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

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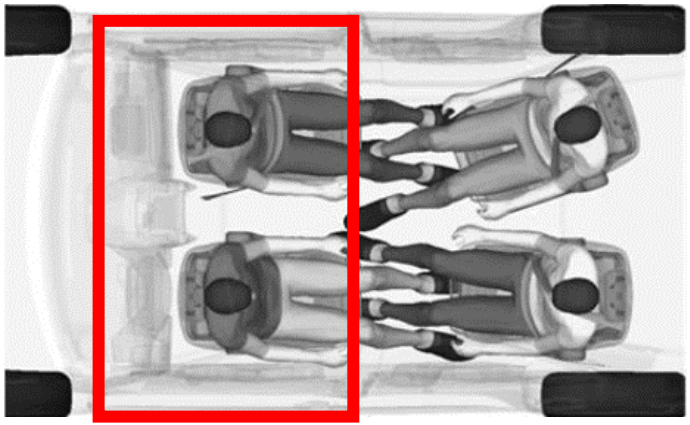
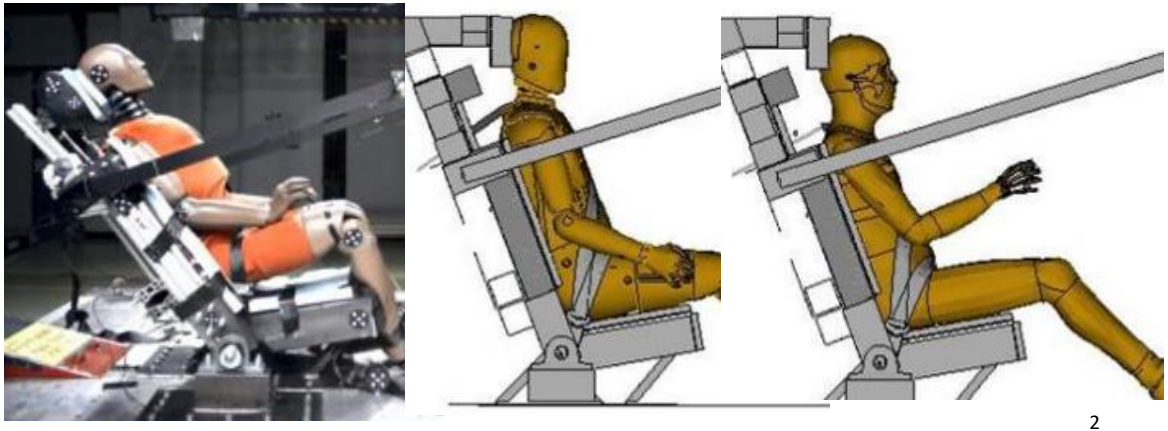
Introduction

- 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
    - ATDs: not validated for rear impacts



Kitagawa et al., 2017



Zellmer and Manneck, 2019; Soni et al., 2020

Content Warning

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

Background and Motivation

- 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

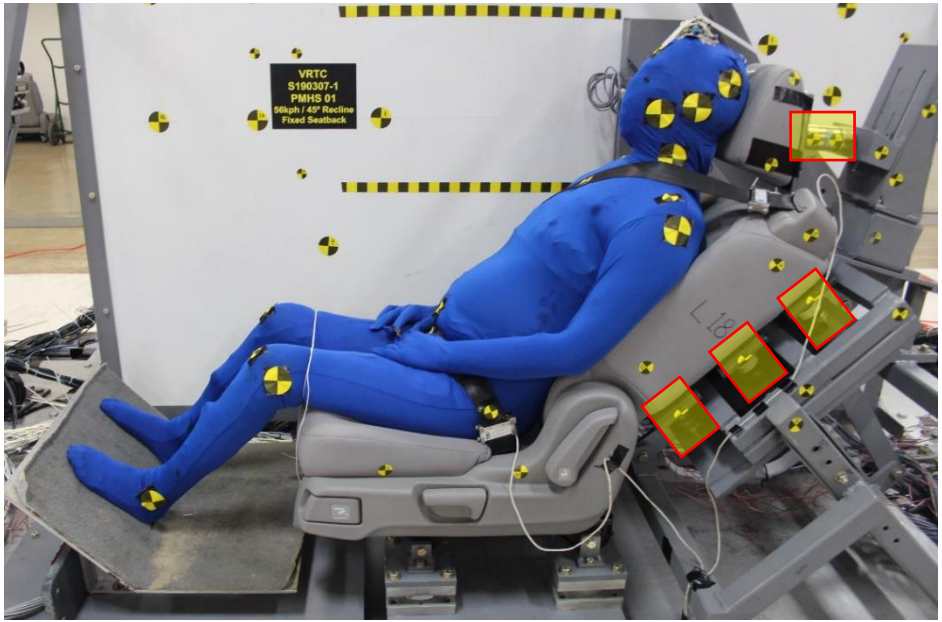
FDR

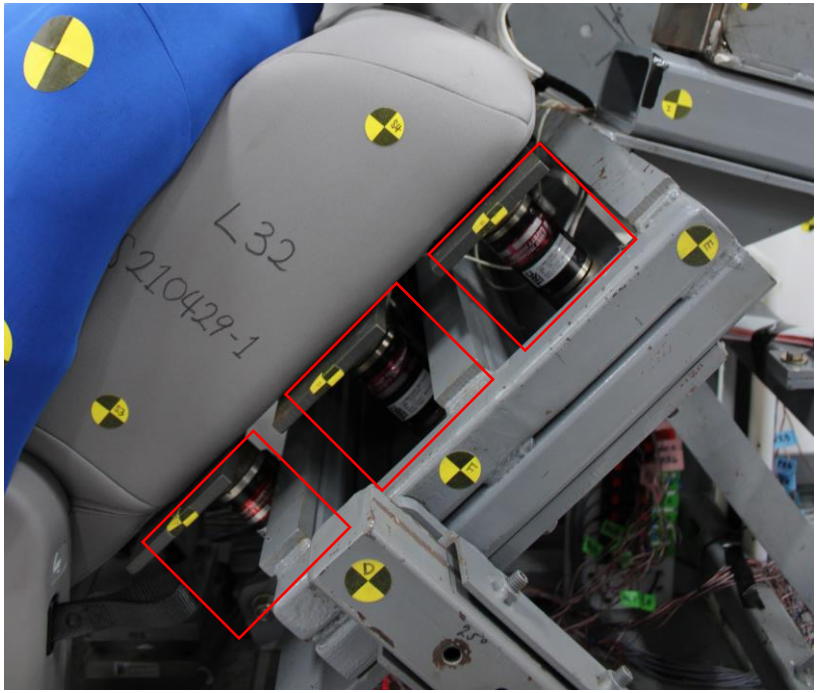
- Rib fracture location, distribution, and timing
- Pelvis fracture with respect to angular kinematics

