NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Female Crash Safety

NHTSA Safety Research Portfolio Public Meeting: Fall 2021

October 21, 2021

Introduction

- This session provides an overview of current female crash safety research efforts at NHTSA.
- Vehicle Safety Research at NHTSA has been executing various projects aimed at developing new knowledge and tools that can be applied towards vehicle crash safety for females.
- These efforts include basic experimental research, development and testing of advanced ATDs, as well as research utilizing finite element human body models.
- Additionally, the National Center for Statistics and Analysis at NHTSA has been completing field data studies of female injury and fatality risks.

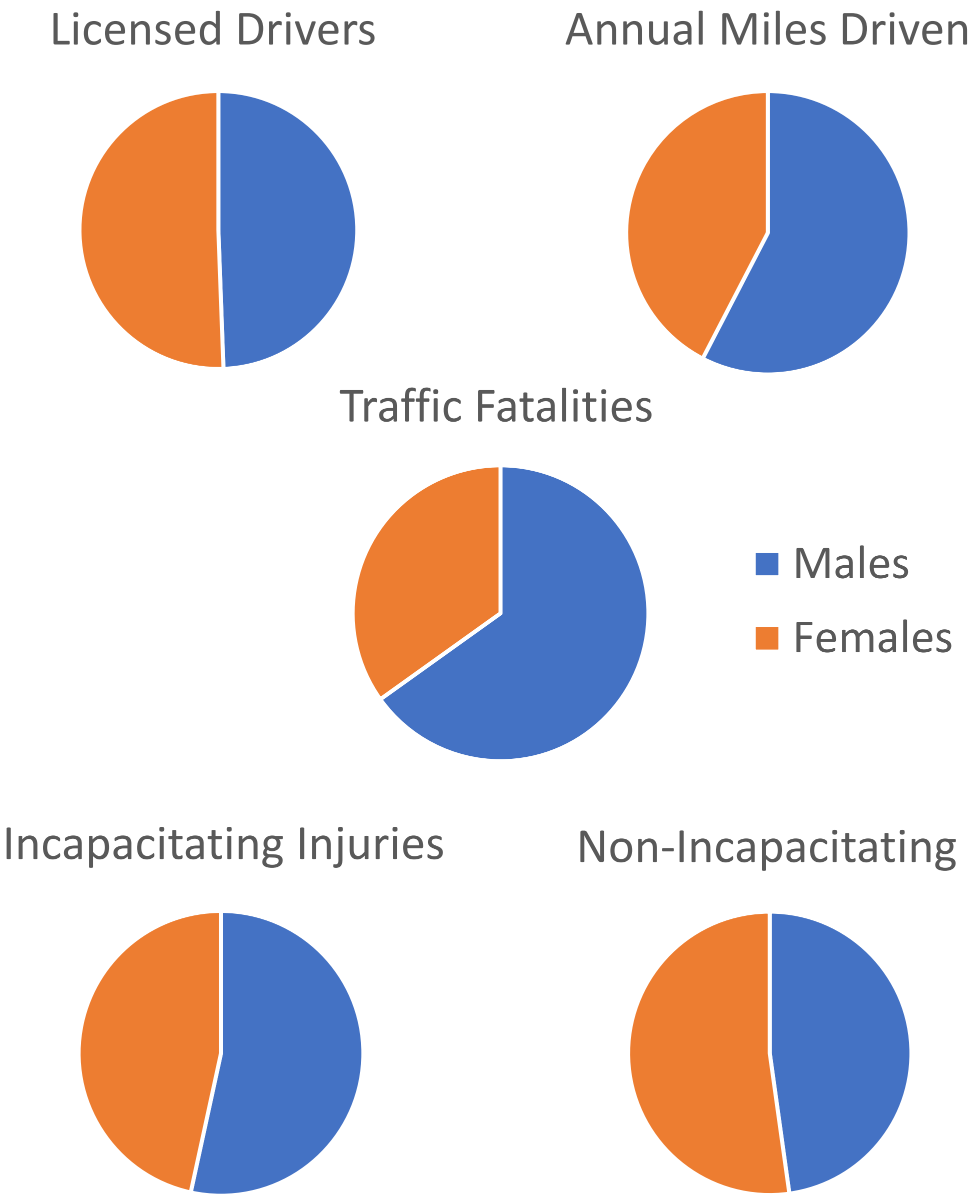
Panel Presentations

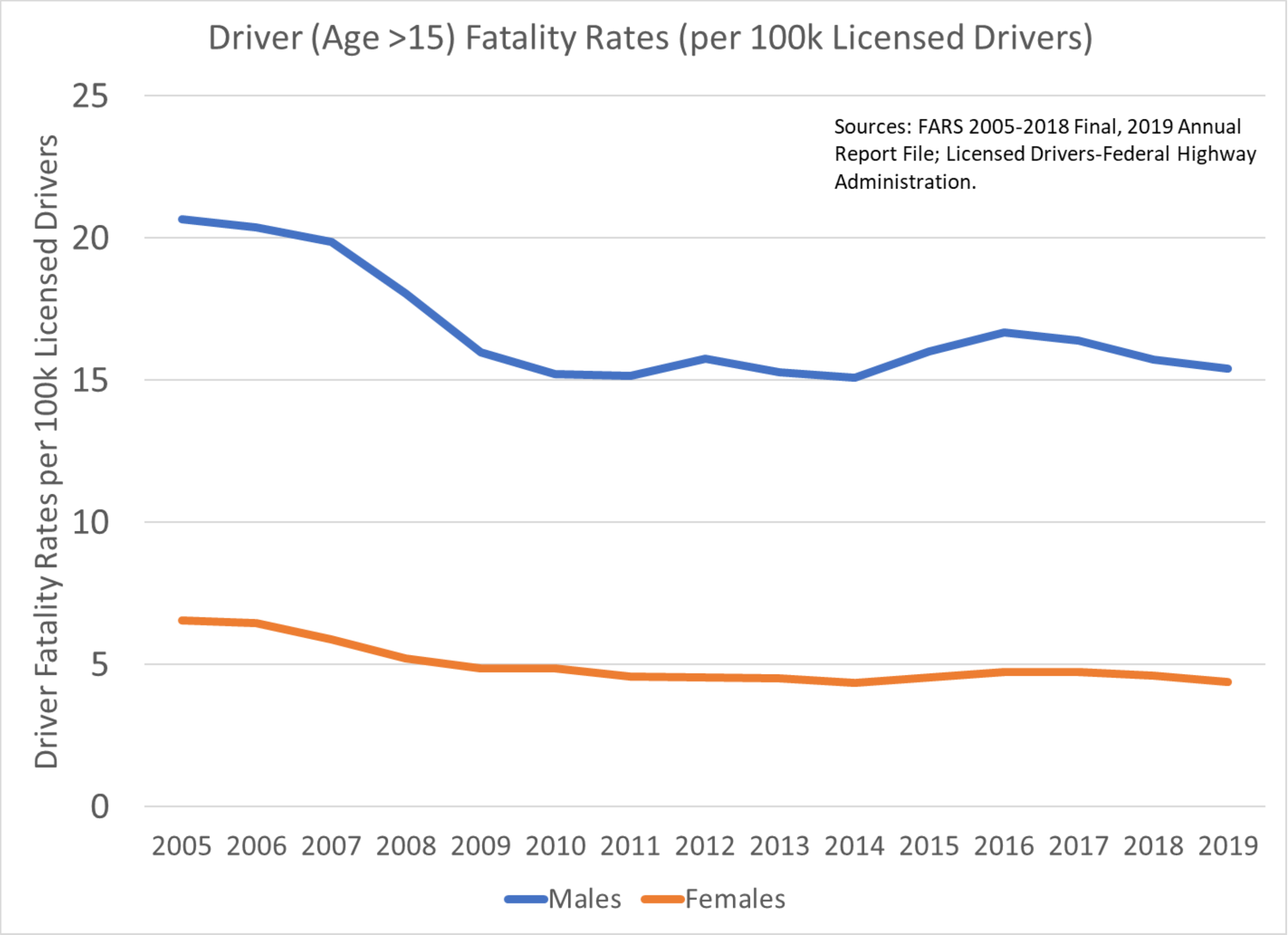
1. **Overview of Female Crash Safety Research –** Ellen Lee
2. **Female Fatality Risk Relative to Males in Similar Crashes –** Jon Atwood
3. **Analytical Methods for Injury Risk Research –** Jacob Enriquez
4. **Human Body Modeling Studies –** Erik Takhounts, PhD
5. **THOR-05F Advanced Crash Test Dummy - Overview & Development –** Erin Hutter, PhD
6. **THOR-05F - Female Experimental Data and Injury Criteria Development –** Ellen Lee

Overview of Female Crash Safety Research

Ellen Lee

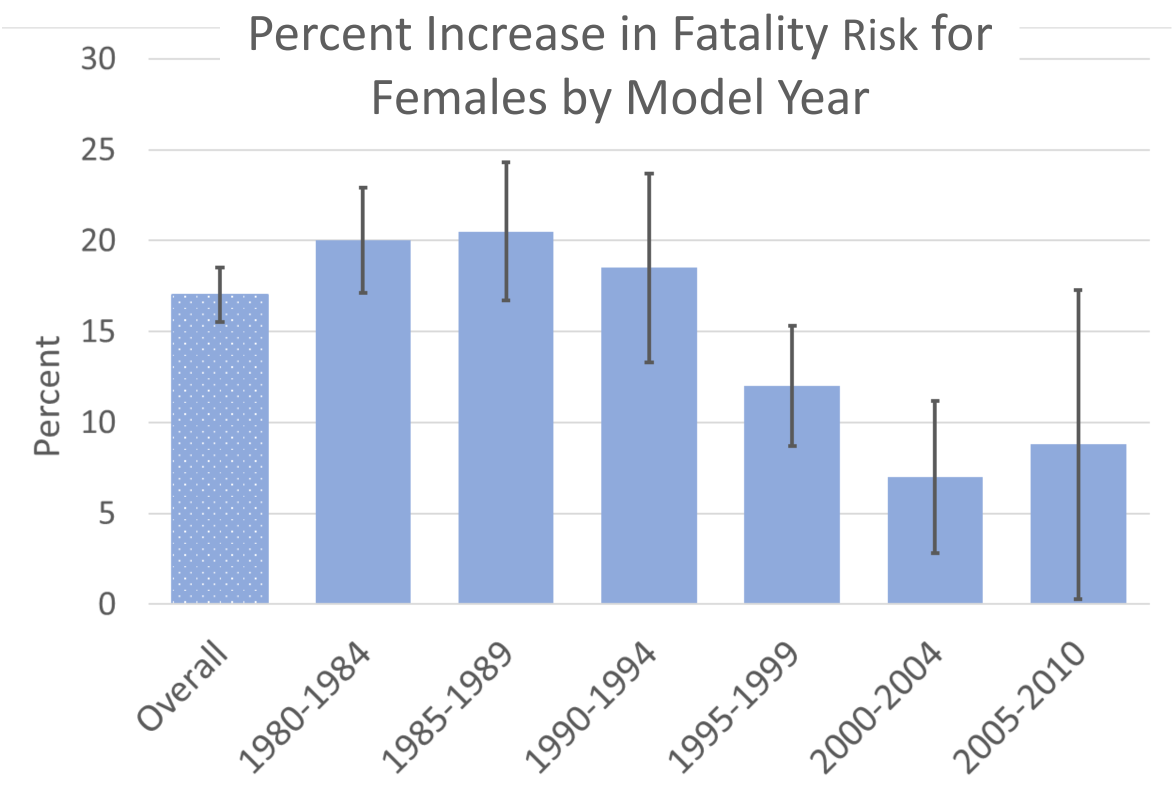
Female/Male Crash Safety – Big Picture

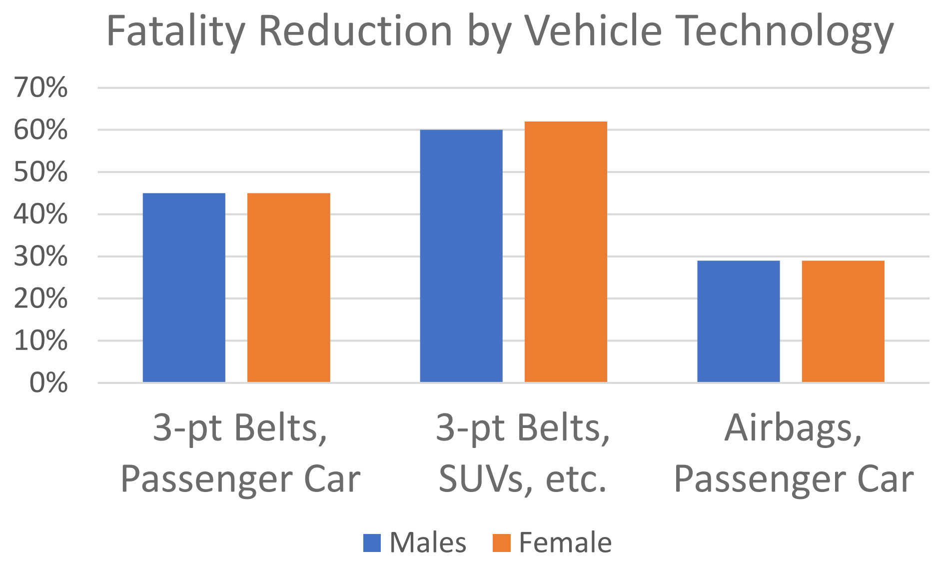




Female/Male Risk Differences

Kahane, 2013 & 2015 (NHTSA)





Insurance Institute for Highway Safety, 2021

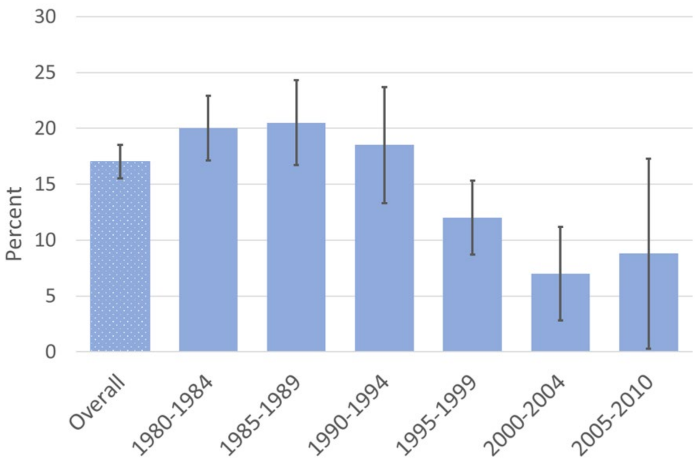
- Female vs. male injury risk differences reduced when crash severity accounted for
- Injury reductions for IIHS "good" rated vehicles show vehicle countermeasures benefit both sexes

Key Research Questions

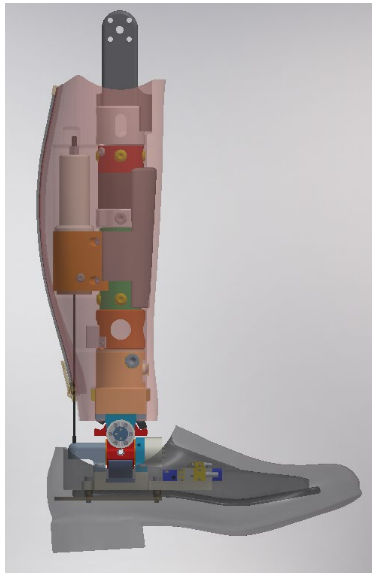
1) Are there differences in fatality and injury risk for females in motor vehicle crashes, relative to males?
2) What are the causes of female/male risk differences?
3) How to better predict and prevent fatality and injury for females involved in motor vehicle crashes?

Research Overview

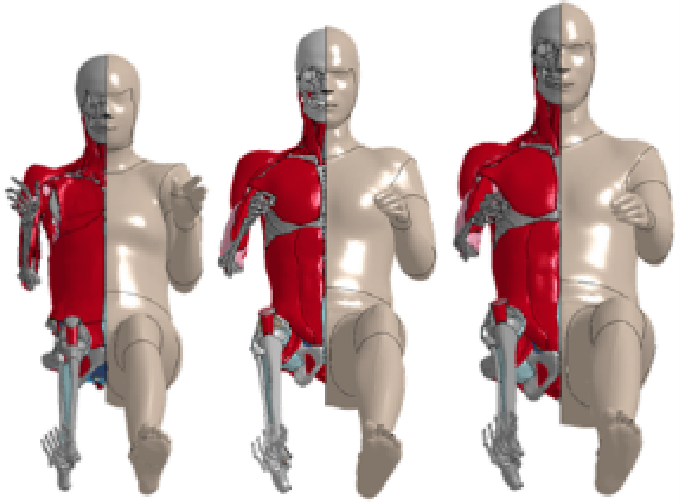
1) Real-world crash data and risk models

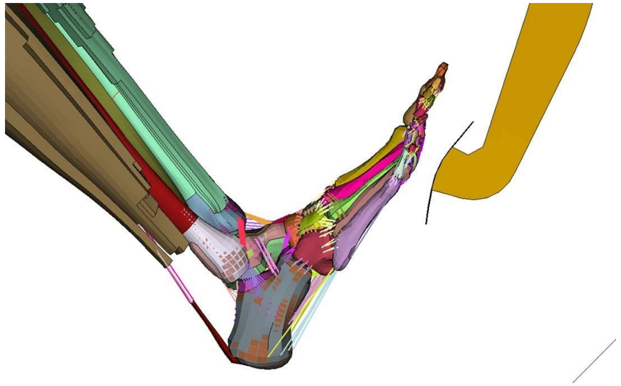


2) Advanced dummies



3) Human body models





Female Fatality Risk Relative to Males in Similar Crashes

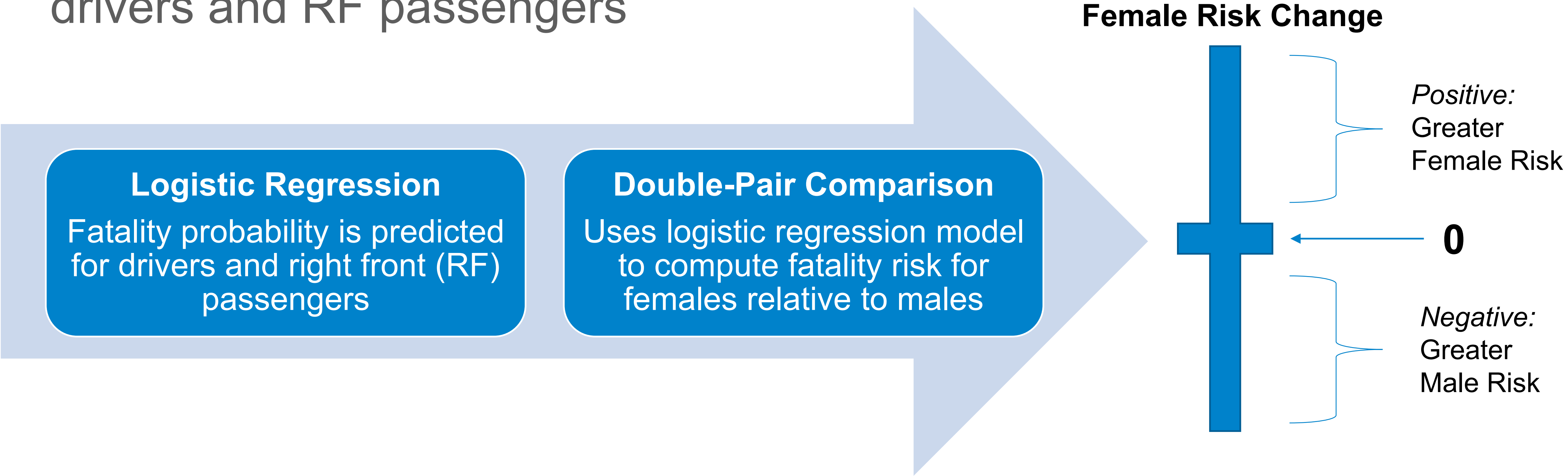
Jon Atwood

Overview

- NHTSA (Kahane, 2013) analyzed FARS (1975-2010) data to determine how female fatality risk relative to males
  - Kahane found that female occupants have had higher fatality rates than male occupants given similar physical impacts
  - Kahane also analyzed the relative risk within model year groups, vehicle types, occupant age groups, occupant protection types, and crash impact locations
- This analysis updates Kahane’s analysis by adding 2011-2019 FARS data and younger age groups.

Methods

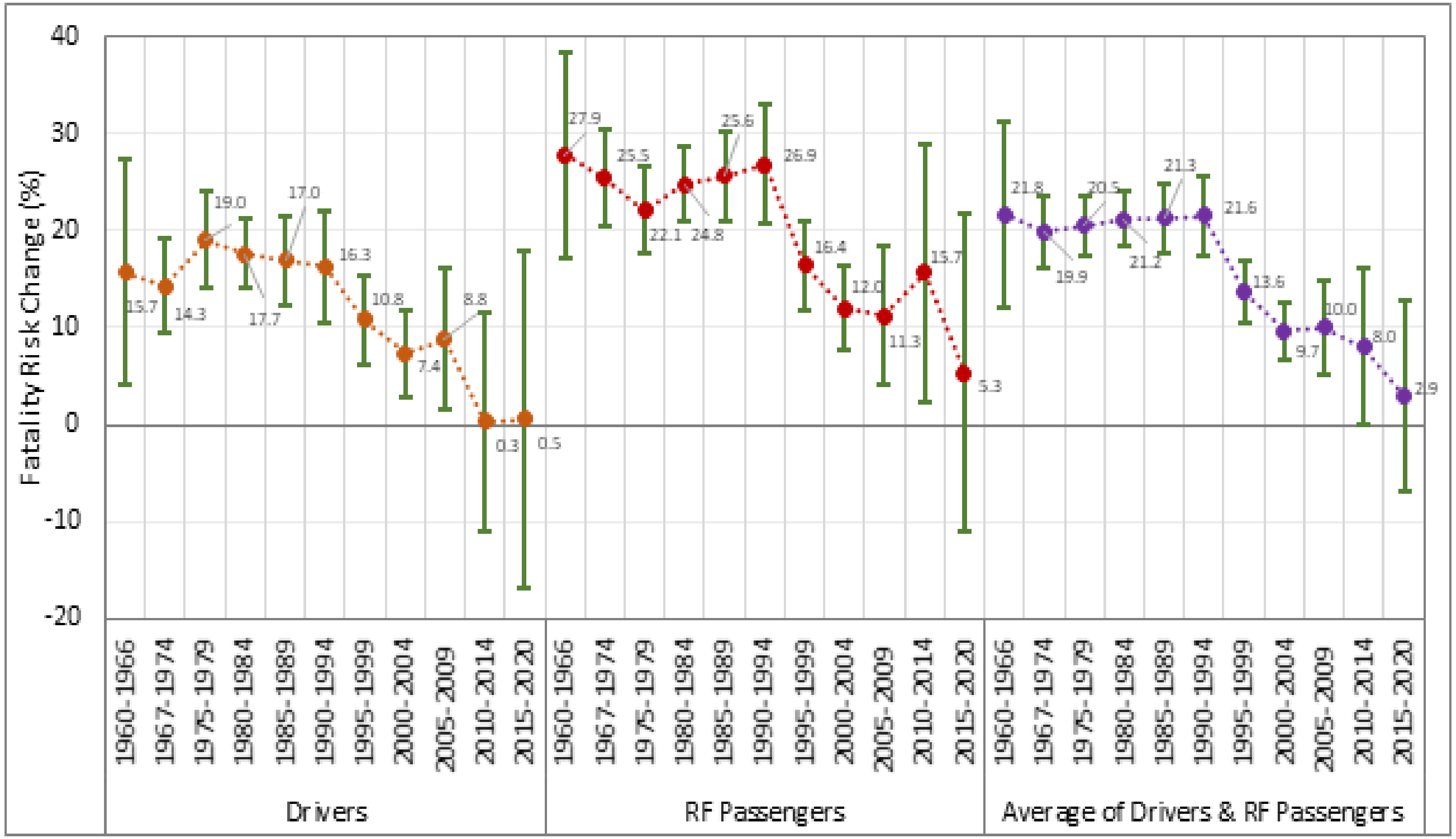
- Female fatality risk relative to males is computed using logistic regression combined with double-pair comparison
- Models used to predict fatality risk account for age and gender of drivers and RF passengers



