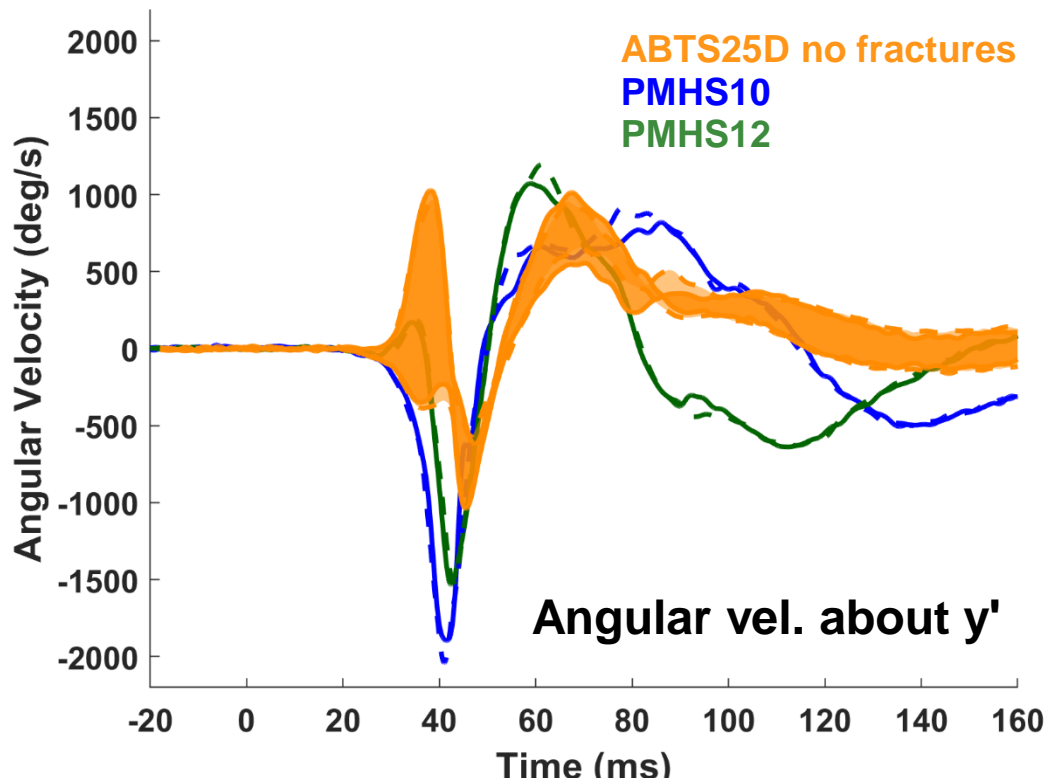
PMHS02



PMHS03