Methods

Sled Buck Description

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

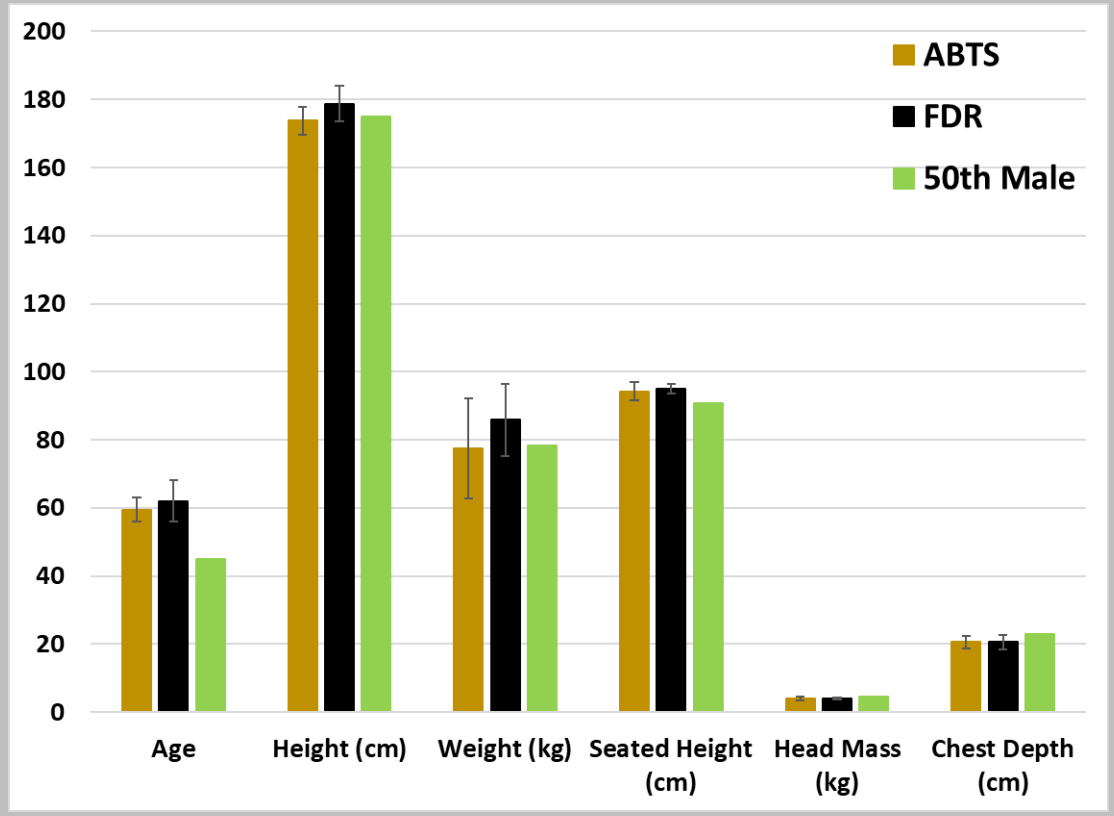




PMHS Characteristics – 56 km/h

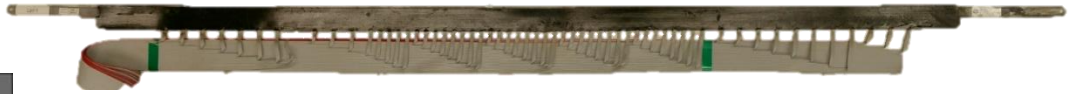
N=14	Speed	Seat	Recline	Age	Height (cm)	Weight (kg)	Seated Height (cm)	Head Mass (kg)	Chest Depth (cm)
PMHS01	56	ABTS	45	57	167.0	62.6	90.0	3.8	20.6
PMHS02	56	ABTS	25	64	171.0	62.6	92.4	3.6	17.6
PMHS03	56	ABTS	25	54	174.0	93.9	97.0	5.0	20.6
PMHS04	56	ABTS	45	59	178.0	96.2	96.5	4.4	23.2
PMHS05	56	ABTS	45	62	176.0	77.1	95.7	3.5	21.2
PMHS06	56	ABTS	25	61	176.5	72.6	94.0	3.9	20.2
PMHS09	56	FDR	45	71	187.5	89.4	96.5	4.3	17.1
PMHS10	56	FDR	25	62	177.8	100.7	94.5	4.4	20.1
PMHS11	56	FDR	25	65	181.0	92.1	96.5	4.3	21.7
PMHS12	56	FDR	25	58	177.8	71.7	94.2	3.9	21.1
PMHS13	56	FDR	45	53	176.3	76.2	95.7	3.7	19.7
PMHS14	56	FDR	45	63	172.3	85.3	93.0	3.8	23.4
PMHS21	56	FDR	25	62	172.7	68.5	89.7	3.8	20.2
PMHS22	56	FDR	45	61	176.6	71.7	94.1	3.6	19.3
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)
50th Male	N/A	N/A	N/A	45	175	78.2	90.7	4.5	22.9

