



RESEARCH CONSORTIUM FOR  
CRASHWORTHINESS IN AUTOMATED  
DRIVING SYSTEMS



# INVESTIGATION OF SUBMARINING RISK IN AVERAGE FEMALES THROUGH EXPERIMENTAL AND COMPUTATIONAL MODELING



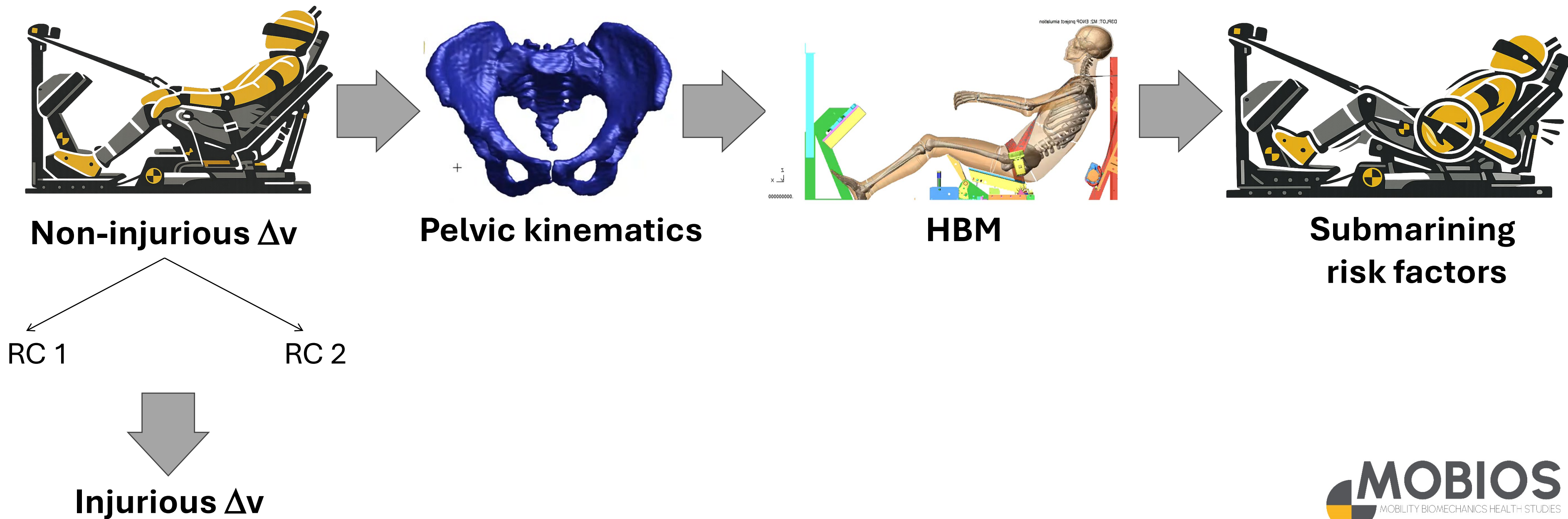
6th ANNUAL RCCADS WORKSHOP

May 20th, 2026

Francisco J. Lopez-Valdes, PhD

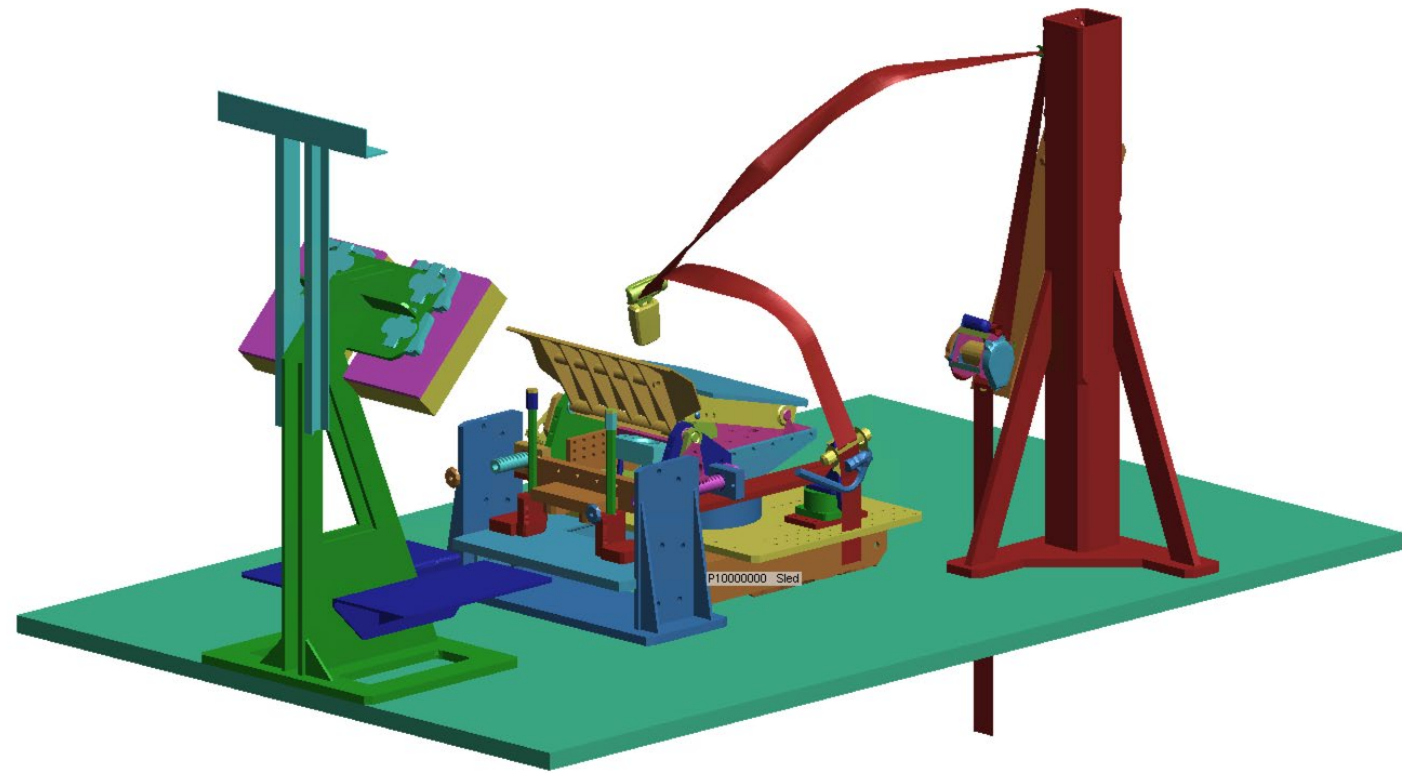
# Goal and objectives

To investigate the influence of restraint system on the risk of submarining of reclined female occupants by performing sled tests with PMHS and by developing matching simulations with HBM.

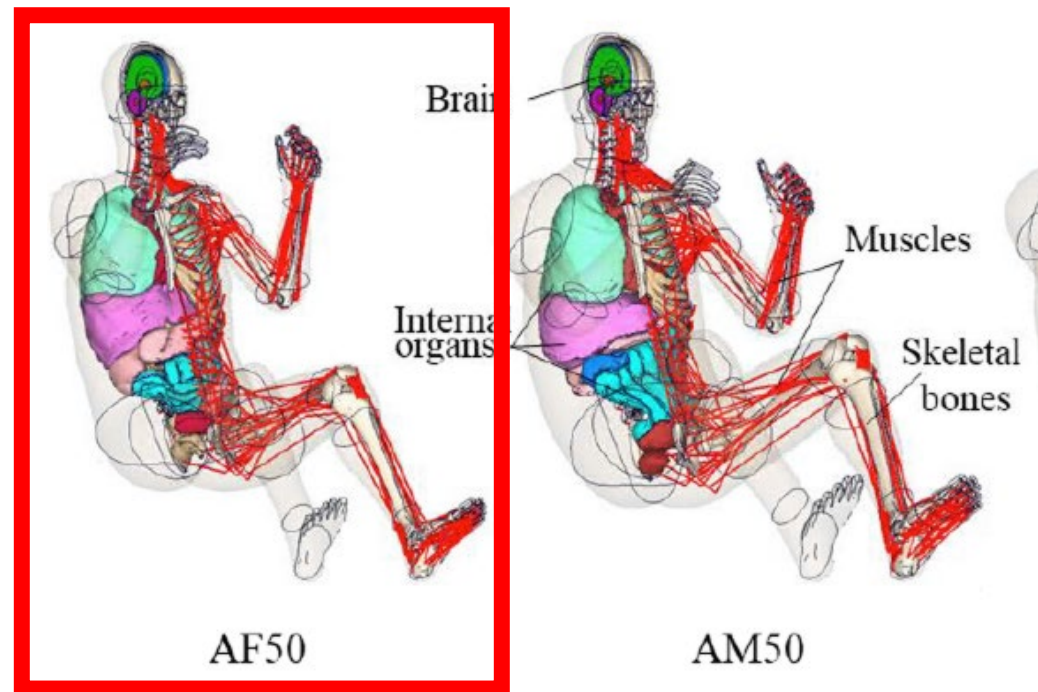


# Initial computational study

ENOP Sled Model

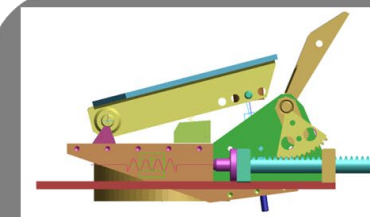
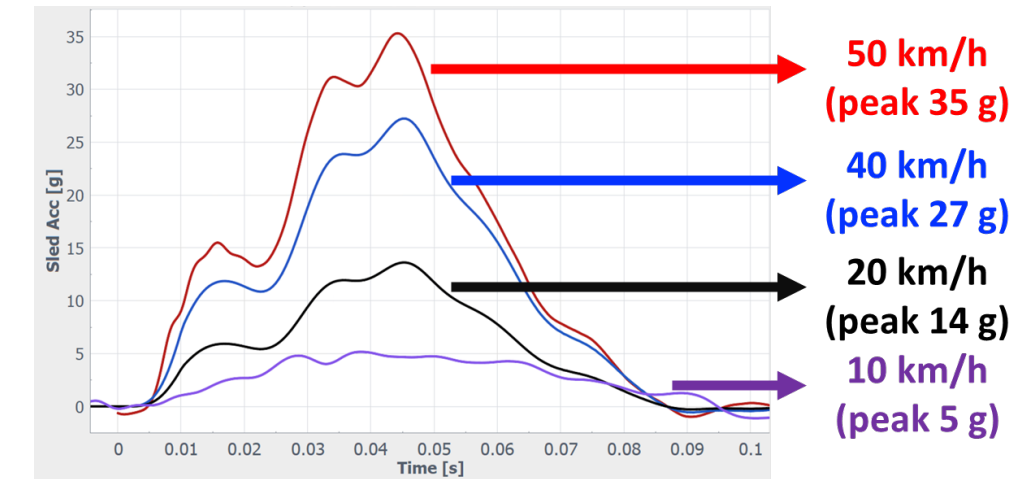


