PMHS Responses in the Rear Seat During Frontal Crash Sled Tests: Early Findings

Warren N. Hardy, Andrew R. Kemper, Devon L. Albert, Allison J. Guettler, and Samuel T. Bianco

Virginia Tech
Center for Injury Biomechanics

Washington, D.C., 19 JAN 2023

Research Objectives

- To help delineate the boundaries of potential issues to be encountered as a result of occupants being seated other than in the front row of ADS-DVs (Automated Driving System-Dedicated Vehicles)

- Investigate the relationships between vehicle design parameters and occupant protection performance

- Evaluate current tools (ATDs) for use in the rear seat environment during frontal crash – Comparison to PMHS tests*

*This presentation contains images of clothed PMHS and radiographs

Research Rationale

- The risk of injury in frontal collisions is higher for rear seat occupants than for front seat occupants, especially in newer vehicles and for older occupants.

- Rear seat occupancy rates may increase in ADS-DVs, particularly in the rideshare environment.

- For many novel seating arrangements, the second or rear row will contain the forward-most front facing seats.

Research Approach Overview

Five primary components of the research approach:

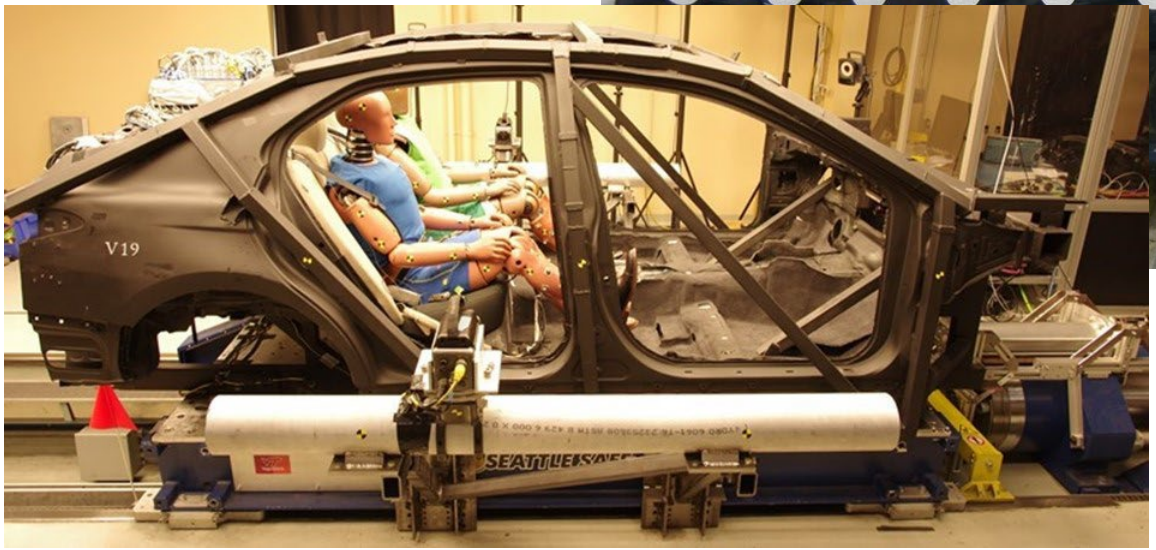
1) REAL-WORLD PROBLEM SCOPING
2) PLATFORM AND ATD MODELING AND VEHICLE SELECTION
3) TEST BUCK PREPARATION
4) ATD AND PMHS SLED TESTING AND MODELING
5) ANALYSES AND OBSERVATIONS

ATD and PMHS Sled Testing

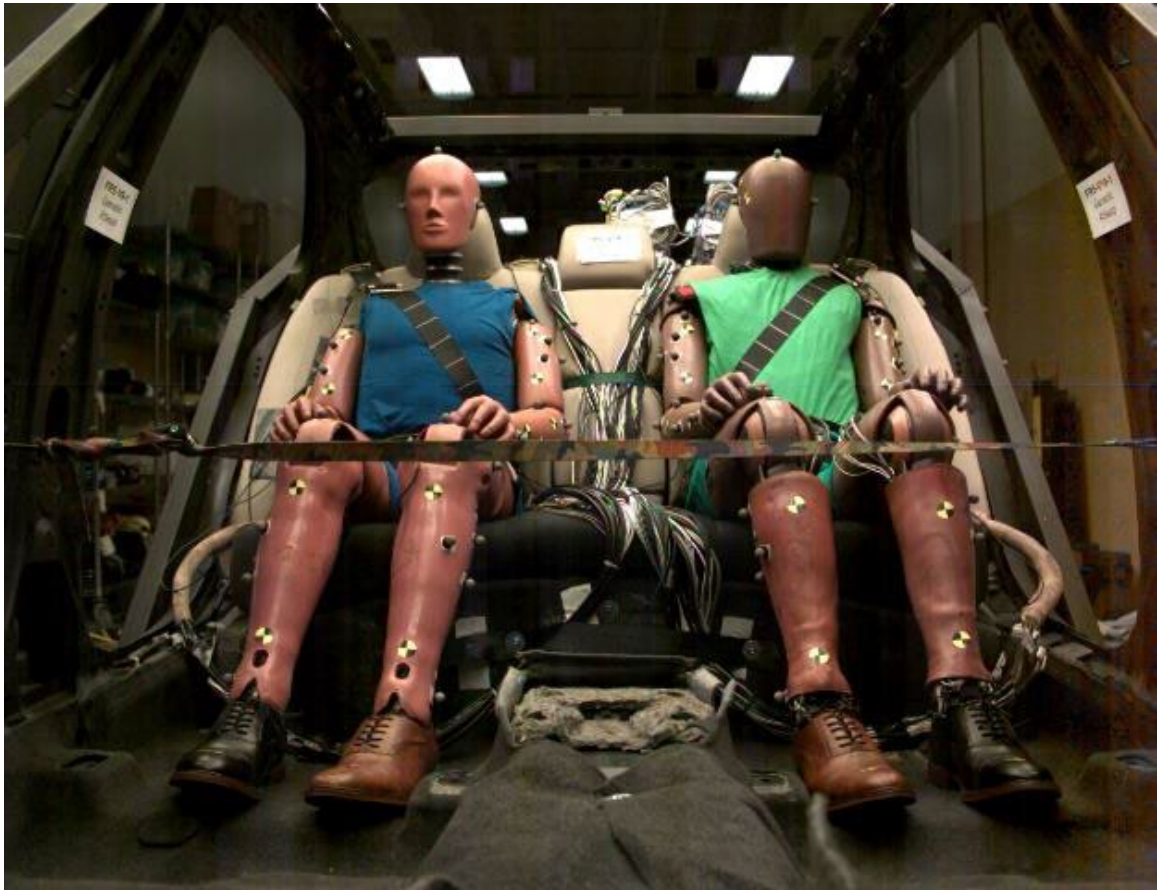
Paired Sled Tests using Vehicle Bucks

- Comparison between Hybrid-III, THOR-50M (ABISUP abdomen), and PMHS for vehicles having different levels of occupant protection
- Selection of four bucks for PMHS testing
- Focus on submarining, lap belt angle, and PMHS damage, including pelvis and lumber spine fracture