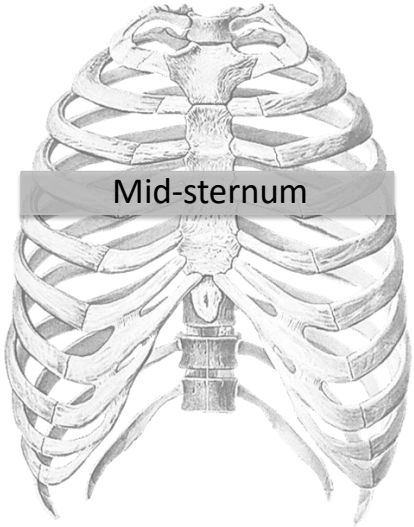
PMHS Characteristics – 56 km/h



PMHS Instrumentation – Chest Band

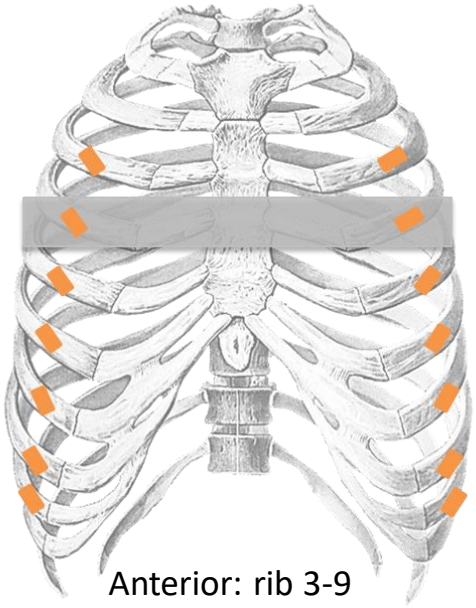
Chestband
Strain Gauges



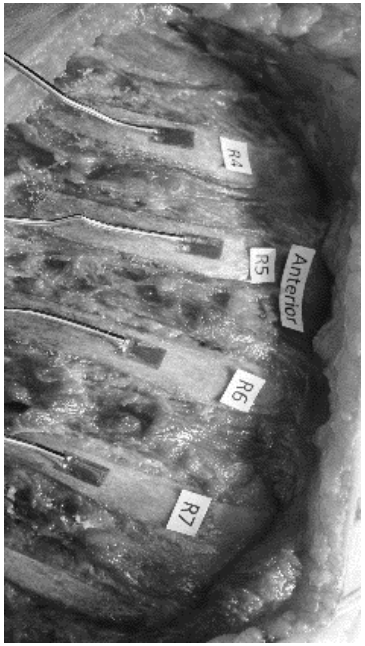


PMHS Instrumentation – Rib Strain Gage

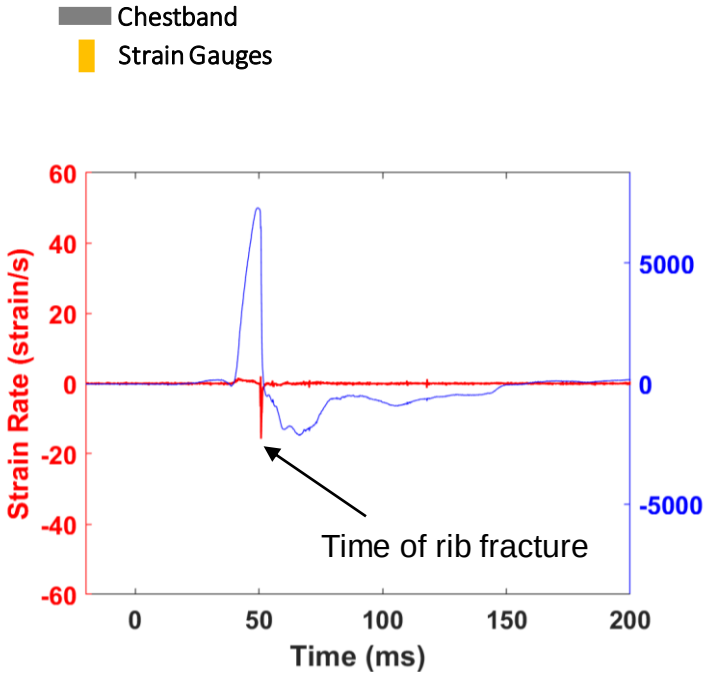
Chestband
Strain Gauges

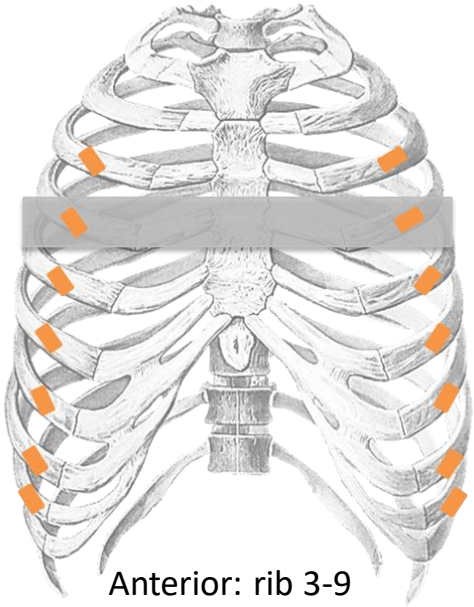


Anterior: rib 3-9
Posterior: rib 3-10

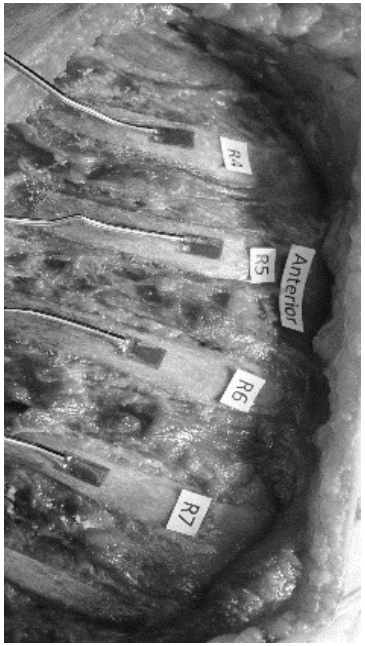


PMHS Instrumentation – Rib Strain Gage



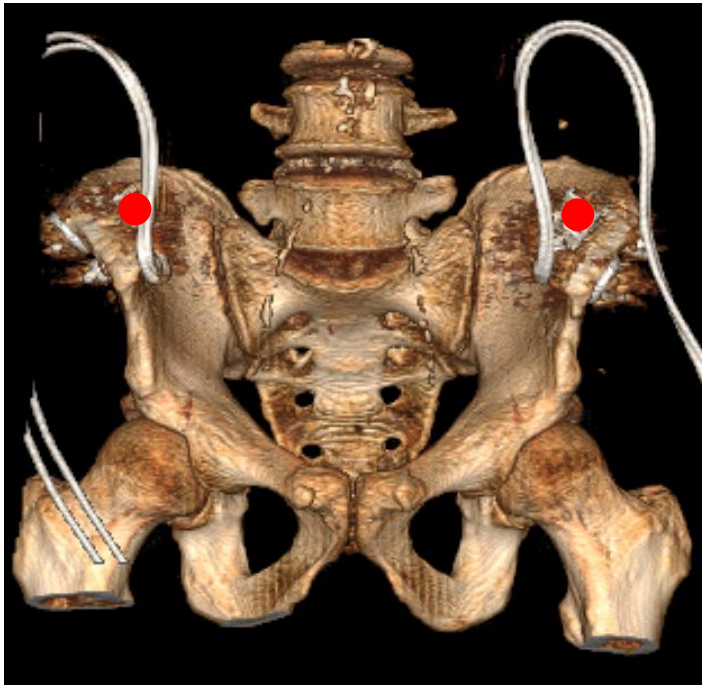


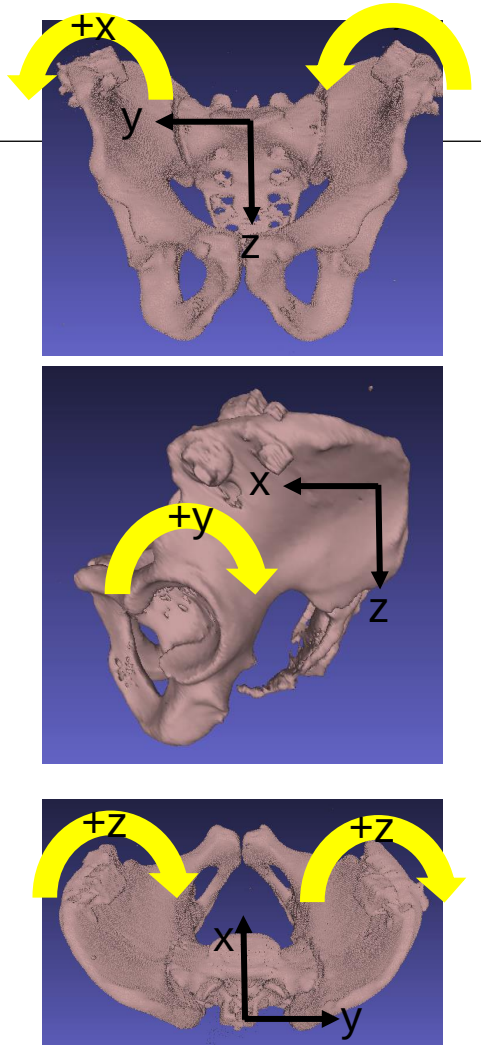
Anterior: rib 3-9
Posterior: rib 3-10



PMHS Instrumentation – Pelvis Kinematics

- 3aω





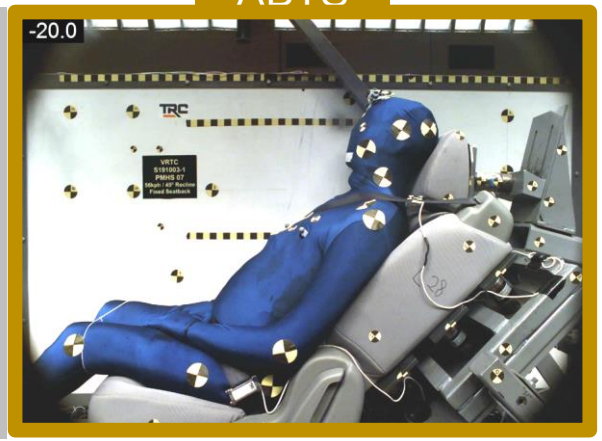
Results
(Preliminary Results)