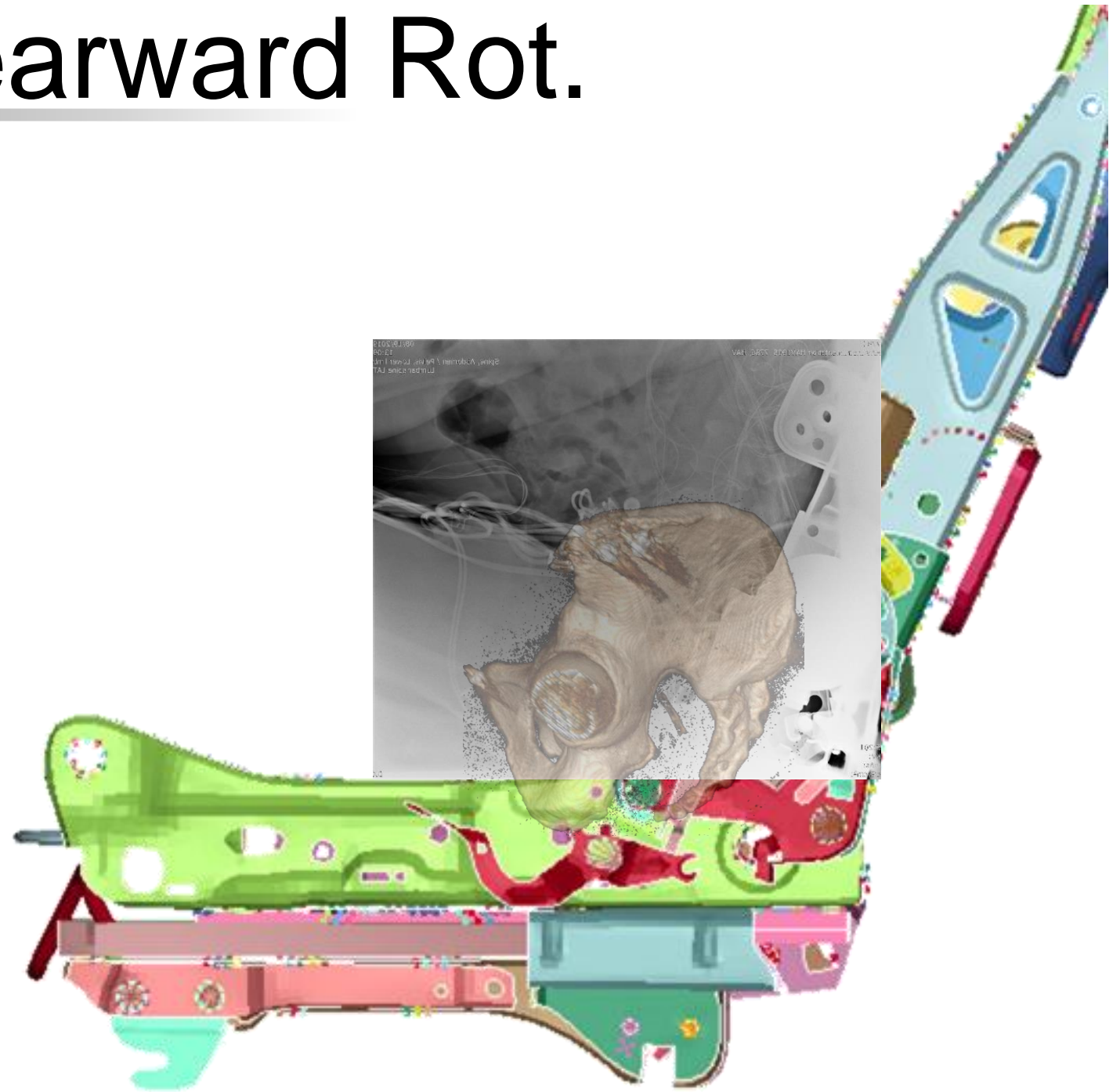
PMHS06



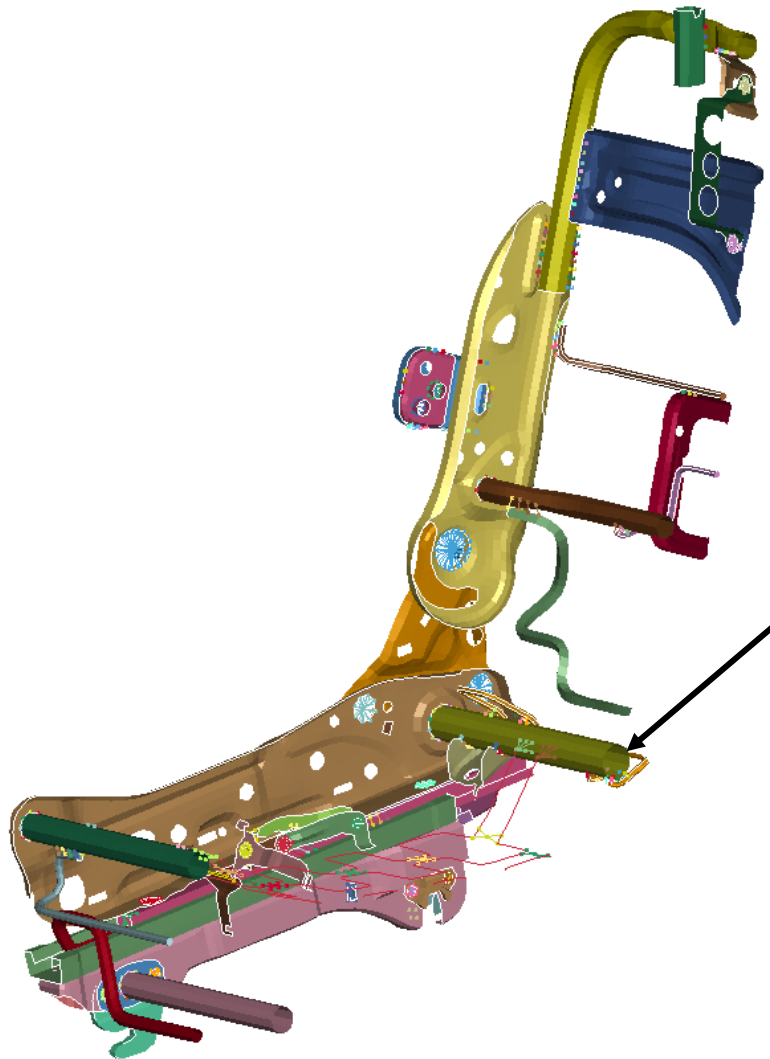
Why?