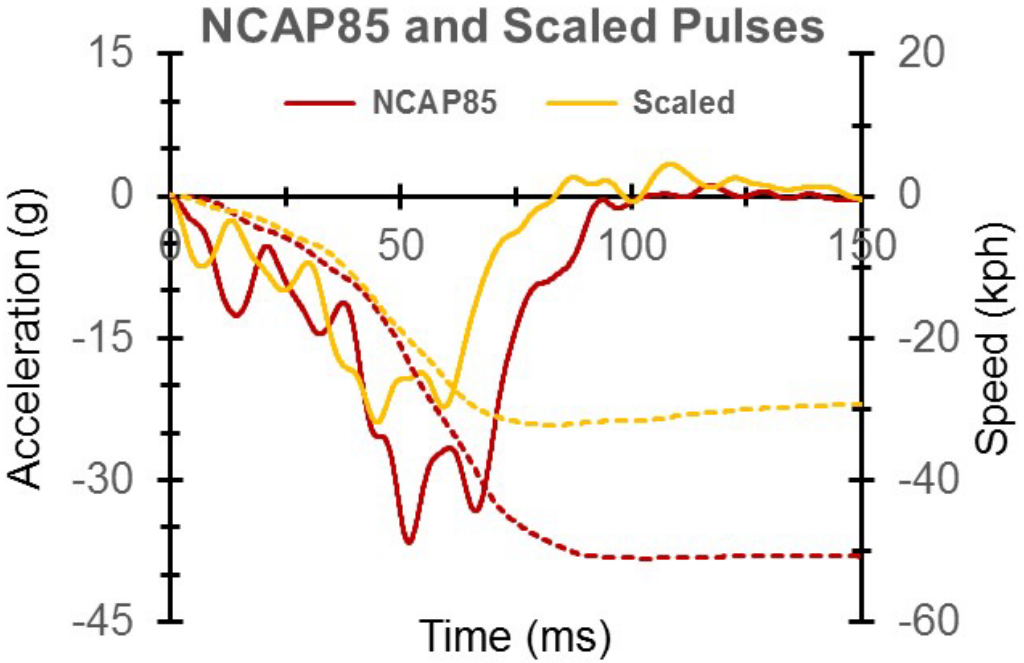
Test Buck Preparation



Hybrid-III/THOR-50M Positions



Vehicle Pulses

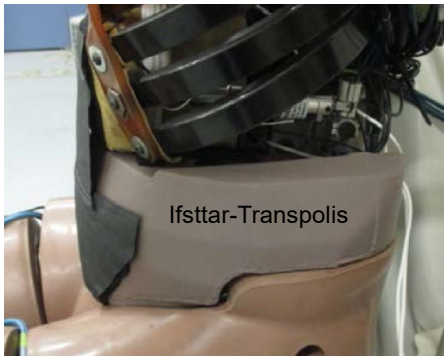


- H: The NCAP pulses were reduced to 85% to provide sled ΔV closer to 56 kph (NCAP85).
- L: The scaled-down vehicle-specific sled pulses (ΔV = 32 kph) were generated by applying a scaling factor (32/56 = 0.57) to the NCAP pulses to test in a more-common real-world range. A generic sled pulse was generated by averaging the scaled-down pulses.

Comparison Test Matrix

Four vehicles selected for use in PMHS testing

- Bottom, middle (2) and top performing vehicles
- Conventional and advanced restraints
- Low and high-energy (NCAP85) pulses
- ATDs and PMHS tested
- ABISUP used in the THOR-50M
- Focal PMHS reperfusion
- Four PMHS abdominal pressure measurements
- 6 DOF PMHS sacrum and pelvis kinematics



Buck	Restraint Type	Test	Pulse	ATD/PMHS
V13 2017 Mazda CX-3	Conventional (Bottom Performer)	1	L	THOR-50M
		2	H	THOR-50M
		3	L	THOR-50M
		4	H	SM129
		5	H	SM155
V14 2018 Mercedes GLC 300	Advanced (Top Performer)	1	L	THOR-50M
		2	L	THOR-50M
		3	H	THOR-50M
		4	H	THOR-50M
V15 2018 Nissan Maxima	Conventional (Middle Performer)	1	L	THOR-50M
		2	L	THOR-50M
		3	L	THOR-50M
		4	H	THOR-50M
		5	H	SM152
		6	H	SM153
V19 2018 Toyota Camry	Advanced (Middle Performer)	1	L	THOR-50M
		2	L	THOR-50M
		3	H	THOR-50M
		4	H	THOR-50M
		5	H	SM154
		6	H	SM095

PMHS Characteristics

Test	Buck	PMHS	Sex	Age	Stature (cm)	Mass (kg)
FRS-V13-4	Mazda	SM129	M	79	178	63
FRS-V13-5	Mazda	SM155	M	65	168	85
FRS-V13-6	Mazda	SM158	M	29	163	73
FRS-V13-7	Nissan	SM159	M	74	178	70
FRS-V14-5	Mercedes	SM156	M	68	188	89
FRS-V14-6	Mercedes	SM157	M	59	173	68
FRS-V15-5	Nissan	SM152	M	63	180	81
FRS-V15-6	Nissan	SM153	M	51	168	64
FRS-V19-5	Toyota	SM154	M	74	178	89
FRS-V19-6	Toyota	SM095	M	74	170	64
Average				64	174	75

PMHS Damage

- Clavicle Fx (1)
- Gladiolus and/or manubrium Fx
- Multiple rib Fx (right-side dominant)
- Pleural tear at hilum (1)
- Possible cardiac contusion (1)
- Minor disruption of the diaphragm (1)
- Liver fractures of the diaphragmatic surface and parenchyma
- Minor spleen damage (1)
- Ileum contusion, disruption, and transection
- Mesenteric tears
- Lumbar spine transverse process Fx
- L2 Fx (1, FRS-V13-5, SM155)
- Bilateral pelvis Fx (2, 1 with viscera intact)