Results

Model Year

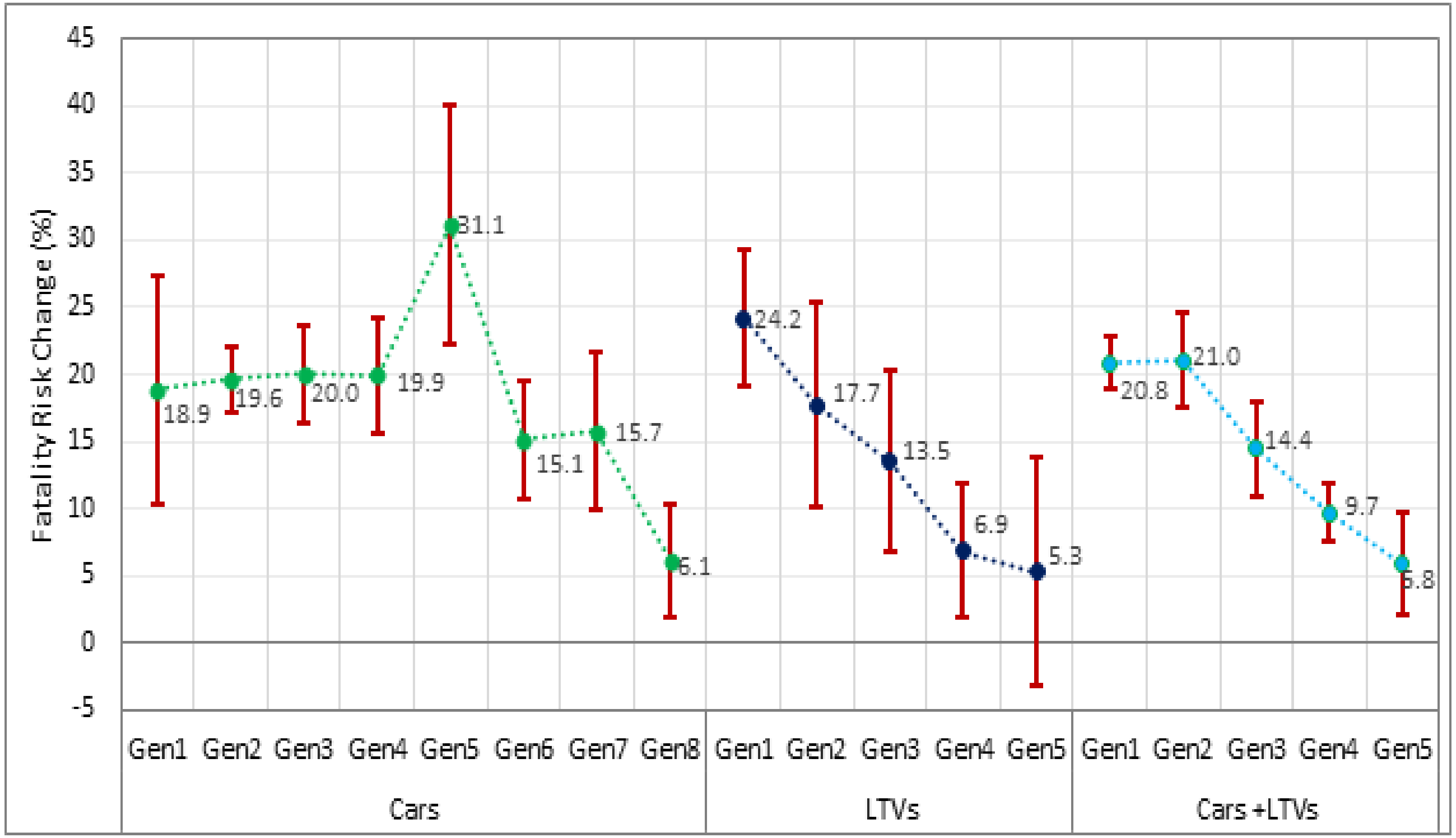
1. Generally, female relative risk decreases with later model years
2. Low sample sizes for later model years create wide confidence intervals



Results

Occupant Protection Type

1. Female relative fatality risk is lowest with the largest amount of occupant protections available and used



Cars

Gen1: Unbelted, pre-MY 1968, no EA columns
Gen2: Unbelted, MY 1969-1982 cars
Gen3: Unbelted, MY 1983-1996, no air bags
Gen4: 3-pt. belted occupants of cars without air bags
Gen5: 2-pt. belted occupants of cars without air bags
Gen6: Unbelted occupants of cars with dual air bags
Gen7: Belted, with dual air bags, no pretensioners/load limiters
Gen8: Belted, with dual air bags, pretensioners, load limiters

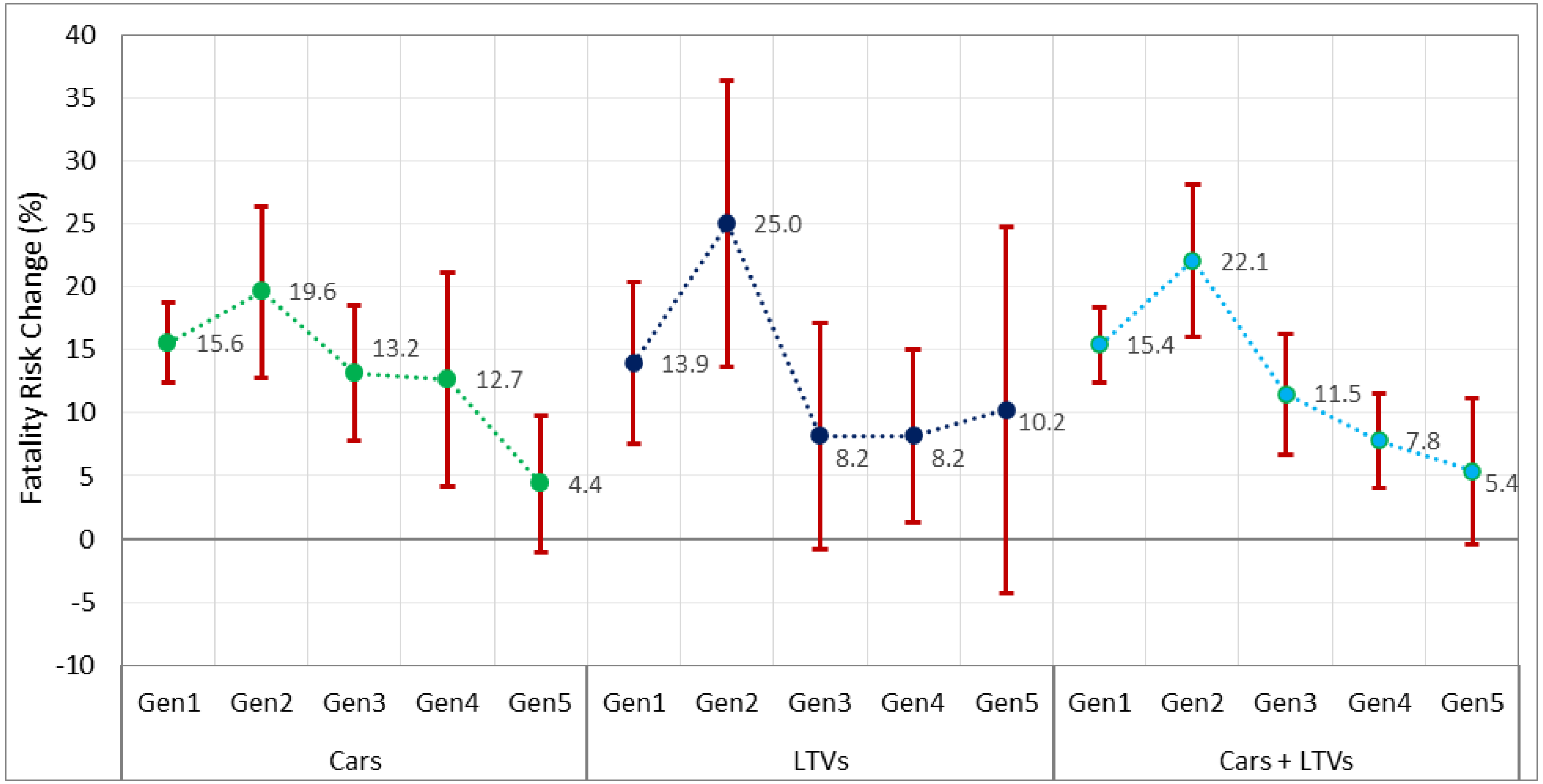
LTVs/Cars + LTVs

Gen1: Unbelted, without air bags
Gen2: Belted, without air bags
Gen3: Unbelted, with dual air bags (no on-off switches)
Gen4: Belted, with dual air bags (no on-off switches)
Gen5: Belted, with dual air bags, pretens/load limiters (LTV MY ≥ 2007)

Results

Frontal Crashes by Occupant Protection Generation

- Female relative fatality risk decreases with newer generations of occupant protection



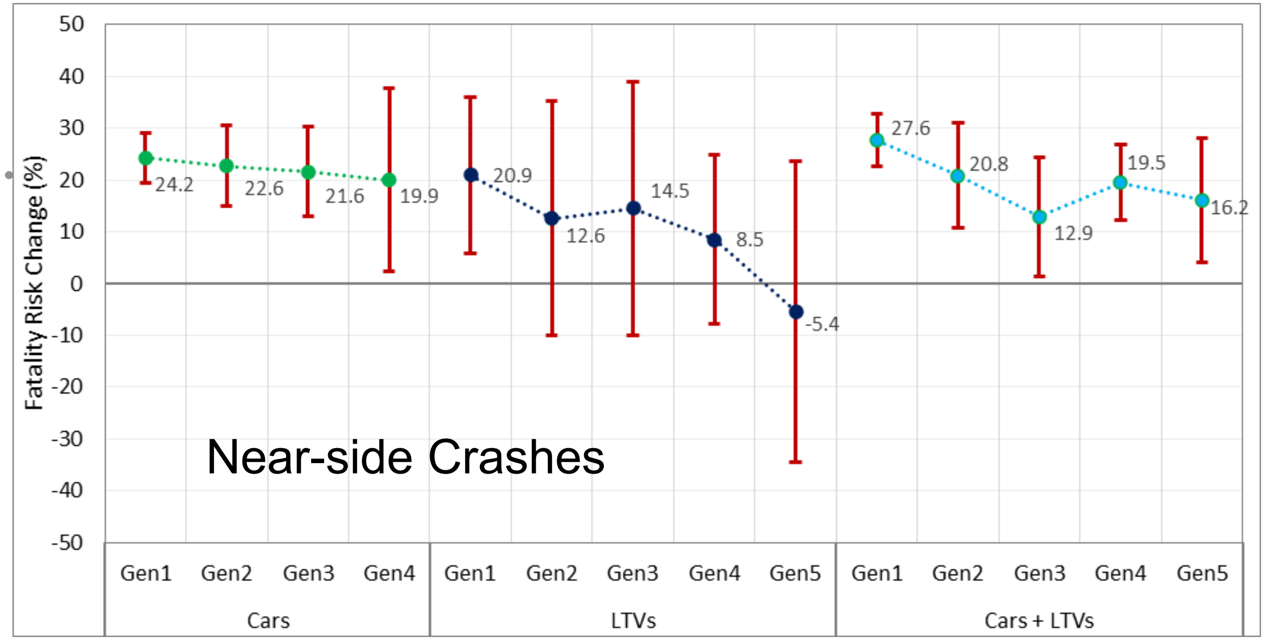
Cars
Gen1: Unbelted, without air bags
Gen2: 3-pt. belted, without air bags
Gen3: Unbelted, with dual air bags
Gen4: Belted, dual air bags, no pretensioners/load limiters
Gen5: Belted, dual air bags, pretensioners, load limiters

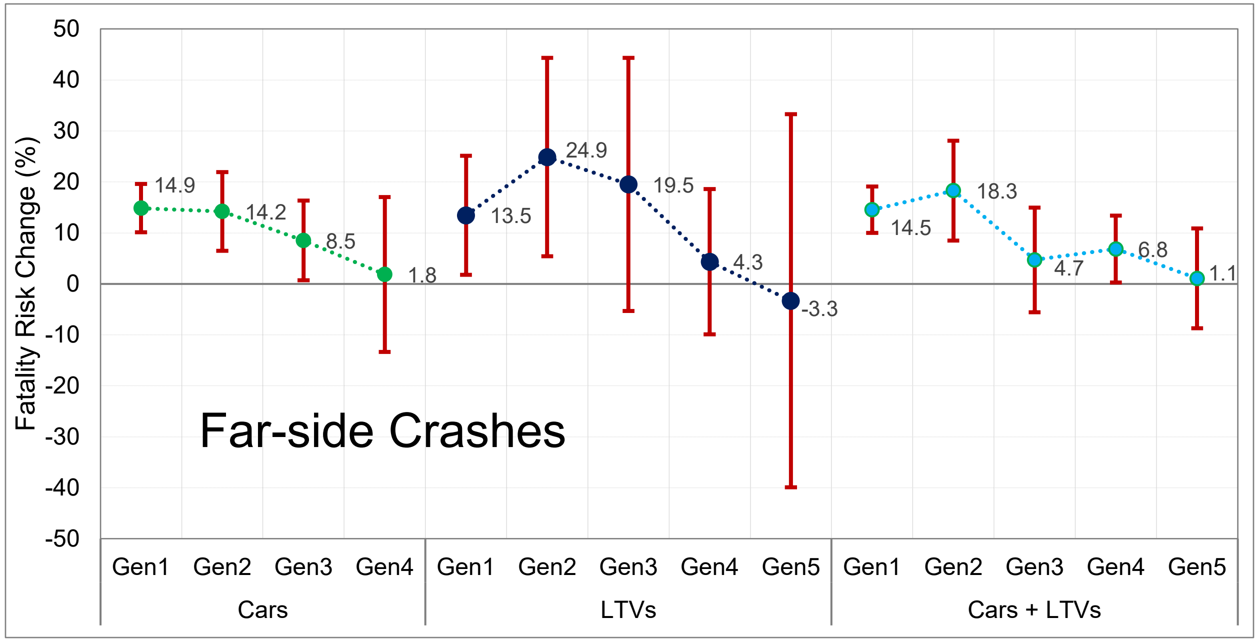
LTVs/Cars + LTVs
Gen1: Unbelted, without air bags
Gen2: Belted, without air bags
Gen3: Unbelted, with dual air bags (no on-off switches)
Gen4: Belted, with dual air bags (no on-off switches)
Gen5: Belted, with dual air bags, pretens/load limiters (LTV MY ≥ 2007)

Results

Side Crashes by Occupant Protection Generation

- Female relative fatality risk decreases with newer generations of occupant protection in near-side and far-side, side impact crashes





Cars
Gen1: Unbelted, without side/curtain bags
Gen2: 3-pt. belted, without side/curtain bags
Gen3: Belted, dual air bags
Gen4: Belted, with curtain+torso or combo bags

LTVs/Cars + LTVs
Gen1: Unbelted, without air bags
Gen2: Belted, without air bags
Gen3: Unbelted, with dual air bags (no on-off switches)
Gen4: Belted, with dual air bags (no on-off switches)
Gen5: Belted, with dual air bags, pretens/load limiters (LTV MY ≥ 2007)

Conclusions

- Later model years show a sharp reduction in female fatality risk relative to males
- Vehicles with dual airbags and belted occupants with pretensioners and load limiters saw the lowest female fatality risk relative to males
- Looking specifically at frontal, near-side and far-side crashes, dual air bags and belted occupants lowered female relative fatality risk (aside from frontal crashes in LTVs)

Analytical Methods for Injury Risk Research

Jacob Enriquez

Research Objective

Use of rigorous analytical methods in a study of female injury risk using NHTSA's Crashworthiness Data System (CDS) and Crash Investigation Sampling System (CISS).

Two Phases

Phase I. Confirm existing studies (e.g., Forman et. al. (2019))

Phase II. Comprehensive expansion of the state of the knowledge.

Phase I

Data: NASS-CDS 1998 - 2015 and CISS 2017- 2019.

Study domain

- Passenger vehicles.
- Frontal impacts (PDOF 300-60).
- Occupants aged 13+, belted, and not pregnant.
- Excluded rollovers, fires, and ejections.

Analytic approach

- Logistic regression model.
- Separate models: MAIS2+, MAIS3+, Ankle AIS 2+, LEx AIS 2+, Thorax AIS 3+, and Rib Fx AIS 3+.
- Predictors: delta-V, sex, age, height, BMI, model year (2009+).

Handling of nonresponse

- High missing rates for key variables in CDS (47% for delta-V, 20% for MAIS).
- **The perils of missing data: Biased estimates, distorts the distribution, imputation variance.**
- Fully Efficient Fractional Imputation (FEFI) - uses all potential donors.
- Advantages:
    - Does not incur imputation variance.
    - Does not distort the observed distribution.
    - Takes complex survey design and non-response mechanism into account.
- Disadvantage: resource intensive.

Phase II – Expand scope of existing studies

- Consider all crash modes (nearside, farside, rear impact, rollover).
- Consider all occupant scenarios (restraint, air bag, ejection, etc.).
- Expand predictor list.

Human Body Modeling Studies

Erik Takhounts

Contents

Overview

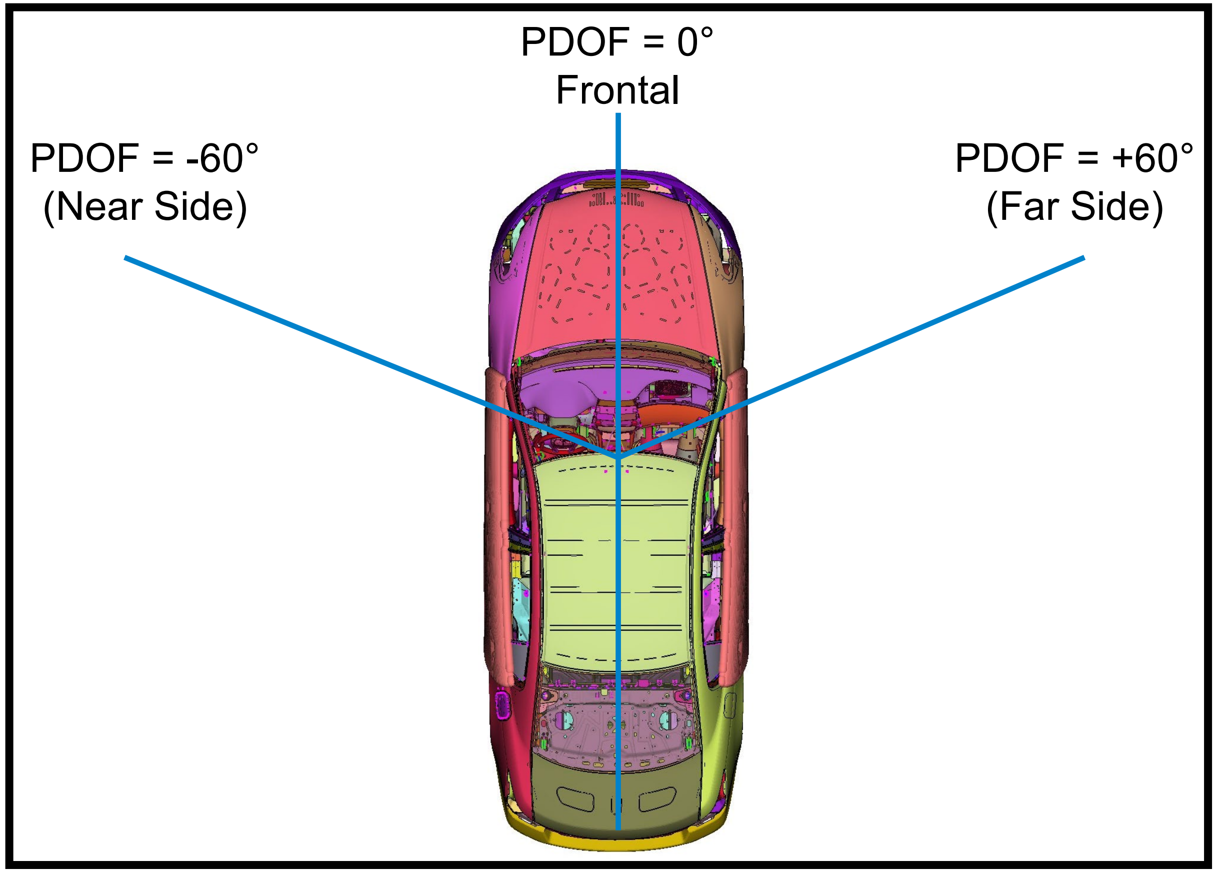
- Field data
- Study 1: 5th Female and 50th Male DOE
- Study 2: Model Scaling and Four-model DOE
- Study 3: Thoracic Geometry Differences – GHBMC Models
- Summary

What Prompted the Research

According to Forman et al. (2019)*:

"Females are at greater risk of AIS 2+ and AIS 3+ injury as compared to males, with increased risk across most injury types"

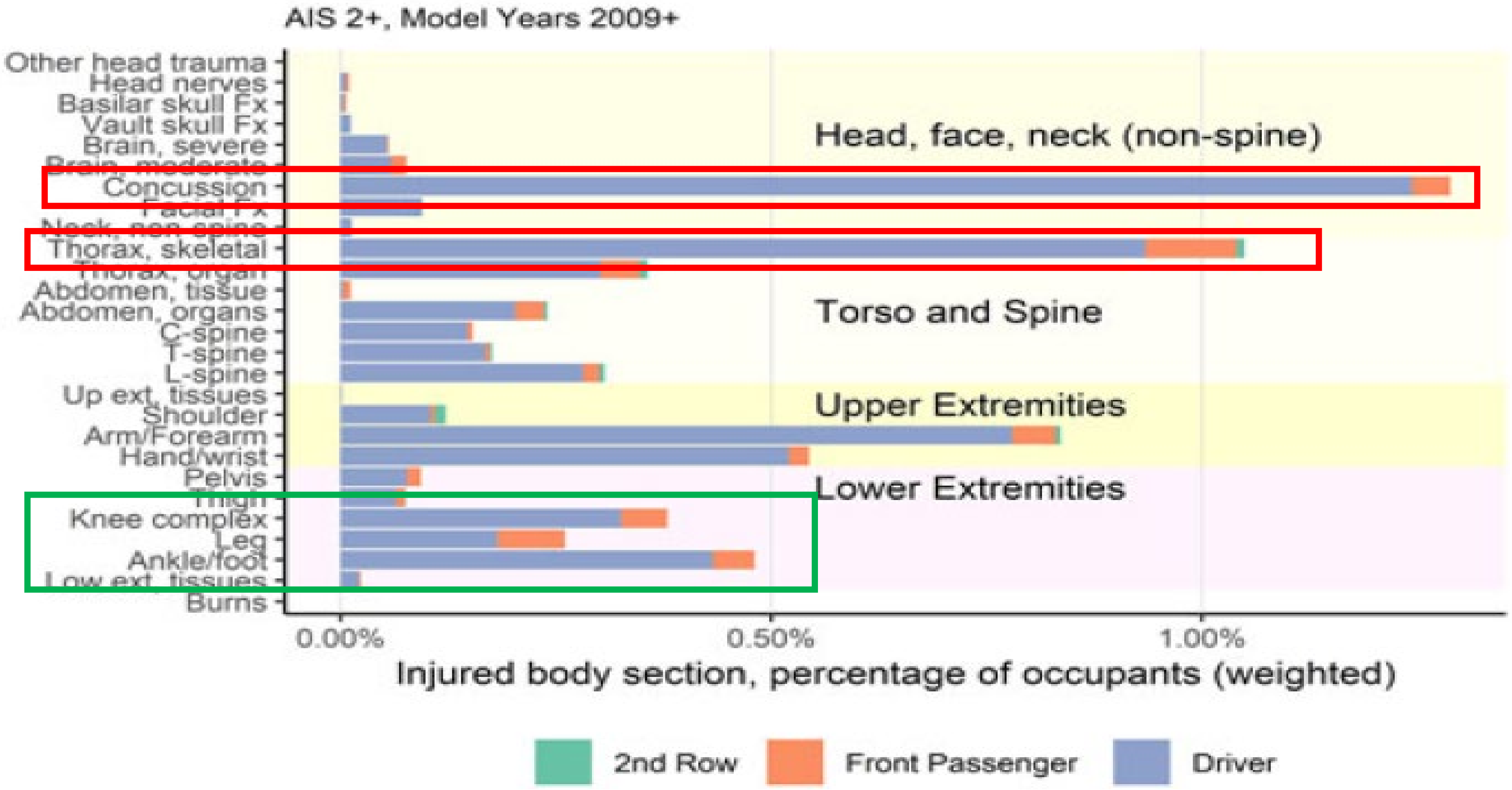
Note: They carried out the data analysis on frontal impact scenarios (PDOF = -60° to +60°)



*Forman et al., "Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions", Traffic Injury Prevention, 2019;20(6):607-612. doi: 10.1080/15389588.2019.1630825. Epub 2019 Jul 8.

