NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

# Injury comparison between 5th percentile female and 50th percentile male simplified GHBMC models in various frontal impact scenarios


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# NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

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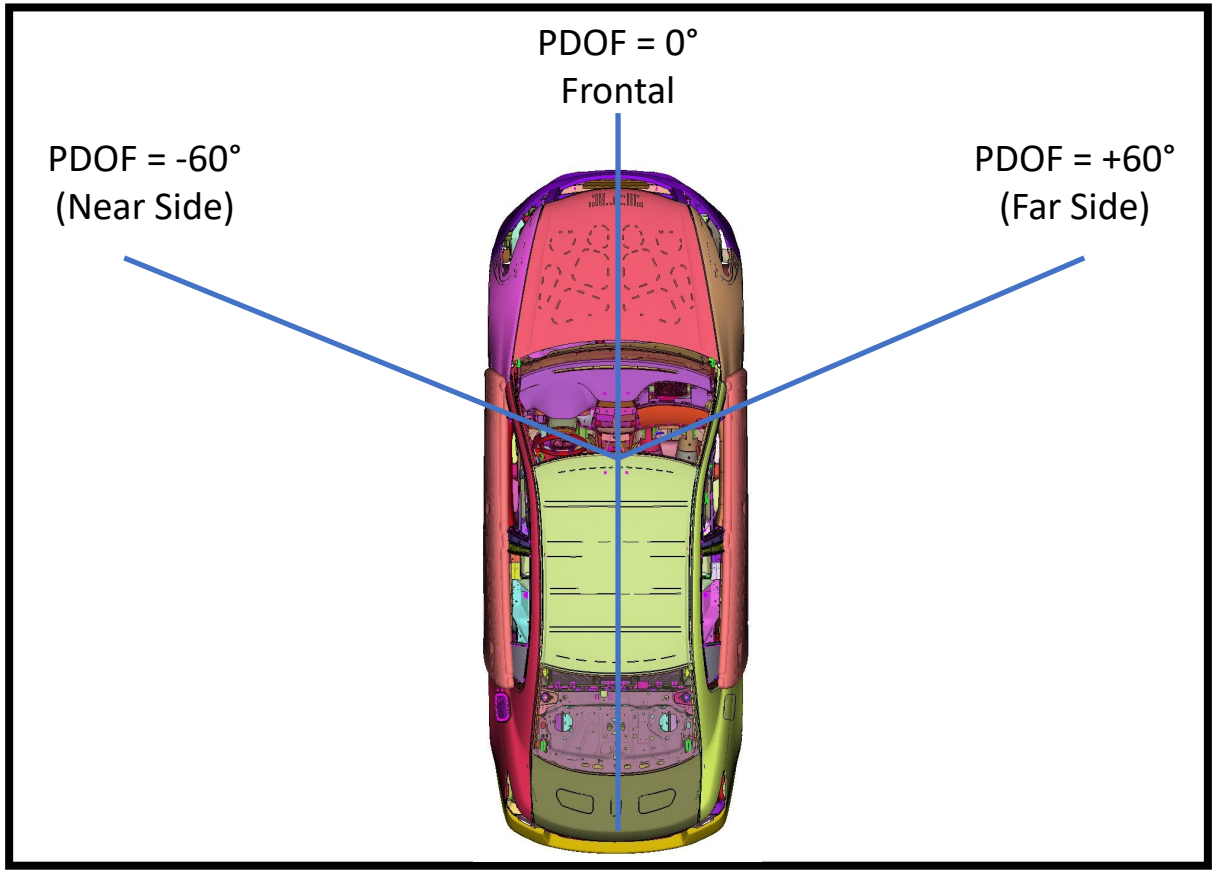
# Motivation



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.

# Objective and FE models



- To analyze 5th female and 50th male Global Human Body Models Consortium (GHBMC) finite element (FE) models in various frontal impact scenarios and compare their injury metrics