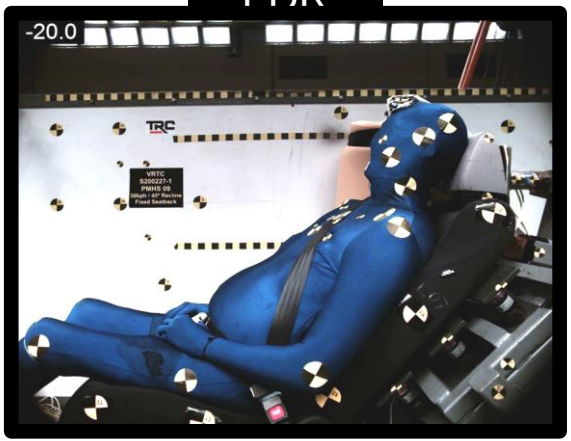
High Speed Videos

ABTS

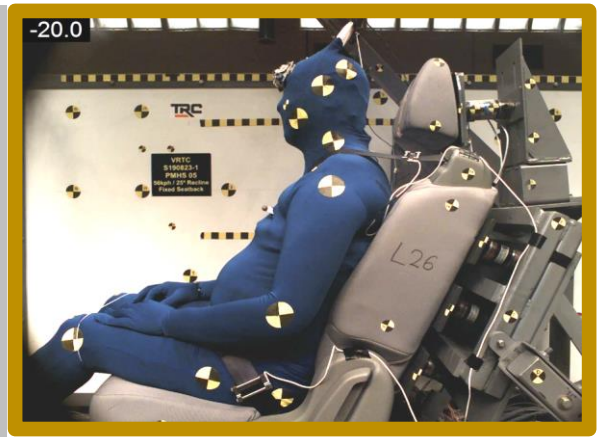
FDR

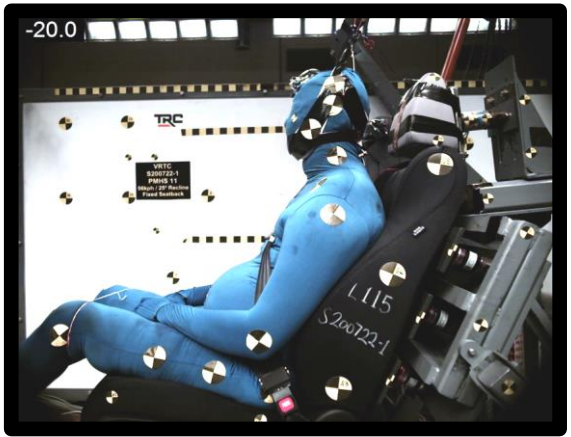
45 deg

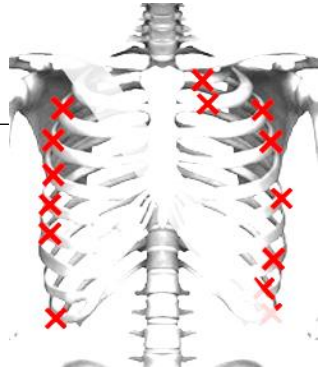




25 deg





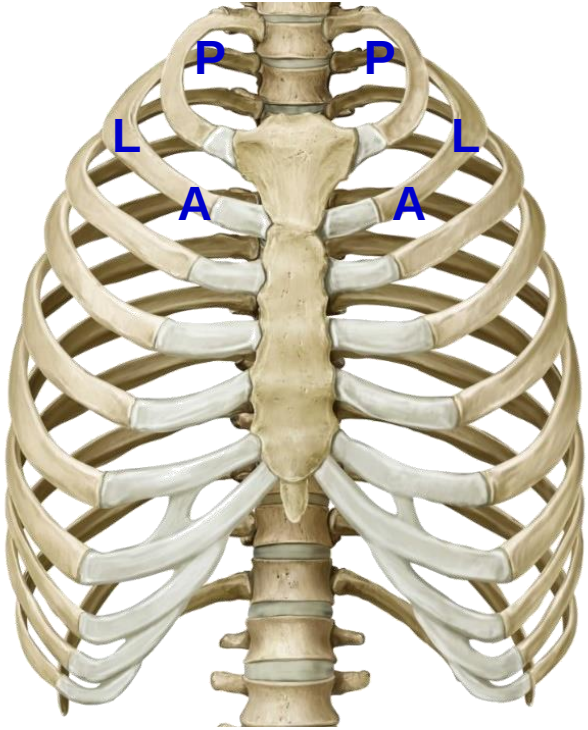


Rib

- Fracture location and frequency?
- Fracture timing?

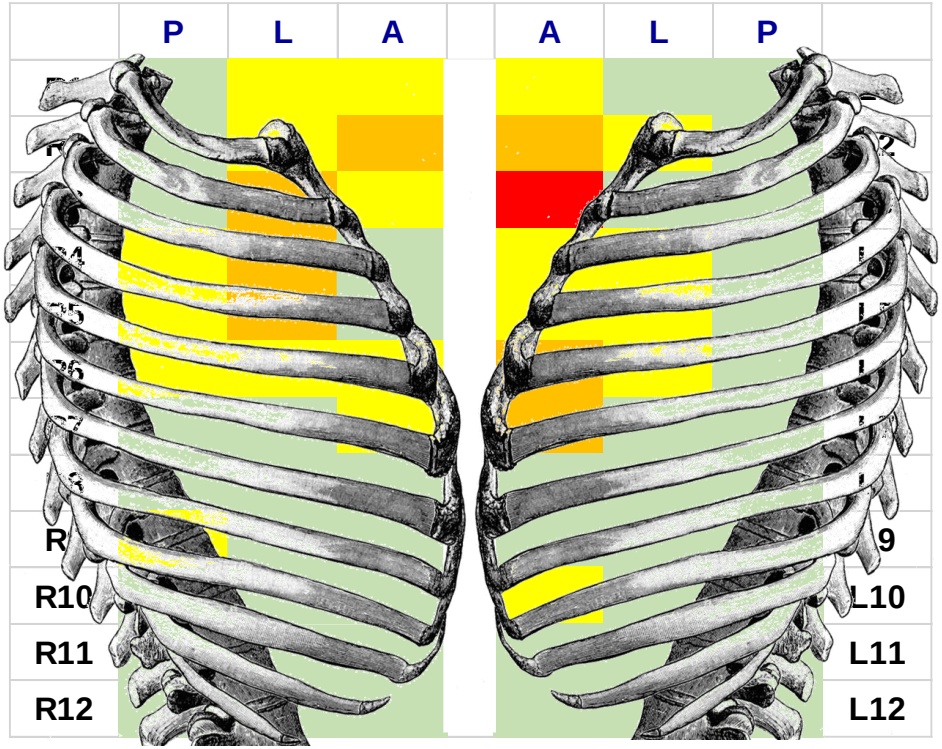
Rib Fracture Location and Frequency

: no fractures
: one PMHS
: two PMHS
: three PMHS



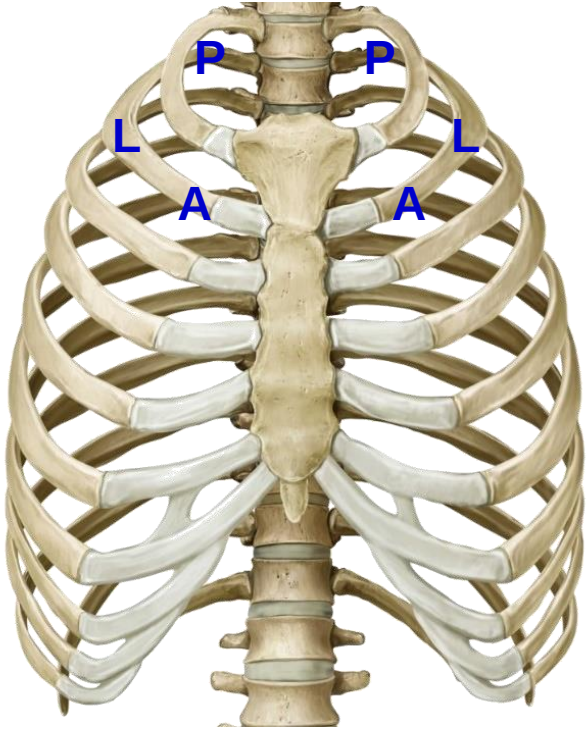
R#

L#



Rib Fracture Location and Frequency

: no fractures
: one PMHS
: two PMHS
: three PMHS



R#

L#

	P	L	A		A	L	P	
R1								L1
R2								L2
R3								L3
R4								L4
R5								L5
R6								L6
R7								L7
R8								L8
R9								L9
R10								L10
R11								L11
R12								L12

Rib Fracture Location and Frequency

: no fractures
: one PMHS
: two PMHS
: three PMHS

ABTS 45deg

	P	L	A		A	L	P	
R1								L1
R2								L2
R3								L3
R4								L4
R5								L5
R6								L6
R7								L7
R8								L8
R9								L9
R10								L10
R11								L11
R12								L12

ABTS 25deg

	P	L	A		A	L	P	
R1								L1
R2								L2
R3								L3
R4								L4
R5								L5
R6								L6
R7								L7
R8								L8
R9								L9
R10								L10
R11								L11
R12								L12

Rib Fracture Location and Frequency

: no fractures
: one PMHS
: two PMHS
: three PMHS

FDR 45deg

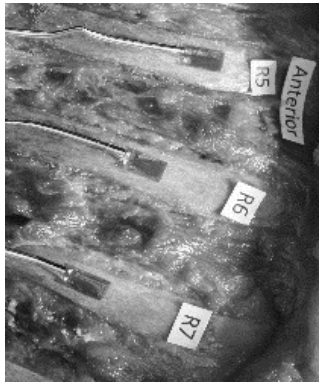
	P	L	A		A	L	P	
R1								L1
R2								L2
R3								L3
R4								L4
R5								L5
R6								L6
R7								L7
R8								L8
R9								L9
R10								L10
R11								L11
R12								L12

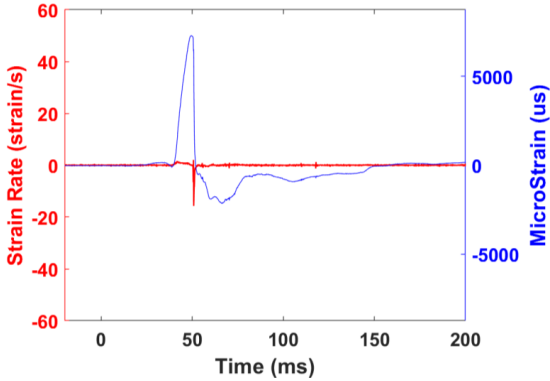
FDR 25deg

	P	L	A		A	L	P	
R1								L1
R2								L2
R3								L3
R4								L4
R5								L5
R6								L6
R7								L7
R8								L8
R9								L9
R10								L10
R11								L11
R12								L12

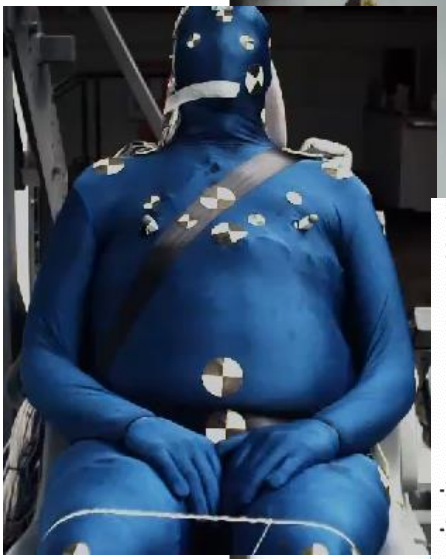
Rib

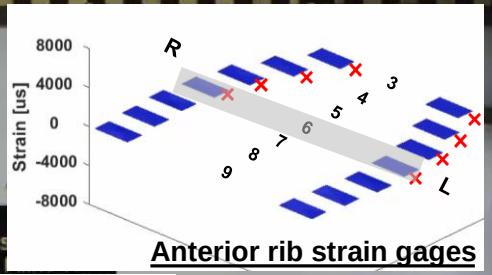
- Fracture location and frequency?
- Fracture timing?