Field Injury Risks: Forman et al. (2019)

Risk of AIS 2+ injuries by body region



Contents

Study 1: 5th female and 50th male HBMs

Utilize existing 5th female, 50th male Global Human Body Models Consortium (GHBMC) simplified finite element (FE) human body models (HBM) in various frontal impact scenarios and compare their injury metrics

5th female HBM

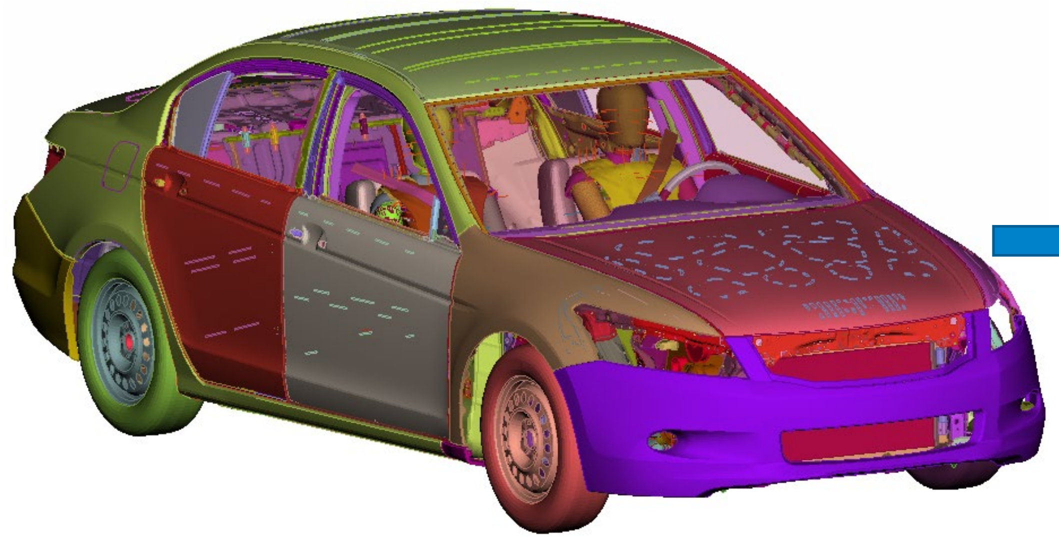
Weight = 54 kg

50th male HBM

Weight = 78 kg

Vehicle FE Model -> Simplified Occupant Compartment

Full vehicle model (2014 Honda Accord)



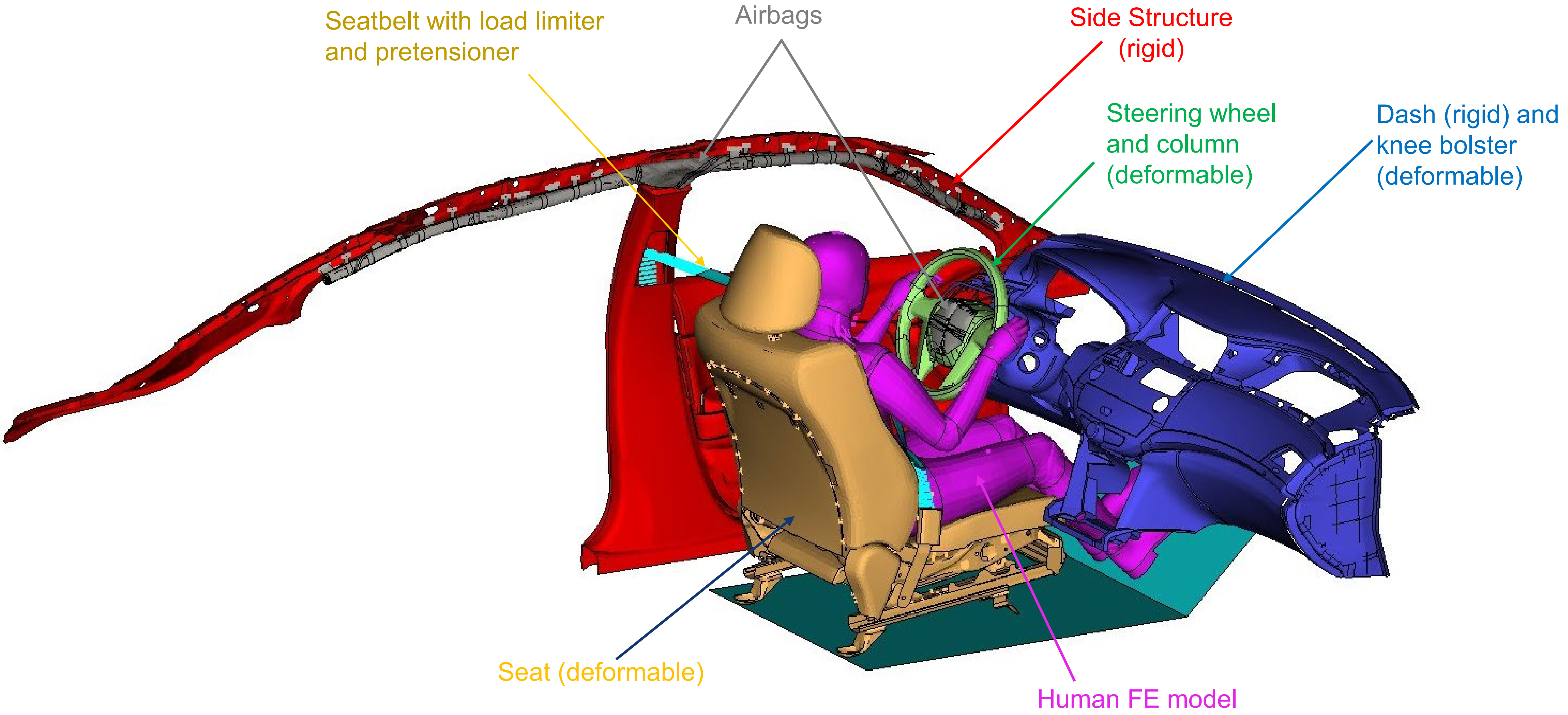
Number of elements: 3.1 million

Vehicle structure extracted for frontal impact analysis

Number of elements: 485,000

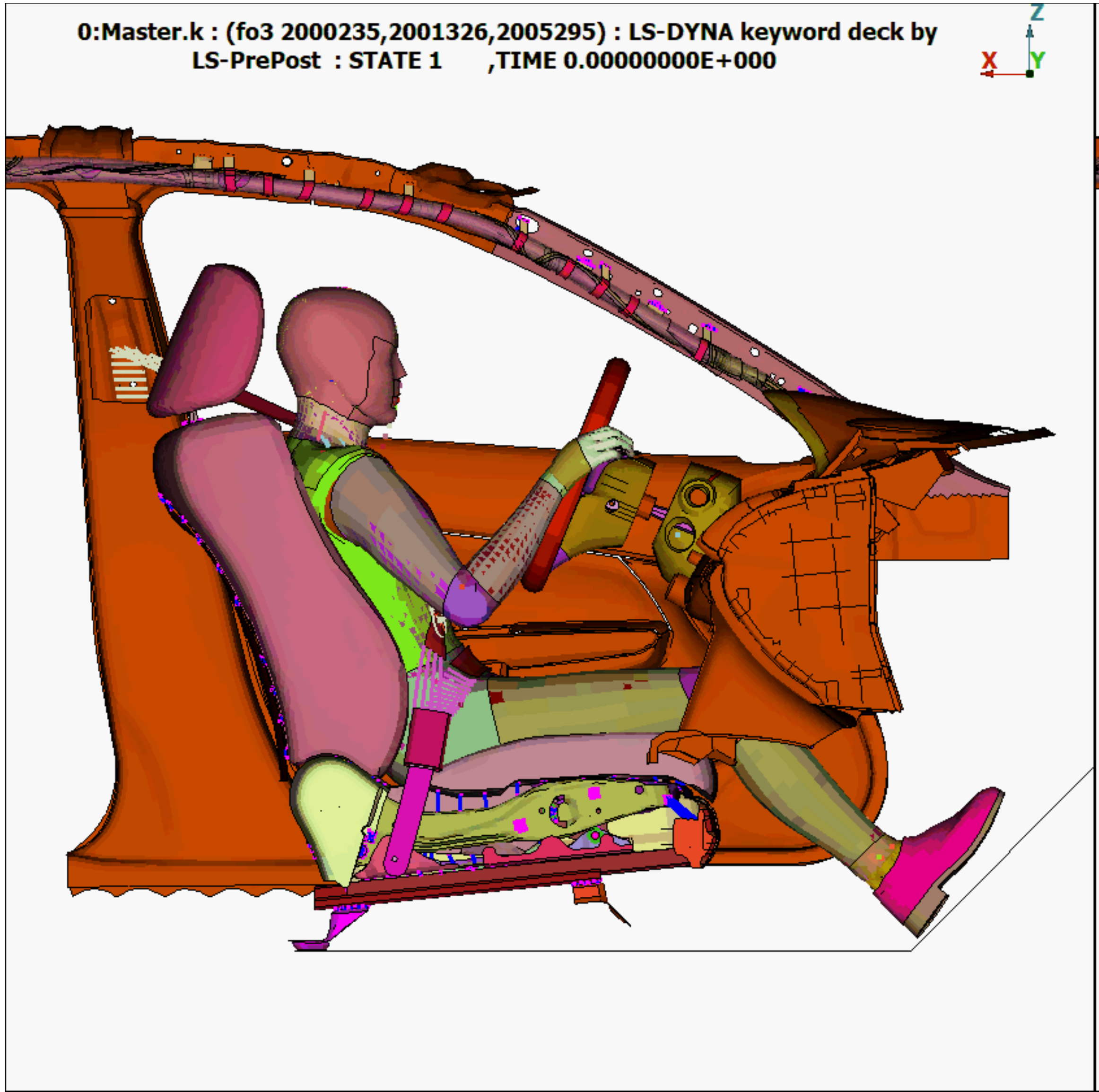
- Frontal impact validated 2014 Honda Accord FE model was available for performing the analysis
- To run several simulations in feasible timeframe, we extracted important components from Honda Accord model for our analysis

FE Model: Simplified Occupant Compartment Details

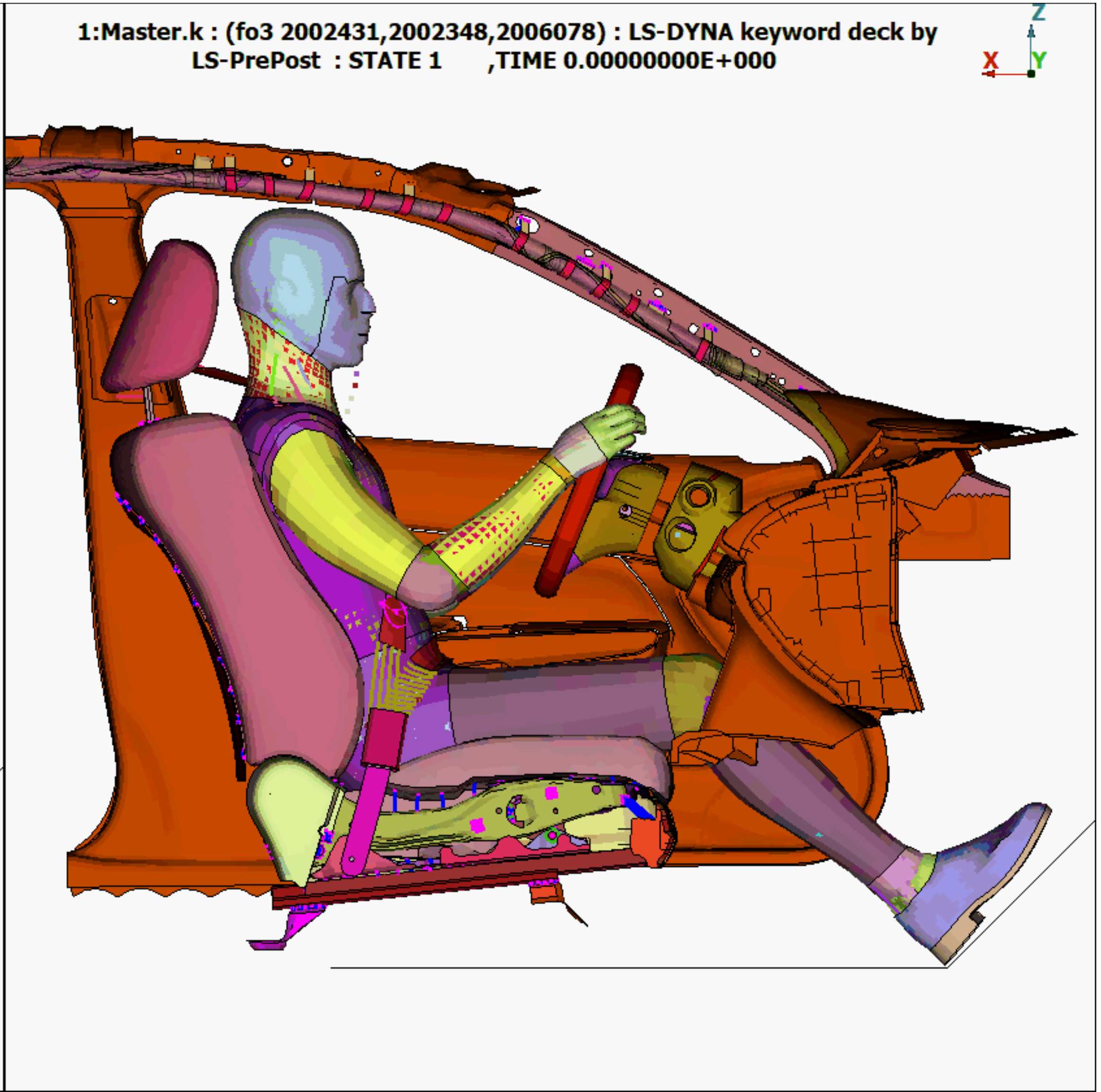


Study 1: Baseline simulations

5th female



50th male



Design of Experiments (DOE) - Parameters

Crash

Restraints

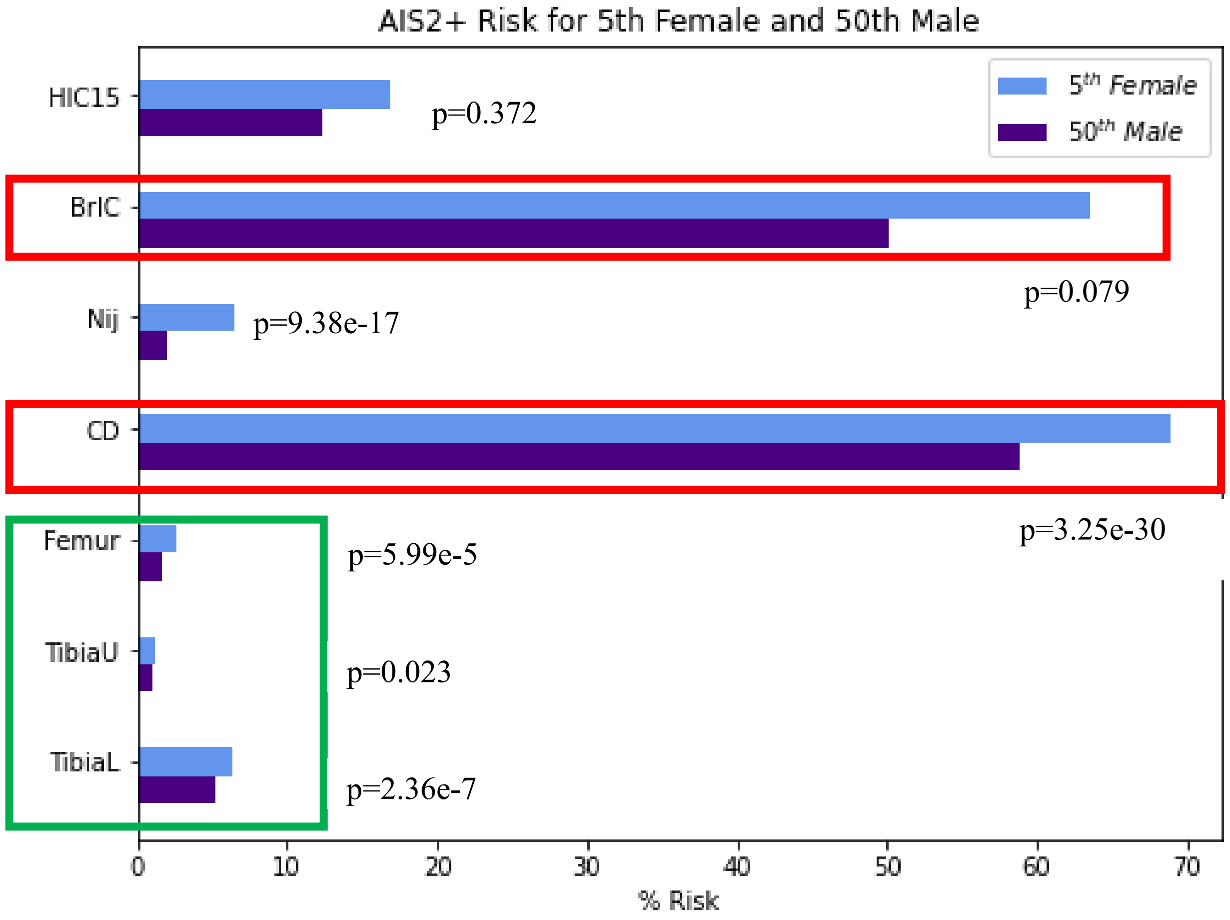
Parameter	Baseline	Minimum value	Maximum value
Delta V	33 mph	25mph	45mph
PDOF	0	-30,-25,-20,-15,-10,-5,0,5,10,15,20,25,30	
Scaling factor for frontal airbag mass flow rate	1	0.75	1.25
Scaling factor for side airbag mass flow rate	1	0.75	1.25
Frontal and side airbag firing time	14 ms	5 ms	45 ms
Collapsible column breaking force	3000 N	3000 N	12000 N
Load limiter	3000 N	1000 N	5000 N
Pretensioner limiting force	1000 N	1000 N	3000 N
Side airbag to human head contact friction	0.3	0	1
Front airbag to human head contact friction	0.3	0	1
Floor to feet friction	0.5	0	0.5
Knee to Knee Bolster distance (50^{th})	145 mm	110 mm	180 mm
Knee to Knee Bolster distance (5^{th})	105 mm	60 mm	130 mm

AIS 2+ Injury Risks/Risk Functions

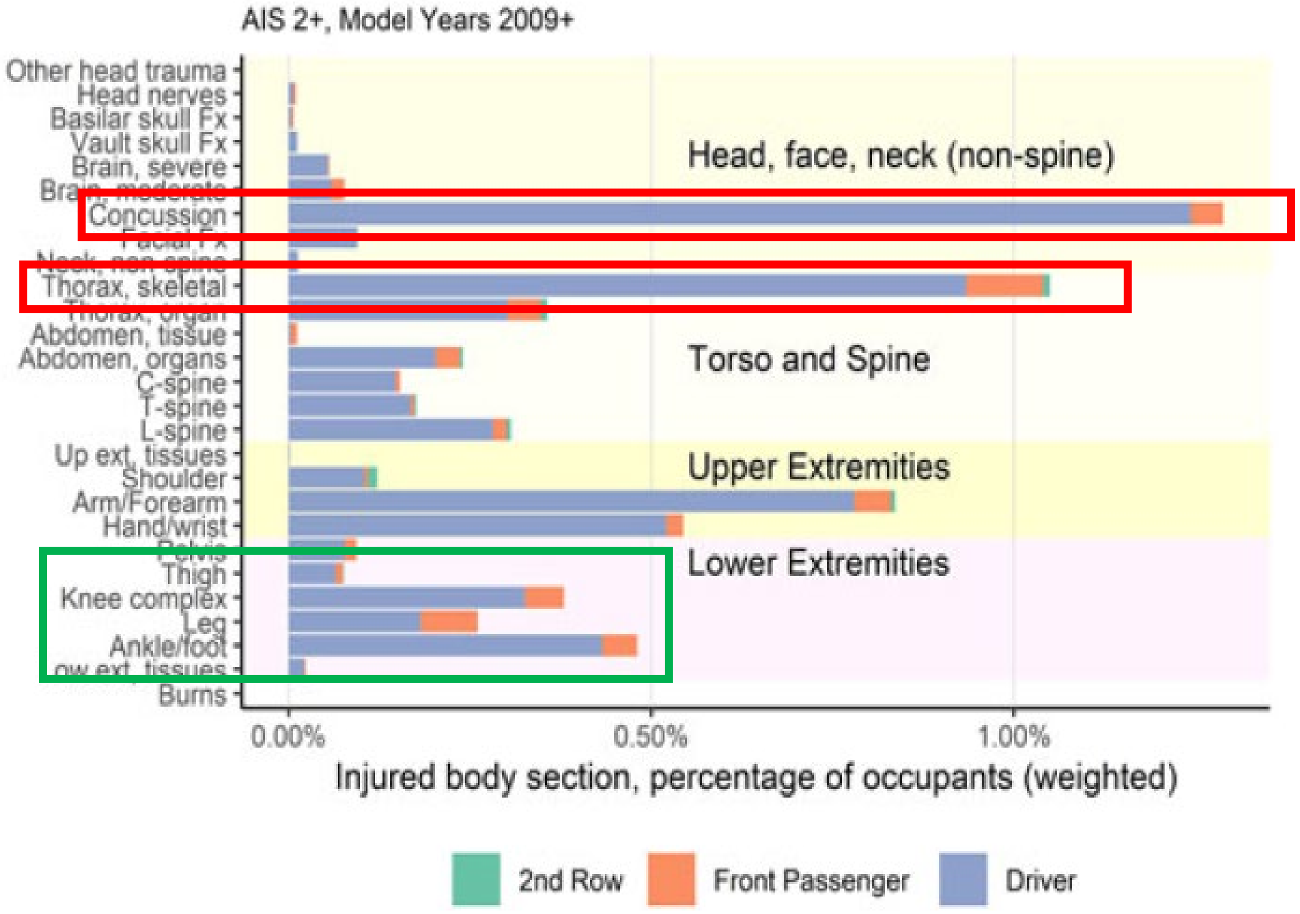
Injury metrics	Risk Function	Source	5th to 50th Scaling Factor (Source)
HIC_{15}	$\Phi\left[\frac{\ln HIC_{15} - 6.96362}{0.84687}\right]$	THOR 50M Injury Criteria Report	1.0
BrIC	$1 - e^{-\left(\frac{BrIC - 0.523}{0.324}\right)^{1.8}}$	Takhounts et al. 2013	1.0
Nij	$\frac{1}{1 + e^{(4.3085 - 5.4079 N_{ij})}}$	THOR 50M Injury Criteria Report	1.0
Chest Deflection	$\frac{1}{1 + e^{(1.8706 - 0.04439 \text{Dmax})}}$	Eppinger et al, 1999	1.212 (Eppinger et al.,1999: 63mm/52mm)
Femur Force	$\frac{1}{1 + e^{5.7949 - 0.6748 F_{LC}}}$	THOR 50M Injury Criteria Report	1.389 (Kuppa et al., 2001)
Upper Tibia Force	$\frac{1}{1 + e^{(5.6654 - 0.8189 F_{upper\ tibia})}}$	THOR 50M Injury Criteria Report	1.389 (Kuppa et al., 2001)
Lower Tibia Force	$\frac{1}{1 + e^{(3.9121 - 0.48 F_{lower\ tibia})}}$	THOR 50M Injury Criteria Report	1.389 (Kuppa et al., 2001)

Injury Risks: 5th female and 50th male

HBM Risk of AIS 2+ injuries by body region (based on average values)



Field Risk of AIS 2+ injuries by body region



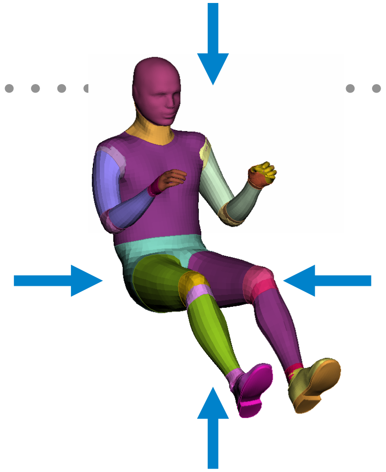
Study 1: Observations

- Based on the 5th female and 50th male HBM DOE study brain and thorax are the two body regions at higher injury risk.
- 5th female HBM is at higher injury risk across all body regions when compared to the 50th male HBM.
- The thoracic injury risk difference (assessed using chest deflection at mid-sternum) between the two models is statistically significant.