THUMS Average Female, Version 7.1



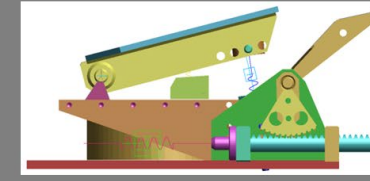
Bone fracture deactivated

## Contributing "external" factors



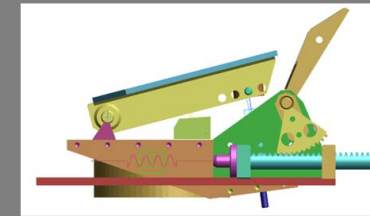
Front seat - Uriot et al. (2015)

Front seat geometry  
Front seat stiffness



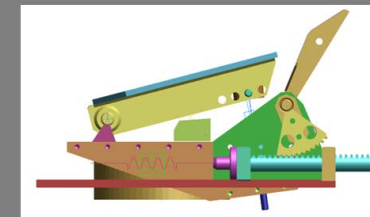
Rear seat - Uriot et al. (2015)

Rear seat geometry  
Rear seat stiffness (lower relative to frontal)



RCCADS 2024

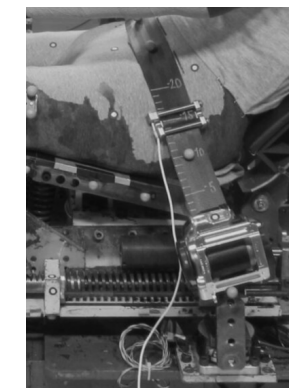
Uriot (2015) front seat geometry  
Uriot (2015) front seat stiffness + Add stiffness



RCCADS 2025

Uriot (2015) front seat geometry  
Uriot (2015) rear seat stiffness

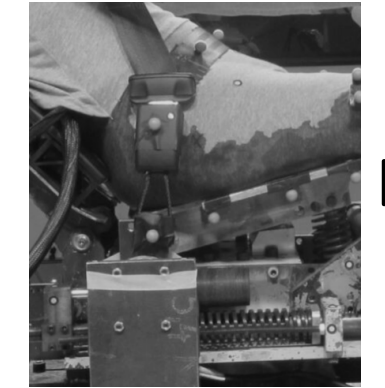
B6



w/PP+LL



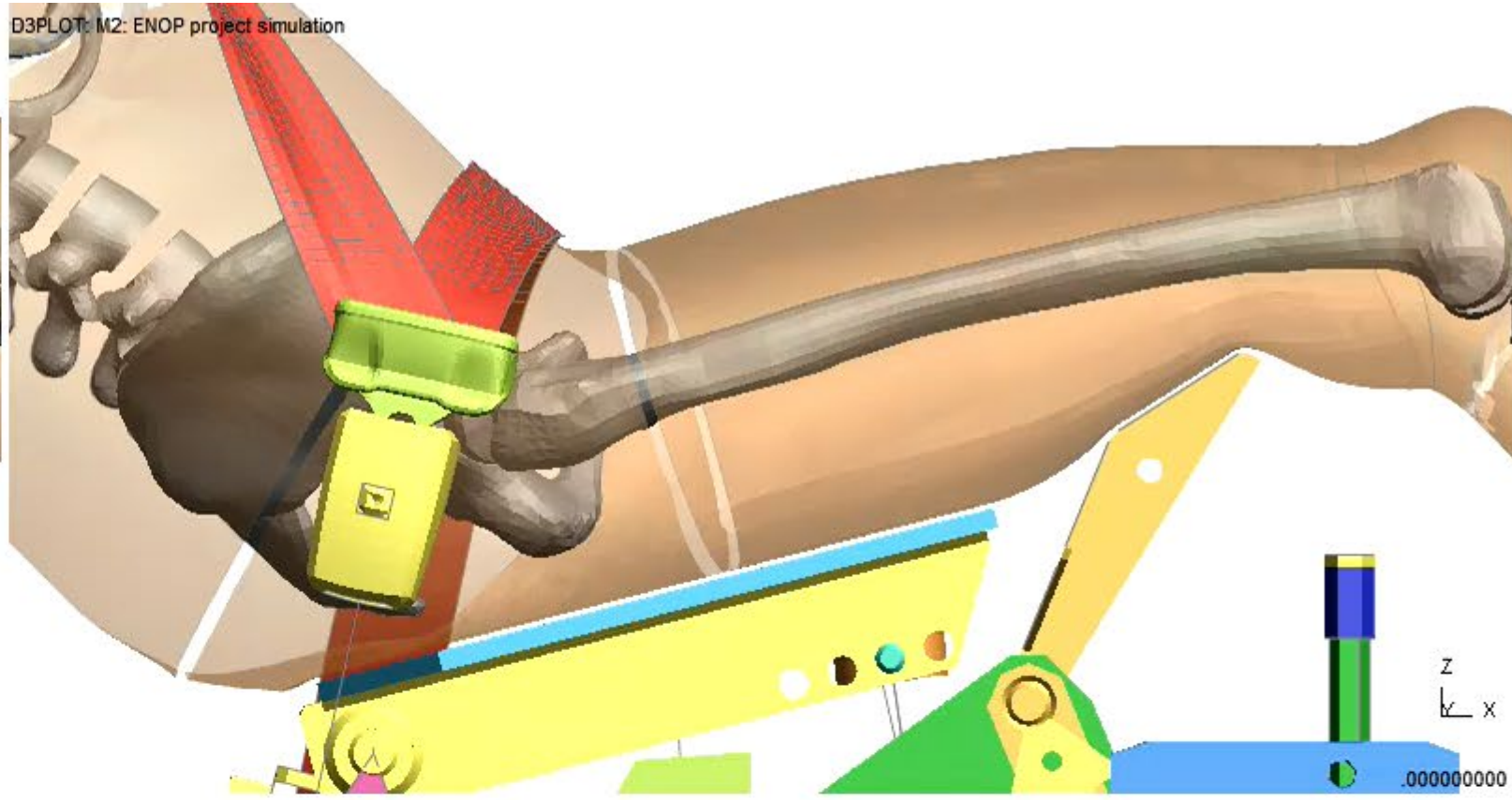
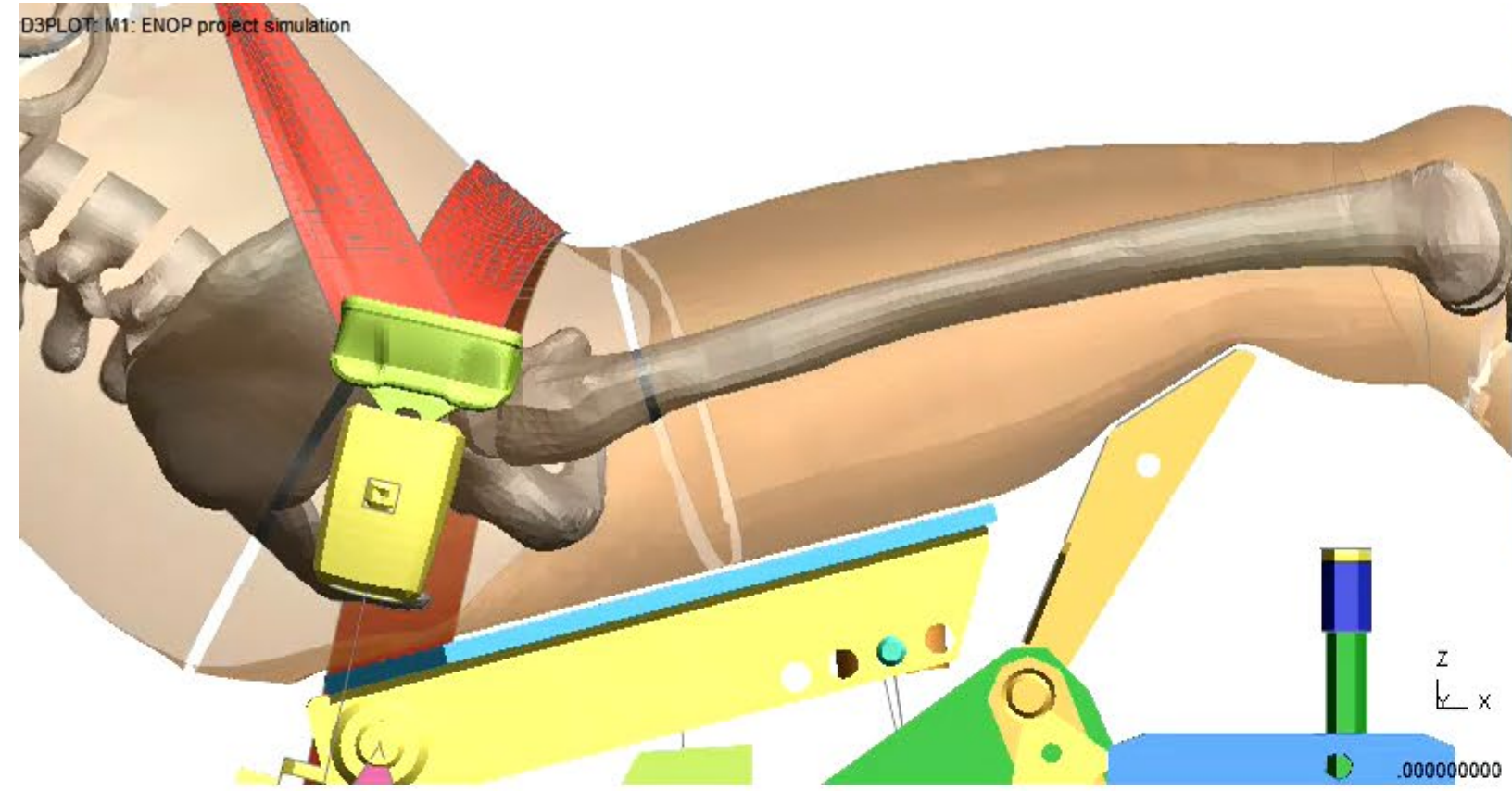
w/PP+LL