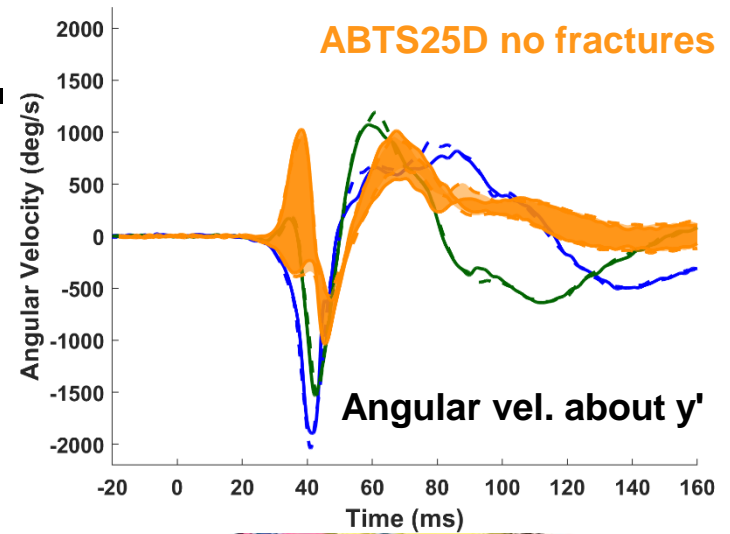
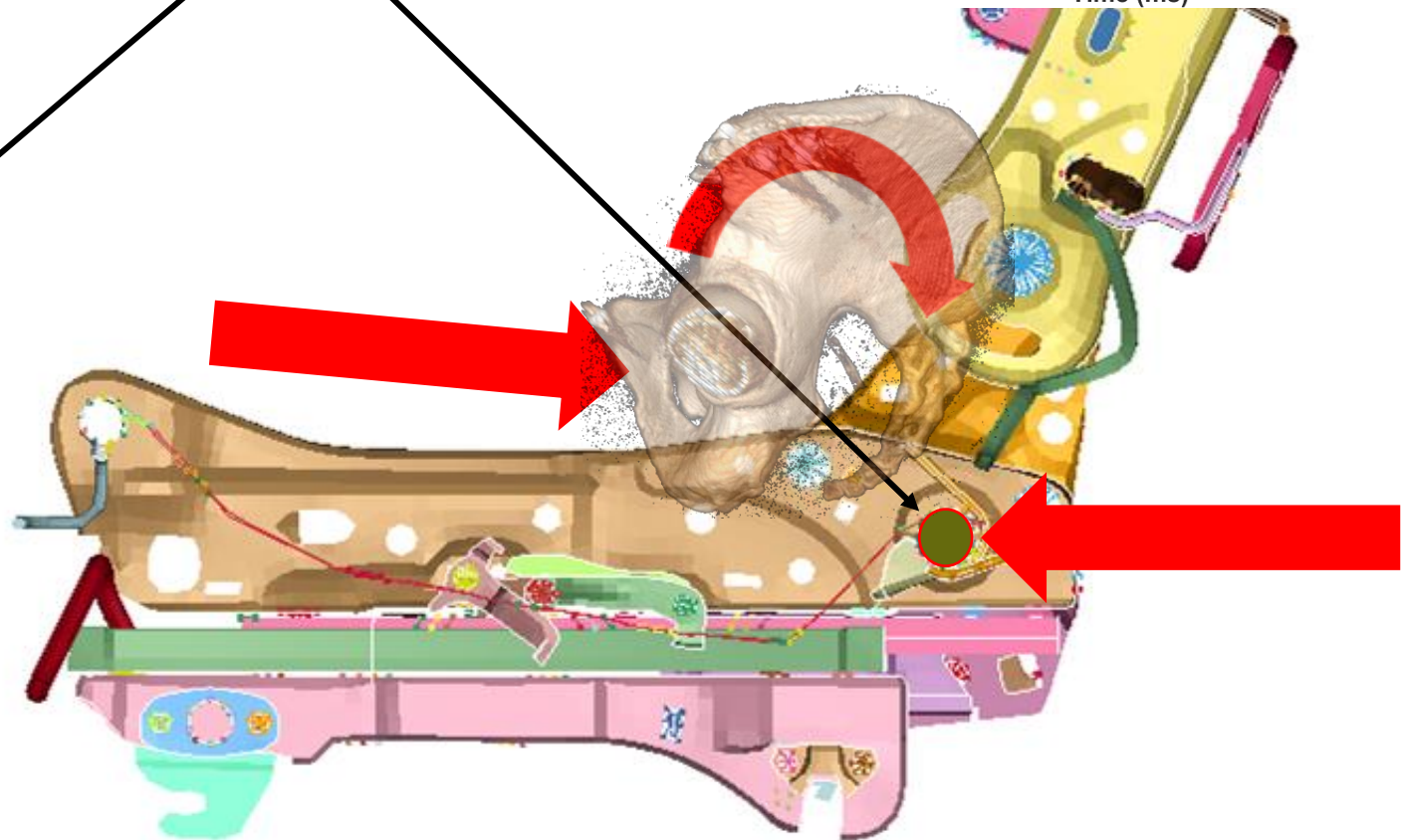
ABTS Pelvis Rearward Rot.