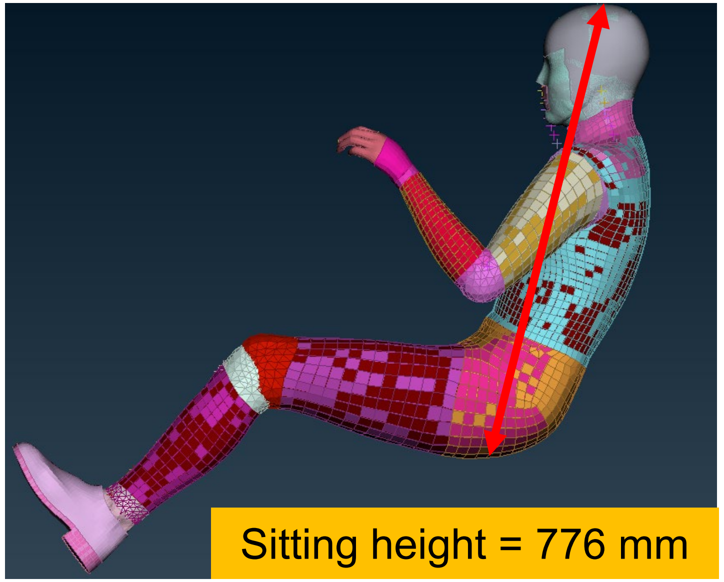
Contents

Study 2: Scale 50th male HBM to size of 5th female

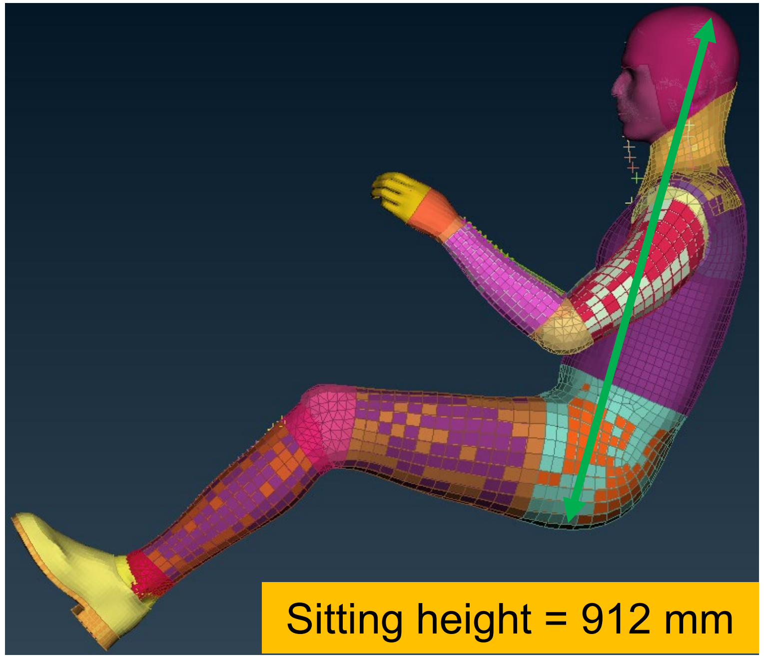
We uniformly scaled (same scaling coefficient in all three directions) the 50th male GHBMC HBM down to the size of the 5th female GHBMC HBM using sitting heights ratio. For simplicity, we will call the new model "5th male".



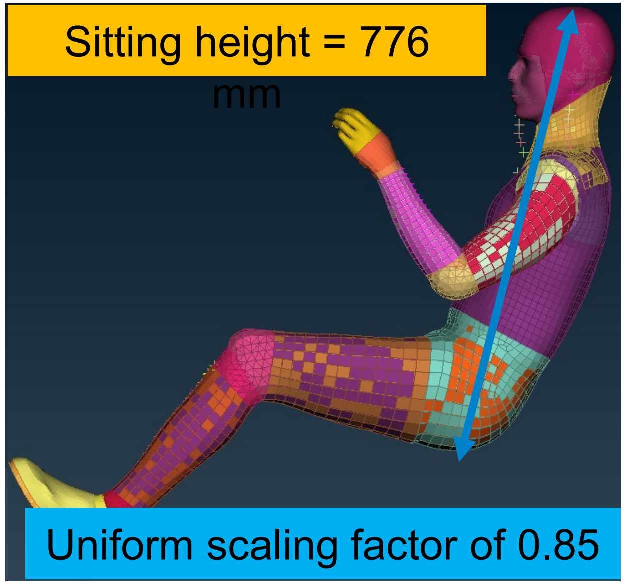
5th female



50th male

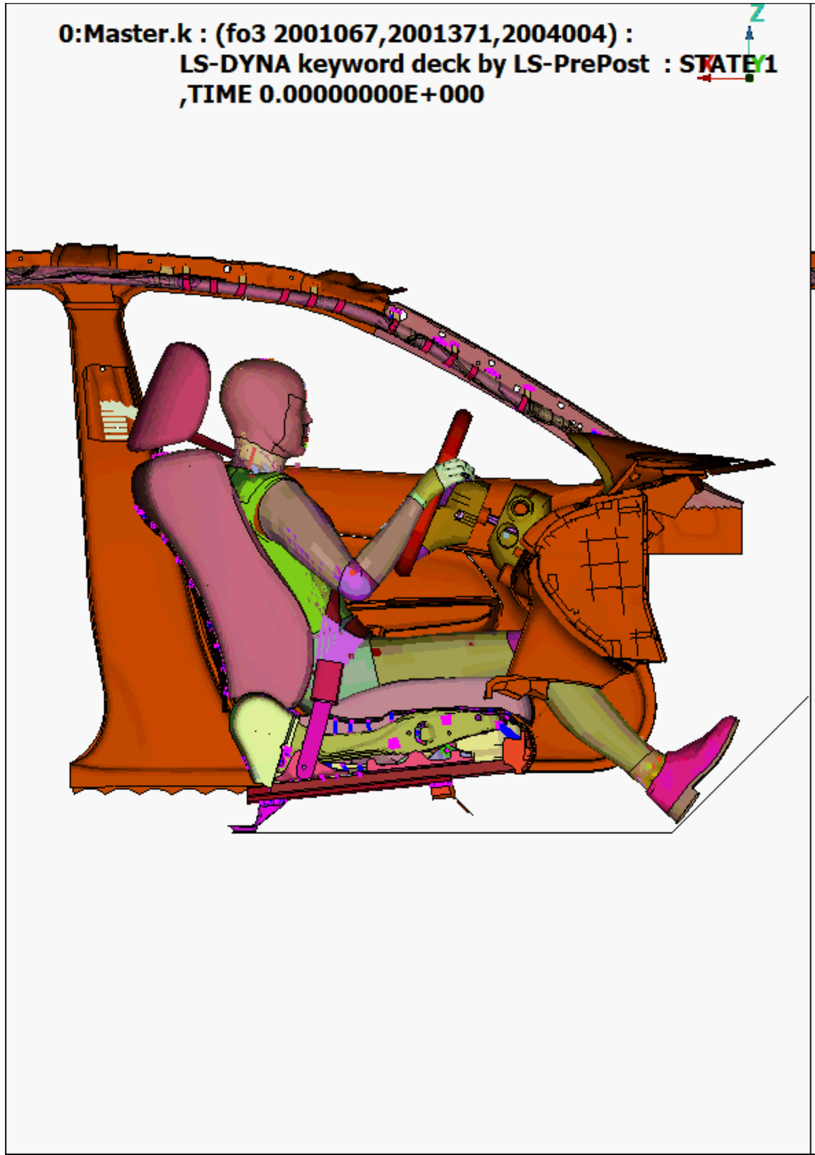


5th male (50th to 5th sitting height)

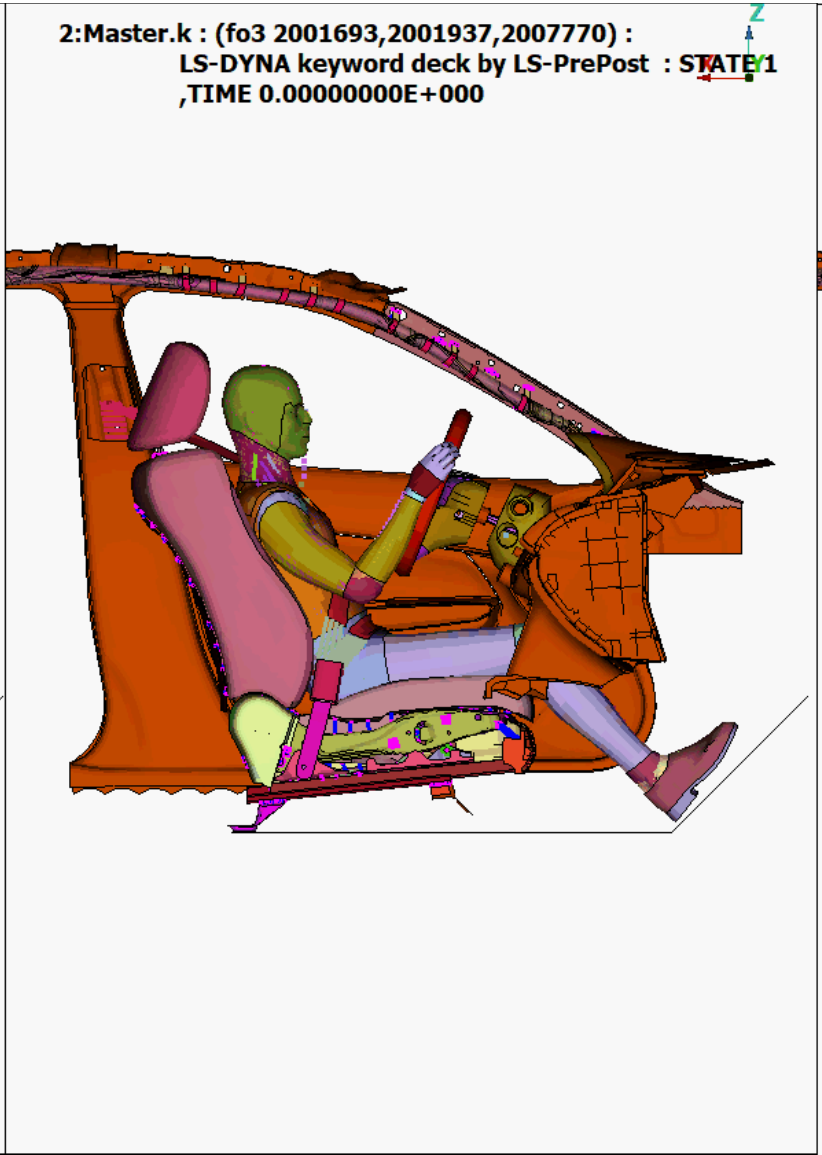


Study 2: 5th female, 5th male and 50th male baseline simulations

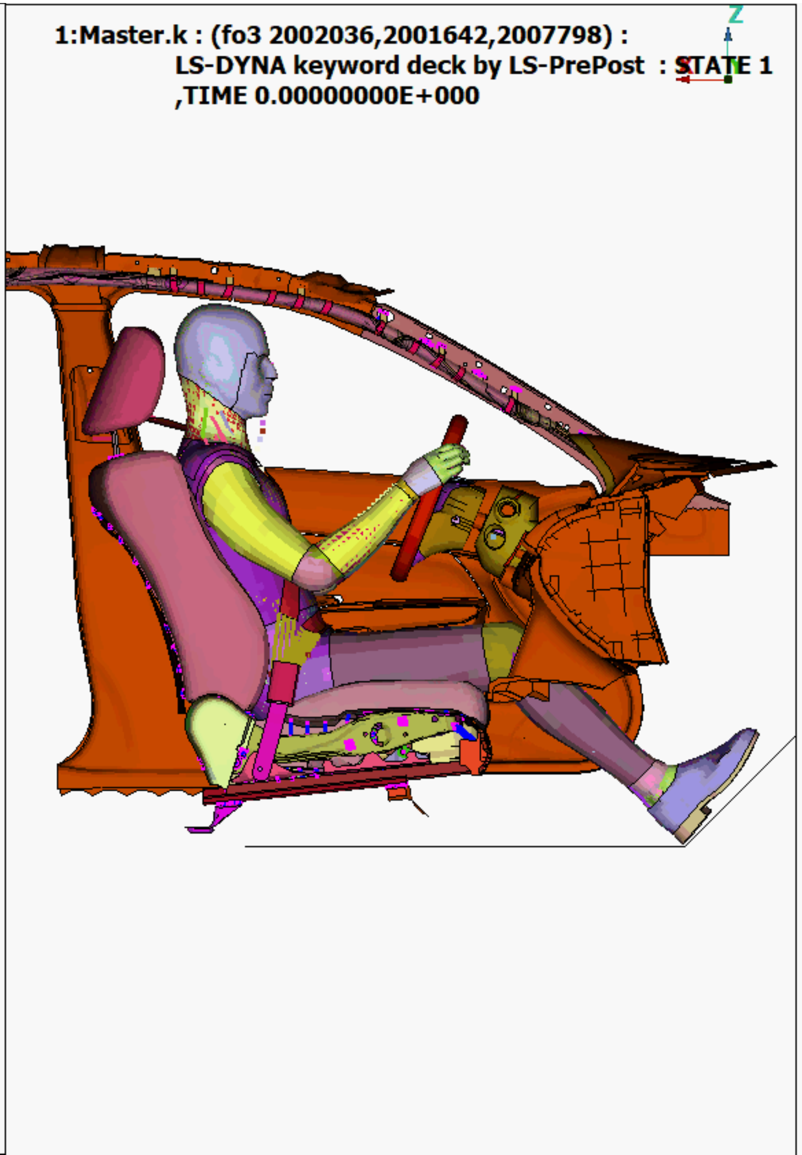
5th female



5th male



50th male

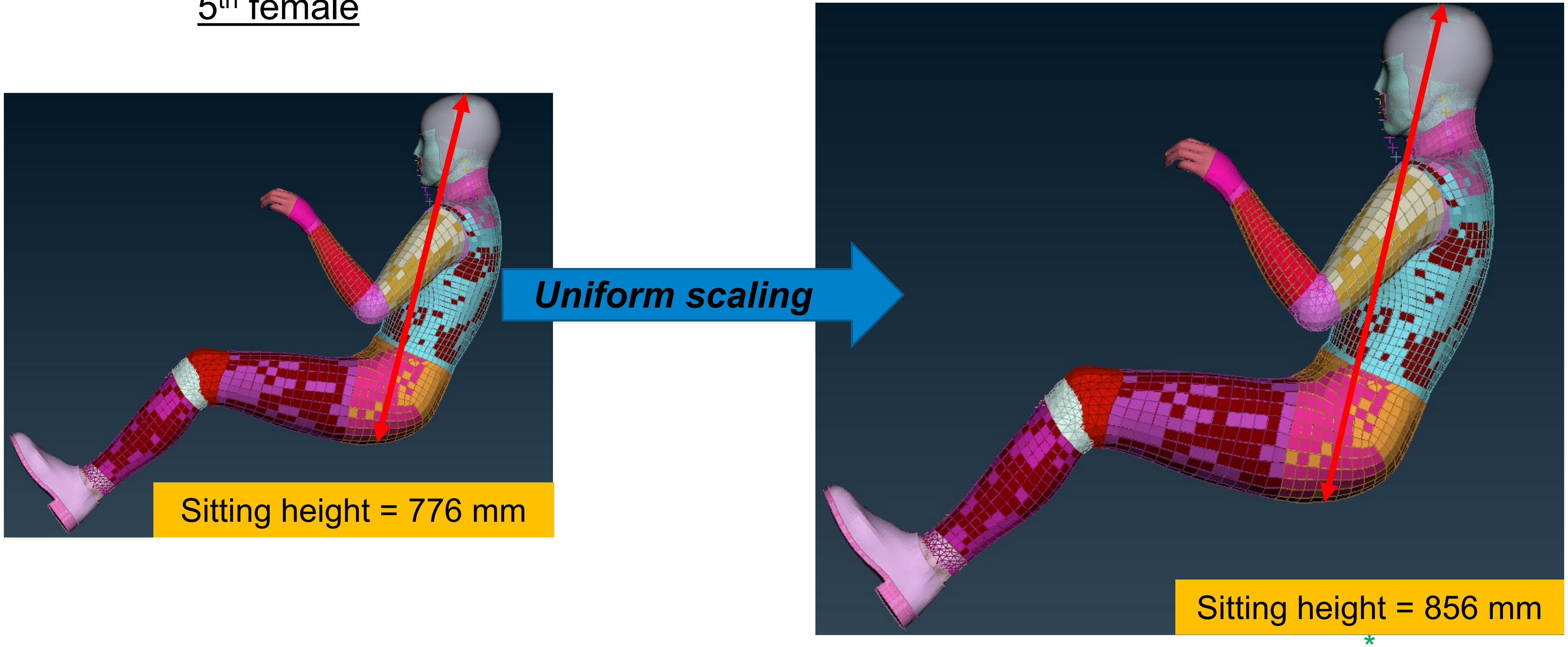


Study 2: Scale 5th female GHBMC model up to the size of 50th female

We also uniformly scaled (same scaling coefficient in all three directions) the 5th female GHBMC HBM up to the size of the 50th female using sitting heights ratio from CDC Anthropometric Reference Data*

50th scaled female (5th to 50th sitting height) = "50th female"

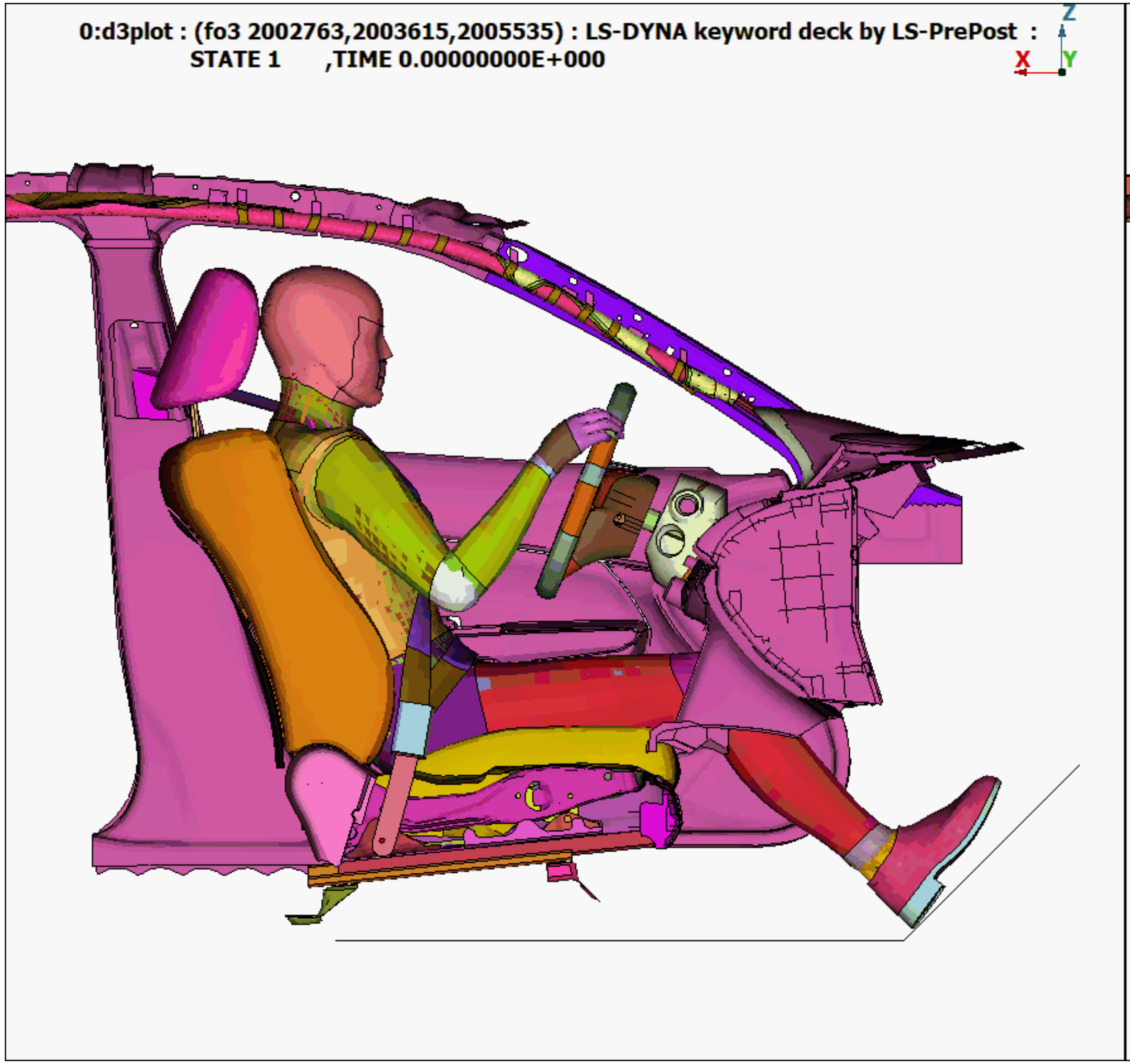
5th female



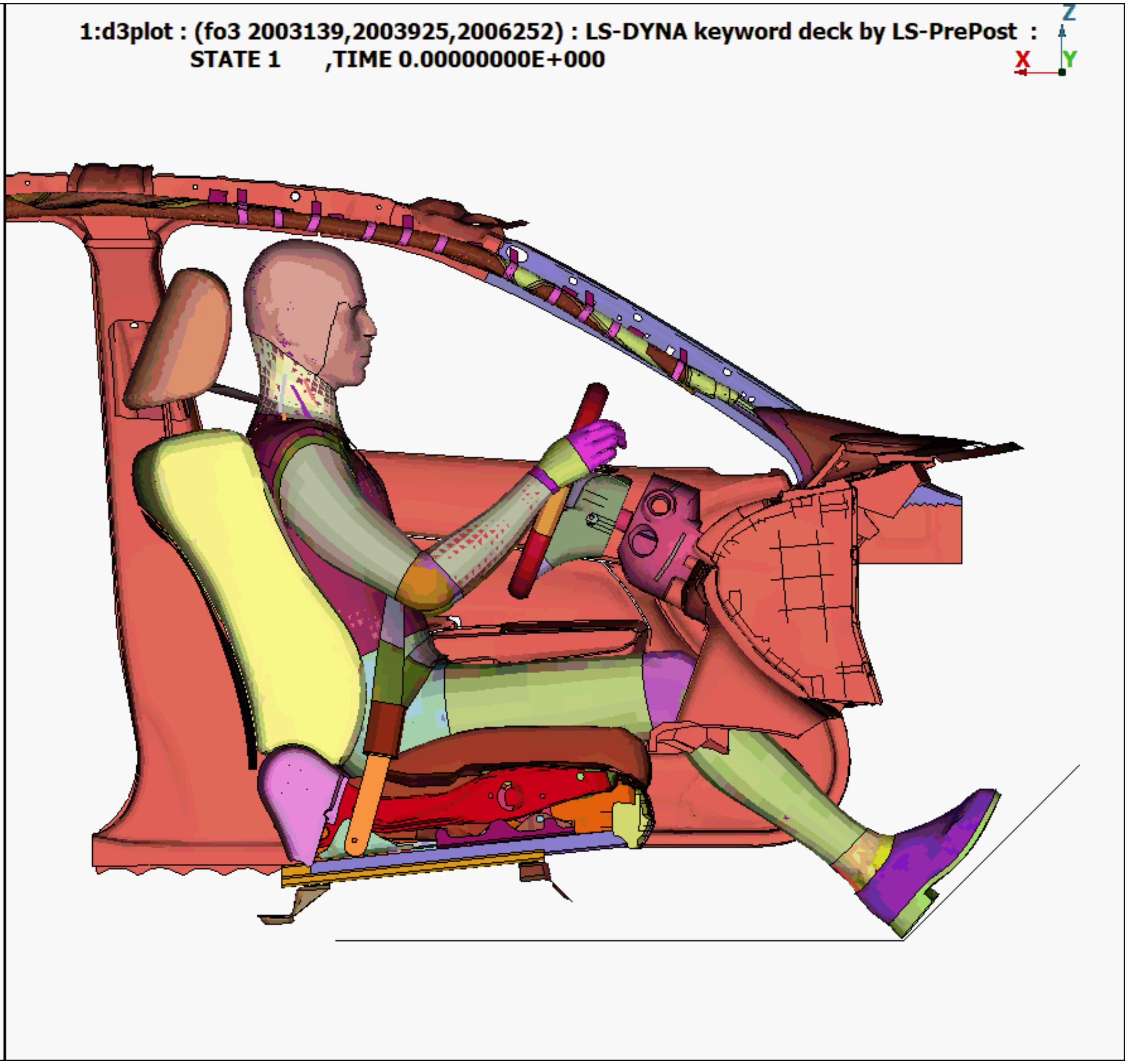
*McDowell MA, Fryar CD, Ogden CL. Anthropometric reference data for children and adults: United States, 1988–1994. National Center for Health Statistics. Vital Health Stat 11(249). 2009.