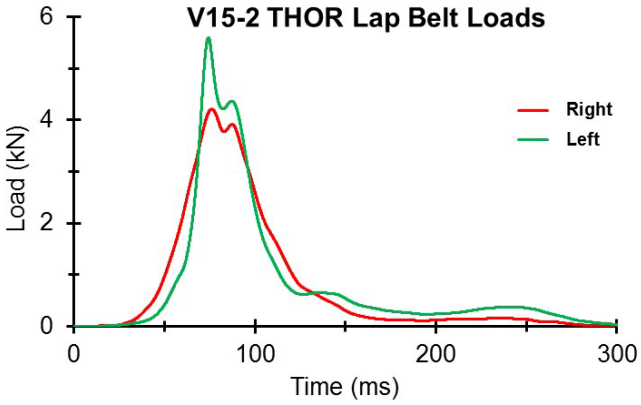
Submarining Events

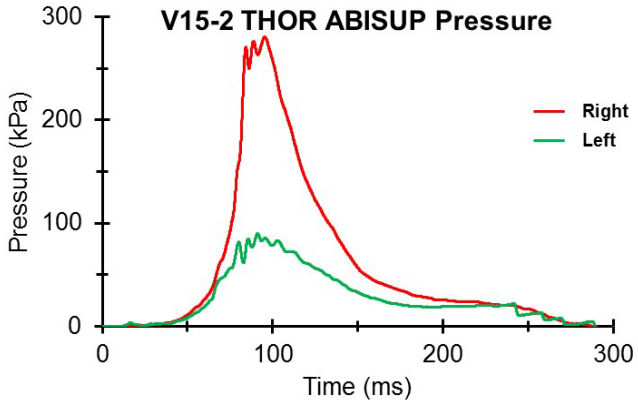
High-speed video, post-test observation, seatbelt loads, ABISUP pressure, and ASIS X-direction loads and moments about Y axis

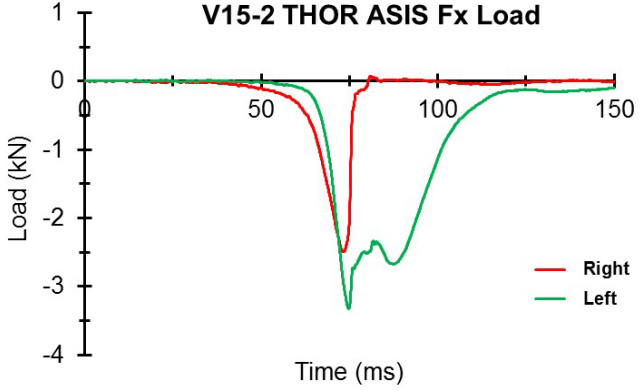
- Minor submarining: Belt encroaching upon the abdomen on one side
- Moderate submarining: Bilateral encroachment of the lap belt upon the abdomen, without substantial penetration as indicated by the ABISUP pressure sensors
- **Severe submarining:** Considerable penetration of the belt into the abdomen, very large ABISUP pressures, and substantial departure of the dummy pelvis from the seat

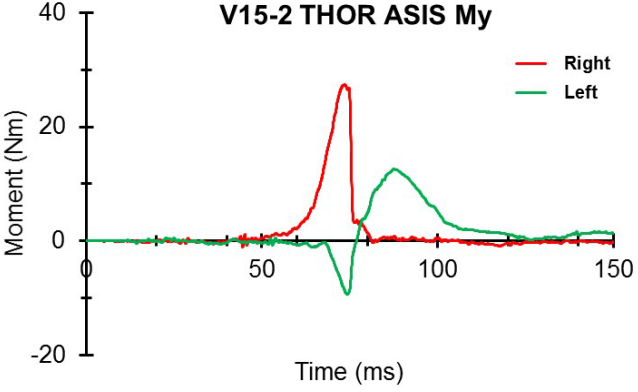
Buck	Restraint Type	Test	Pulse	Degree	ATD/PMHS
V13 2017 Mazda Cx-3	Conventional (Bottom Performer)	2	H	Severe	THOR-50M
		4	H	Severe	SM129
		5	H	Severe	SM155
V14 2018 Mercedes GLC 300	Advanced (Top Performer)	4	H	None	THOR-50M
V15 2018 Nissan Maxima	Conventional (Middle Performer)	2	L	Minor	THOR-50M
		4	H	Moderate	THOR-50M
		5	H	None	SM152
		6	H	None	SM153
V19 2018 Toyota Camry	Advanced (Middle Performer)	4	H	Moderate	THOR-50M
		5	H	None	SM154
		6	H	None	SM095