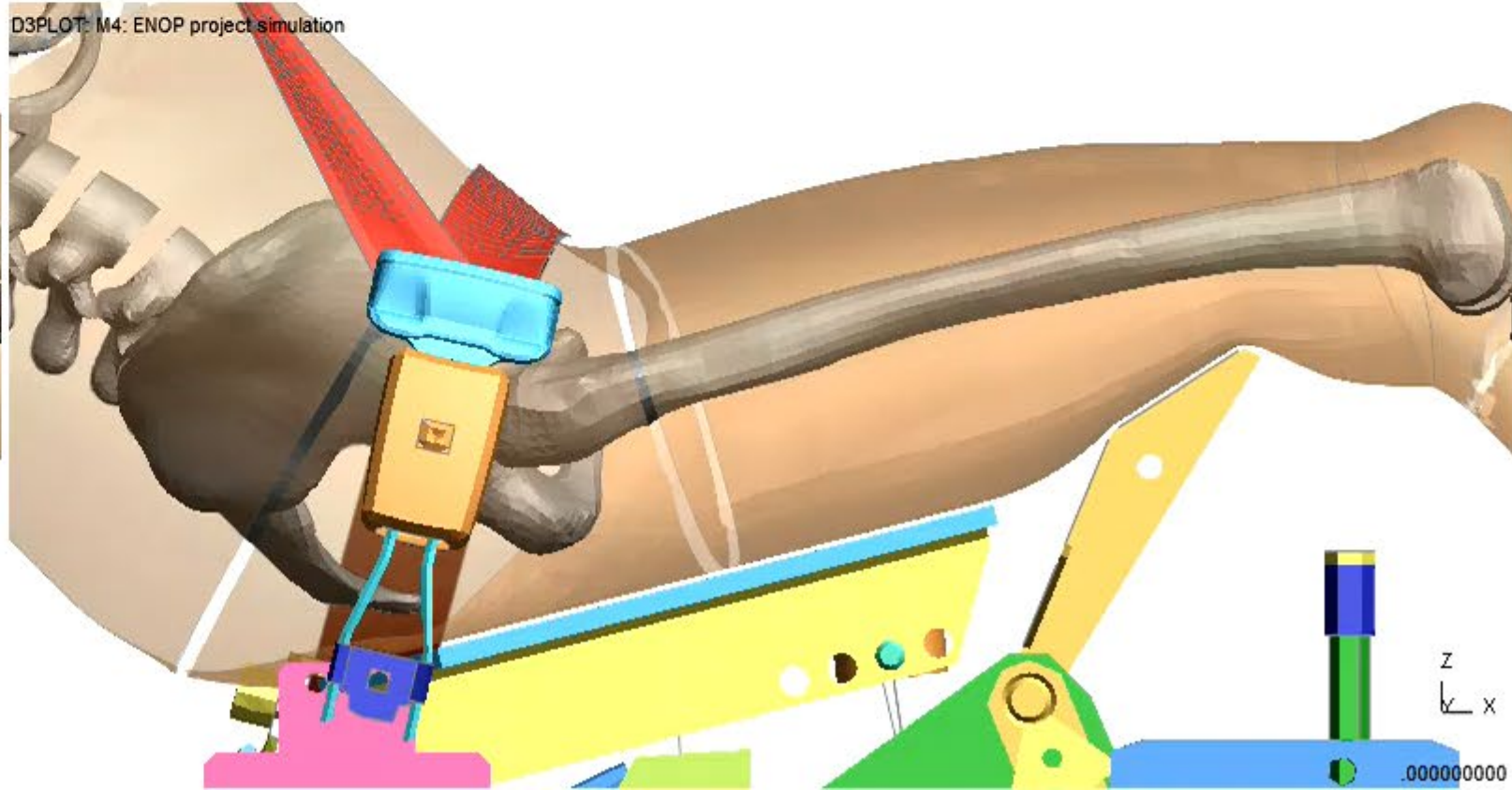
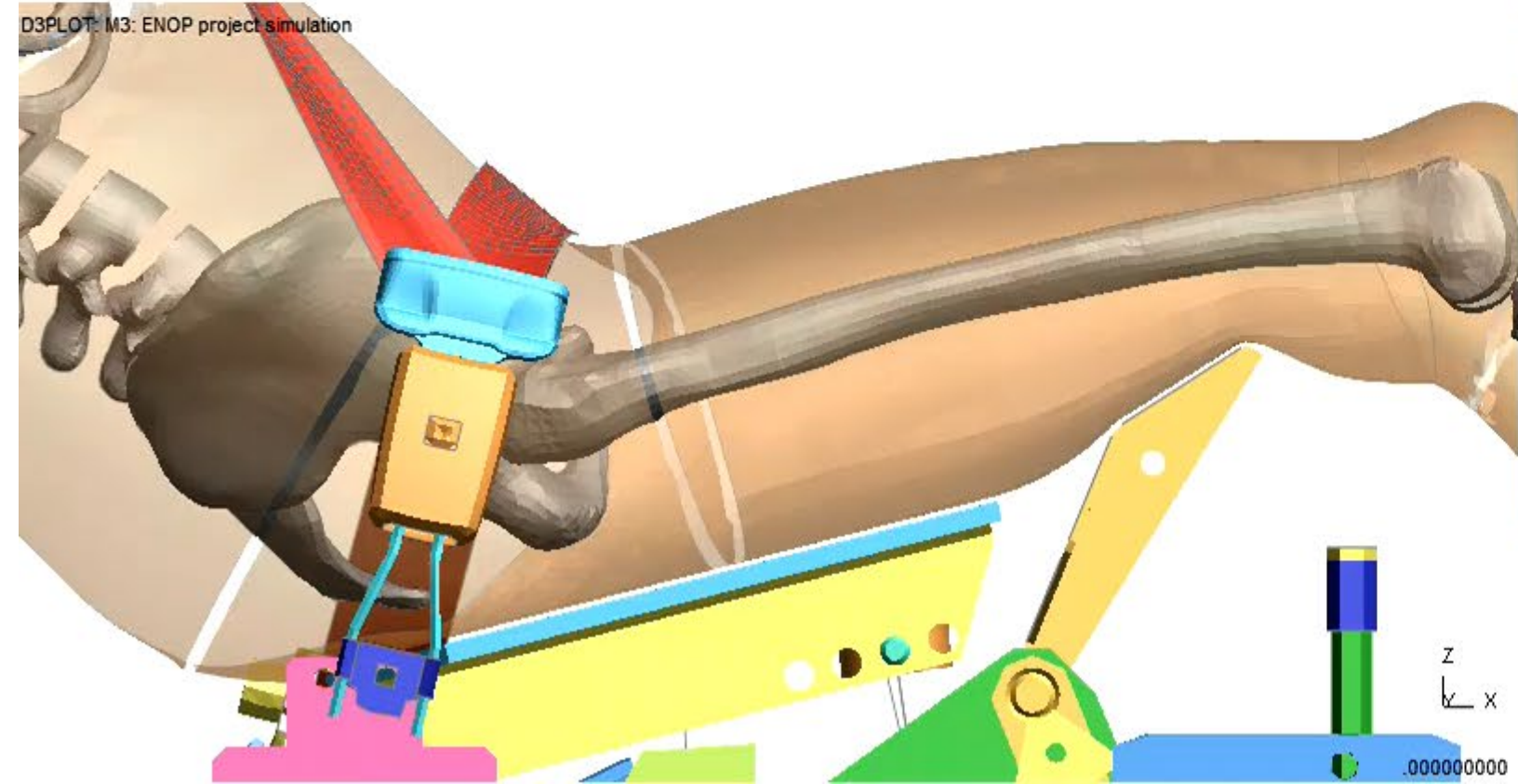
wo/PP+LL

Buckle

Pretensioners in the lapbelt (Activated/Deactivated)