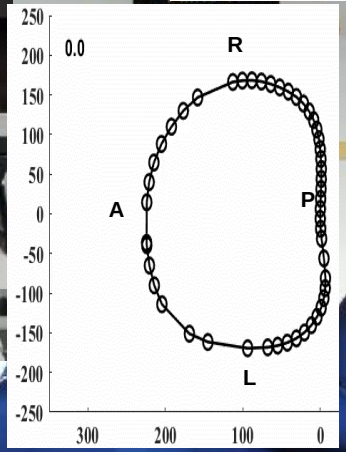


ABTS 45deg at 56 km/h





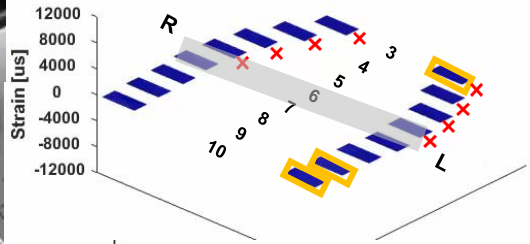
Anterior rib strain gages

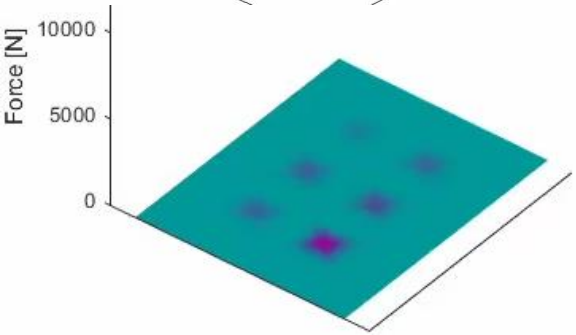


Fracture
Broken gage

0.0

Posterior rib strain gages





Rib Fracture Timing

: no fractures
: one PMHS
: two PMHS
: three PMHS

ABTS 45deg

Unit: ms

	P	L	A		A	L	P	
R1		N/A	N/A		N/A			L1
R2		N/A	N/A		N/A	N/A		L2
R3		52.5	64.3		48.7			L3
R4	54.4	54.5			45.9	53.8		L4
R5	55.2	55.8			46.8	56.4		L5
R6	57.7	57.5	54.9		34.9	60.2		L6
R7			44.7		44.8			L7
R8								L8
R9	N/A							L9
R10					N/A			L10
R11								L11
R12								L12

Peak chest compression @ 44.1 ± 1.0ms

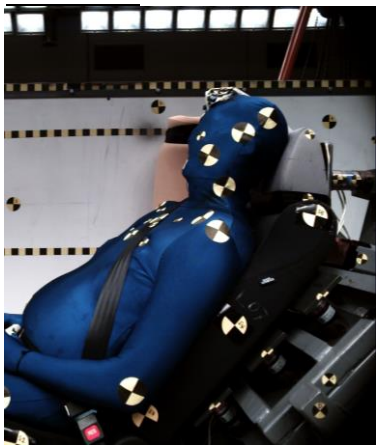
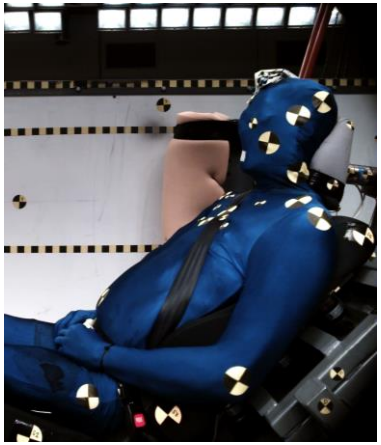
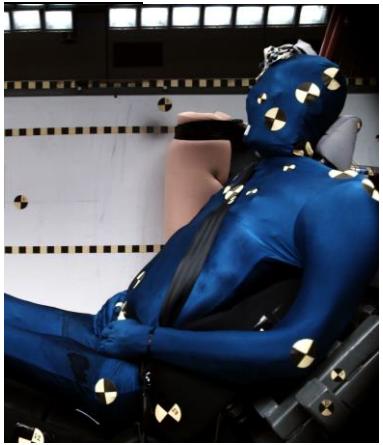
FDR 45deg

	P	L	A		A	L	P	
R1	N/A		N/A		N/A		N/A	L1
R2	N/A	N/A	N/A		N/A	N/A	N/A	L2
R3	53.5	57.9	54.2		54.7	55.6	N/A	L3
R4	49.6	48.7	49.6		42.2	53.0	63.5	L4
R5	54.6	57.7	55.4		N/A	46.8	62.9	L5
R6	57.1	53.1			55.1	61.9	57.6	L6
R7	57.7	47.0	49.3		49.3	46.1	60.5	L7
R8	66.7	49.1	49.1		47.2		67.7	L8
R9			46.1		51.5		N/A	L9
R10			N/A					L10
R11	N/A	N/A						L11
R12								L12