Study 2: 50th female and 50th male baseline simulations

50th female



50th male



Study 2: DOE - Four GHBMC Models

5th female HBM

Weight = 54 kg
Sitting height = 776 mm

5th male HBM

Weight = 51.2 kg
Sitting height = 776 mm

50th male HBM

Weight = 78 kg
Sitting height = 912 mm

50th female HBM

Weight = 69.71 kg
Sitting height = 856 mm

Design of Experiments (DOE) - Parameters

Crash

Restraints

Parameter	Baseline	Minimum value	Maximum value
Delta V	33 mph	25mph	45mph
PDOF	0	-30,-25,-20,-15,-10,-5,0,5,10,15,20,25,30	
Scaling factor for frontal airbag mass flow rate	1	0.75	1.25
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Frontal and side airbag firing time	14 ms	5 ms	45 ms
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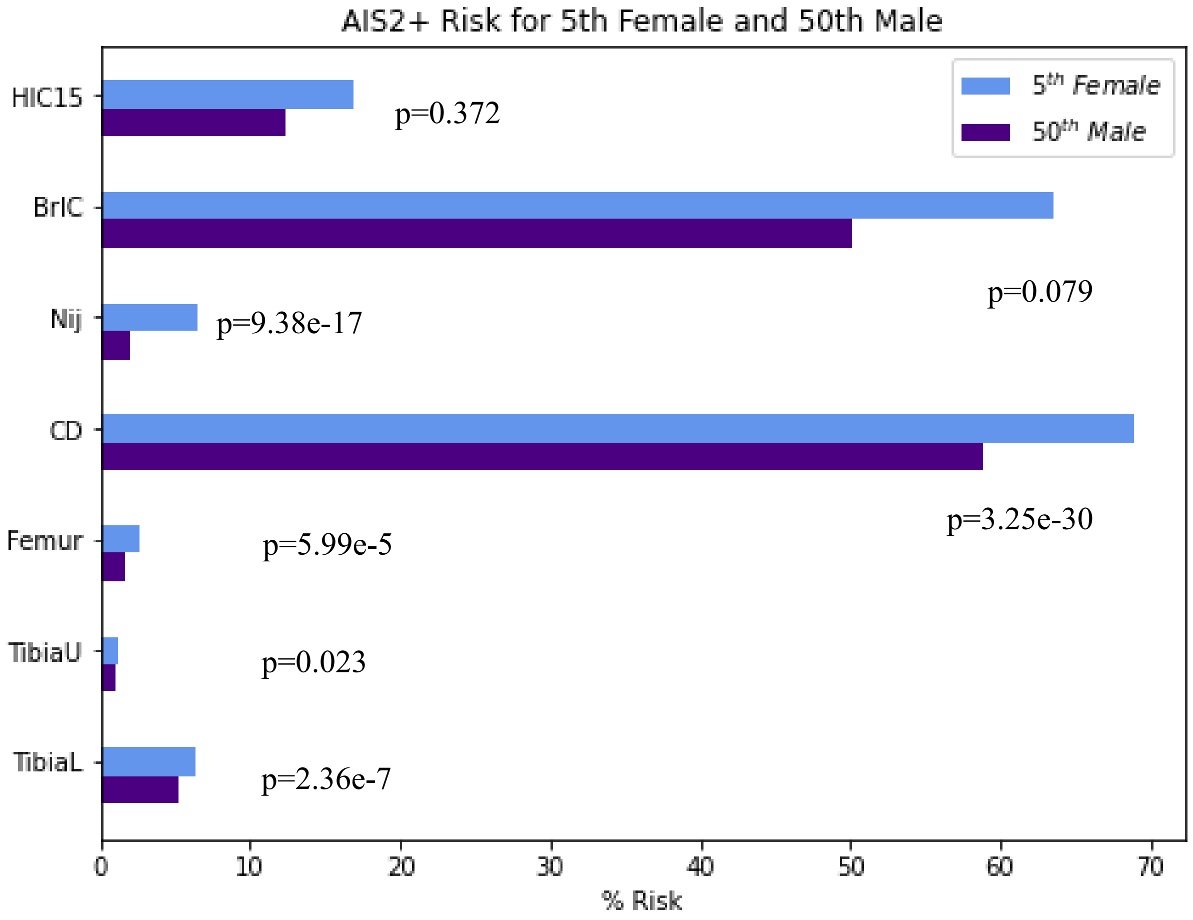
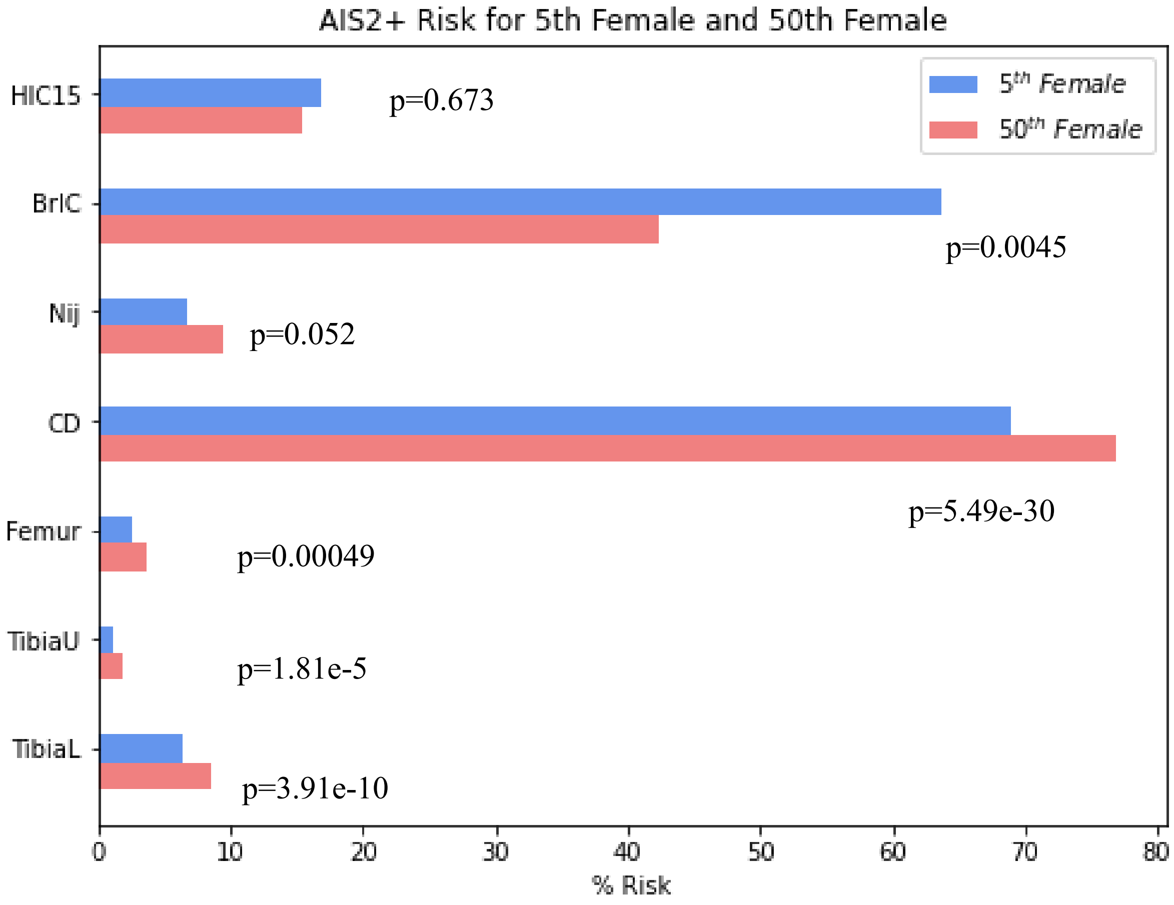
Injury Risks: 5th female and 50th female

HBM Risk of AIS 2+ injuries by body region (based on average values)

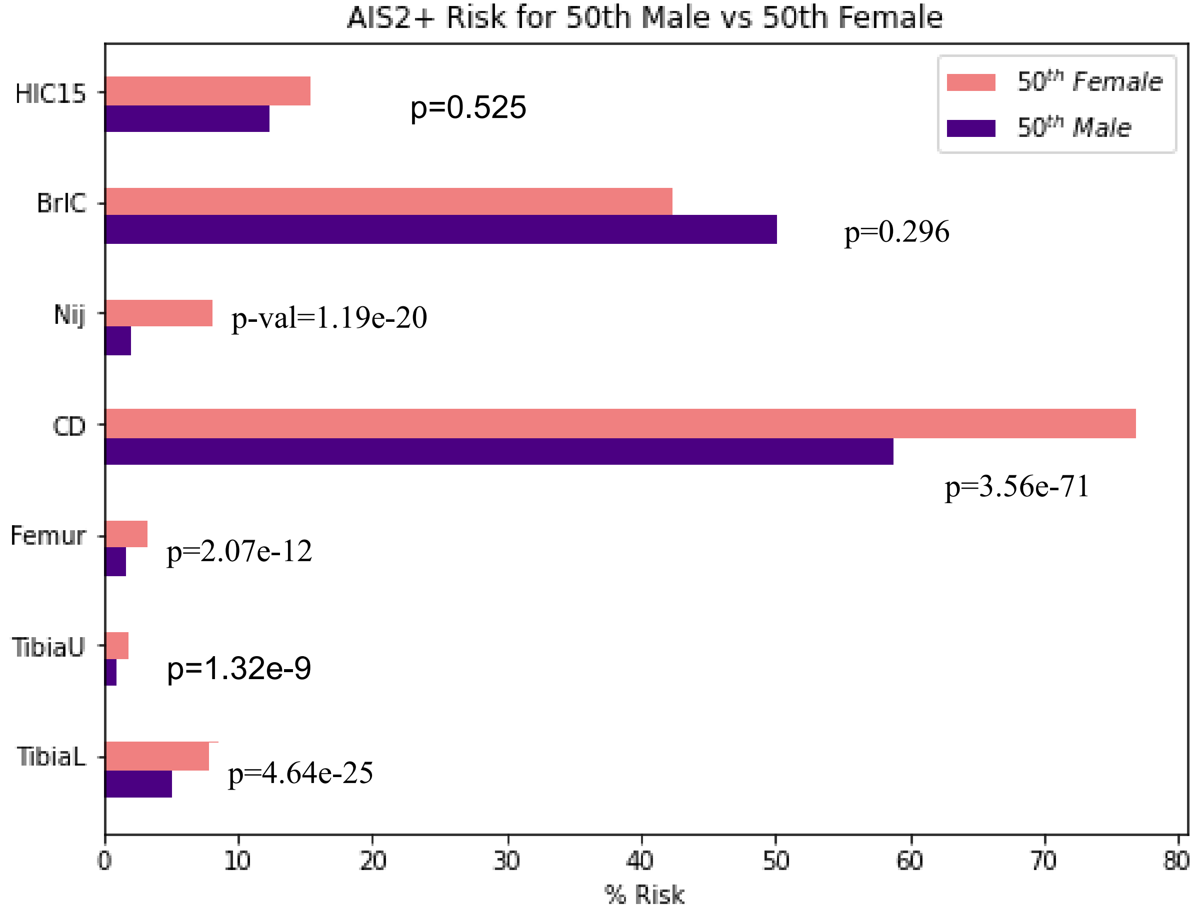


HBM Risk of AIS 2+ injuries by body region (based on average values)

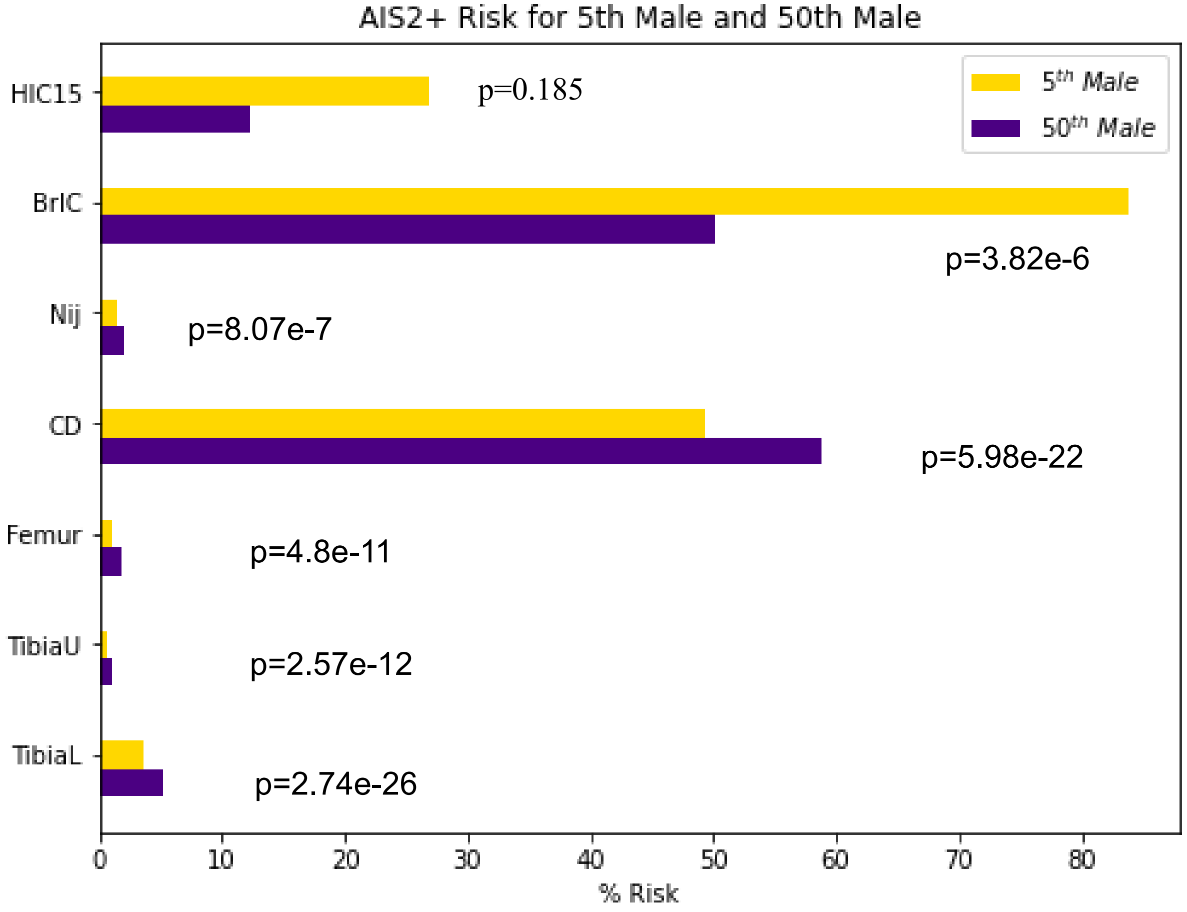


Injury Risks: 50^{th} female, 50^{th} male and 5^{th} male

HBM Risk of AIS 2+ injuries by body region (based on average values)



HBM Risk of AIS 2+ injuries by body region (based on average values)



Study 2: Observations

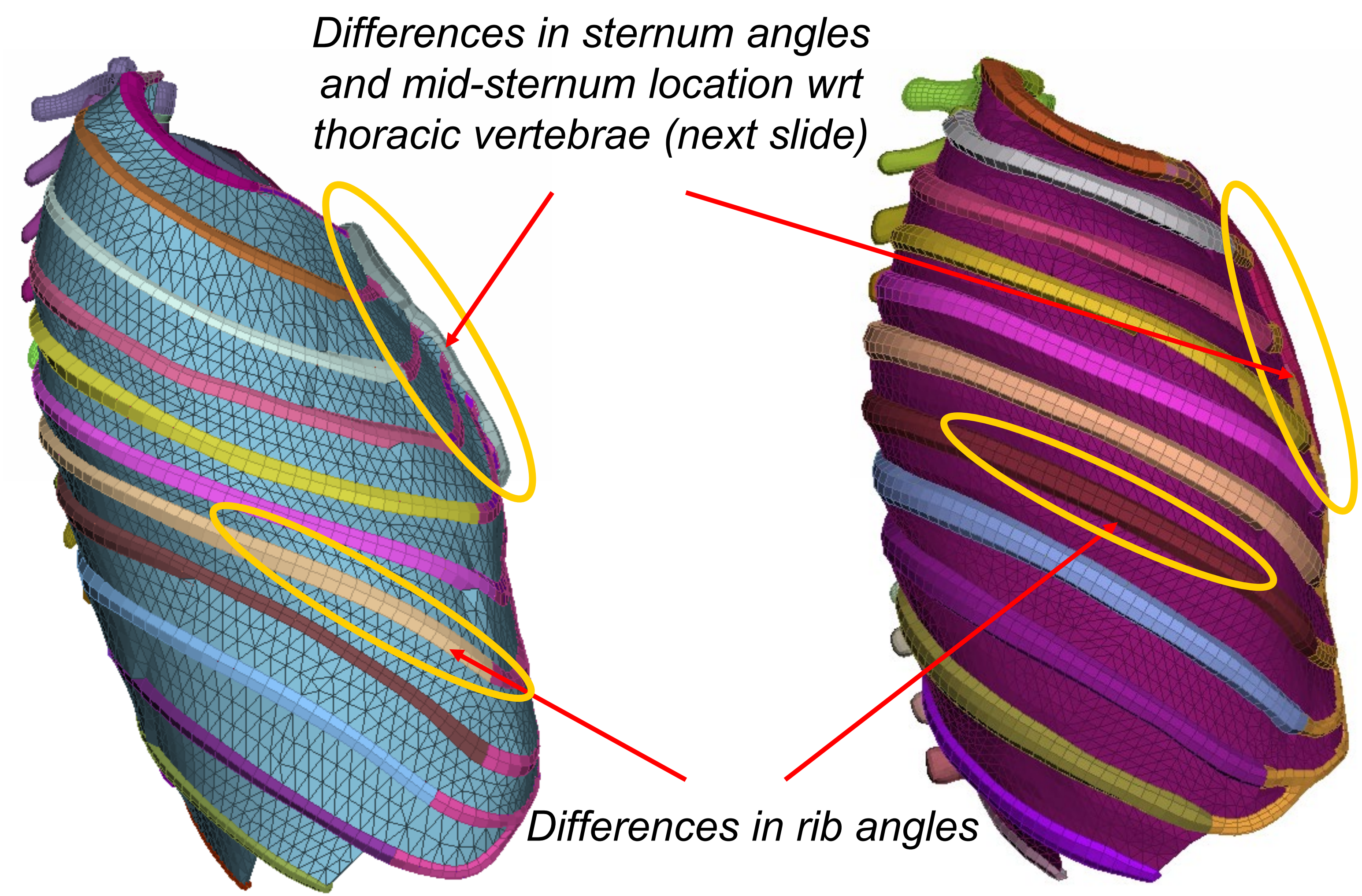
DOE – Four HBMs

- 5^{th} female HBM is at greater risk of brain injury compared to 50^{th} female HBM, while 50^{th} female is at greater chest injury risk compared to 5^{th} female HBM.
- 50^{th} female HBM is at the highest chest injury risk of four HBMs.
- 5^{th} male HBM is at the highest brain injury risk of four HBMs.

Contents

Study 3: Thoracic geometry

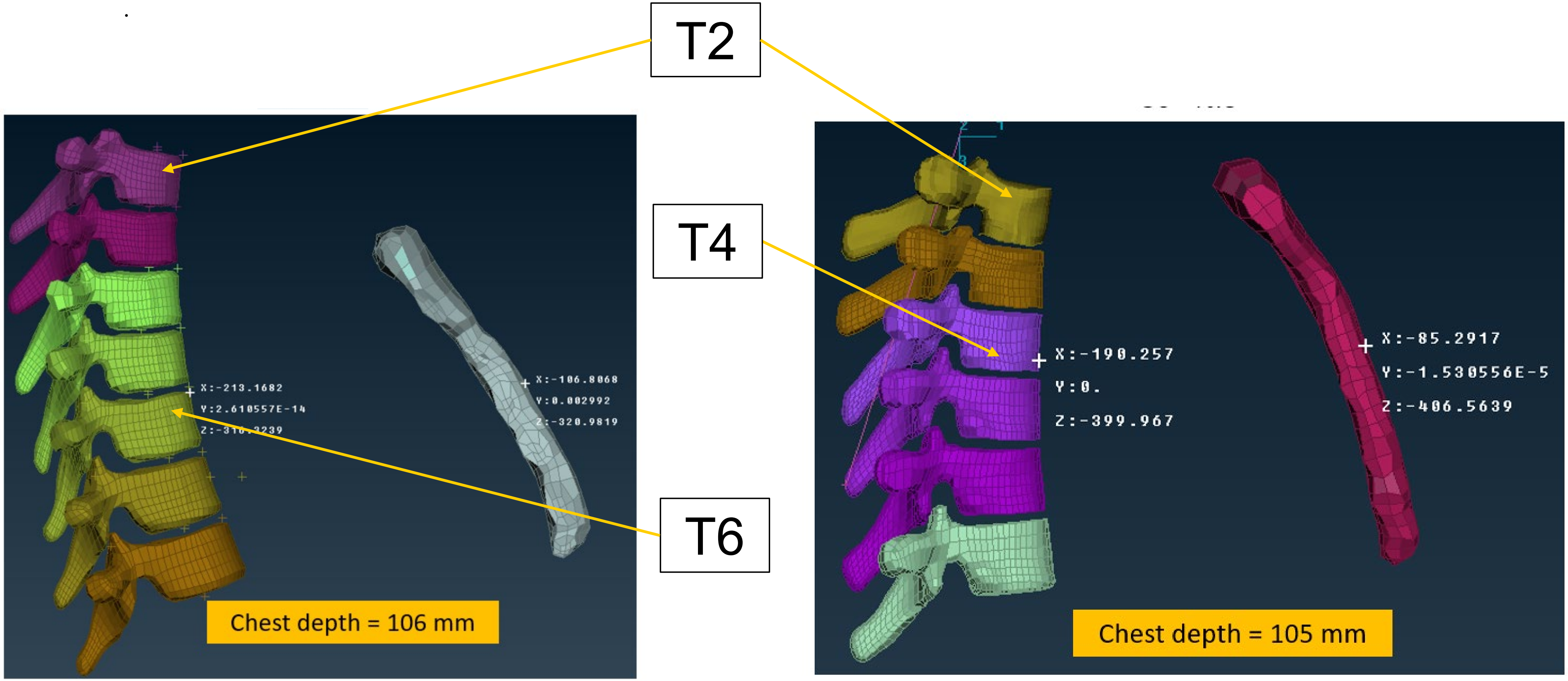
<u>5^{th} female</u> <u>50^{th} male</u>



Both GHBMC models were built using internal geometries of individuals (one person each), whose external geometry fit those of 5^{th} female and 50^{th} male.

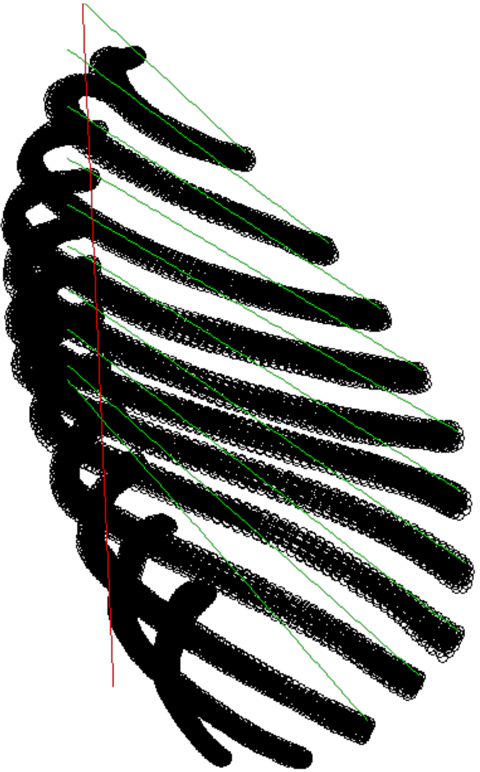
Study 3: Thoracic geometry

5th female | 50th male

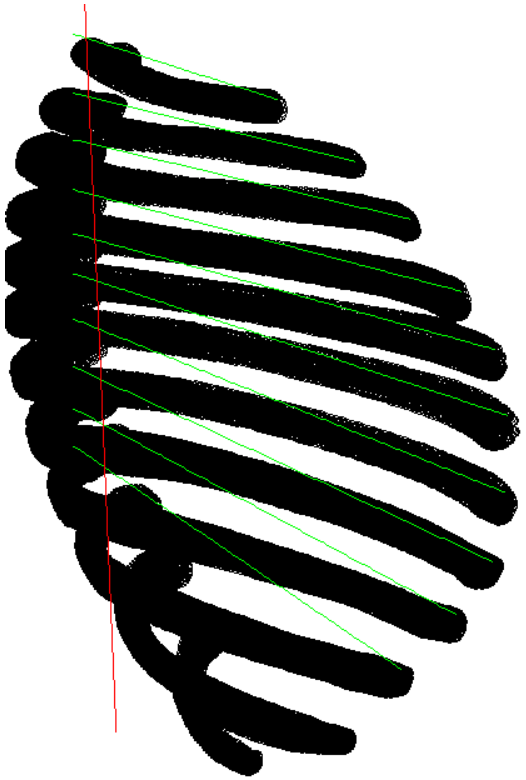


Study 3: Thoracic geometry

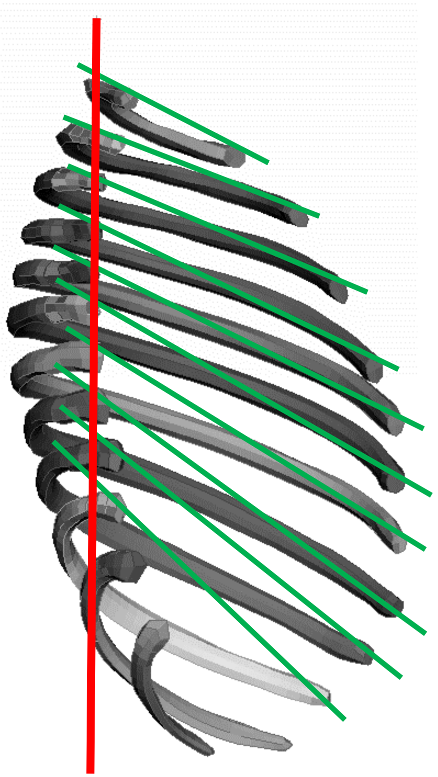
5th female GHBMC



5th female (average)



50th male GHBMC



Wake Forest compared 5th female GHBMC with average 5th female

Comparable rib angles

Rib #	Rib Angles		
	5th female GHBMC	5th female: average (F05 45YO)	50th male GHBMC
1	41.31	68.95	65.06
2	47.46	73.32	68.24
3	51.38	73.67	65.95
4	53.51	72.17	64.19
5	54.20	71.46	63.94
6	52.31	68.58	61.42
7	49.66	64.63	59.40
8	46.37	61.49	57.02
9	42.60	57.99	53.24
10	35.44	51.94	49.06
11	---	---	---
12	---	---	---
Average Rib Angle of 4-8	51.21	67.67	61.19

Study 3: Observations

- Thoracic geometry of the 5^{th} female GHBMC model was obtained from an individual whose external geometry and weight fits the size and weight of the 5^{th} female.
- Similarly, thoracic geometry of the 50^{th} male GHBMC model was obtained from an individual whose external geometry and weight fits the size and weight of the 50^{th} male.
- While both models represent the size and weight of their respective modeling targets (5^{th} female and 50^{th} male), the internal geometries may vary from that of the corresponding population.
- The seated postures, the sternal angles, rib angles, and mid-sternum locations are different between the two models.
- There is a need to define average thoracic geometries for both males and females in seated position.