**B1 w/PP+LL**  
**B6 w/PP+LL**  
**Buckle w/PP+LL**

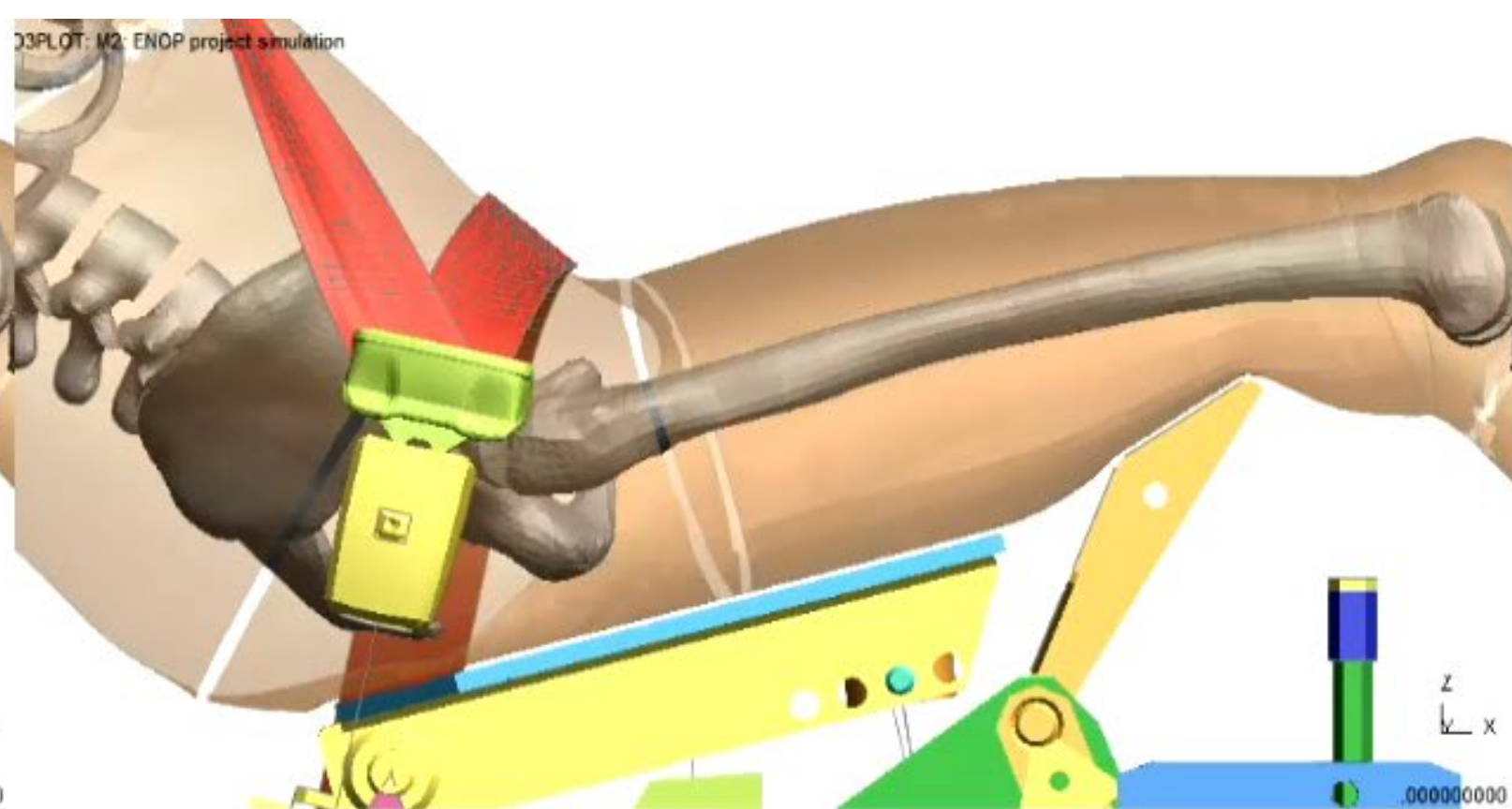
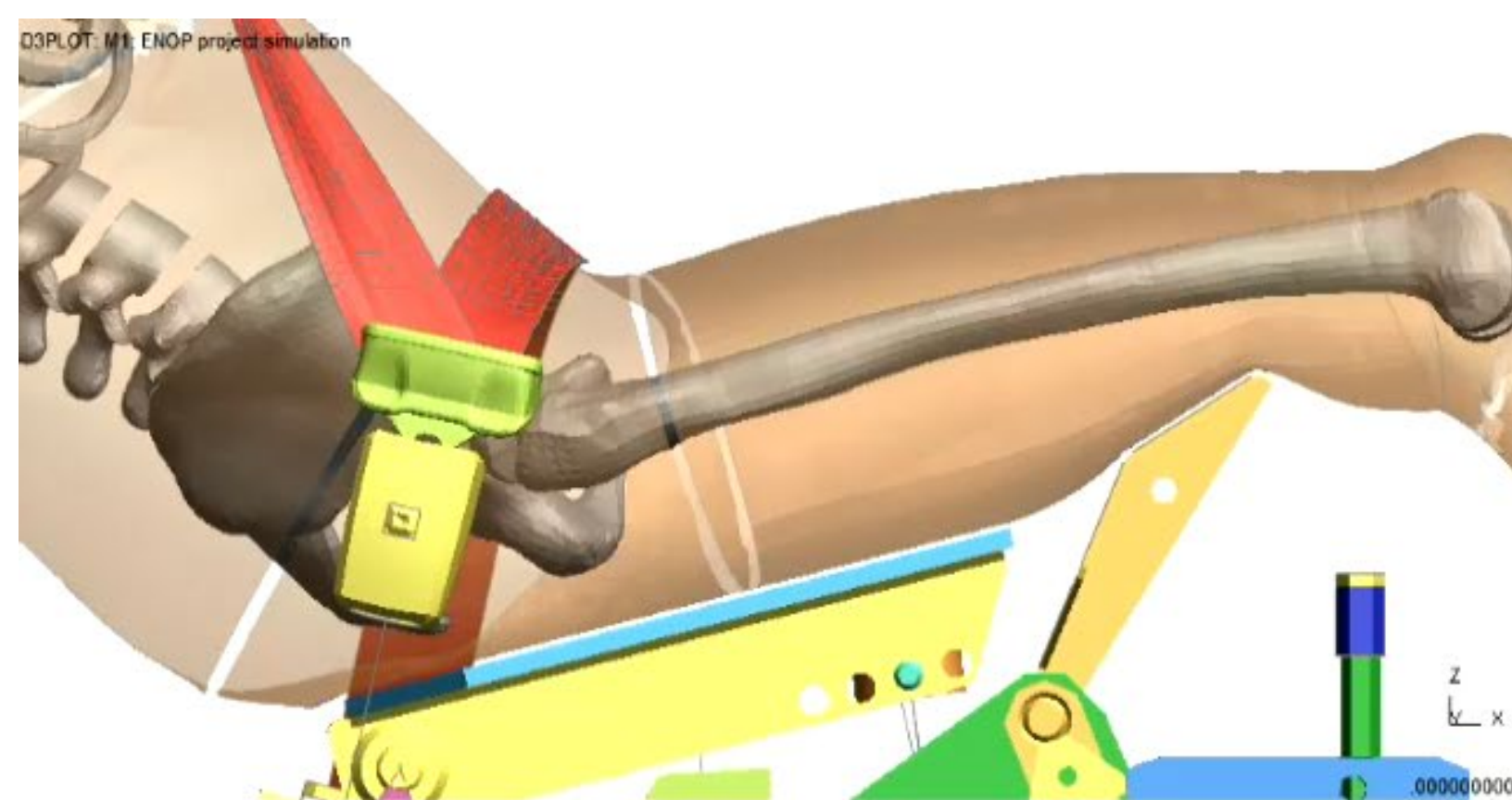


**B1 w/PP+LL**  
**B6 w/PP+LL**  
**Buckle**

**50 km/h**

**40 km/h**

**Lapbelt PP activated**



**B1 w/PP+LL**  
**B6 w/LL**  
**Buckle w/LL**



**B1 w/PP+LL**  
**B6 w/LL**  
**Buckle**

**50 km/h**

**40 km/h**

**Lapbelt PP deactivated**

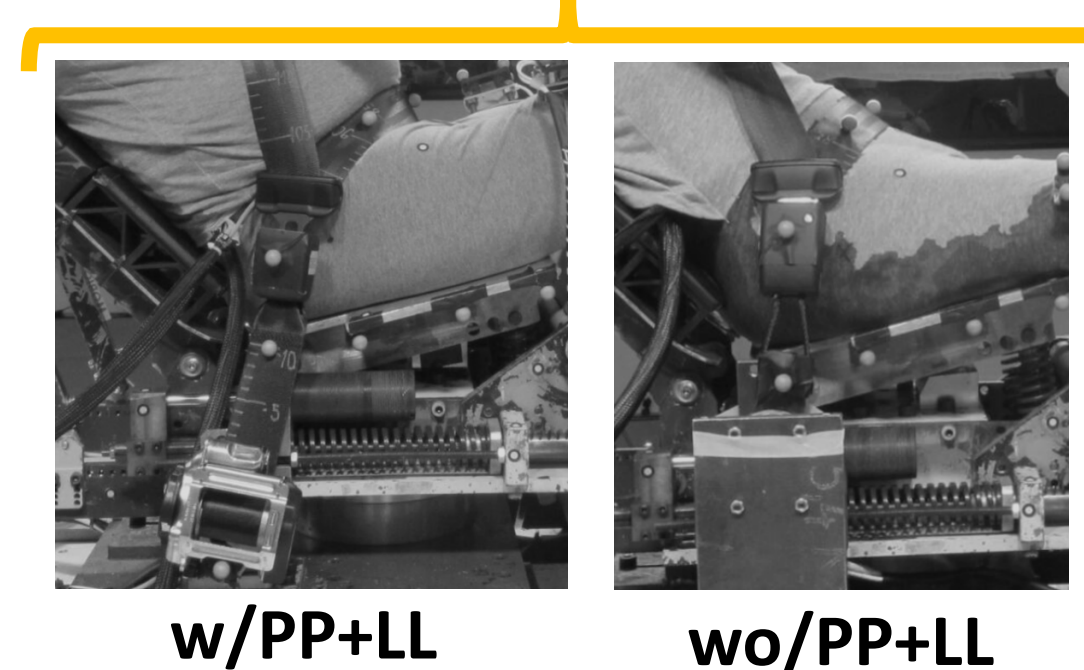
# Testing conditions for submarining for high delta-v