Submarining Analysis: THOR-50M





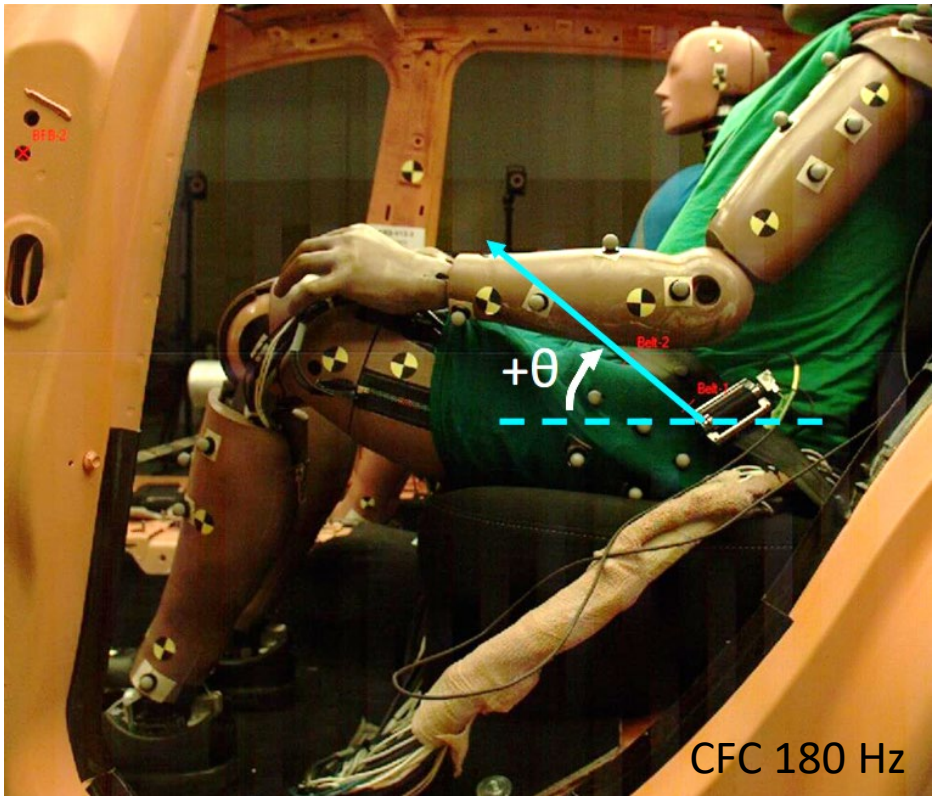




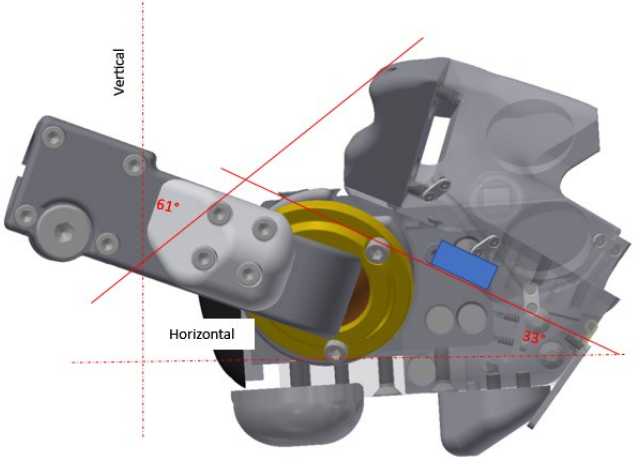
Submarining Timing Relative to Belt Load

Test	Surrogate	Restraint Type	Performance Category	Submarining Level	Submarining Timing (ms)			
					Pressure	ASIS Fx	Belt Angle	Video
FRS-V13-2	THOR-50M	Conventional	Bottom	Severe	2.6	0.1	1.3	5.2
FRS-V13-4	PMHS	Conventional	Bottom	Severe	4.3	na	na	0.7
FRS-V13-5	PMHS	Conventional	Bottom	Severe	0.7	na	na	0.5
FRS-V15-4	THOR-50M	Conventional	Middle	Moderate	1.6	-0.6	-1.1	0.5
FRS-V19-4	THOR-50M	Advanced	Middle	Moderate	3.4	-0.3	0.9	1.7

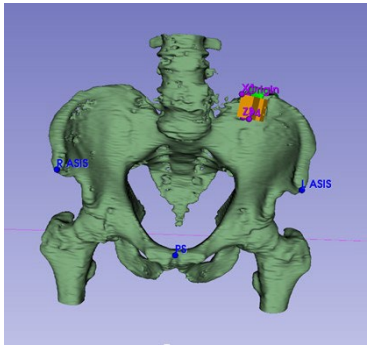
Pelvis and Lap Belt Angle



33° THOR -> 29° PMHS



Humanetics Innovative Solutions, Inc.