Contents

Summary

Based on the DOE studies using 5th female and 50th male GHBMC HBMs as well as the uniformly scaled 5th male and 50th female HBMs:

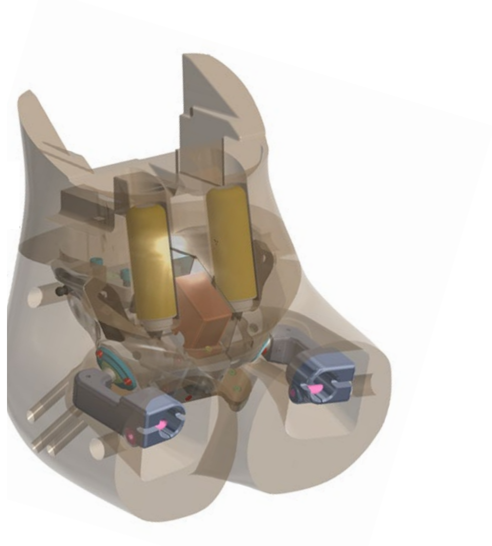
- Brain and thorax are the two body regions at higher injury risk for both males and females (in agreement with the field data).
- 5th female is at higher injury risk across all body regions when compared to the 50th male (current regulatory sizes).
- 5th female is at greater risk of brain injury compared to 50th female HBM, while 50th female is at greater chest injury risk compared to 5th female.
- 50th female is at the highest chest injury risk compared to any other HBM.
- 5th male is at the highest brain injury risk compared to any other HBM.
- There is a need to define average thoracic geometries for both males and females in seated position.

THOR-05F Advanced Crash Test Dummy - Overview & Development

Erin Hutter

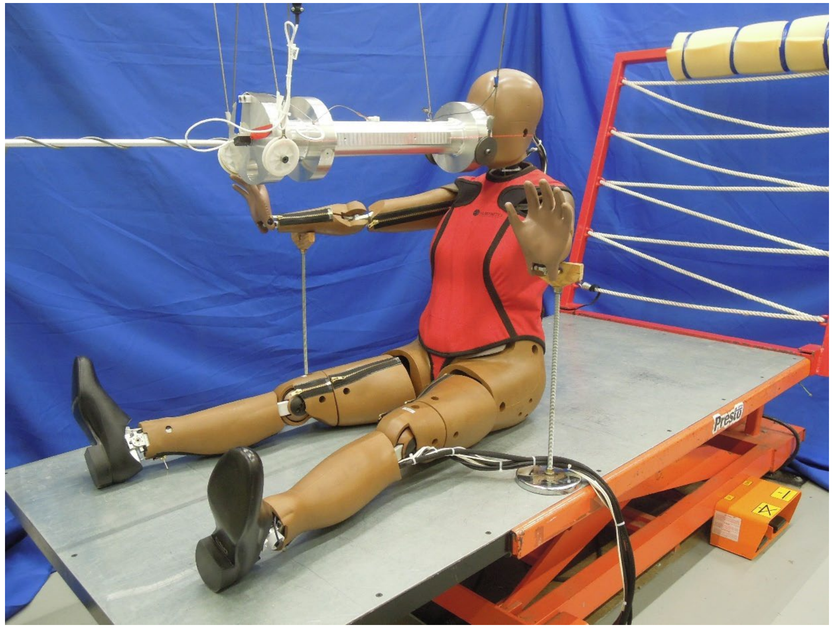
THOR-05F: 5^{th} Percentile Female ATD

- Motivation: Better evaluate injury risk of small female occupants
  - Alternative to Hybrid-III in frontal crash tests
- Incorporates key improvements from THOR-50M
- Human-like characteristics that mimics human seat belt interaction
- Designed to match small female-specific anthropometry and mass properties
- State-of-the-art measurement capabilities, including built-in capacity for on-board DAS
- Improved injury prediction capabilities, e.g. abdominal pressure sensors



Current Research

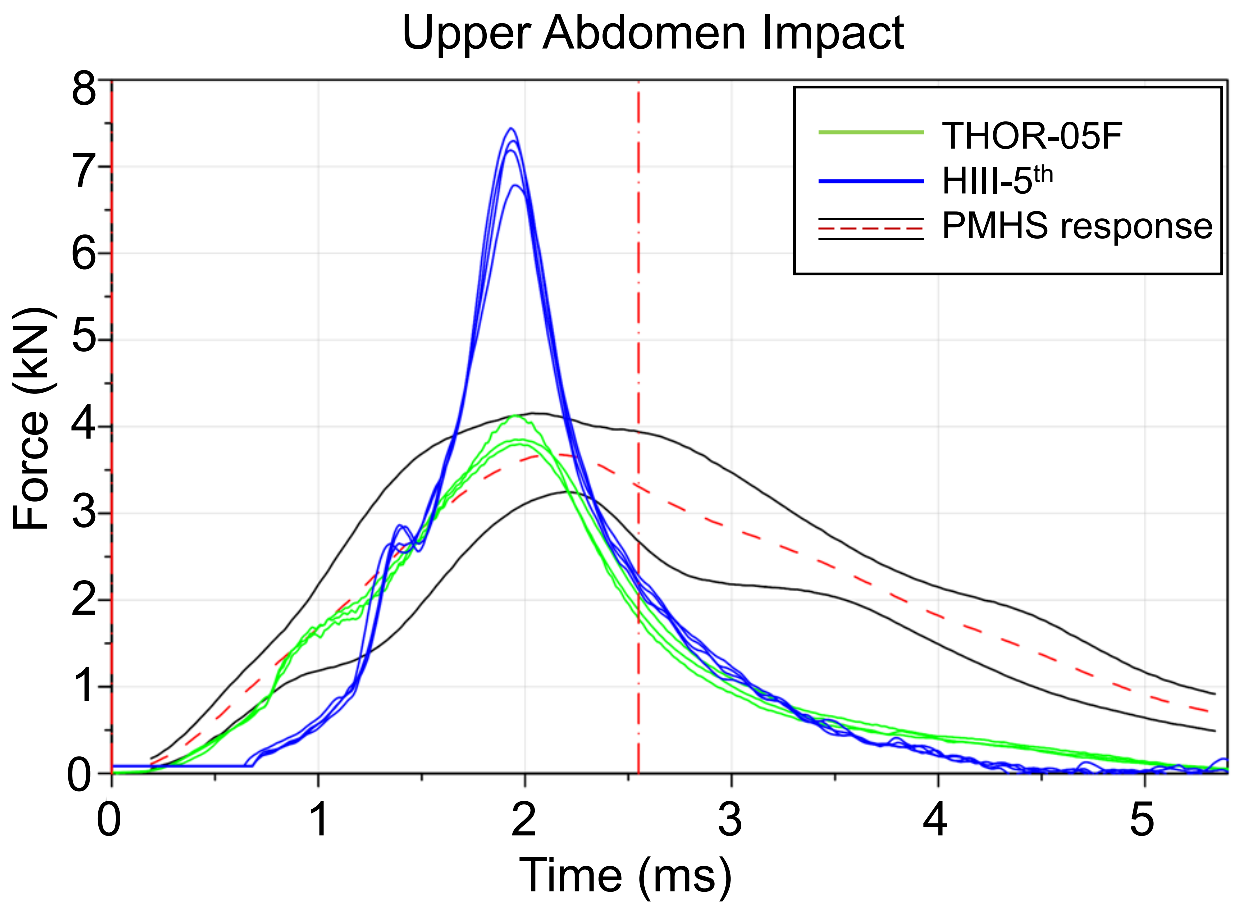
- Evaluated 3 prototypes
- Biofidelity
  - Describes the similarity of the ATD to a human
- Repeatability and Reproducibility (R&R)
  - Evaluates the consistency of the ATD's response
- Durability
  - Evaluates the robustness of the design



THOR-05F Biofidelity

Biofidelity of THOR-05F

- ATD response compared to responses from PMHS or volunteers
- Quantified using Biofidelity Ranking System (BioRank) developed by NHTSA[1]
- Lower BioRank = better biofidelity
  - BioRank Score represents multiples of standard deviations from mean PMHS response



1. Hagedorn, A. et al. (In review for 2022) *Biofidelity Evaluation of THOR-50M in Rear-Facing Seating Configurations Using an Updated BioRank System.* SAE International Journal of Transportation Safety, Special Issue: Occupant Protection & Crashworthiness for ADS-Equipped Vehicles.

Biofidelity of THOR-05F

- THOR-05F has been evaluated using sled & qualification-type tests for which there were corresponding biofidelity target corridors.
  - 11 test modes are complete
    - Head impact
    - Face rigid disk
    - Face rigid bar
    - Neck flexion sled
    - Neck flexion pendulum
    - Neck lateral bending pendulum
    - Upper thorax
    - Upper abdomen
    - Lower abdomen
    - Knee slider
    - Ball-of-foot
  - Additional data collection & BioRanking is ongoing
    - Focusing on newer test modes that include females in the cohort.
    - Additional test modes include shoulder ROM, ankle response, and KTH impacts.

Biofidelity of THOR-05F

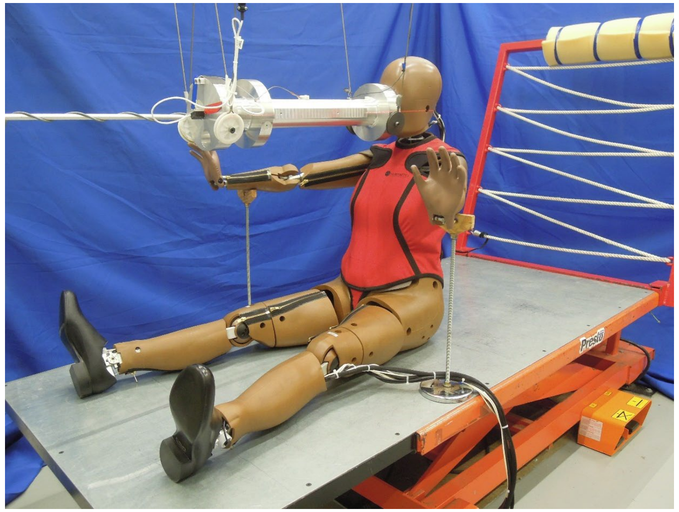
- THOR-05F demonstrates a more biofidelic response than the HIII 5th.
- Average BioRank improves for all regions.
- Lower extremity data will be collected in 2022.

Body Region	THOR-05F	HIII-5th	% Improvement
Head	1.3	1.8	27.8
Neck	1.1	2.1	47.6
Thorax	0.9	1.8	50.0
Abdomen	1.7	3.4	50.0
Lower Extremity	To be collected in 2022		
Overall	1.2	2.3	45.1

THOR-05F R&R

THOR-05F R&R

- **<u>Purpose:</u> Test 3 THOR-05F ATDs at VRTC to begin evaluating the repeatability of the ATD & developing qualification criteria**
- Based on THOR-50M qualification tests
  - Scaled probe masses & velocities (DOT HS 812 811)
  - 15 test modes: Probe impacts & pendulum tests
    - Head
    - Face
    - Neck flexion
    - Neck extension
    - Neck lateral (L & R)
    - Neck torsion (L & R)
    - Upper thorax
    - Lower thorax (L & R)
    - Lower abdomen
    - Upper leg (L & R)
    - Knee slider (L & R)
    - Ankle inversion (L & R)
    - Ankle eversion (L & R)
    - Ball-of-foot (L & R)
    - Heel-of-foot (L & R)



5 repeats x (15+9) modes x 3 ATDs = 360 tests

THOR-05F R&R

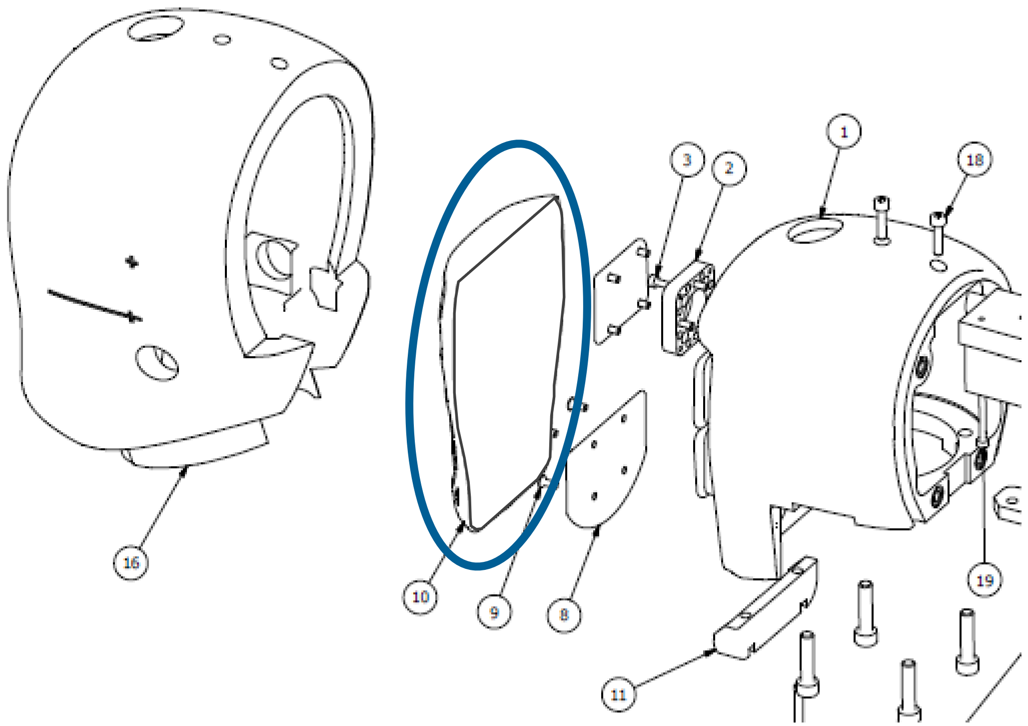
- Depending on the test mode, measures of interest include:
  - Peak forces
  - Peak moments
  - Peak displacements
- To evaluate R&R, the following were calculated for each measure of interest:
  - Average
  - Standard deviation
  - Coefficient of variation $\left(CV = \frac{StDev}{Avg}\right)$

CV	Action
≤ 5%	No further investigation
> 5% & ≤ 10%	Sources of variability investigated; outliers may exist
> 10%	Test procedure thoroughly reviewed & ATDs inspected.

THOR-05F R&R

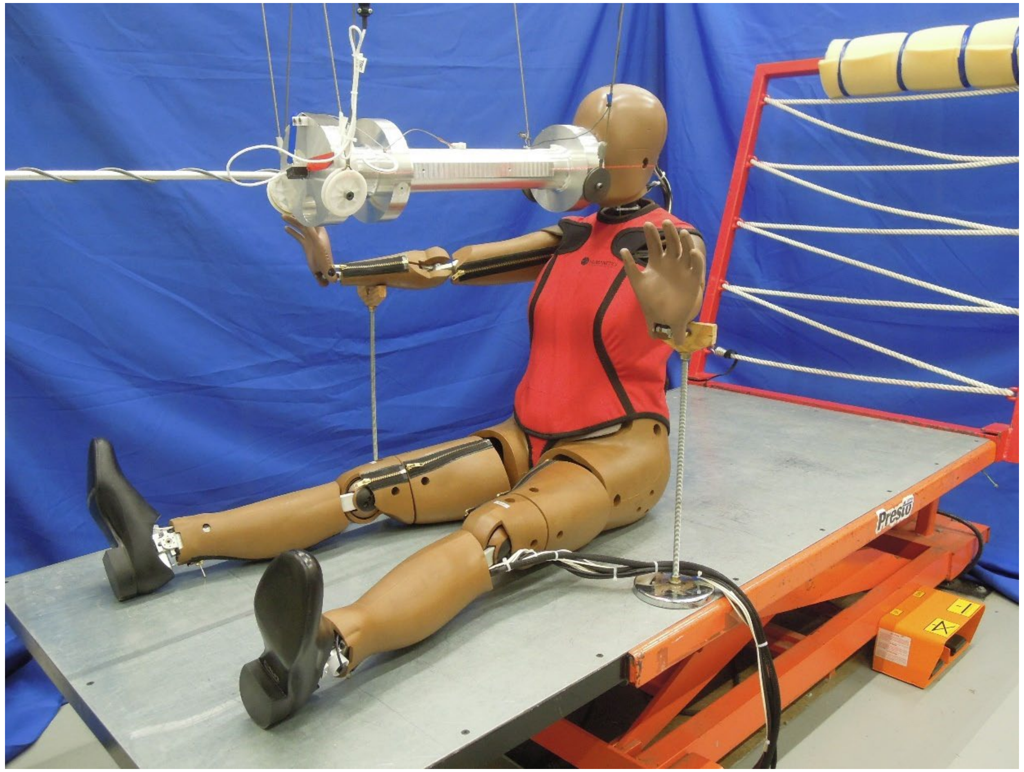
Mode	Max CV (%)	Follow-up Action
Head	4.2	N/A
Face	27.5	Improve face insert design
Neck Flexion	7.5	Continue to monitor
Neck Extension	6.5	Continue to monitor
Neck Lateral Bending	2.2	N/A
Neck Torsion	2.1	N/A
Upper Thorax	10.2	Continue to monitor
Lower Thorax	4.1	N/A
Abdomen	12.9	Investigate root cause of variance: test series scheduled for Dec 2021
Upper Leg	14.4	Improve test procedure
Knee Slider	5.0	N/A
Ankle Inversion	5.1	N/A
Ankle Eversion	3.9	N/A
Ball of Foot	12.5	Improve test procedure
Heel of Foot	4.2	N/A

THOR-05F R&R: New face insert design



- Initial face insert was made from Confor Foam
  - Common material to THOR-50M
  - Similar issues with R&R
  - Performance changes with the total number of hits and the time between impacts
- Investigated a new design
  - Thermoset material
  - Modified geometry

THOR-05F R&R: New face insert design



Inputs: 10.7 kg probe at 6.73 m/s
Outputs: Peak probe force
Peak head CG resultant acceleration

- New design has improved biofidelity

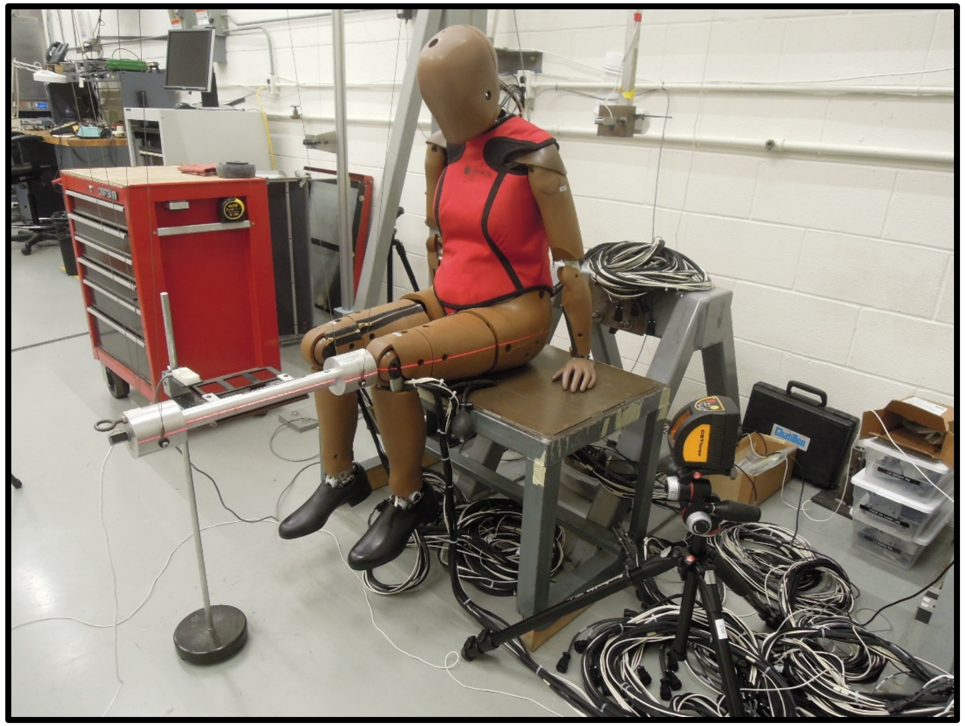
Test Mode	Initial Design BioRank	New Design BioRank
Rigid disk face impact	1.6	0.8

- New design has improved R&R performance

Initial Design	Max Probe Force (N)	Max Head CG Resultant (G)
Mean	8052	291
Standard Deviation	521	79.9
CV	6.5%	27.5%

New Design	Max Probe Force (N)	Max Head CG Resultant (G)
Mean	5961	162
Standard Deviation	411	15.8
CV	6.9%	9.7%

THOR-05F R&R: Upper Leg



- Acetabulum force had a CV greater than 10%.
- CV increases as the load travels from knee to hip.
- Loading during qualification test < crash events
- Similar observation with THOR-50M.

Upper Leg Test	Max Probe Force (N)	Max Femur Z-Force (N)	Max Acetabulum Res. Force (N)
Mean	3641	2160	953
Standard Deviation	147	128	137
CV	4.0%	5.9%	14.4%

Inputs: 2.99 kg probe at 2.6 m/s

Outputs: Peak probe force
Peak femur z-force
Peak resultant acetabulum force

THOR-05F R&R: Upper Leg

- Increase energy to ensure that ATD is loaded similarly to crash events during qualification tests
  - Increased mass and speed of probe.
  - Only 1 leg tested (5 trials). Plan to test more legs in late 2021
  - All CVs decreased!