	Delta-v	Lapbelt PP Activated	Max Excursion at [ms]		Submarining	
			Left	Right	Left	Right
Buckle w/PP+LL	50	Yes	85	86	No	No
		No	86	<b>91</b>	No	<b>88</b>
	40	Yes	80	83	No	No
		No	84	89	No	No
Buckle wo/LL	50	Yes	83	<b>88</b>	No	<b>80</b>
		No	<b>97</b>	<b>104</b>	<b>77</b>	<b>68</b>
	40	Yes	80	80	No	No
		No	84	<b>104</b>	No	<b>80</b>

Buckle

## Risk of submarining:

- Increased when using larger delta-v
- Increased with buckle wo/LL
- Increased deactivated lap belt PP





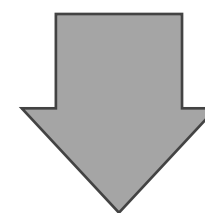
**Non-injurious: 20 km/h  $\Delta v$**

B1 w/LL  
B6 w/PT+LL  
Buckle

**RC 1**

**RC 2**

B1 w/LL  
B6 w/LL  
Buckle



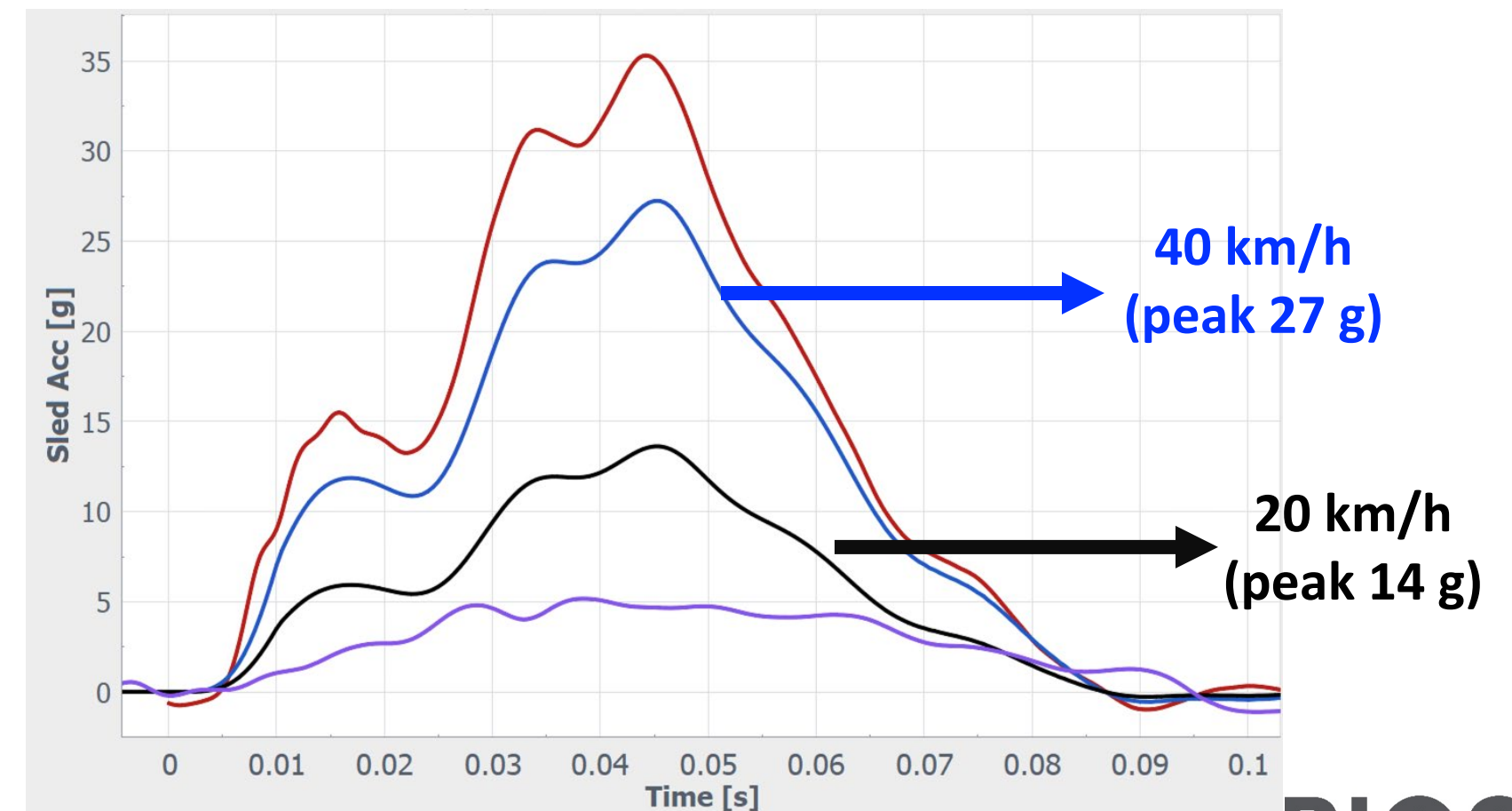
**Injurious: 40 km/h  $\Delta v$**

B1 w/PP+LL  
B6 w/LL  
Buckle

# Test subjects and crash pulse

Donor ID	Age	Weight (kg)	Stature (cm)	Cause of death
0122F	76	51.5	160	Squamous cell carcinoma with lymph node involvement
0142F	73	55	168	Breast cancer

Test ID	Donor ID	Delta-v (km/h)	Restraint condition
RCCADS2-01-LS-01	0122F	20	RC1
RCCADS2-01-LS-02	0122F	20	RC2
RCCADS2-01-HS-01	0122F	40	RC1
RCCADS2-02-LS-01.1	0142F	20	RC1
RCCADS2-02-LS-02	0142F	20	RC2
RCCADS2-02-HS-01	0142F	40	RC1



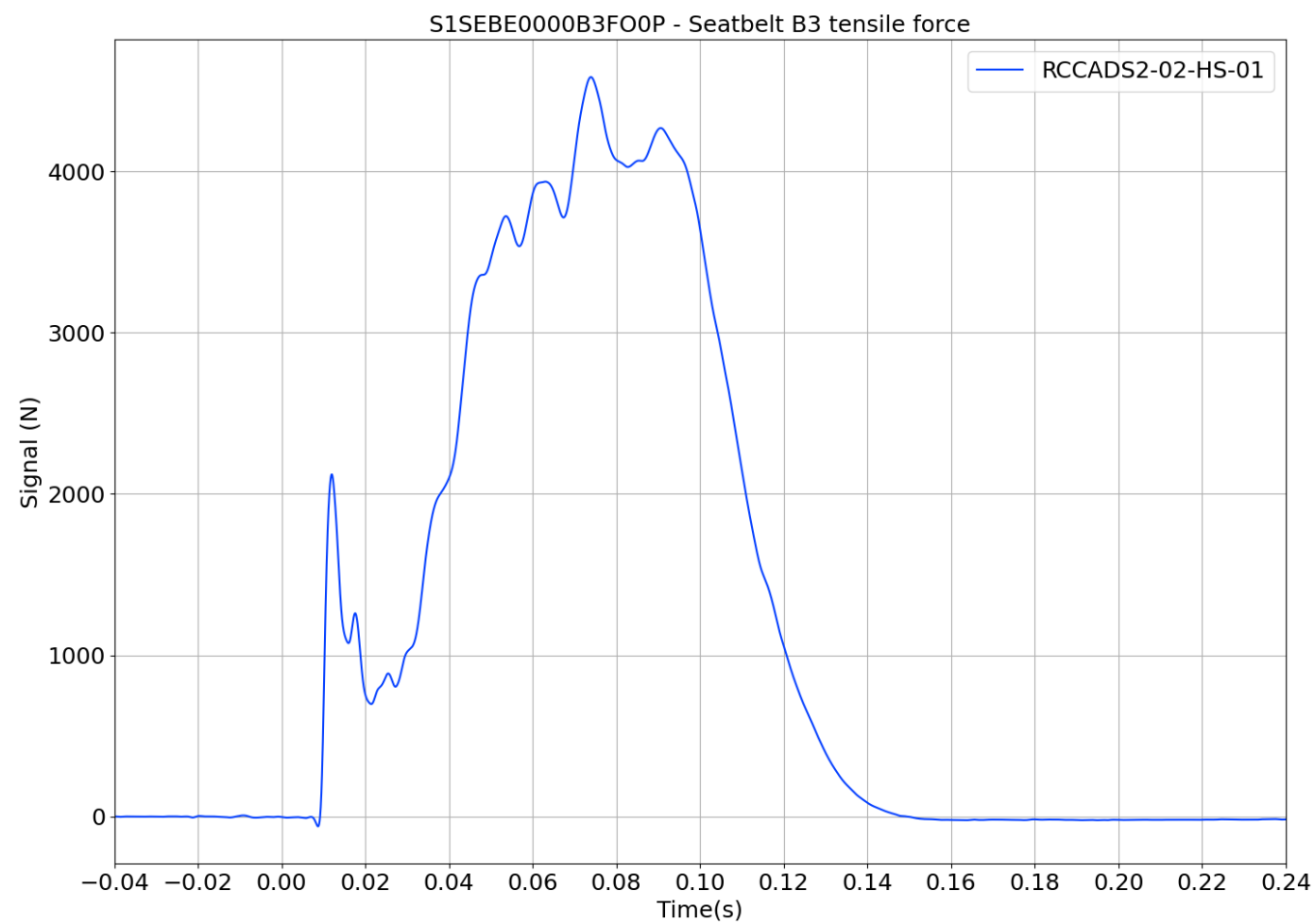
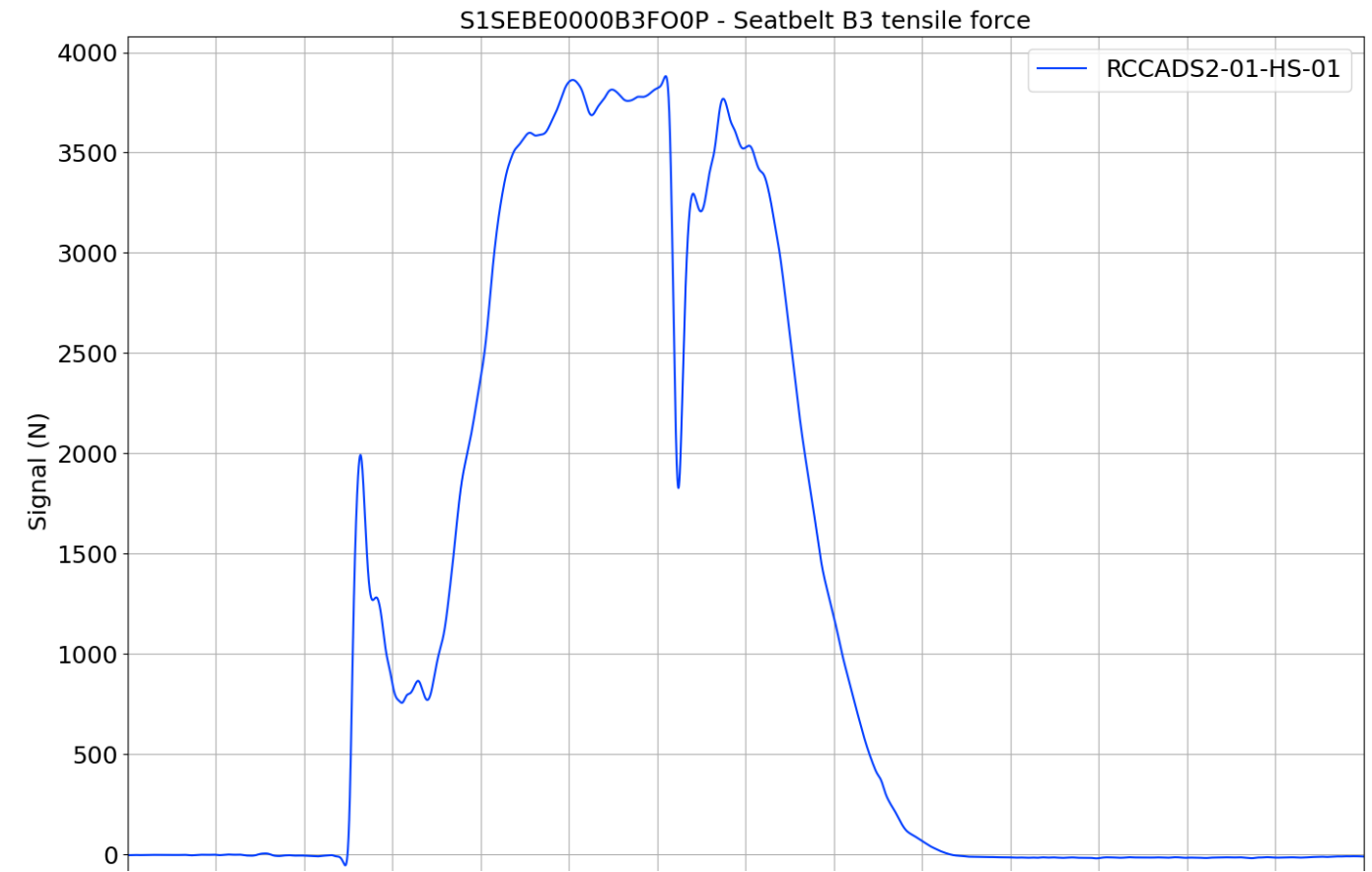
# Initial position comparison