## Human FE models

*5th female Simplified GHBMC FE model*

- Weight = 54 kg
- Sitting height = 776 mm

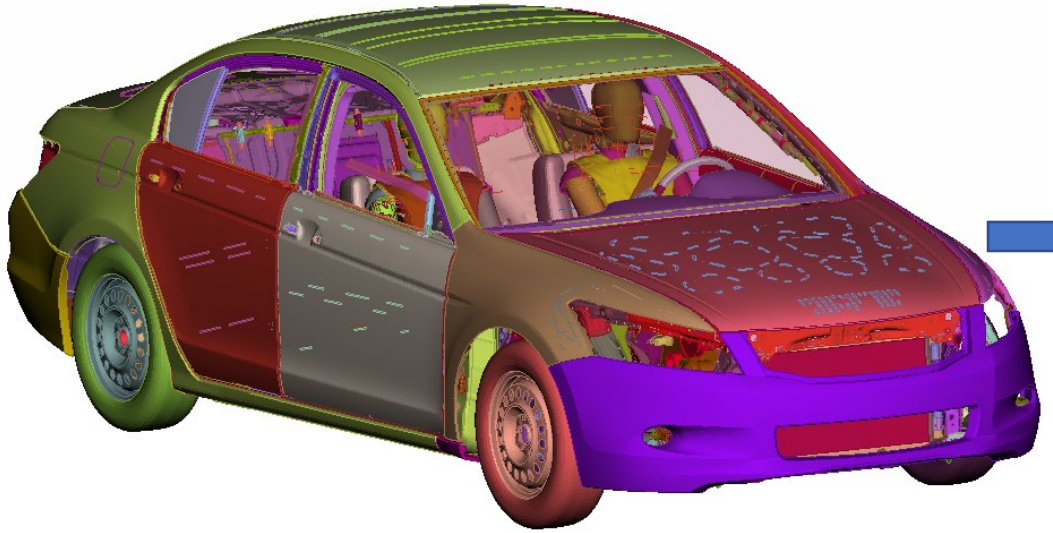
50th male Simplified GHBMC FE model

- Weight = 78 kg
- Sitting height = 912 mm

# FE Model: Simplified Occupant Compartment

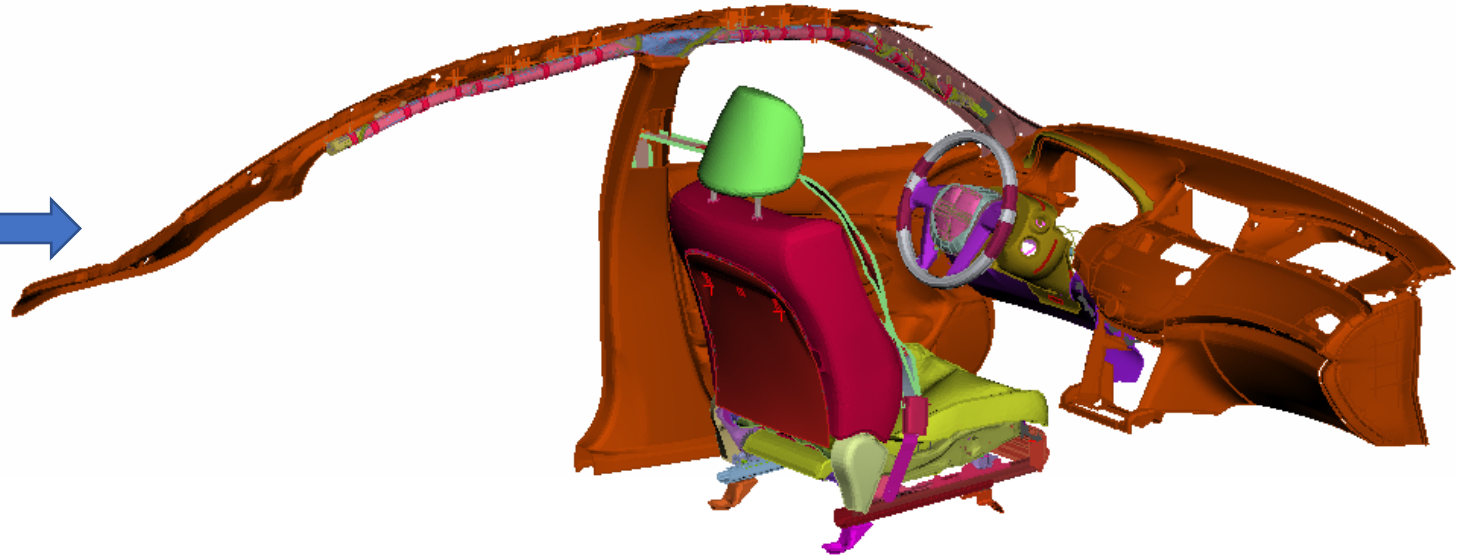


*Full vehicle model (2014 Honda Accord)*



Number of elements: 3.1 million

*Vehicle structure extracted for frontal impact analysis*



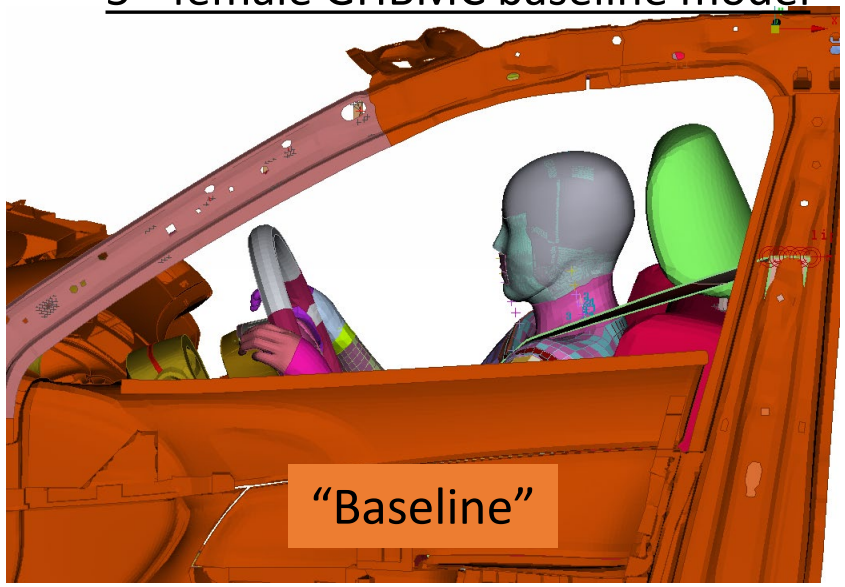
Number of elements: 485,000

- Front impact validated, 2014 Honda Accord FE model was available for performing the analysis
- To run multiple simulations (Design of Experiments) in feasible timeframe, we extracted important components from Honda Accord model for our analysis