Original Test Procedure (n=6)

Inputs: 2.99 kg probe at 2.6 m/s

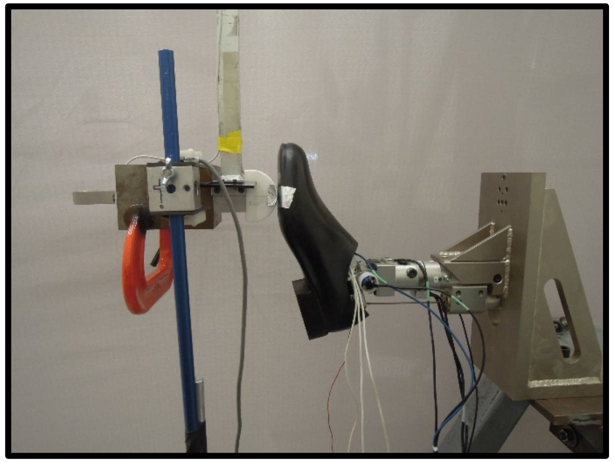
Initial Design	Max Probe Force (N)	Max Femur Z-Force (N)	Max Acetabulum Res. Force (N)
Mean	3641	2160	953
Standard Deviation	147	128	137
CV	4.0%	5.9%	14.4%

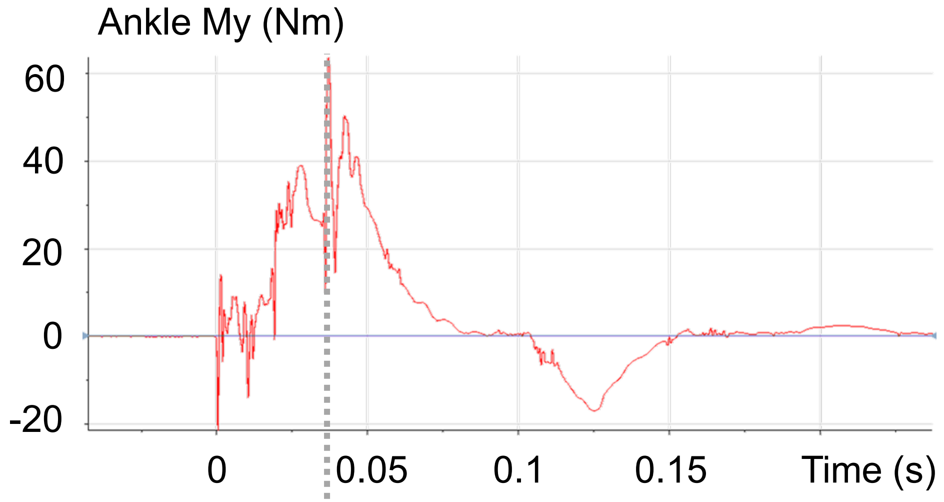
Increased Energy Procedure (n=1)

Inputs: 7.26 kg probe at 3.3 m/s

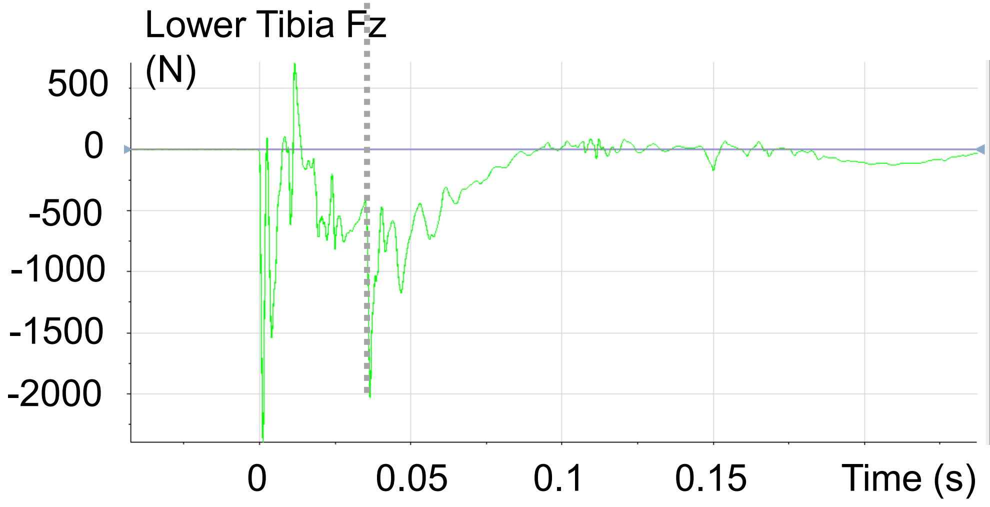
Initial Design	Max Probe Force (N)	Max Femur Z-Force (N)	Max Acetabulum Res. Force (N)
Mean	6836	3975	1661
Standard Deviation	178	81	31
CV	2.6%	2.0%	1.8%

THOR-05F R&R: Ball of Foot



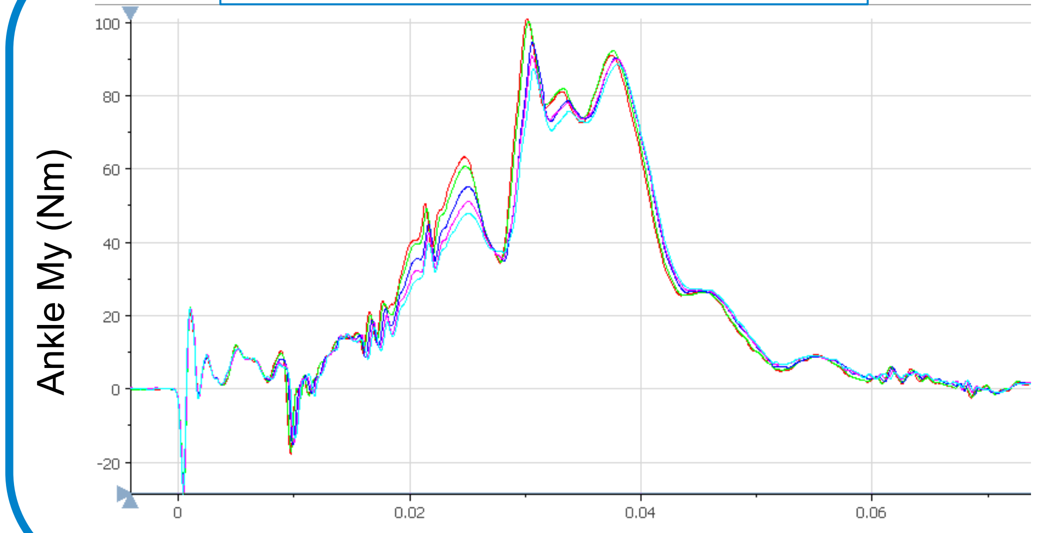


- THOR-05F has a different ankle design than THOR-50M
  - Not just scaled
- Initial Ball of Foot test caused a double hit
  - 3.00 kg mass at 5.0 m/s
  - Peak ankle moment occurs at 2nd hit
  - Increase mass & lower speed!

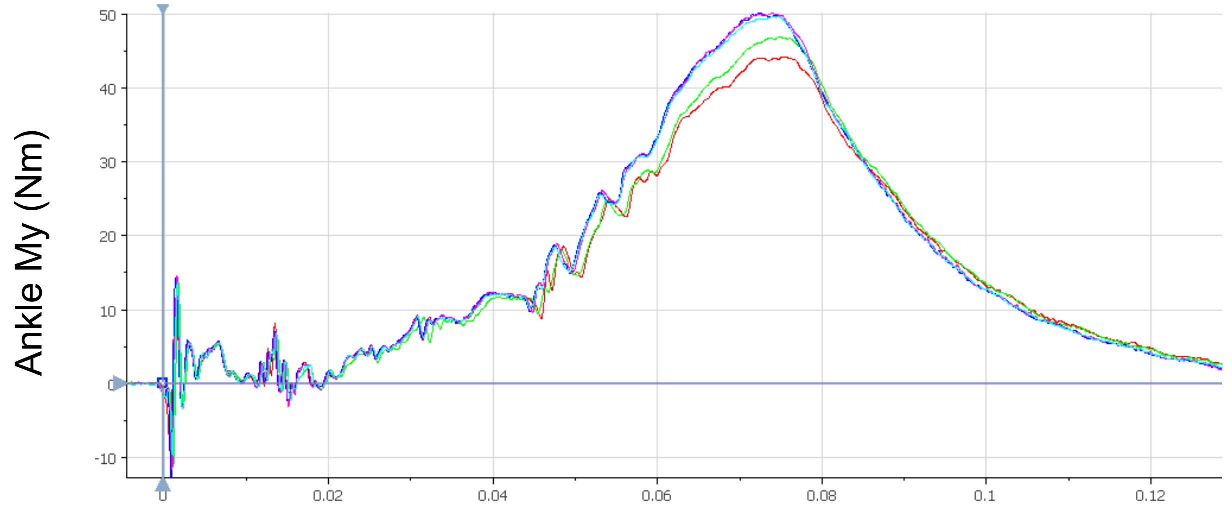


THOR-05F R&R: Ball of Foot

Original Test Procedure
3.0 kg mass, 5.0 m/s



New Test Procedure
8.5 kg mass, 2.0 m/s

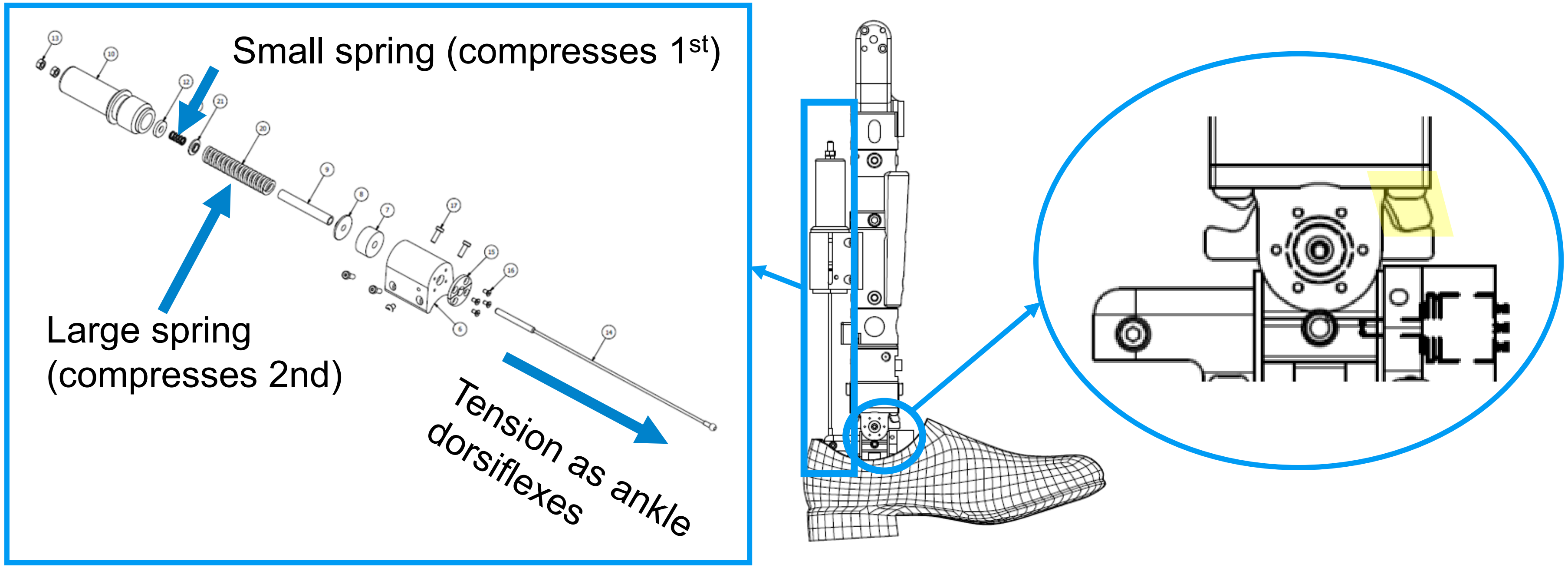


Ball of Foot	Peak Lower tibia Z-Force (N)	Peak Ankle Y-Moment (N·m)	Peak Ankle Rotation (°)
Mean	970	47.7	30.3
Standard Deviation	90	6.0	1.2
CV	9.4%	12.5%	4.0%

- New test procedure
- “Cleaner” data
- Peaks are clear
- Some variation in ankle moment

THOR-05F R&R: Ball of Foot

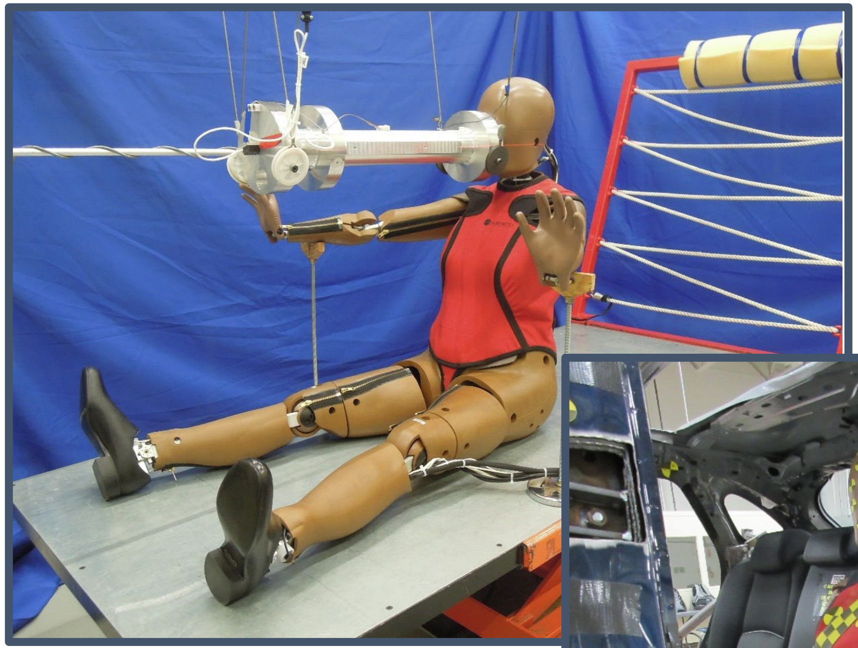
- Ankle mechanics during this test are affected primarily by:
  - Dorsiflexion stopper
    - Probably not the source of variation
    - Same material used for inversion/eversion stoppers
  - Achilles cable tension
    - Investigating a robust method to ensure initial conditions are repeatable



THOR-05F Durability

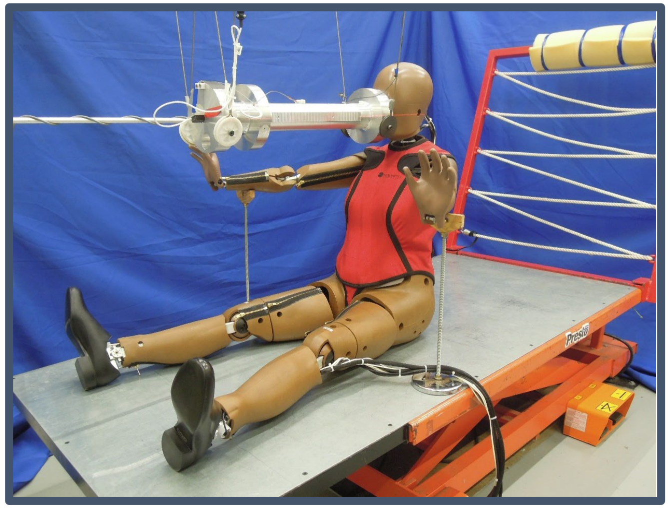
THOR-05F Durability

- Durability evaluated by 2 methods:
  - Increased energy qualification style tests
    - Baseline qualification test followed by tests with +10%, +20%, and +30% increased energy.
    - Final test is another baseline.
  - Sled tests
    - Objective was to test a worst-case scenario.
      - Severe pulse, rear seat, no load limiter on seat belt



THOR-05F Durability

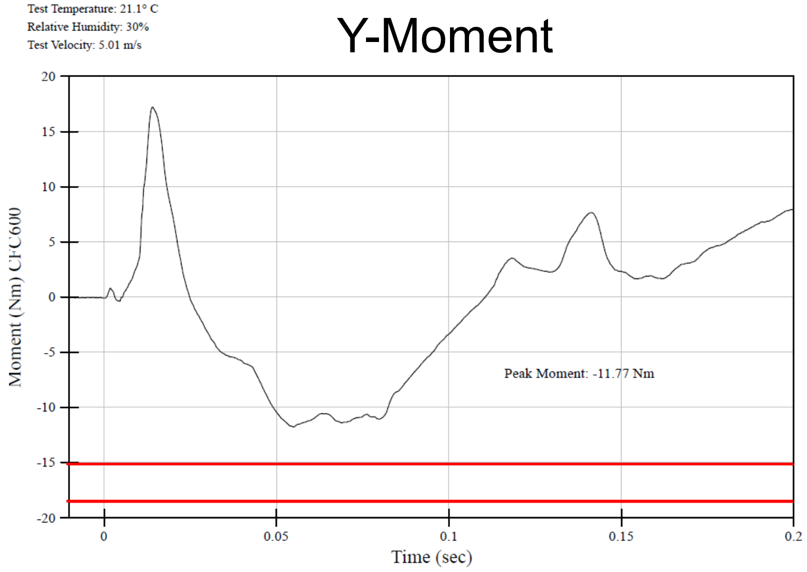
- Increased energy qualification tests
- Pass = Final baseline test is within preliminary R&R corridors

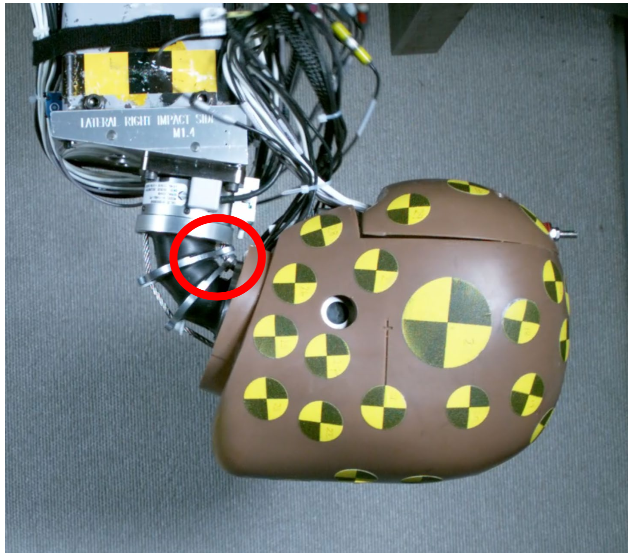


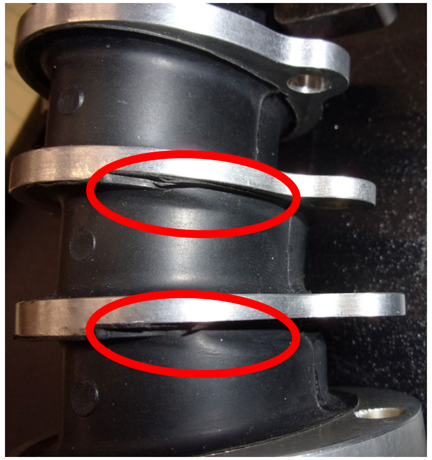
Mode	Durability Pass/Fail	Details
Head	Pass	
Face	Pass	Evaluated with new insert
Neck Flexion	Pass	
Neck Extension	Fail	Y-Moment failed, 3 Nm too low
Neck Lateral Bending	Pass	
Neck Torsion	Pass	
Upper Thorax	Pass	
Lower Thorax	Pass	
Abdomen	Fail	Abdomen pressure failed. 1-5 N too high
Upper Leg	Pass	Evaluated w/ updated procedure
Knee Slider	Pass	
Ankle Inversion	Pass	
Ankle Eversion	Pass	
Ball of Foot	Pass	Evaluated w/ updated procedure
Heel of Foot	Pass	

THOR-05F Durability: Neck

- Y-moment in extension was too low in the final baseline extension test.
- Video showed contact between neck plates during baseline test.
- Post-test inspection: damage to internal cables & rubber components.
- Investigating design changes to the neck.







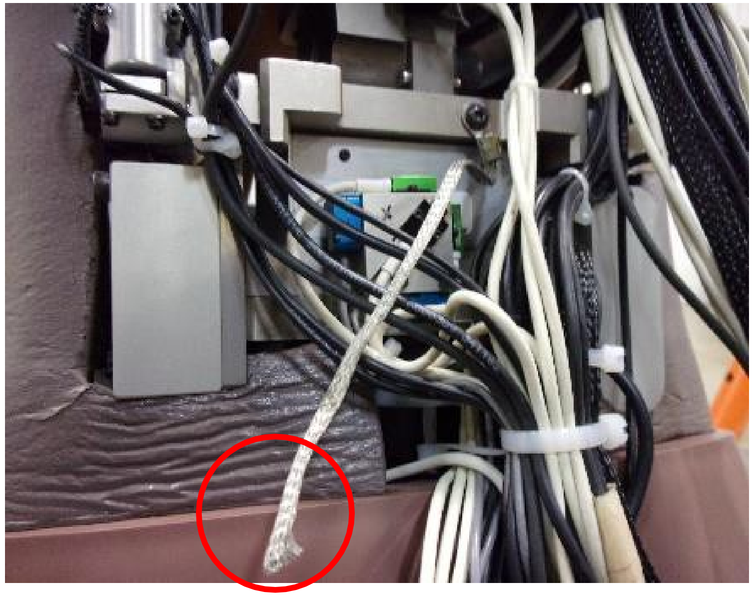
THOR-05F Durability

- Conducted 5 sled tests with THOR-05F
  - Main purpose was to evaluate durability early in development.
  - 3 tests in January 2020, 2 tests in July 2021
  - Pulse: 35 mph ΔV, 40 G (similar to NCAP)
  - Rear seat occupant
  - No load limiter or pretensioner

THOR-05F Durability: Sled video

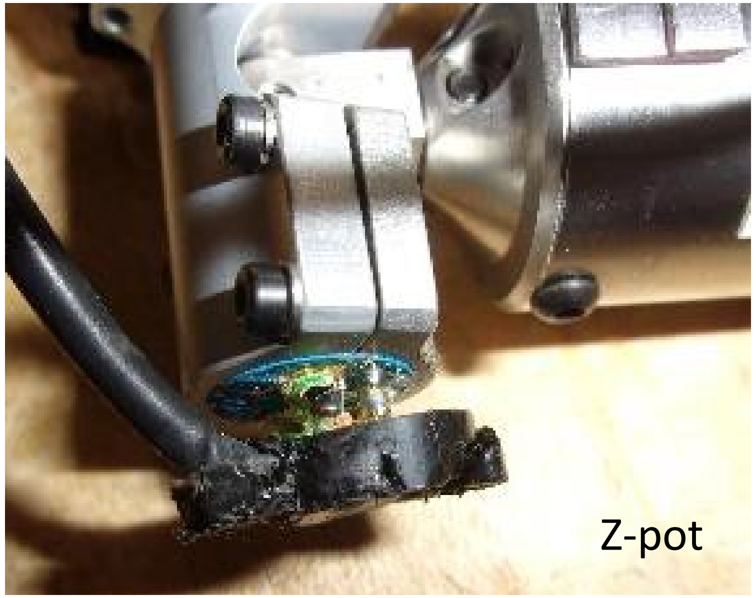
THOR-05F Durability

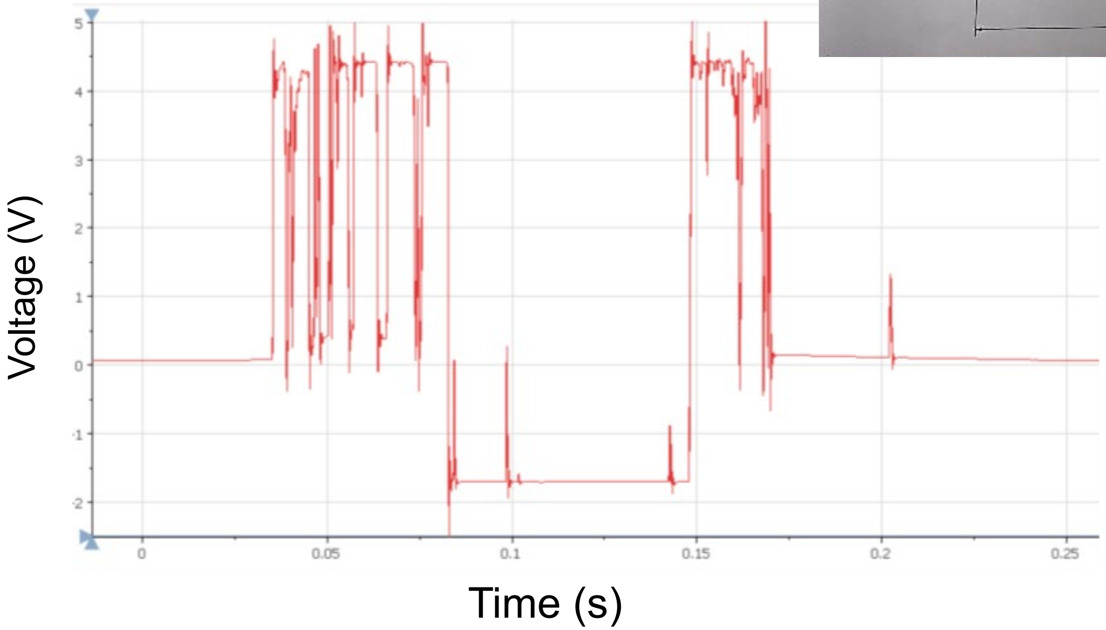
- Sled testing durability findings:
  - Minor damage: cosmetic, easily repairable, easily preventable in the future
  - Ex: Scuffing, tearing of grounding cables, loosening of bolts, etc.



THOR-05F Durability

- Sled testing durability findings:
  - Major issues: IR-TRACCs and ribs
  - Damage to IR-TRACC pots & data collection failures.
    - Likely contacting spine and ribs during crash event.
  - Significant rib deformation.