Landmarks	RCCADS2-01-LS-01	RCCADS2-01-LS-02	RCCADS2-01-HS-01
H-point L (x, mm)	47.00	46.60	41.90
H-point R (x, mm)	40.90	36.20	35.80
Pelvic angle (deg)	70.60	72.90	77.20
PS (y, mm)	3.00	5.10	-4.50
Sternal notch (y, mm)	-10.89	-9.69	-15.61
Frankfort plane (deg)	28.0 / 26.0	29.0 / 30.0	27.5 / 25.0

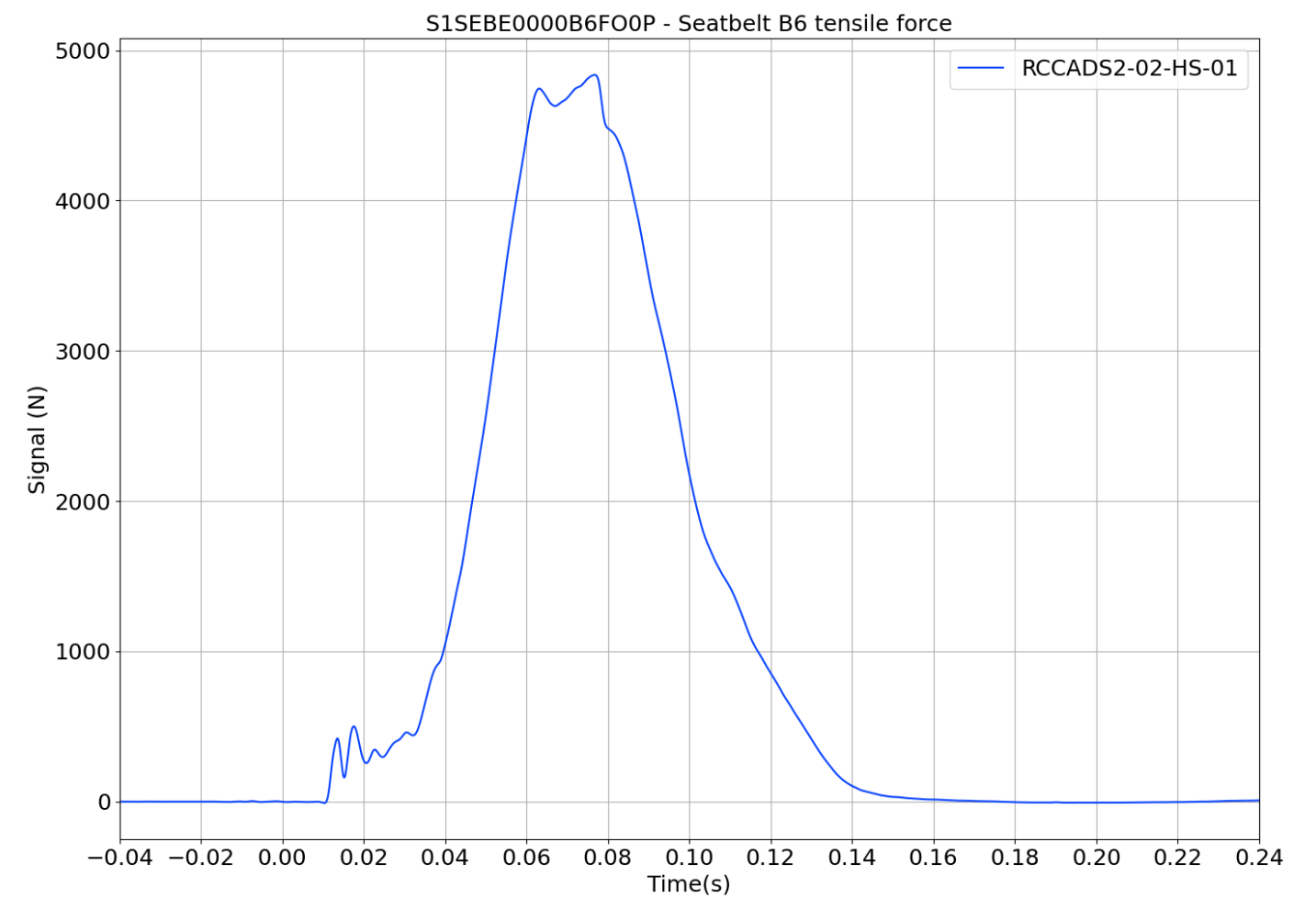
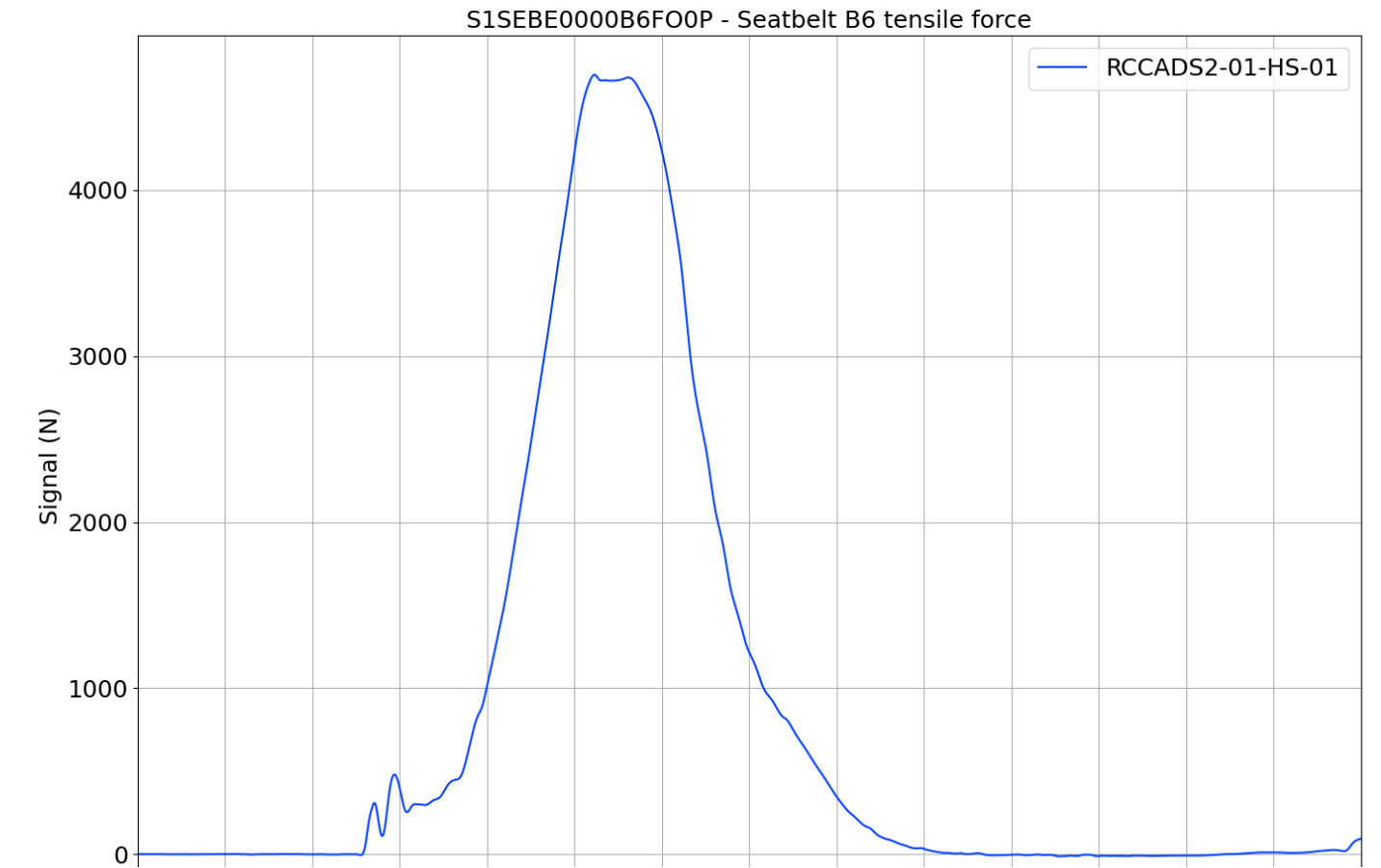
Landmarks	RCCADS2-02-LS-01.1	RCCADS2-02-LS-02	RCCADS2-02-HS-01
H-point L (x, mm)	49.70	44.30	45.60
H-point R (x, mm)	51.30	43.40	42.70
Pelvic angle (deg)	70.60	69.10	70.60
PS (y, mm)	-4.10	2.00	-2.80
Sternal notch (y, mm)	0.69	-0.16	-6.00
Frankfort plane (deg)	27.5	28.0	23.5