# Baseline FE Model Setup



5th female GHBMC baseline model




5th female H-III physical test

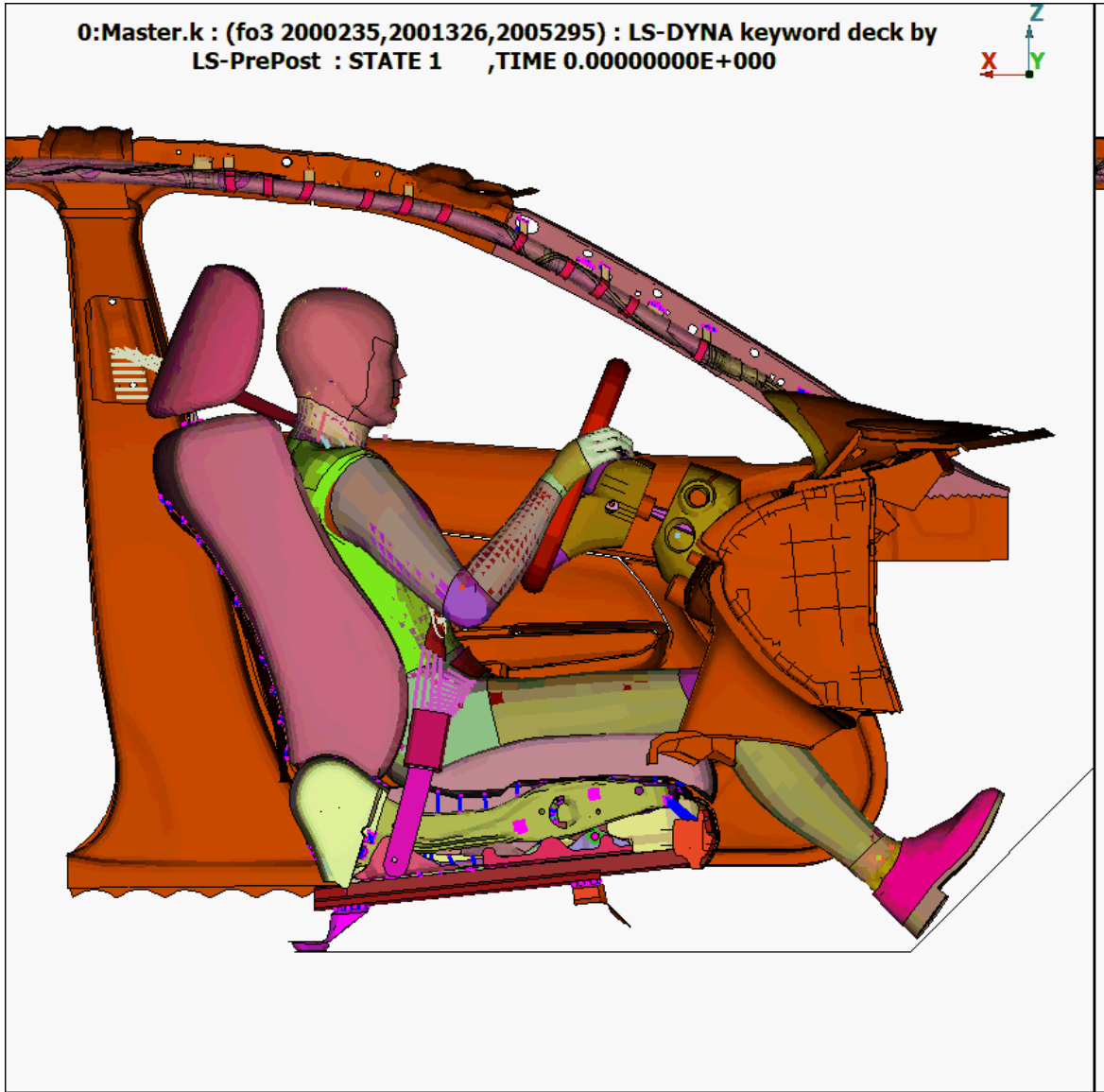

50th male GHBMC baseline model


50th male H-III physical test

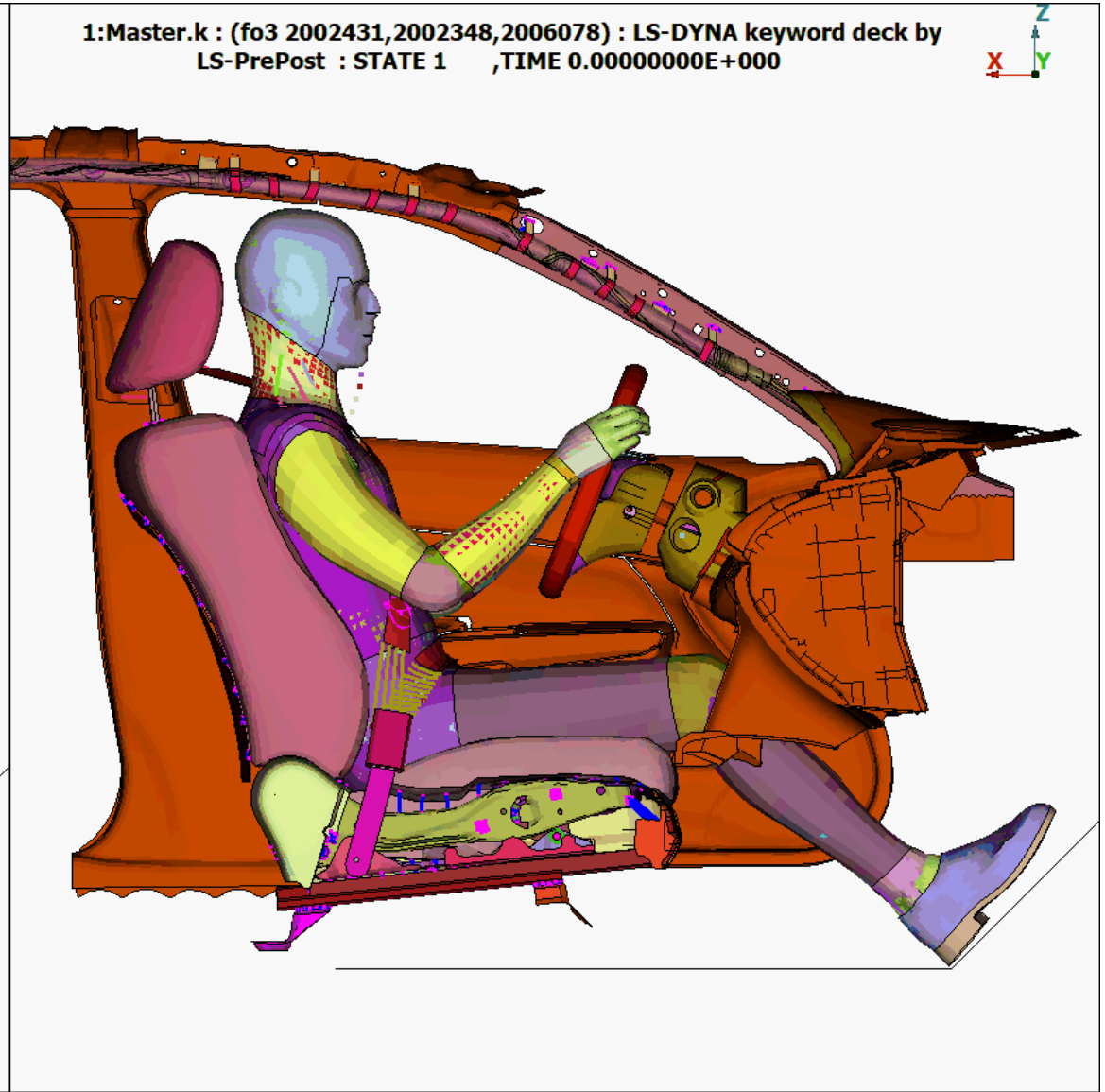
# Videos: Baseline Models



5th female




50th male