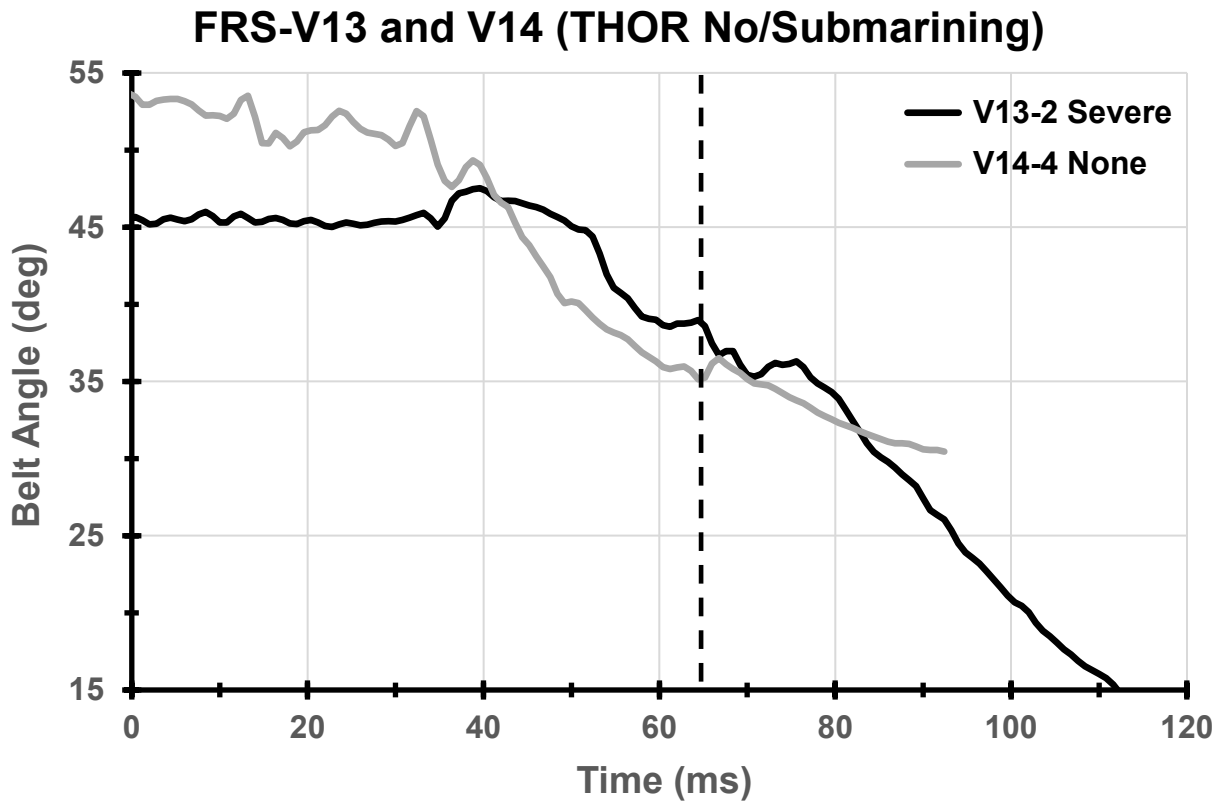
Belt angle is referenced to the buck

PMHS and THOR-50M Submarining Comparison

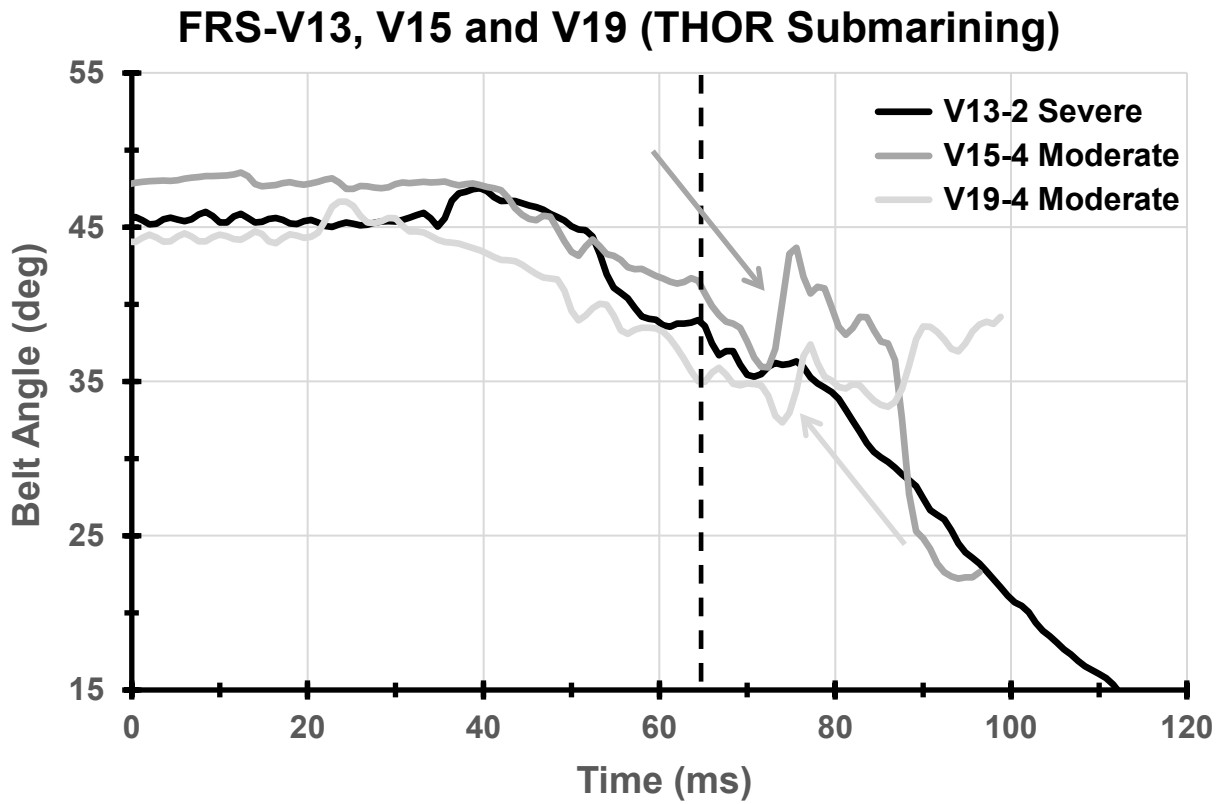
FRS-V13-4 (PMHS)

FRS-V13-2 (THOR-50M)

THOR-50M No/Submarining Belt Angle Comparison



THOR-50M Submarining Belt Angle Comparison

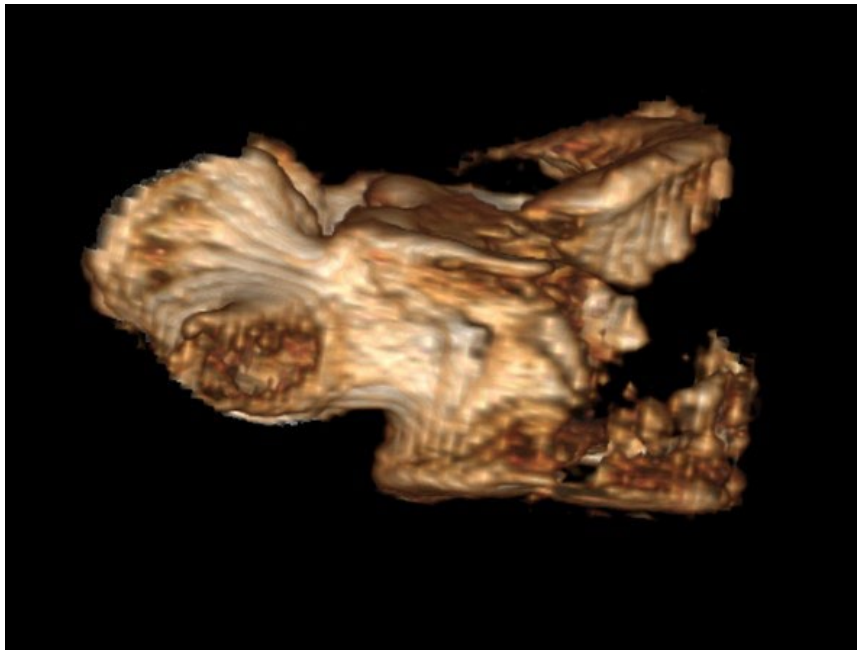


PMHS Submarining Comparison by Size

FRS-V13-4 (Lighter, Taller)

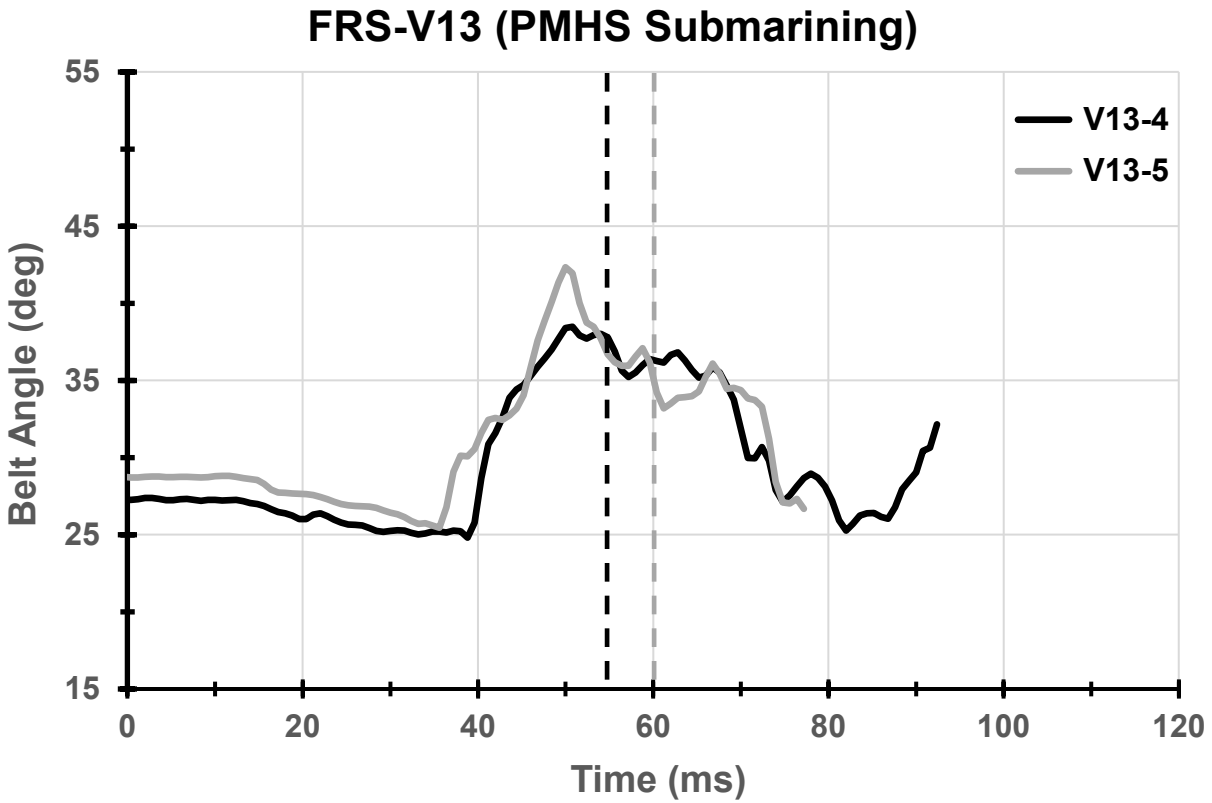
FRS-V13-5 (Heavier, Shorter)