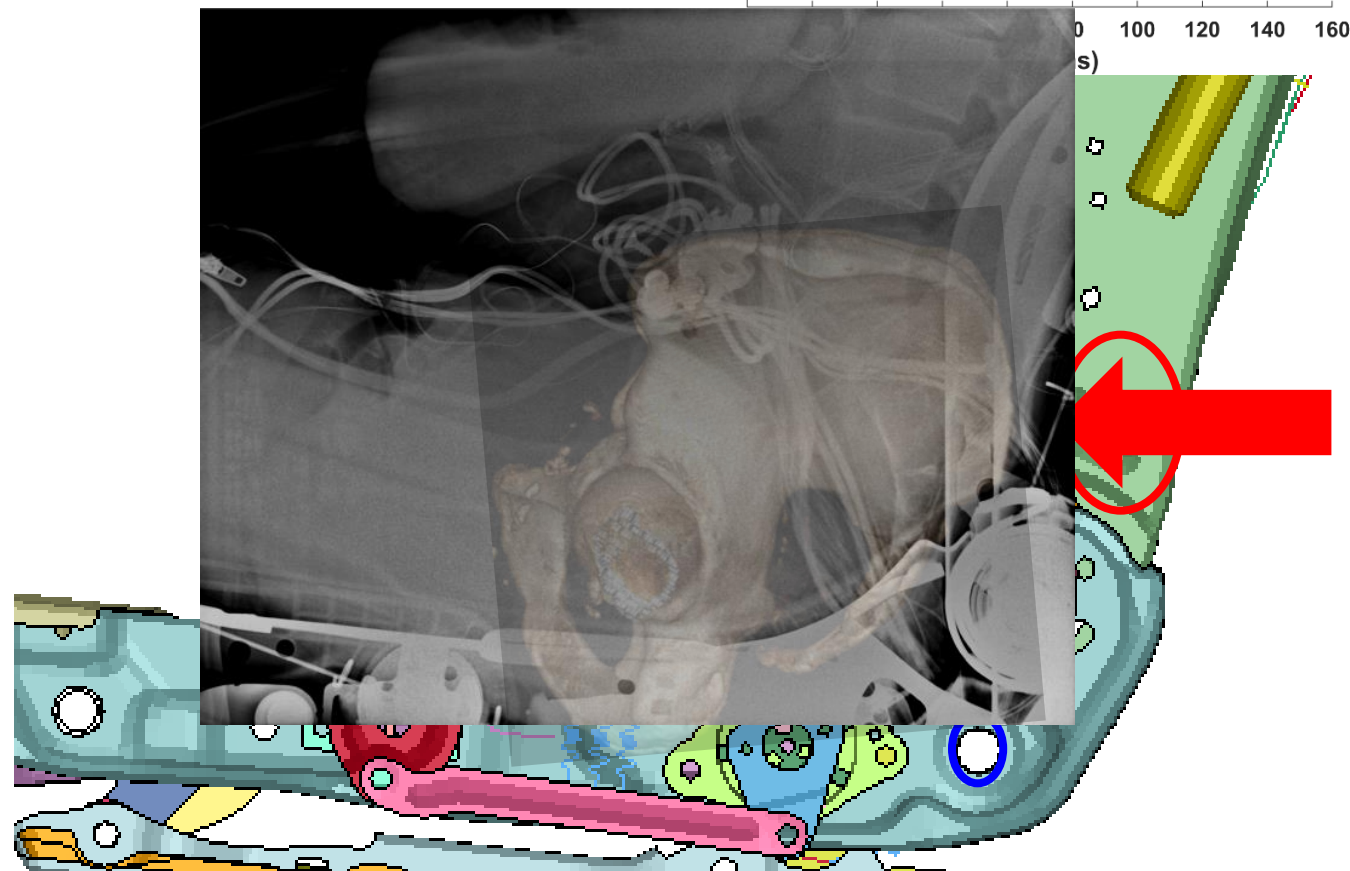
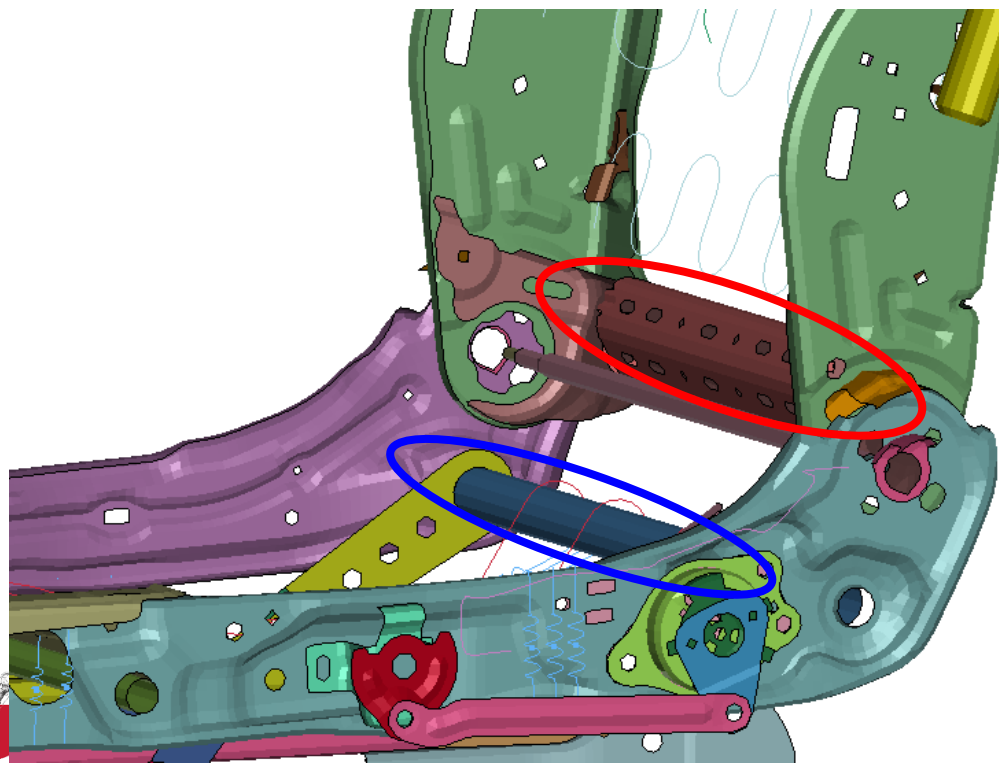
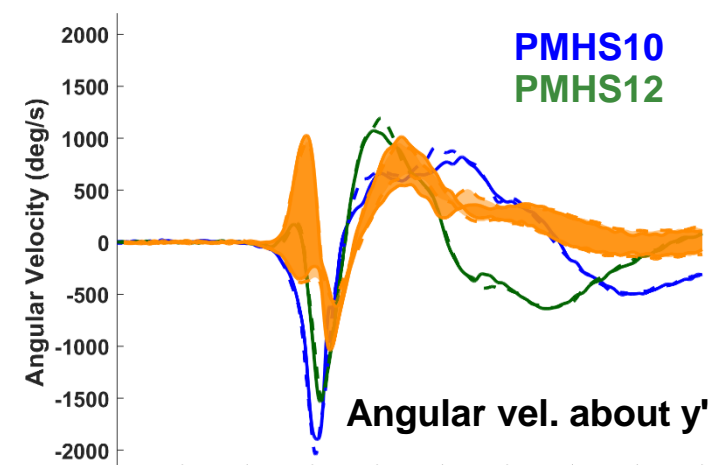
ABTS Pelvis Rearward Rot.