Peak chest compression @ 47.0 ± 1.8ms

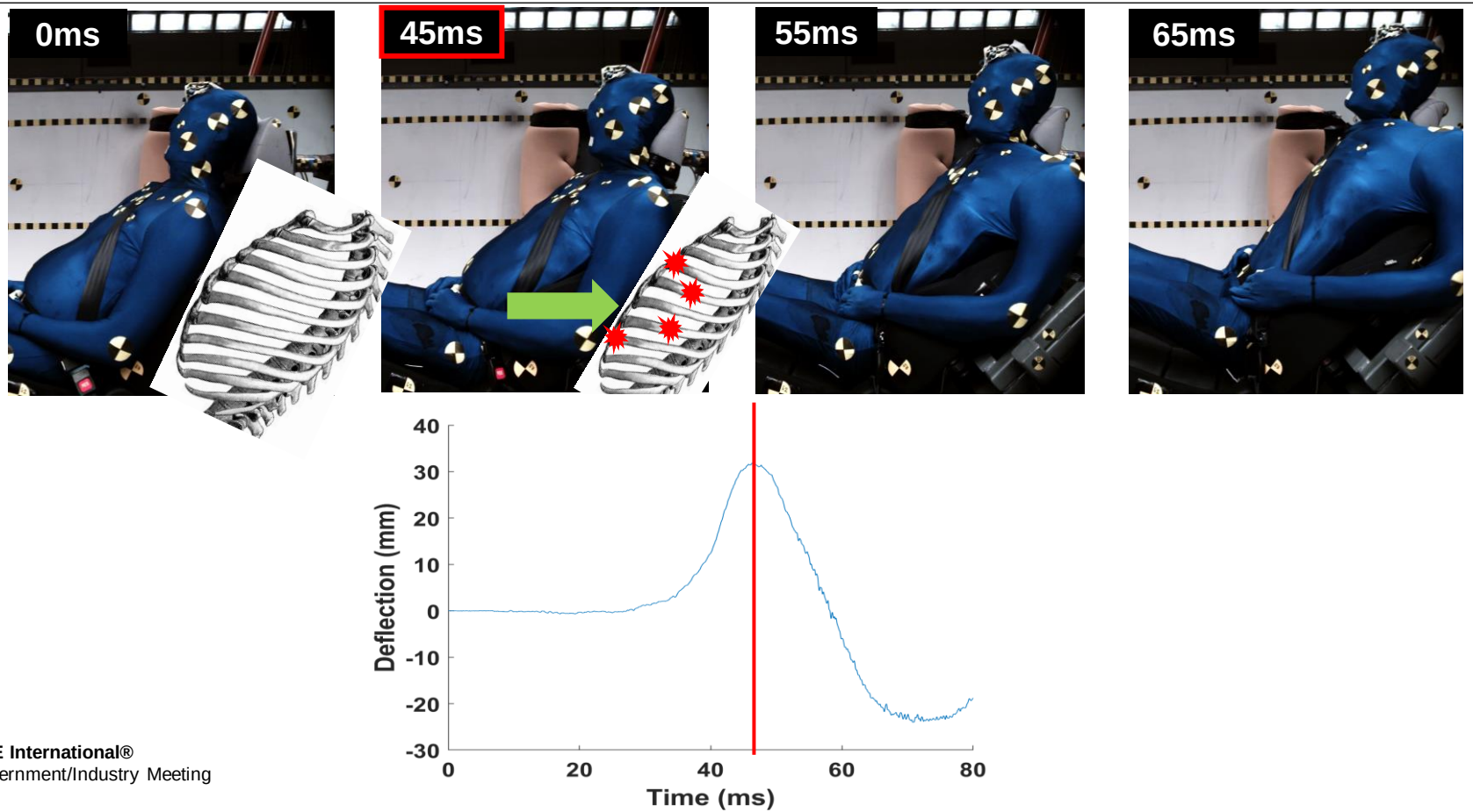
Rib Fracture Timing

FDR 45deg

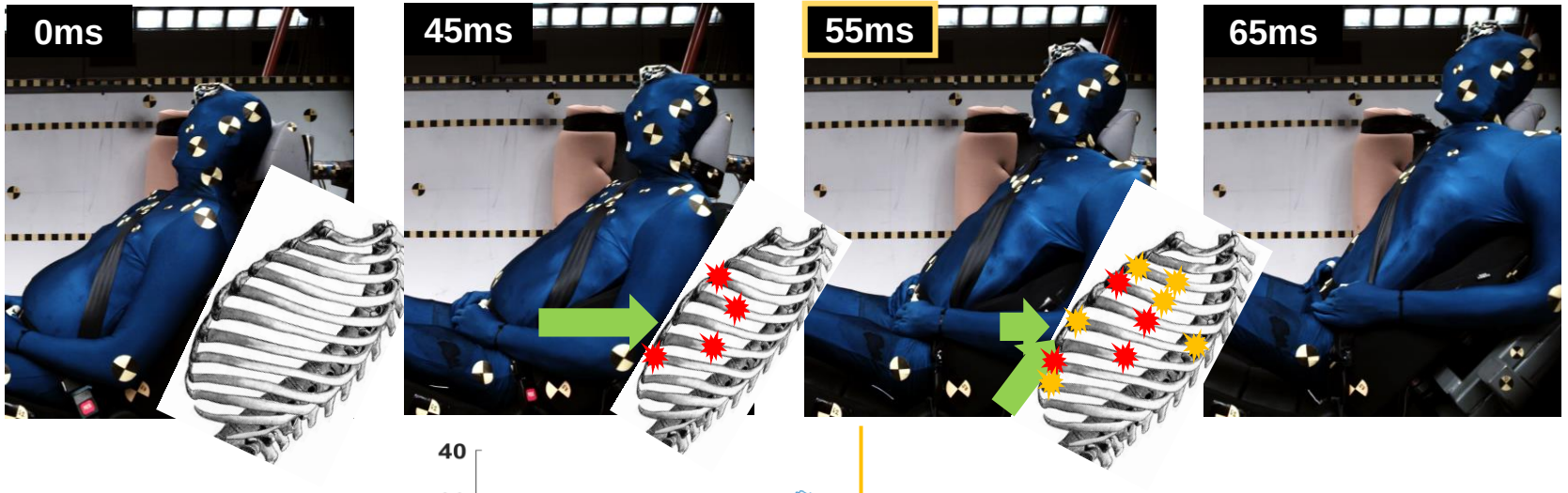

Rib Fracture Timing

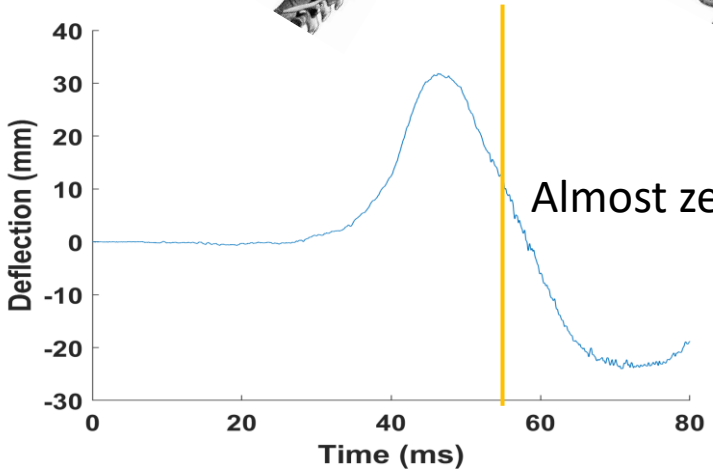
FDR 45deg



Rib Fracture Timing

FDR 45deg

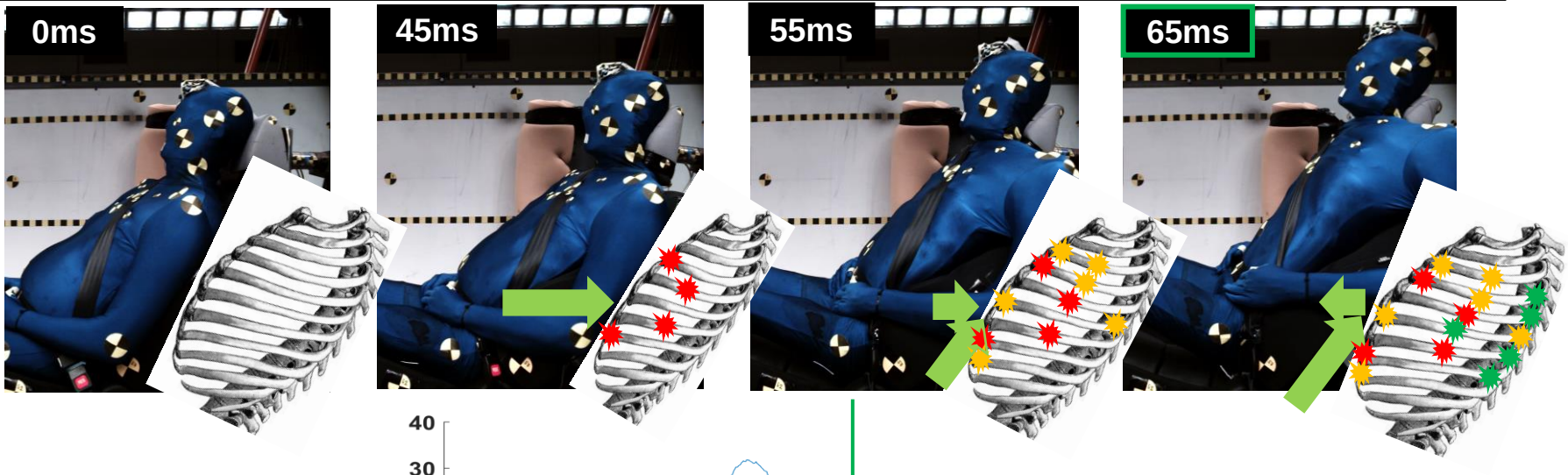


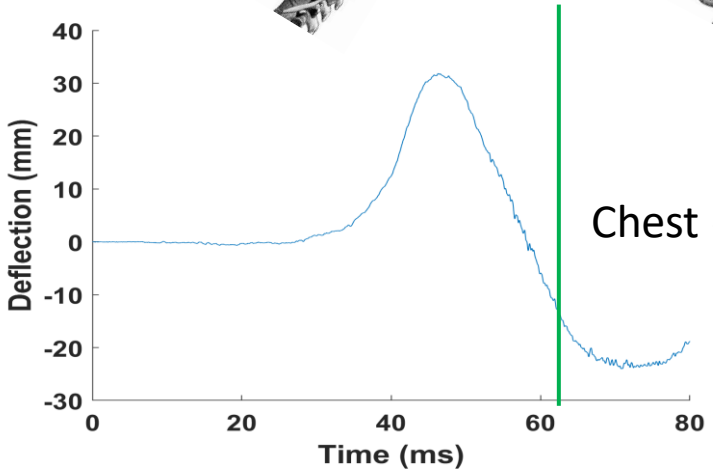


Almost zero chest deflection

Rib Fracture Timing

FDR 45deg





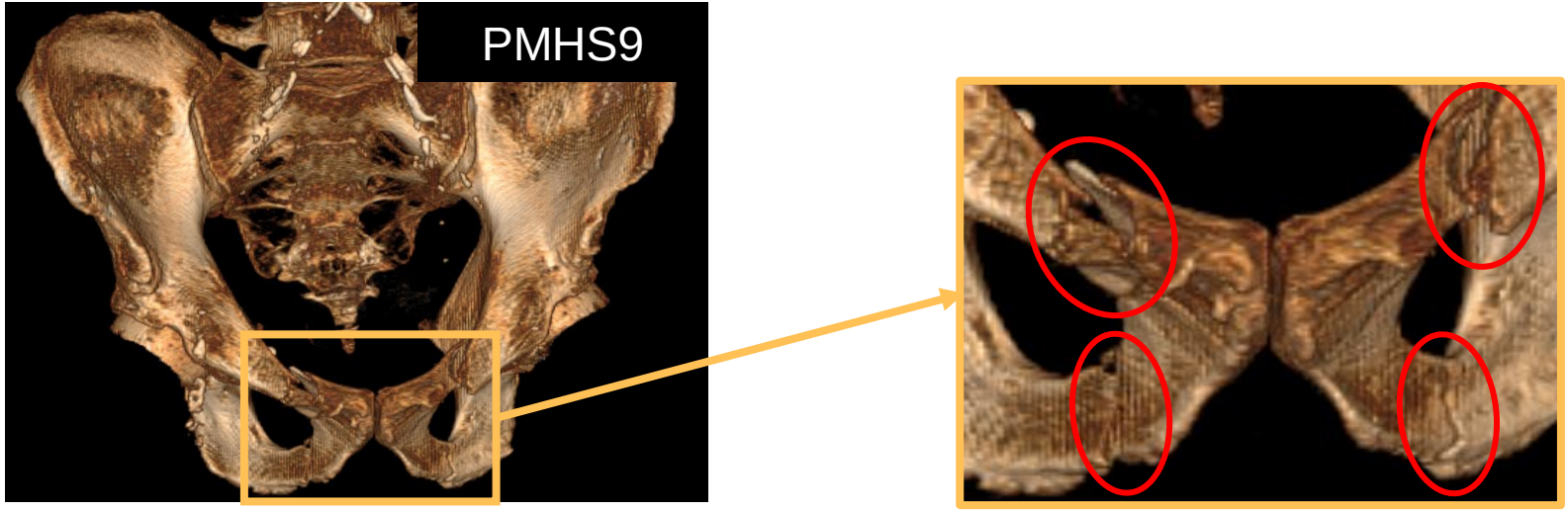
Chest expansion

Pelvis

- Pubic ramus fractures

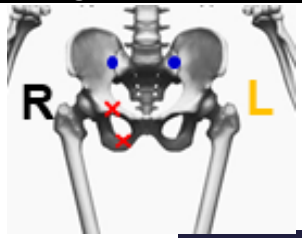
Pelvis Fractures – 56 km/h

FDR			
Recline Angle	PMHS#	Injury Description	AIS Code
45	PMHS9	Bilateral pubic ramus fxs with unstable sacroiliac joints: left and right superior (iliopubic) and inferior (ischiopubic) ramus fxs	856171.4
	PMHS13	No pubic ramus fxs	
25	PMHS11	No pubic ramus fxs	
	PMHS12	Right superior (iliopubic) ramus fx	856161.3
		Right inferior (ischiopubic) ramus fx	856161.3