L2 Fracture from FRS-V13-5 (SM155, Submarining)



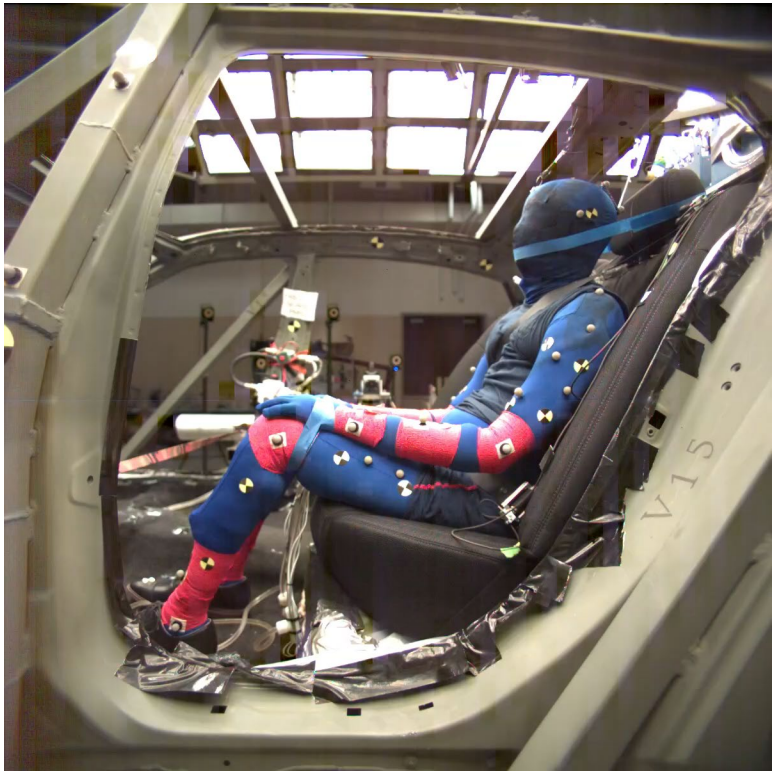
L2 was damaged at both the cranial and caudal aspects of the ventral surface. There was no loss of body height. This resulted from a combination of extreme extension and AP belt loading.

PMHS Submarining Belt Angle Comparison



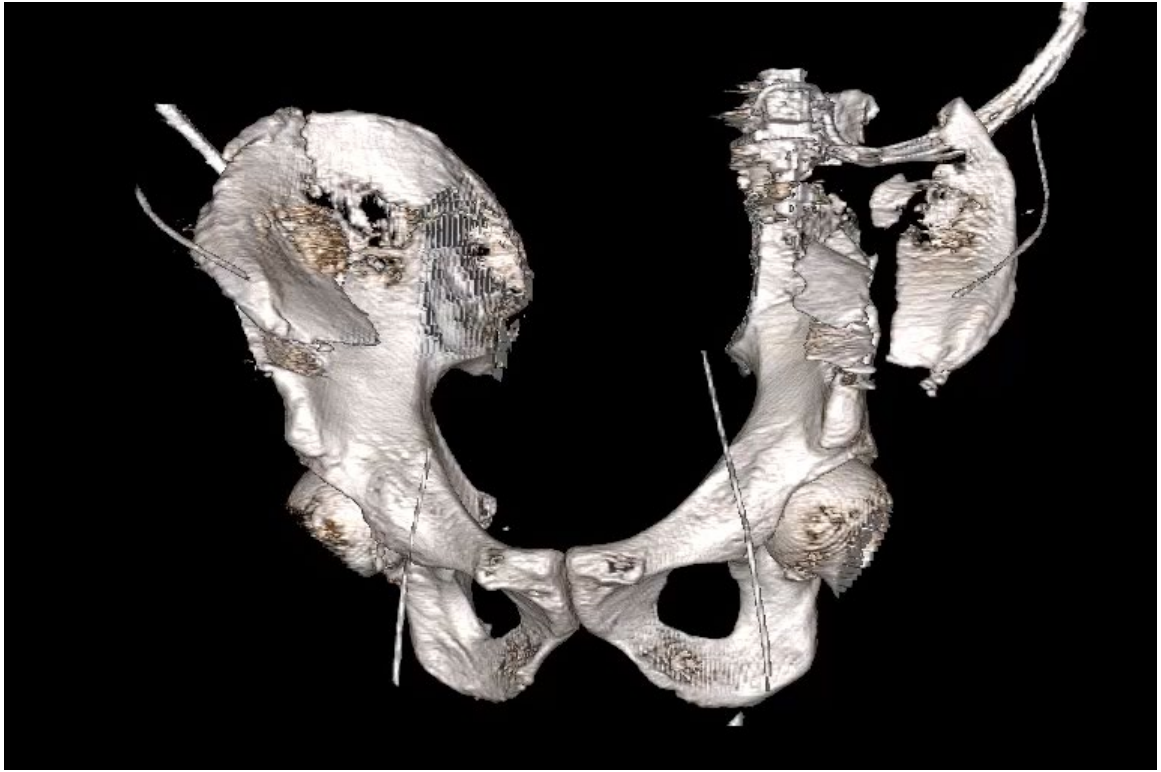
PMHS Pelvis No/Fracture Comparison (Conventional)

FRS-V15-5 (Fx, Heavier)



FRS-V15-6 (No Fx, Lighter)

Pelvis Fractures from FRS-V15-5 (SM152)