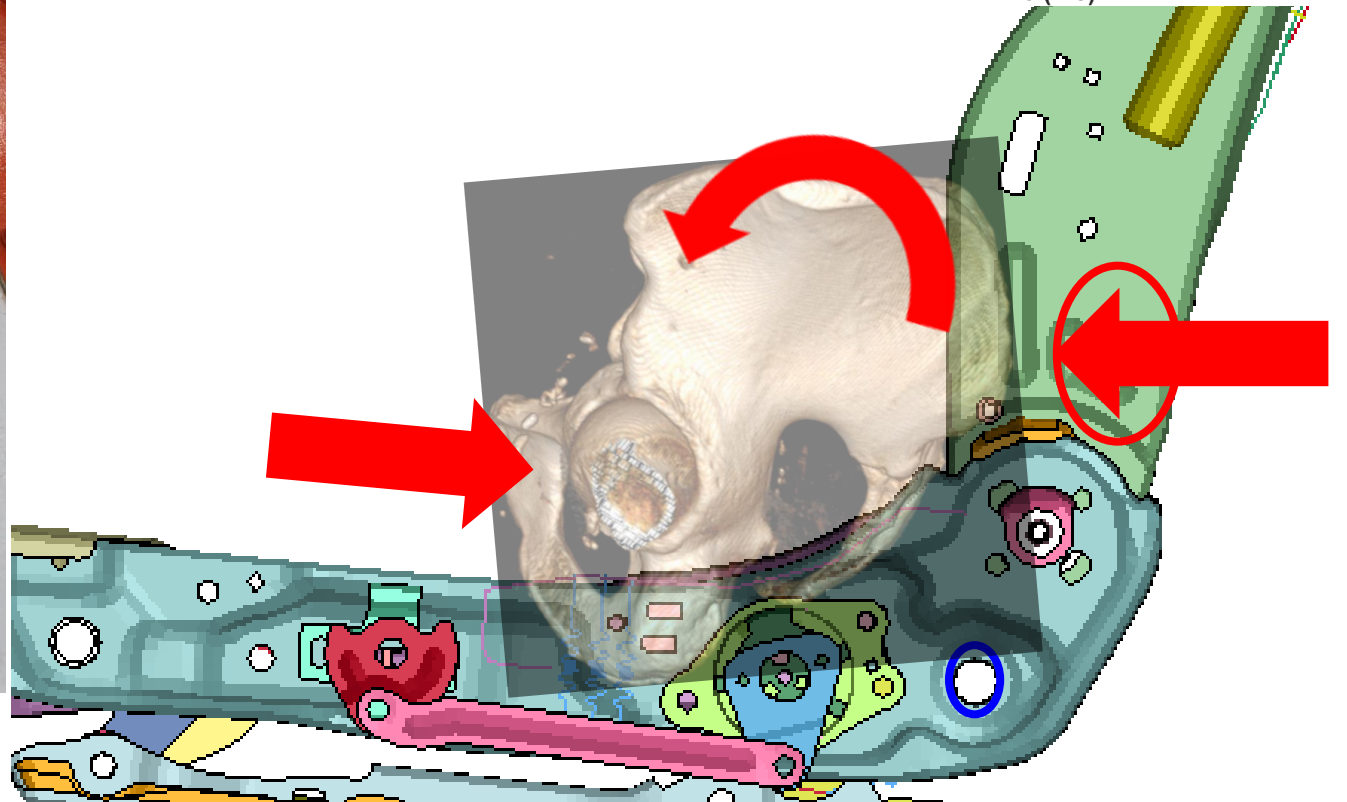
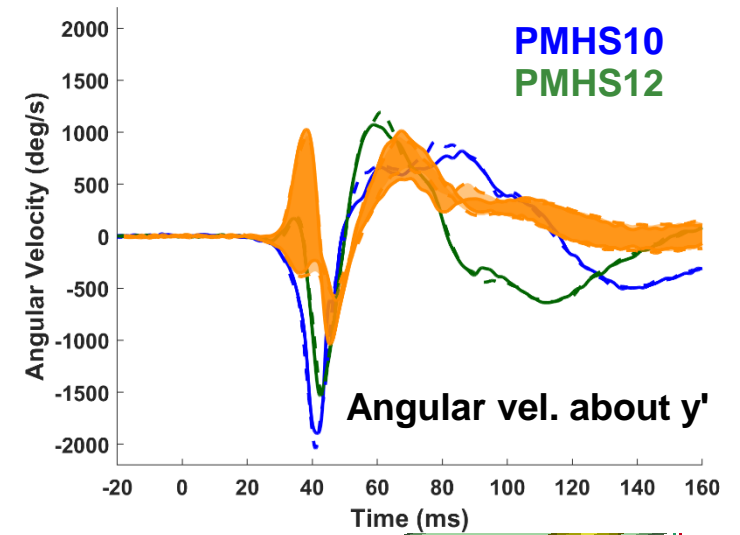