THOR-05F Overall Status

- THOR-05F development is progressing.
- Significantly improved biofidelity over the Hybrid III 5th.
  - Collecting more data (ATD & PMHS) to comprehensively evaluate biofidelity.
  - Evaluation will be ongoing as more female-specific data becomes available.
- THOR-05F has demonstrated good R&R (CV < 10%) at VRTC for:
  - Head, face, neck, thorax, knee, upper leg, ankle in/eversion, and heel.
  - Considering ATD design and/or test procedure changes for abdomen & ball of foot.
  - Round robin testing to occur once ATD design is closer to being finalized.
- Focus on improving neck and thorax durability.
- Preliminary design drawing package is available on the docket.
  - Drawing updates, test manuals, PADI, & reports will be added as they become finalized.
  - https://www.regulations.gov/docket/NHTSA-2019-0107

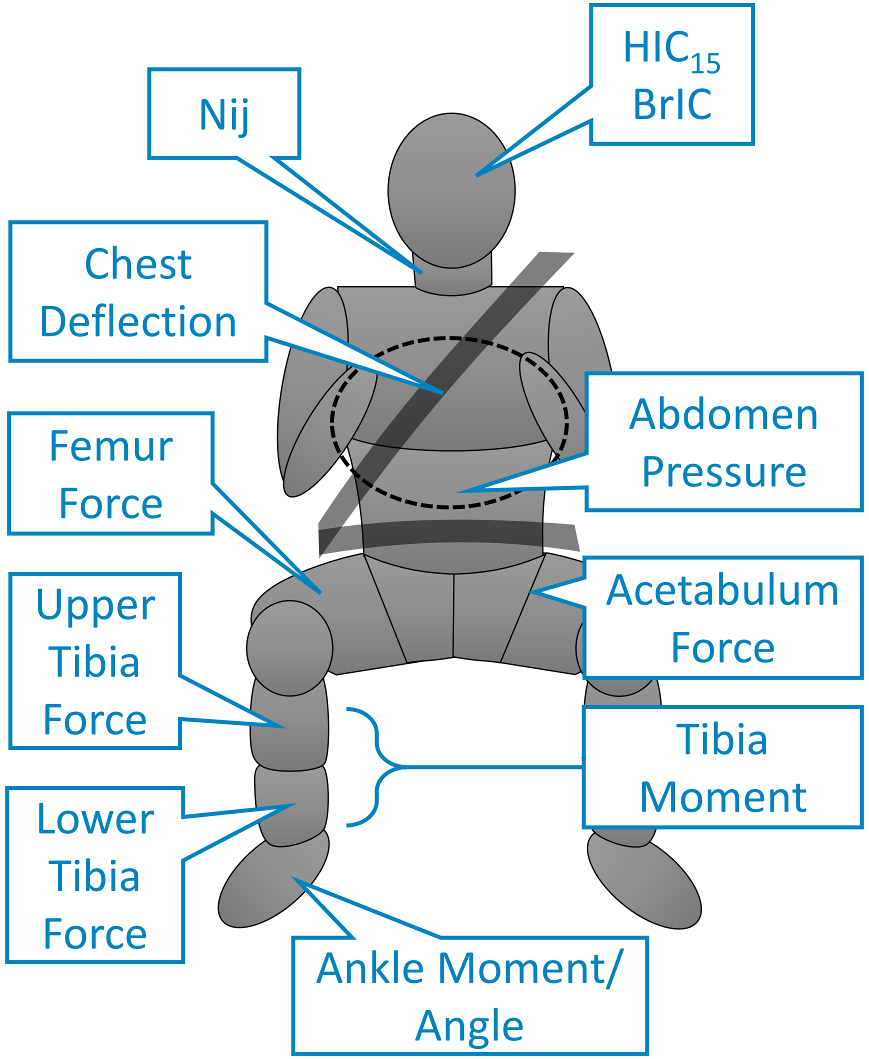
THOR-05F - Female Experimental Data and Injury Criteria Development

Ellen Lee

THOR-05F Injury Criteria Development

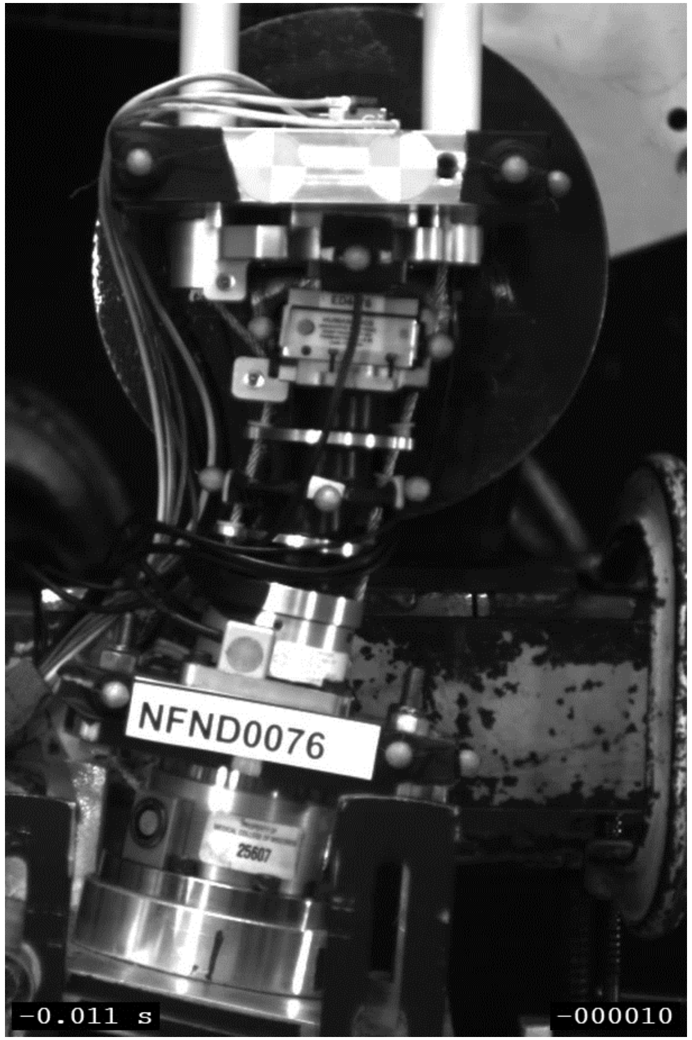
- For each body region
  - Field and Historical Fleet Data
  - Literature Review
  - Design & Instrumentation
  - Biofidelity
  - Review of Available Data
    - Collection of Female-Specific Data
  - Injury Risk Function Formulation
  - Application of Risk Function to THOR-05F
  - Fleet Test Data
  - Limitations

- To be published when complete



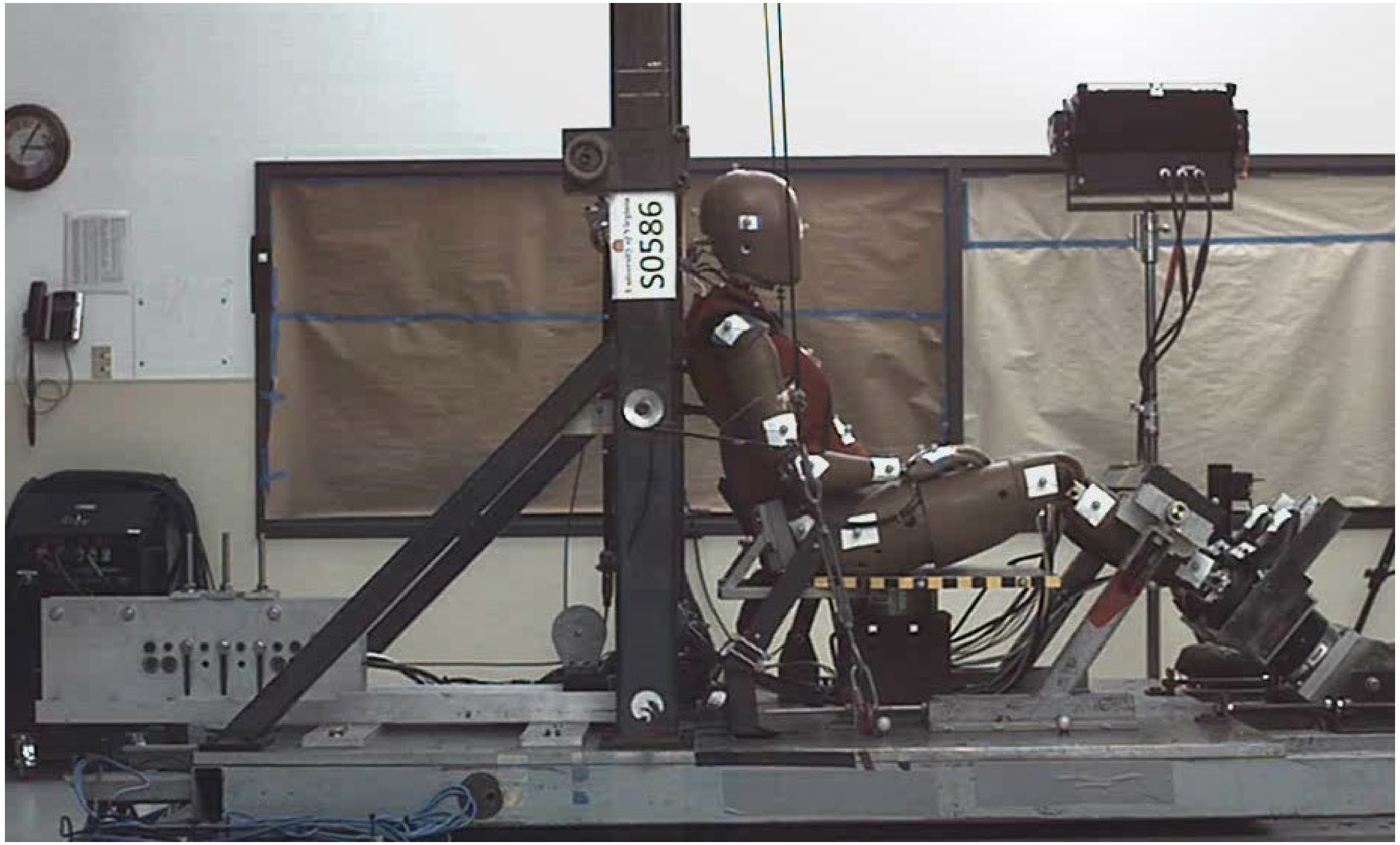
Experimental Data: Neck

- NHTSA recently conducted a series of tests on THOR 5th ATD to evaluate the performance of the neck in primary loading modes
  - PMHS/ATD transfer functions for injury criteria
- NHTSA just kicked off a new task order to study the cervical kinematics of females in front and side crashes
  - This task will modernize an older study that was conducted on male volunteers
  - Naval Biodynamics Laboratory “NBDL” conditions: 15g frontal; 7g lateral
  - Enhanced biofidelity assessment



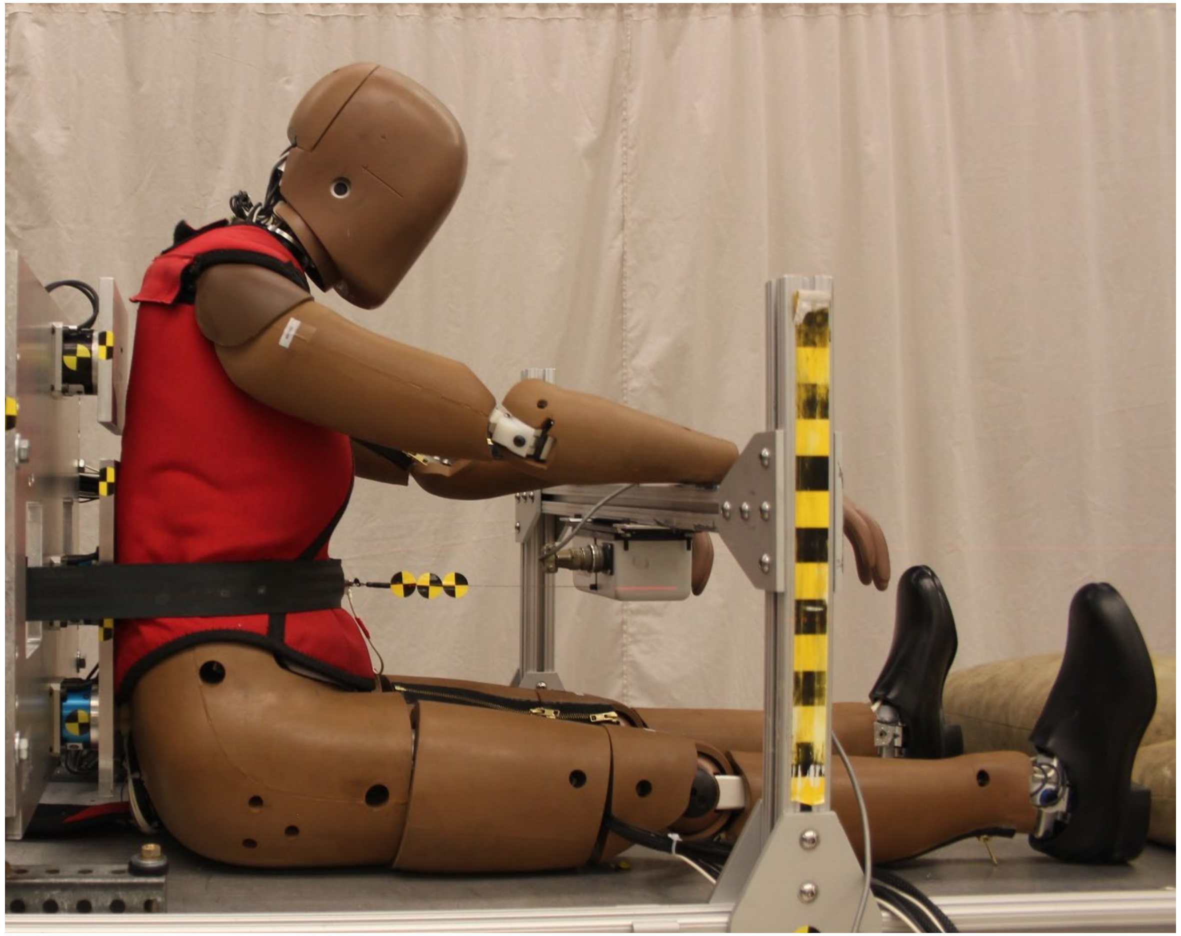
Experimental Data: Thorax

- NHTSA recently completed a series of 37 sled tests using female subjects to study thoracic response
  - Majority of tests in simplified seat/restraint conditions
- New task order just kicked off to continue this work
  - Biofidelity assessment in varied restraint conditions
  - Improve injury criteria robustness
- New biofidelity targets from female PMHS in frontal hub impacts



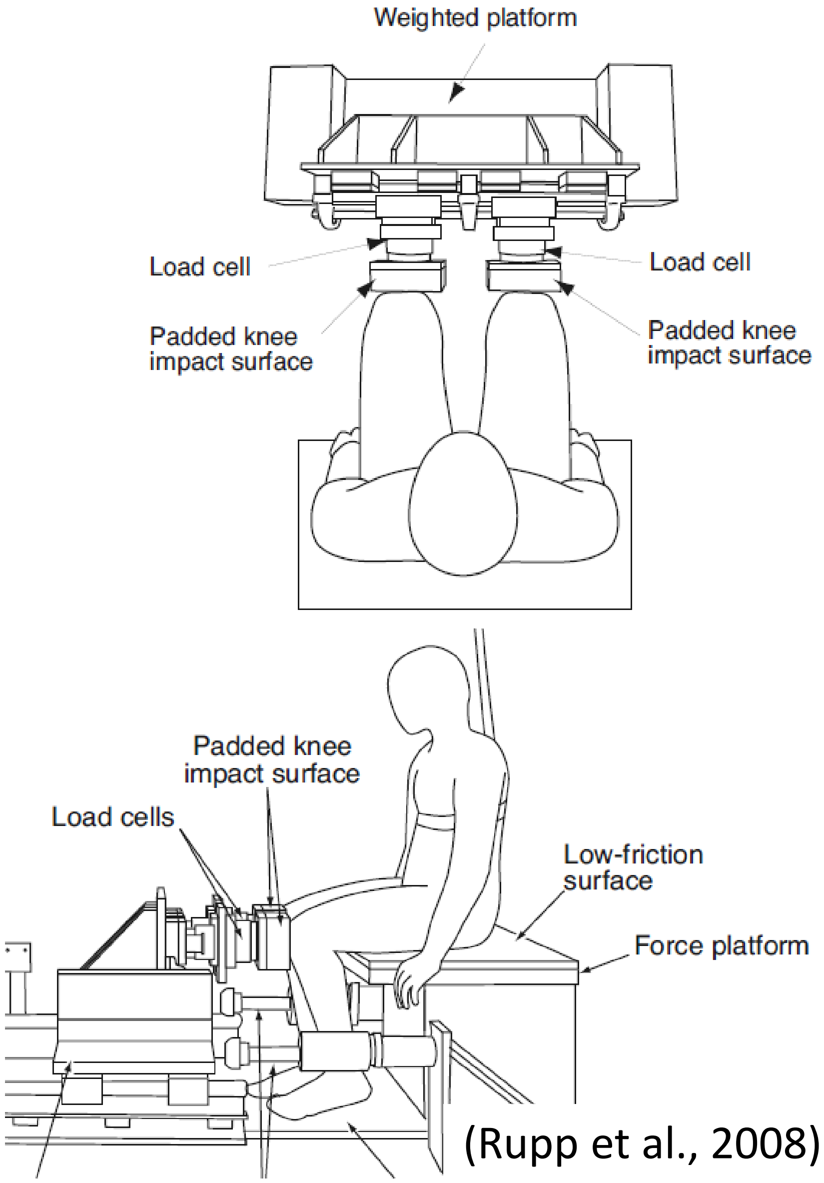
Experimental Data: Abdomen

- NHTSA recently completed a series of 8 tests using female subjects to study abdominal response
  - Belt loading at 4 m/s
  - Rigid bar impact loading at 6 m/s
- Additional tests planned this year
  - Finalization of biofidelity assessment and injury criteria
- Determine whether female biofidelity targets and injury risk are different from males



Experimental Data: Knee-Thigh-Hip

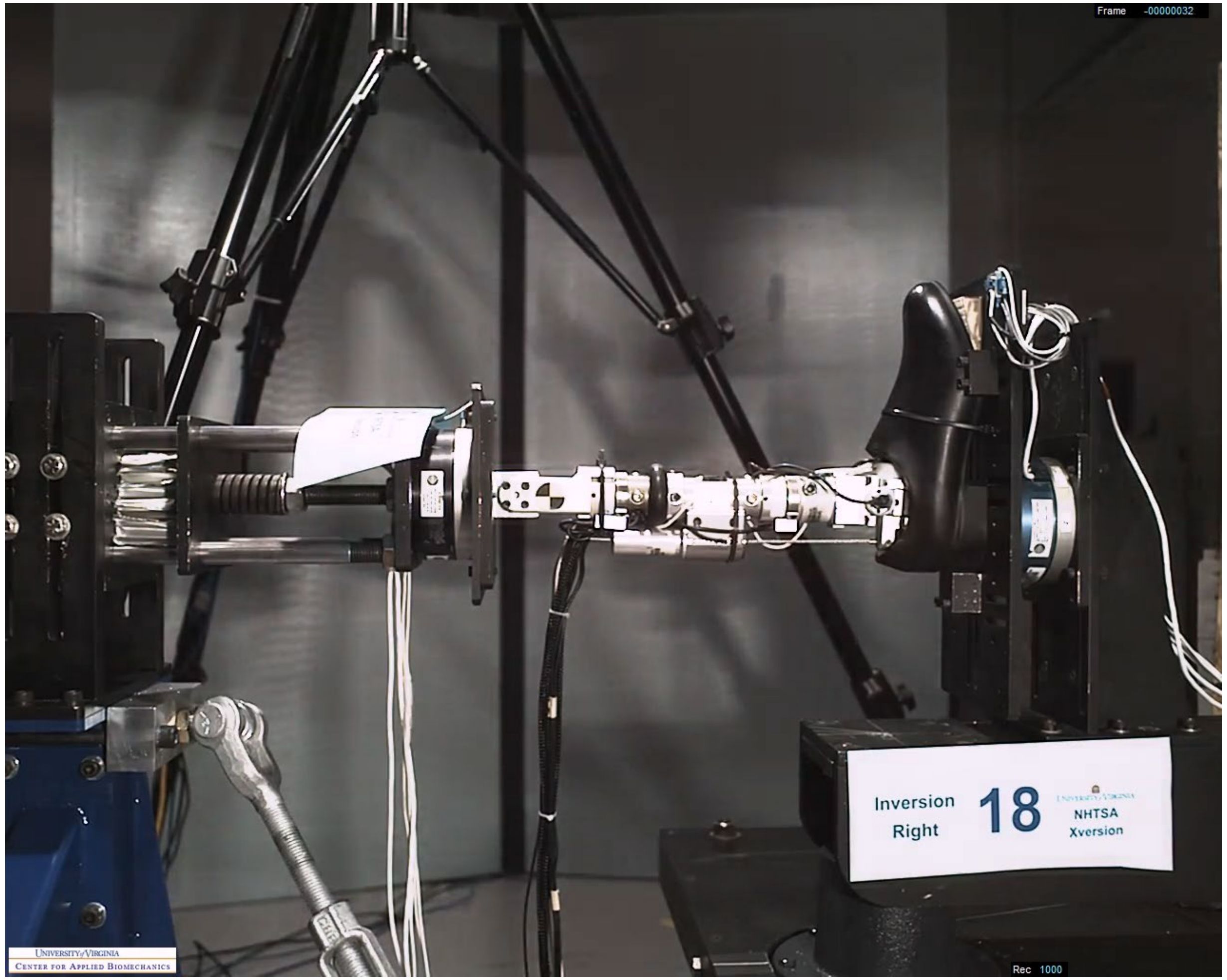
- Contract with University of Virginia kicked off September 2020
- Currently collecting data on female subjects in a knee-impact condition previously tested on male subjects
  - 4 subjects
  - Symmetric impact to both knees
  - 4 test speeds: 2.5 m/s, 3.5 m/s, 4.9 m/s, 7.2 m/s
- Modeling planned to study other factors such as effect of hip/torso angle and impact asymmetry
- Female-specific injury criteria



(Rupp et al., 2008)

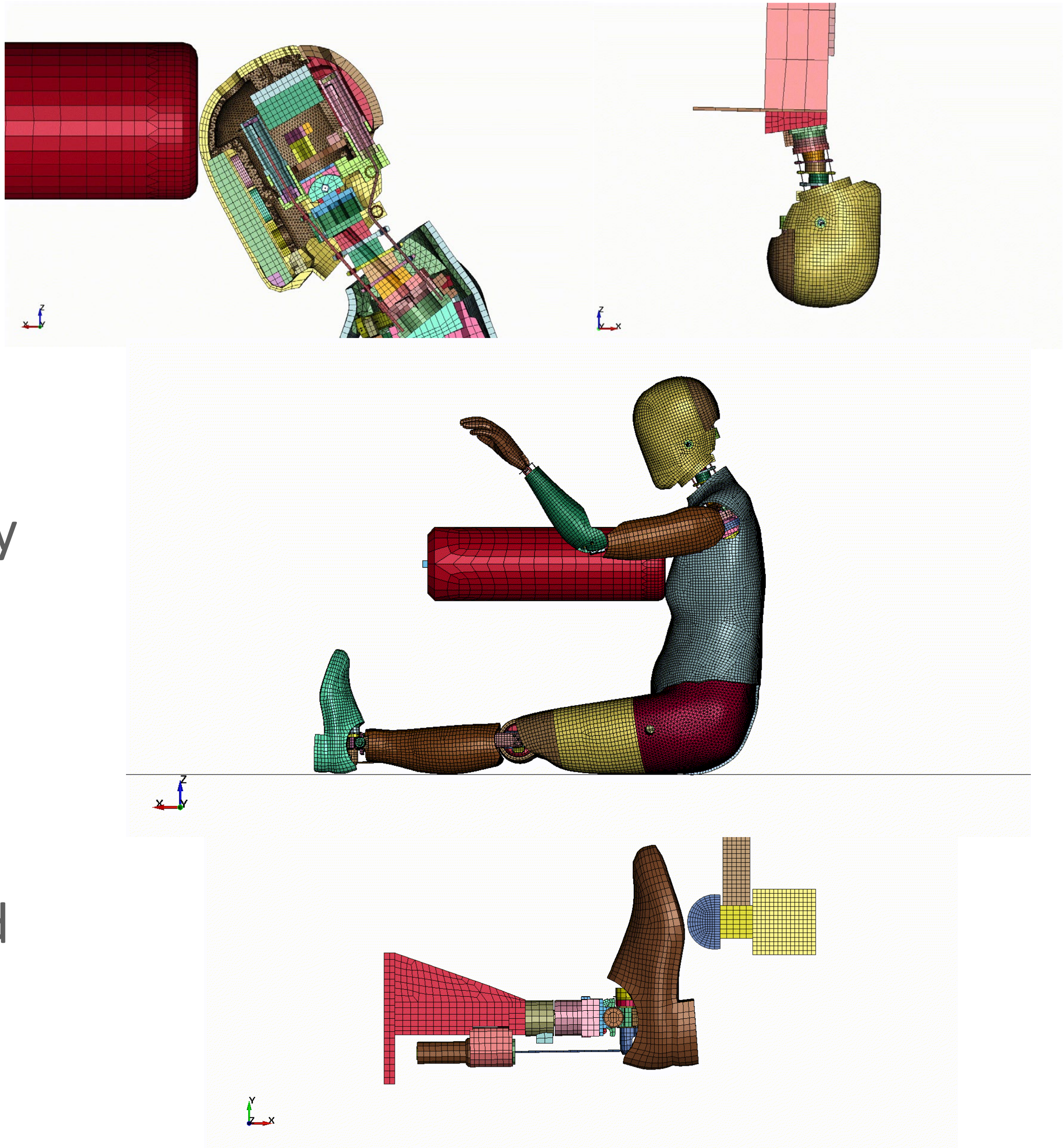
Experimental Data: Foot/Ankle

- NHTSA recently completed a series of tests using female subjects to study response
  - Heel impact
  - Dorsiflexion
  - Inversion/eversion
- Matched pair tests using THOR 5th ATD currently being completed
  - Biofidelity update
  - Female-specific injury criteria



THOR-05F Finite Element Model

- Goal: Develop and validate a finite element model of the THOR 5th ATD
- Contract with George Mason Univ. initiated in September 2020
- Current status:
  - Model developed based on drawing package and 3D scans of physical dummy
  - Qualification test suite setup complete
- Next steps:
  - Validate model against ATD data (qualification tests)
  - Verify computational stability in sled and full-scale test simulations



Thank you for your time and attention

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