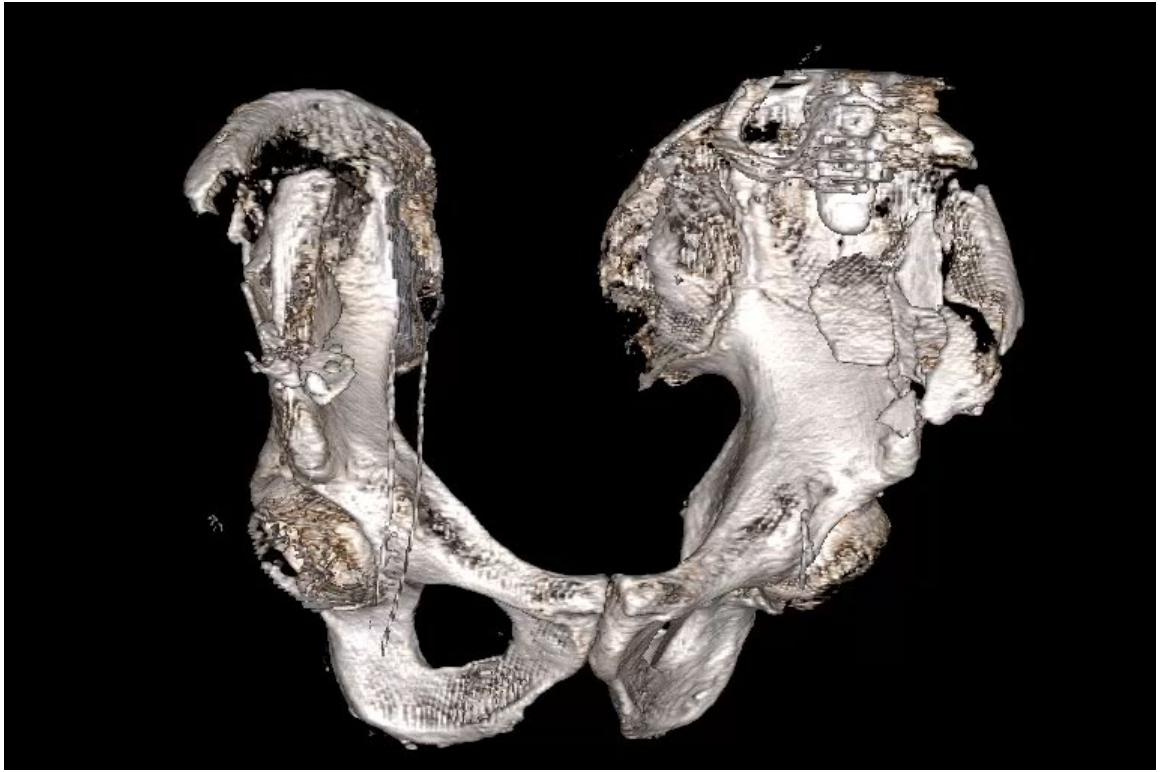
The right pelvis fracture is indicative of lateral-medial compression.
The left pelvis fracture was indicative of anteroposterior loading.

PMHS Pelvis No/Fracture Comparison (Advanced)

FRS-V19-5 (Fx, Heavier)

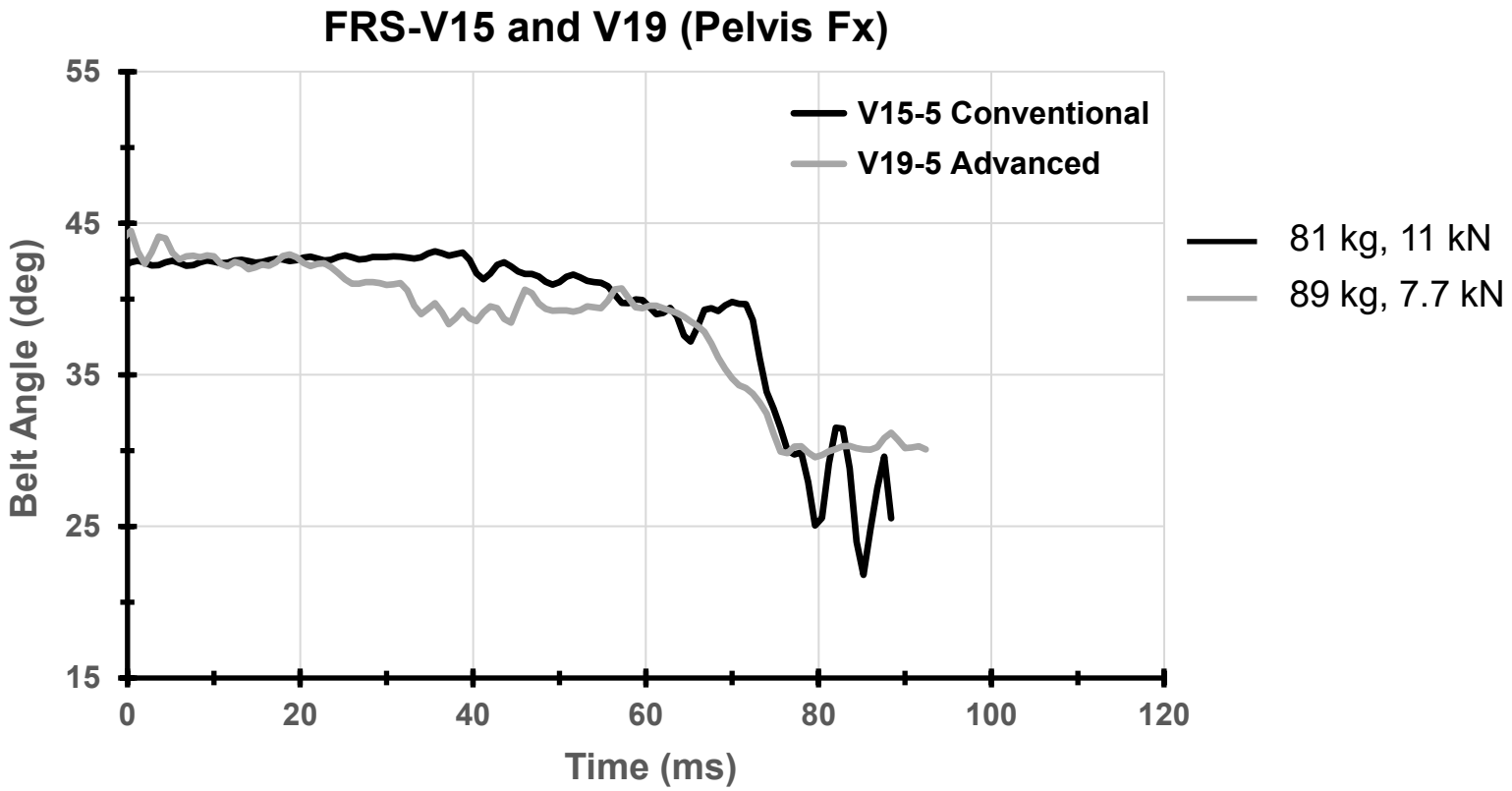
FRS-V19-6 (No Fx, Lighter)