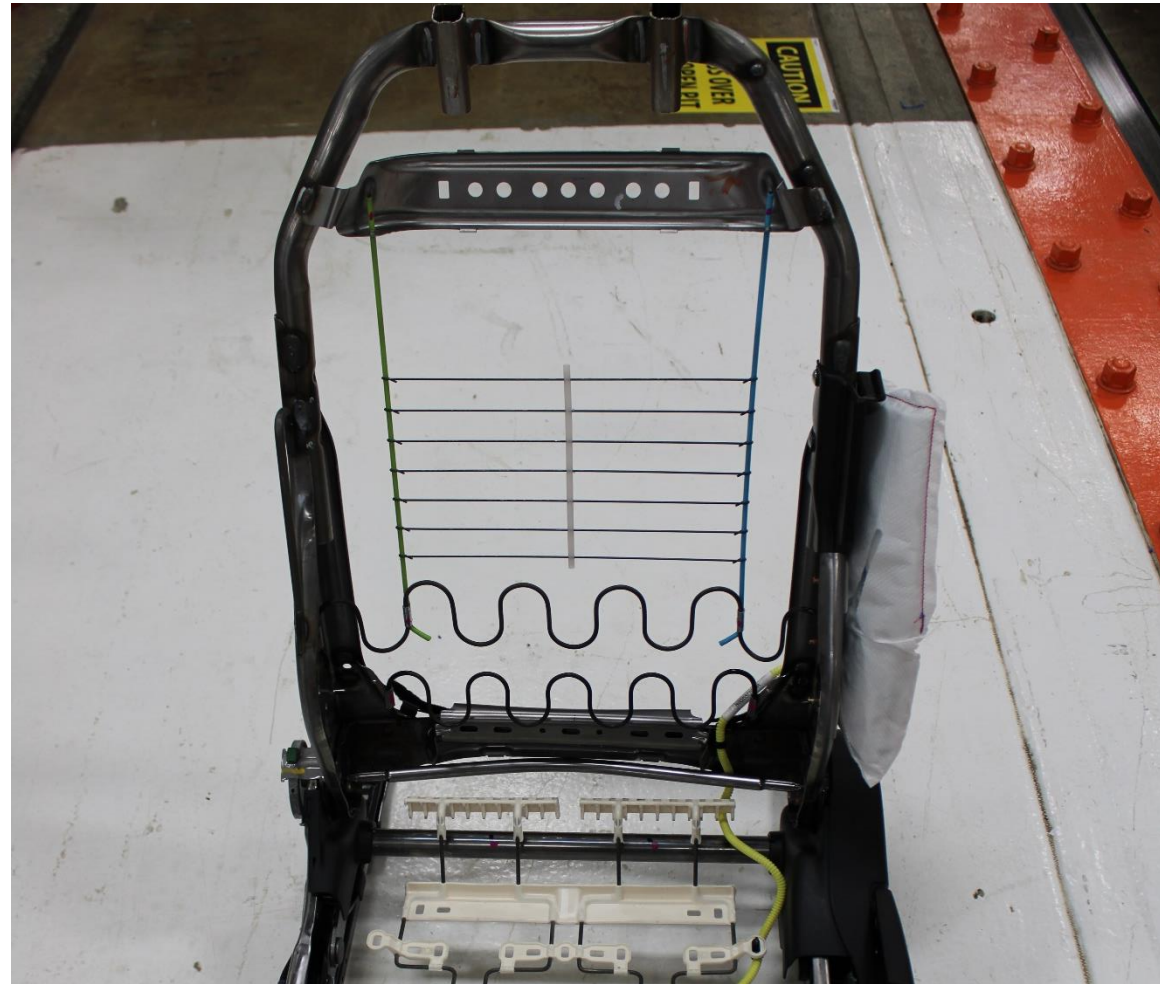
Lower anchor bar