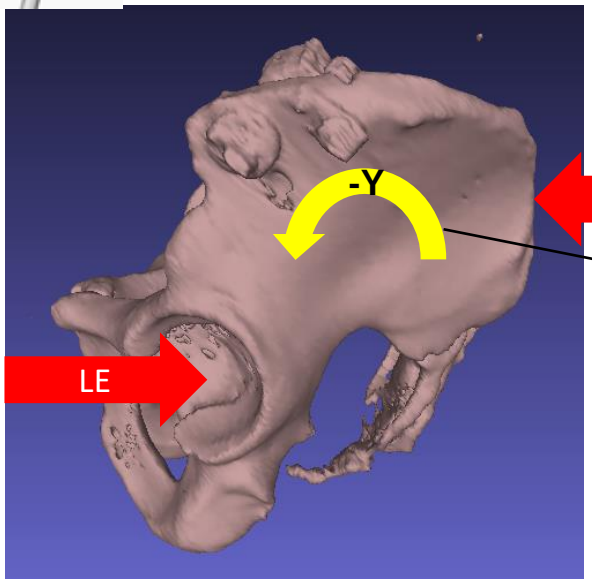


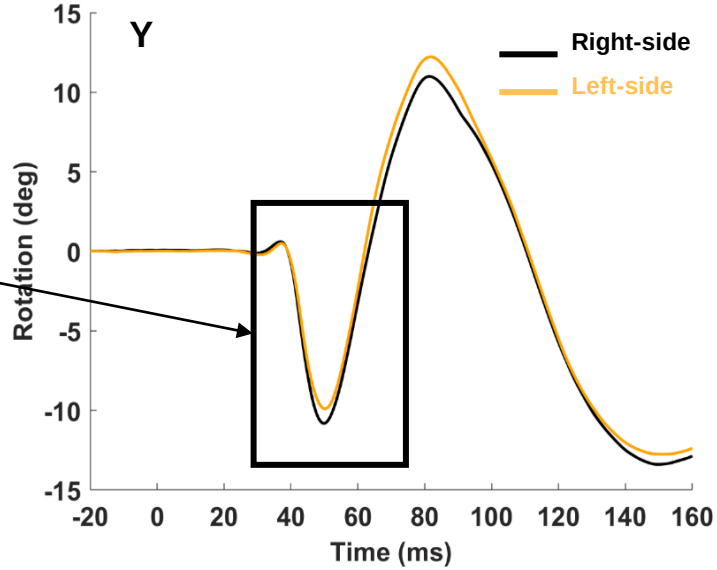
Pelvis Fractures – 56 km/h

25 deg & 56km/h in FDR



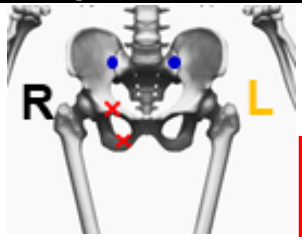
PMHS12



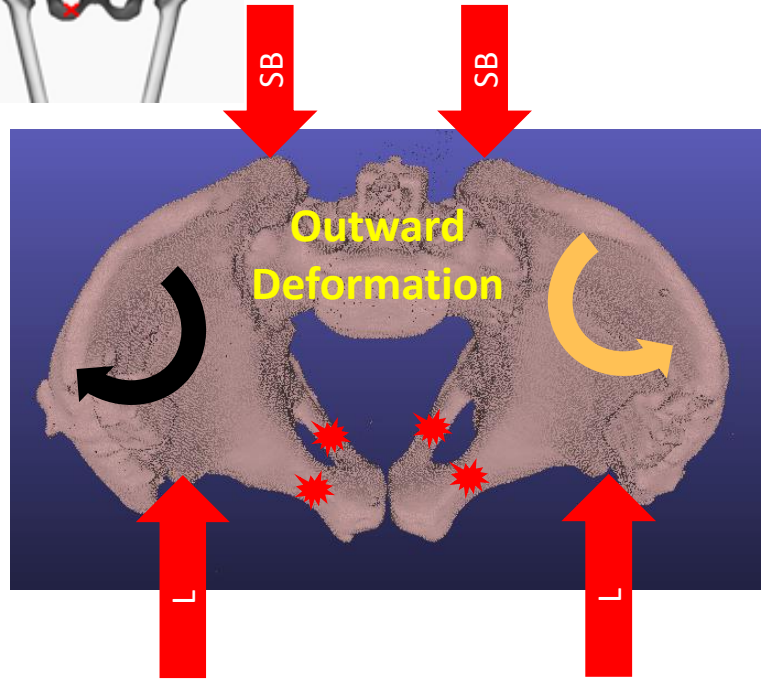


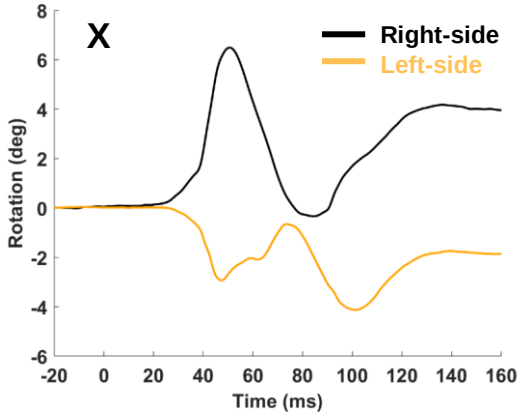
Pelvis Fractures – 56 km/h

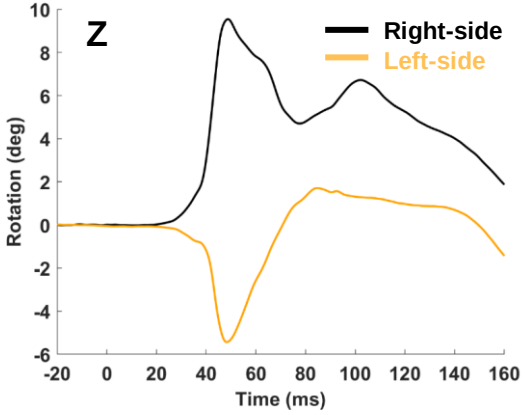
25 deg & 56km/h in FDR



PMHS12





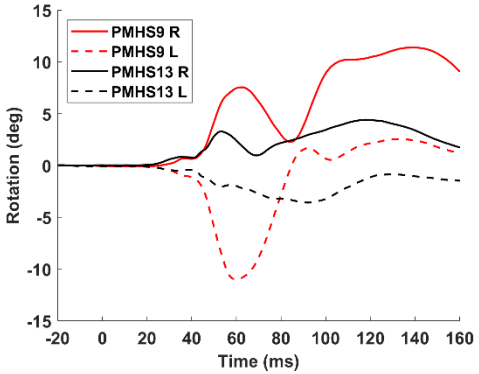


Outward deformation: explained by off-axis rotations → may be an indicator of fractures

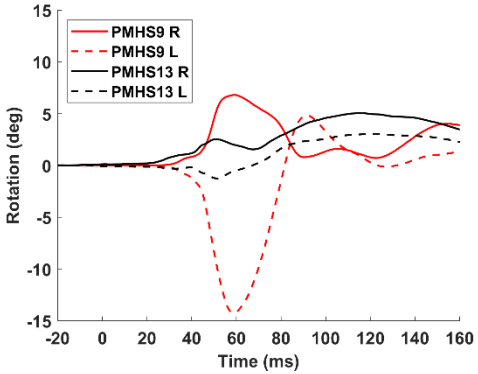
Pelvis Off-axis Rotations – 56 km/h

Pubic ramus fxs
No pubic ramus fxs

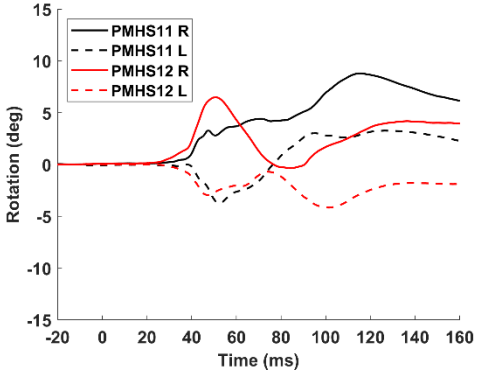
FDR 45deg



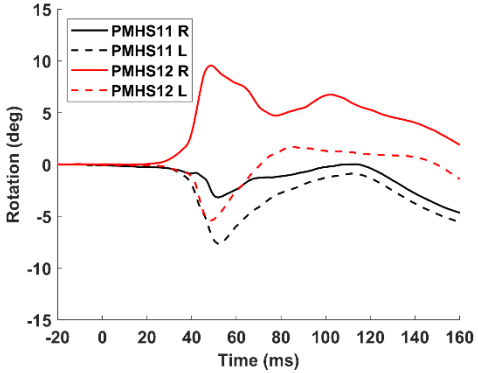
PMHS9: bilateral fxs



FDR 25deg



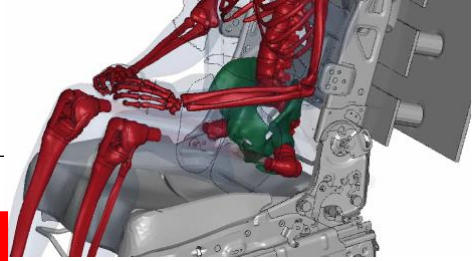
PMHS12: right side fxs

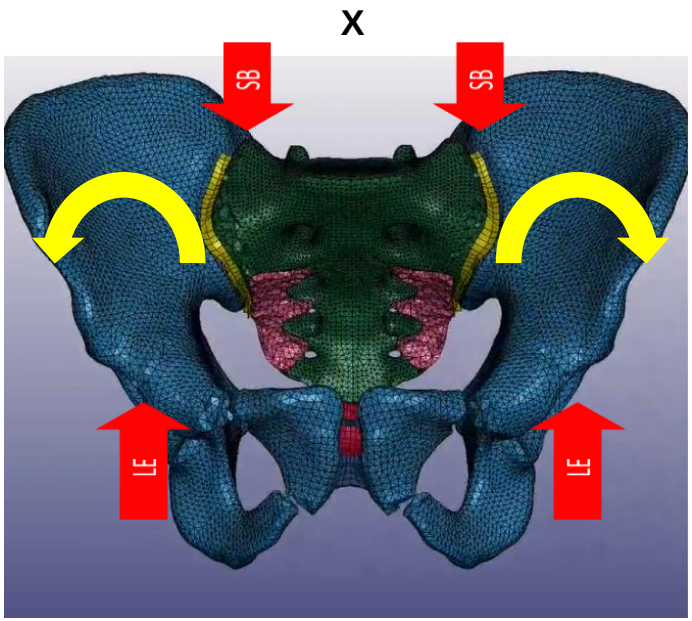


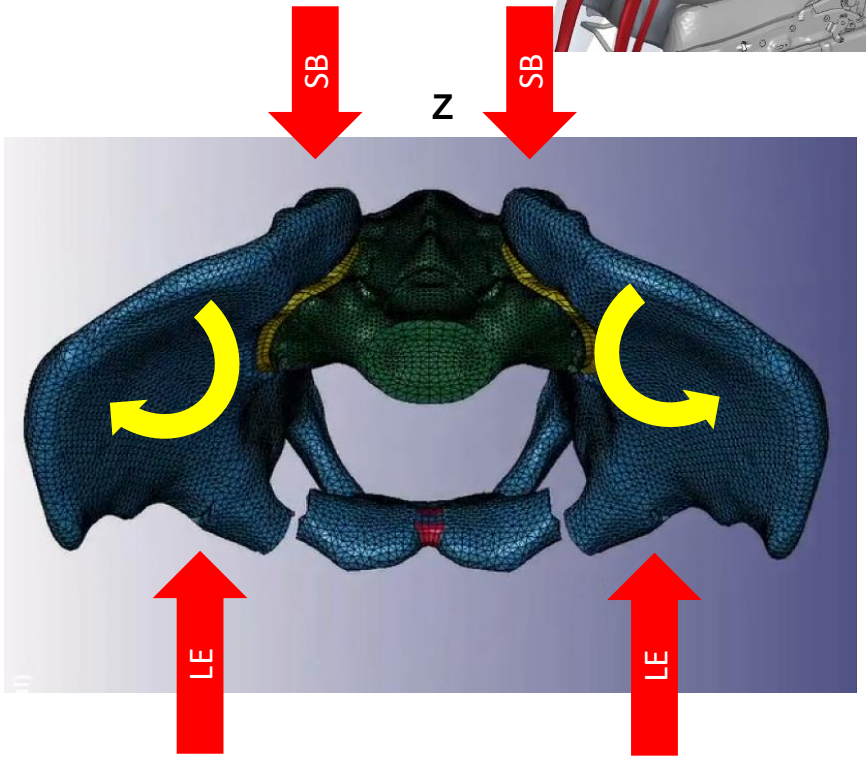
Rotation about X-axis

Rotation about Z-axis

Pelvis Outward Deformation







Summary

- Rib fracture
  - Difference in fracture distribution between ABTS and FDR
    - More rib fractures in 45deg condition
    - Anterior and lateral fractures occurred due to chest inertial loads
    - Seatback properties and structure design influenced fracture locations
  - Rib fractures after maximum chest deflection and seat load
    - Thorax may experience complex combined loadings, especially in the 45deg recline condition
      - Compression due to A-P inertial loading
      - Shear due to ramping up motion
- Pelvis fracture
  - Off-axis rotations from both iliac wings represent pelvis outward deformation
    - Maybe an indicator of the pubic ramus fractures

Contact Info

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

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