# Seat belt forces (high-delta-v)

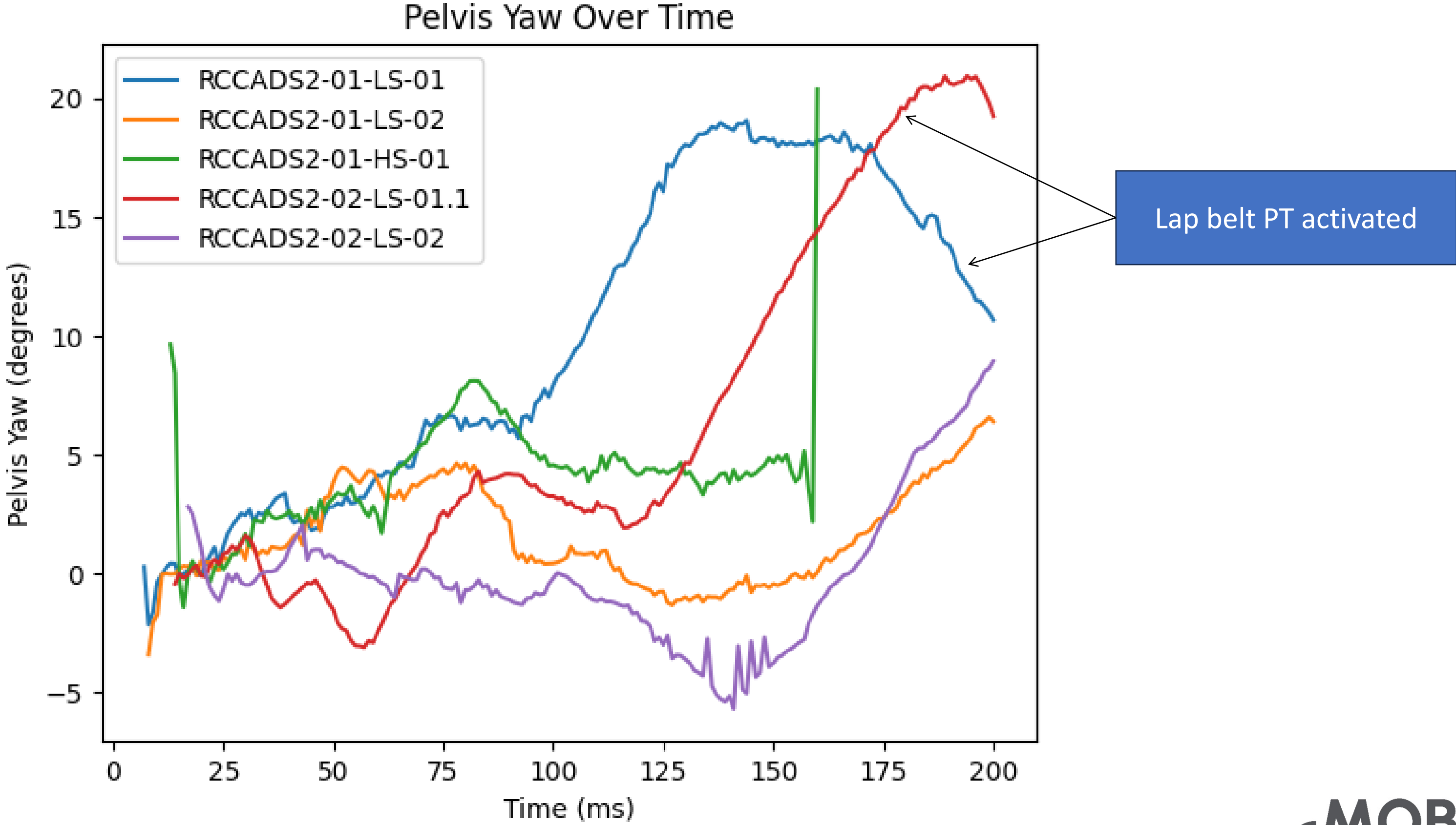
## Shoulder belt



## Lap belt

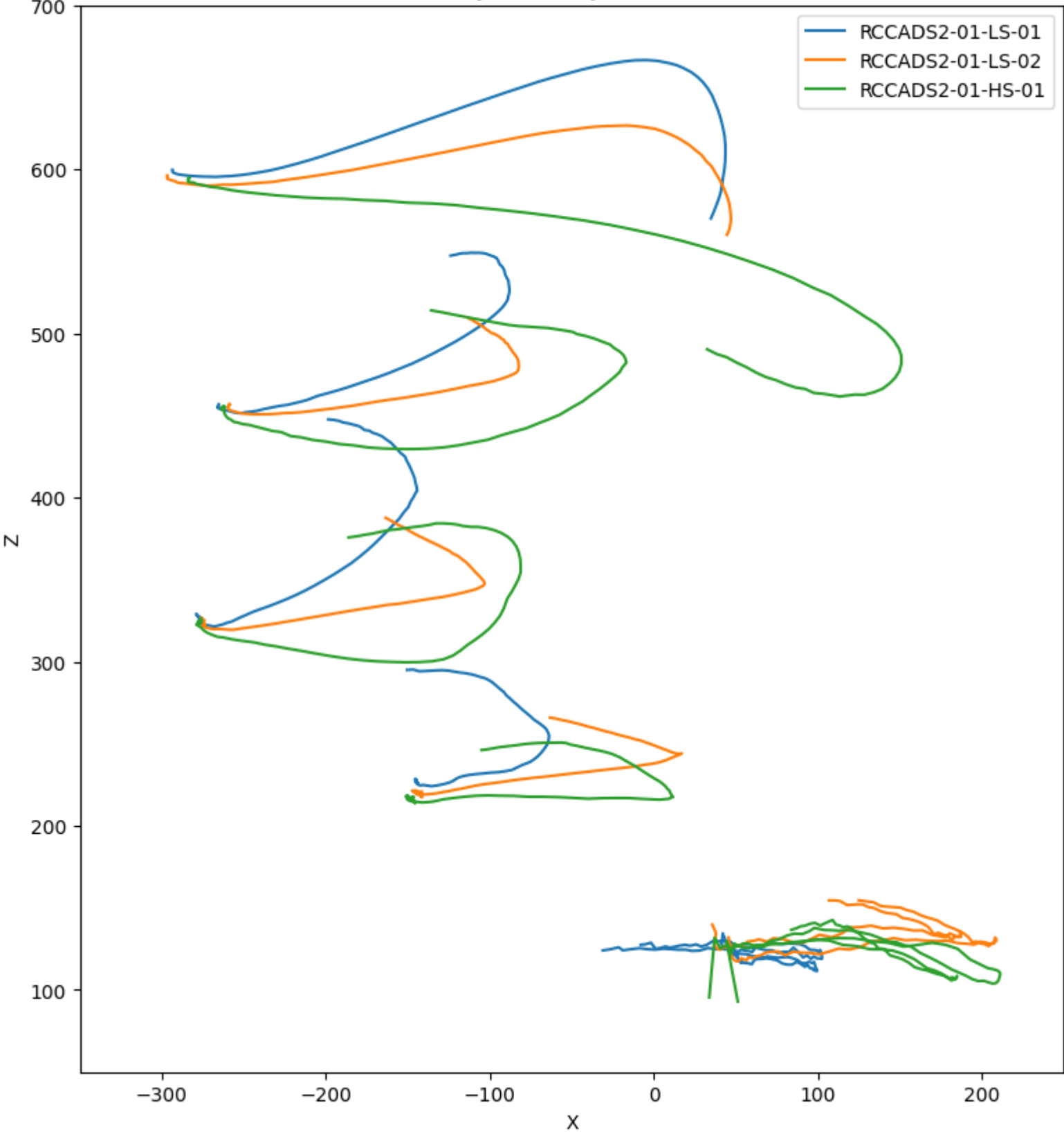


# Pelvis rotation (local y-axis)



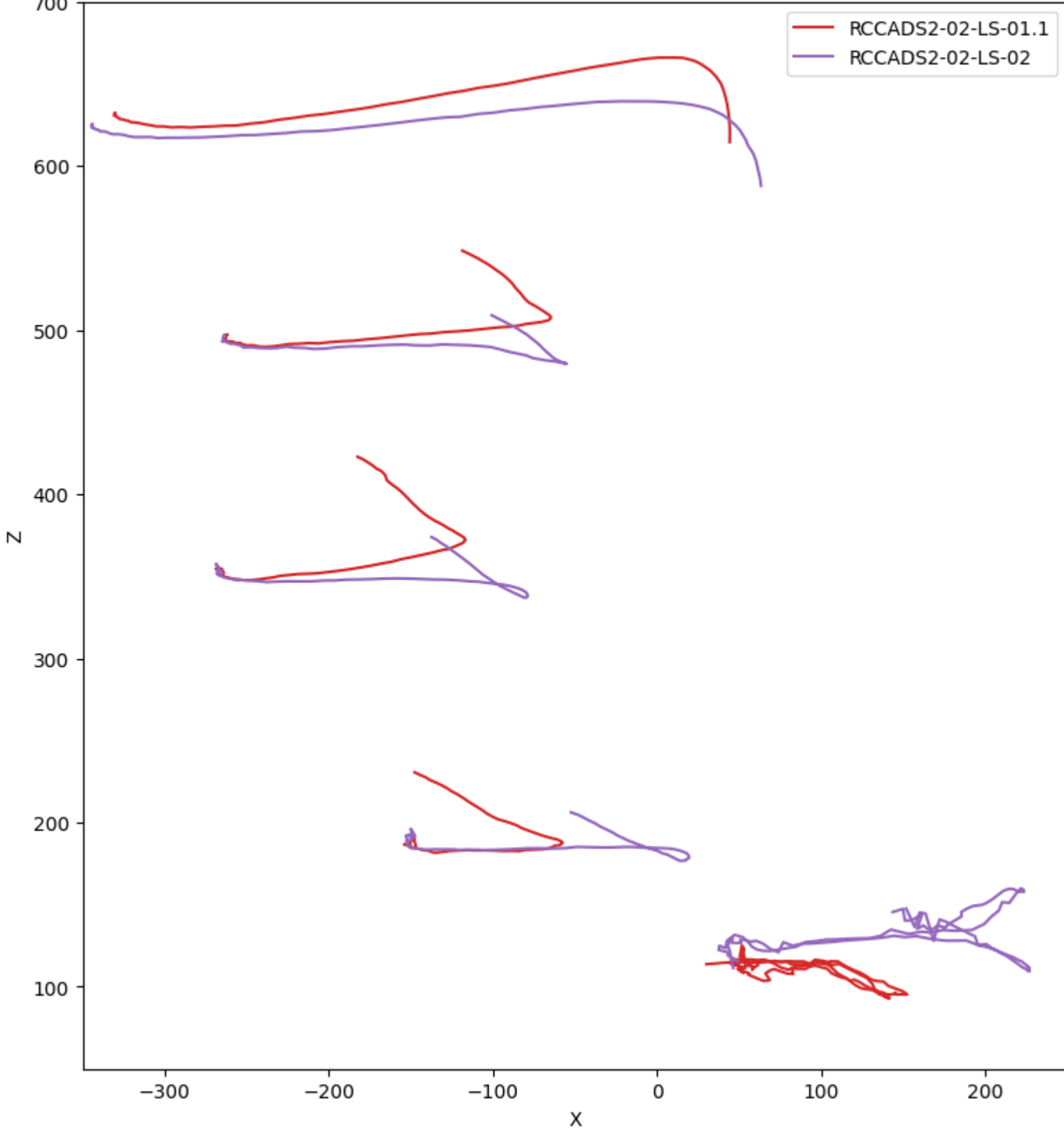
# Sagittal trajectories- VICON analysis

Full-Body Pose Trajectories In XZ



No ShB PT, 20 km/h  
No LB ShB PT, 20 km/h  
No LB PT, 40 km/h

Full-Body Pose Trajectories In XZ



RCCADS2-02-LS-01.1  
RCCADS2-02-LS-02

# Sagittal trajectories- VICON analysis

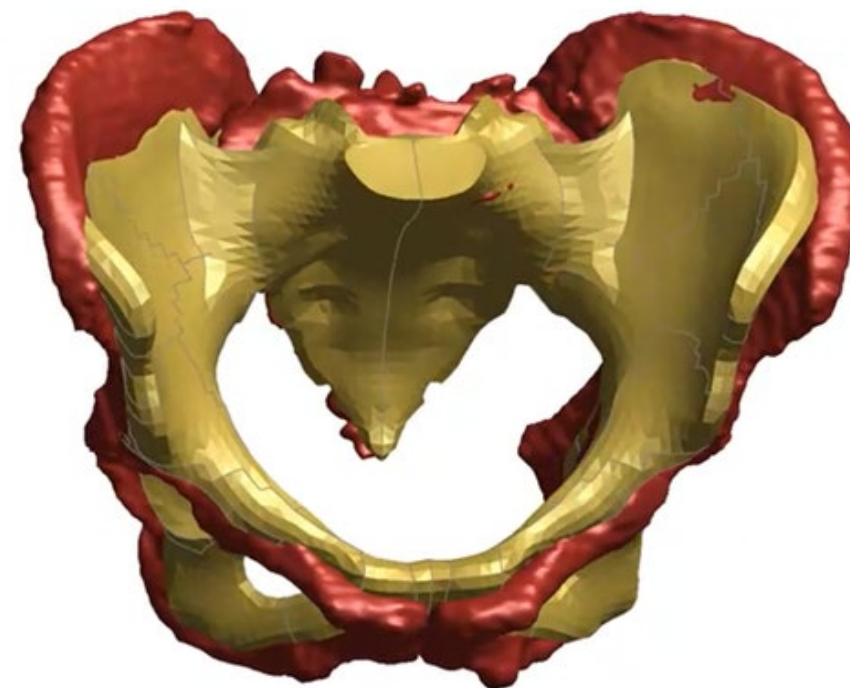
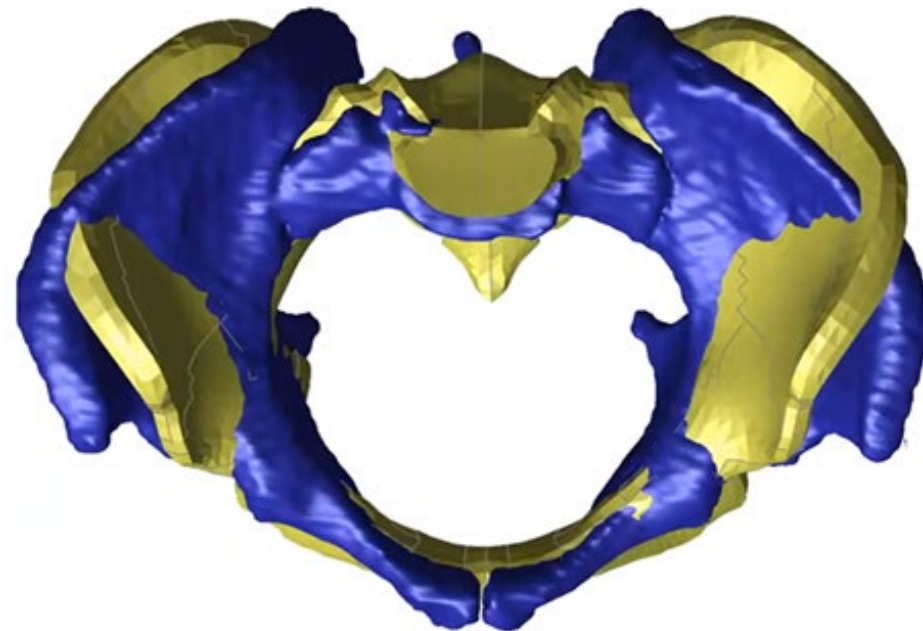
- Influence of activating B6 PT (20 km/h)
  - Reduced forward excursion of pelvis
  - Similar forward displacement of the head and upper spine
  - More upwards trajectory of head and spine segments: interaction with seat belt and airbag
- Influence of delta-v (20 vs. 40 km/h), without LP PT
  - Similar forward excursion of pelvis
  - 40 km/h: downward excursion of mid Hpoint (larger LB tension pulling downwards on seat)

# Injury summary

	RCCADS2-01	RCCADS2-02
<b>Spine</b>		
Cervical	C5-C6 endplate, C7 anterior body fx,	C4 lamina fx, C5-C6 endplate
Thoracic	T1 burst fx	T1 lamina fx
Lumbar	--	--
<b>Shoulder</b>	--	Scapula fracture
<b>Pelvis</b>	--	ASIS left fracture, displaced, Sacrum fracture (4 <sup>th</sup> -5 <sup>th</sup> )
<b>Rib cage</b>	14 rib fractures (w/o flail chest)	18 rib fractures (w/o flail chest)
<b>Sternum</b>	Body fracture	Body fracture

# Next steps

- 1) Performing sled tests on 3rd PMHS. **Changing conditions to facilitate submarining**
- 2) Developing and validating a **matching computational model** of the PMHS tests using advanced HBM.
  - Investigate contribution of individual anthropometry, specifically pelvis



0122F, 0142F vs THUMS AF50

# Acknowledgements

Thanks to the donors and their families for their generous support of the research performed at MOBIOS.

Thank you to the RCCADS consortium for providing funding for the project.

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