FDR Pelvis Forward Rot.

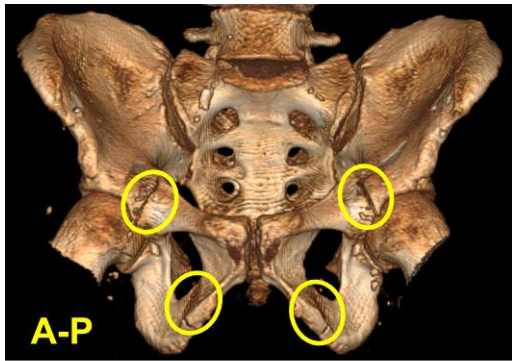


FDR Pelvis Forward Rot.

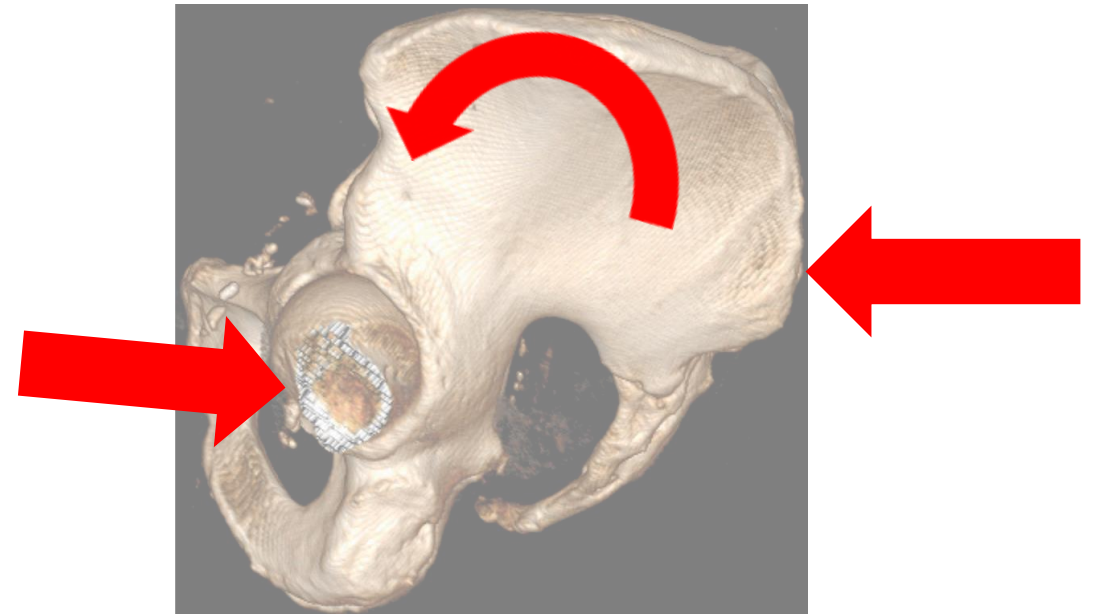
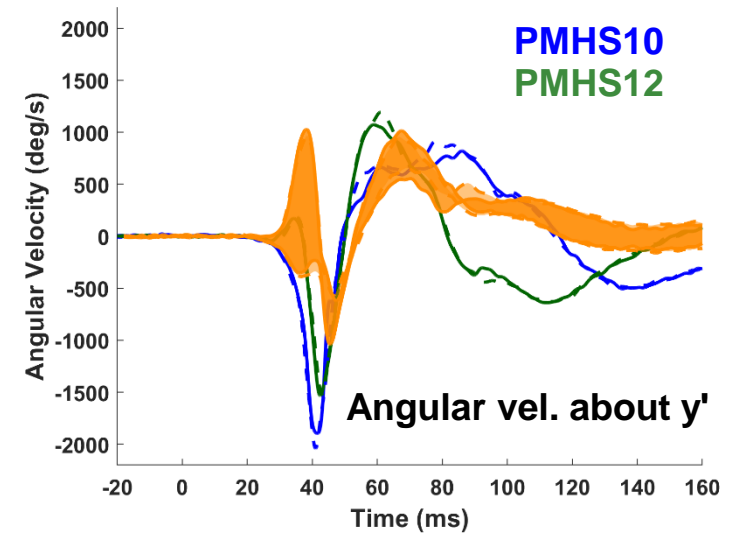
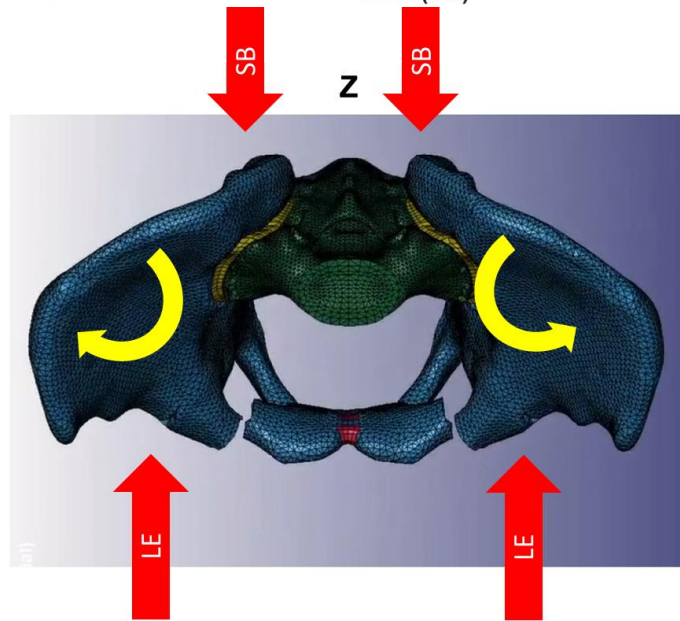
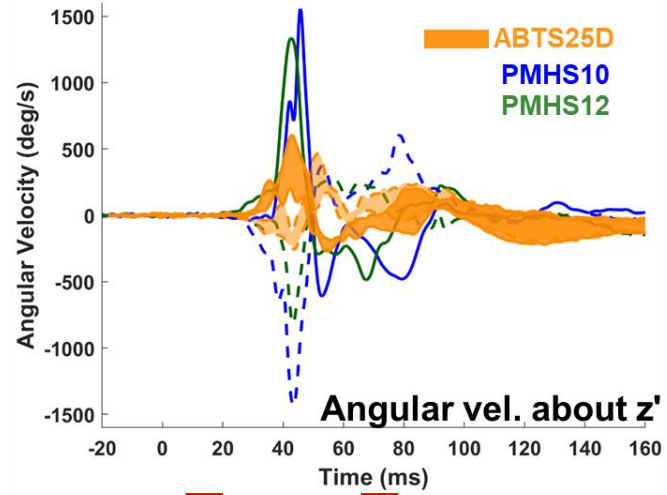
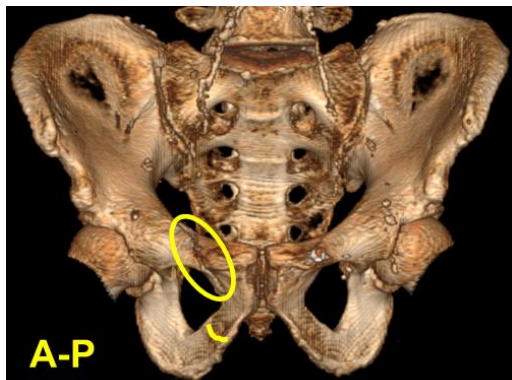