Pelvis Fractures from FRS-V19-5 (SM154)

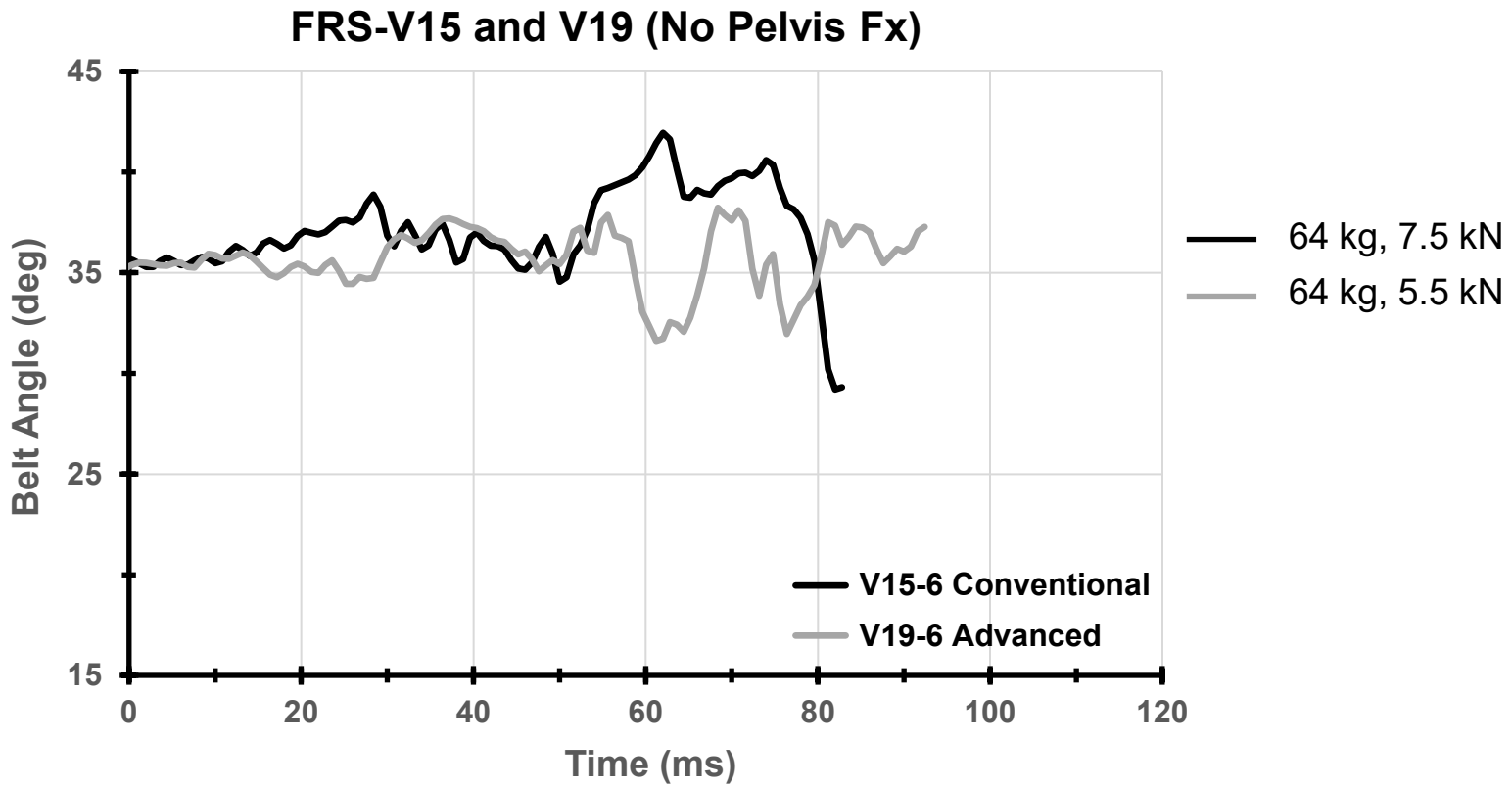


The right pelvis fracture is indicative of lateral-medial compression. The left pelvis fracture was indicative of anteroposterior loading.

PMHS Pelvis Fracture Belt Angle Comparison



PMHS Pelvis No Fracture Belt Angle Comparison



Summary Remarks: PMHS Damage

- Multiple rib fractures occurred with and without submarining
- The abdominal viscera can be damaged with and without submarining
- Pelvis fracture can occur in the absence of submarining
- Pelvis fracture can occur with both advanced and conventional restraints
- Pelvis fracture occurred for heavier PMHS
- Pelvis fracture was characterized by a pronounced decrease in lap-belt angle
- Lap-belt angle associated with the absence of pelvis fracture changed less and/or more gradually than for the two fracture cases
- Lumbar spine fracture can occur when extreme extension is combined with extreme lap belt penetration of the abdomen

Summary Remarks: THOR-50M Submarining

- For different bucks having different restraint systems, the responses are remarkably similar up to the time of submarining, which occurs at nearly the same time
- The belt angle for both FRS-V15-4 and FRS-V19-4 tests exhibits a pronounced transition at the time of submarining
  - This is a result of the belt rapidly slipping off of the pelvis and into the abdomen, which can produce a rapid increase in belt angle
  - Submarining begins after approximately the same change in belt angle for both tests

Summary Remarks: PMHS Submarining

- Although the PMHS used for FRS-V13-5 was 20 kg heavier and 10 cm shorter than the one used for FRS-V13-4, both submarining cases, the curves look remarkably similar
- For the PMHS, the majority of the submarining response is characterized by increase in belt angle as the pelvis slides and rotates beneath the lap belt, which differs from the belt angle characteristics for the THOR-50M

Thank you!

The statements in this presentation are those of the authors' and do not necessarily reflect the opinions of the sponsors.

NHTSA Contract No., DTNH2214D00328L
Task Order, DTNH2217F00177

TRC Agreement No., AUCVCN4J
Research Consortium for Crashworthiness in Automated Driving Systems

Warren N. Hardy
Virginia Tech Center for Injury Biomechanics
443 Kelly Hall, 325 Stanger Street, Blacksburg, VA 24061
540-231-0778
whardy@vt.edu