FDR Pelvis Forward Rot.

PMHS10
FDR25D



PMHS12
FDR25D



Summary

- Pelvis injury patterns
 - Posterior aspect fractures (e.g., PSIS, SI joint damage)
 - Pubic ramus fractures
- Pelvis local angular kinematics
 - Importance of pelvis instrumentation on each iliac wing
 - Angular velocities about local y' and z' axes
 - An indicator of the pubic ramus fractures
 - **Combination of large forward angular velocity about y' axis with book opening deformation (angular velocity about z')**
 - Global rotation peak occurred later
- Seatback frame design
 - ABTS lower anchor bar → pelvis rearward rotation
 - FDR lower cross bar → pelvis forward rotation



Acknowledgements

Anatomical Donors of...



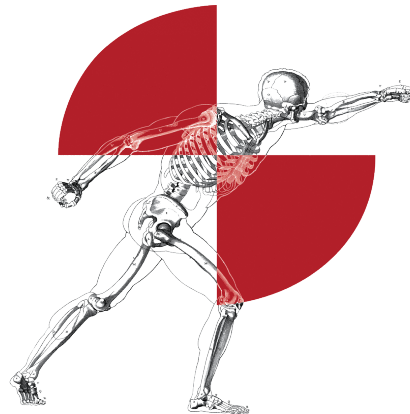
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collaborators



Hyun Jung Kwon, PhD
Oliver Lindemer
Jason Jenkins



Students and staff of the Injury
Biomechanics Research Center



Pelvic responses and injuries to male post-mortem human subjects (PMHS) in rear-facing seat configurations in high-speed frontal impacts

Yun-Seok Kang¹, Jason Stammen², Amanda Agnew¹, Gretchen Baker¹, Vikram Pradhan¹, Angela Tesny¹, Alexander Bendig¹, Alena Hagedorn³, Kevin Moorhouse², John H. Bolte IV¹

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

RCCADS Public Workshop

5/25/2023



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