# Design of Experiment (DOE) Study



***PURPOSE:***

To generate multiple frontal impact scenarios (*115 simulations-paired tests*) by varying the *crash and restraint parameters*

***QUESTION:***

What are crash and restraint parameters?

# Design of Experiments Study (DOE) - Parameters



| | Parameter | Baseline | Minimum value | Maximum value |
|---|---|---|---|---|
| Crash | 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 |
| Restraint | 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 |

# Results

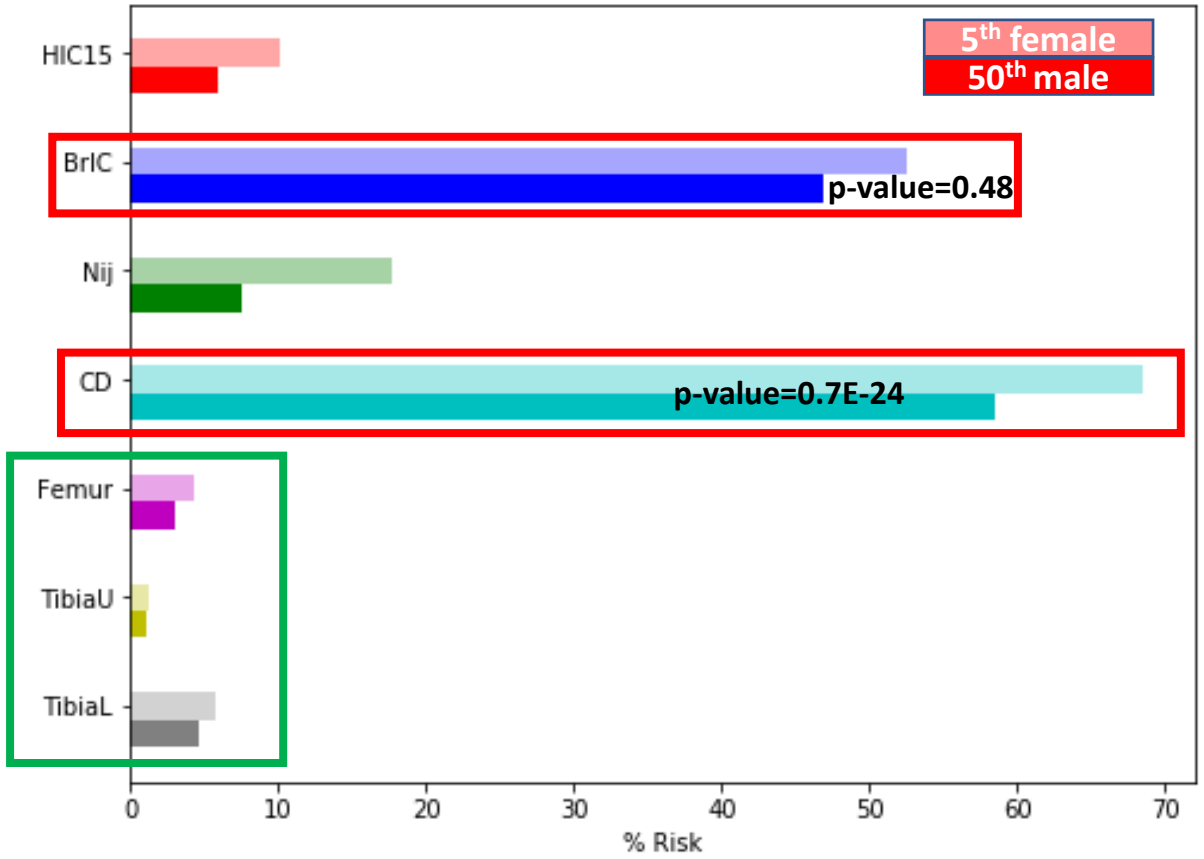
# Injury Risks: 5th female and 50th male



## 5th female and 50th male

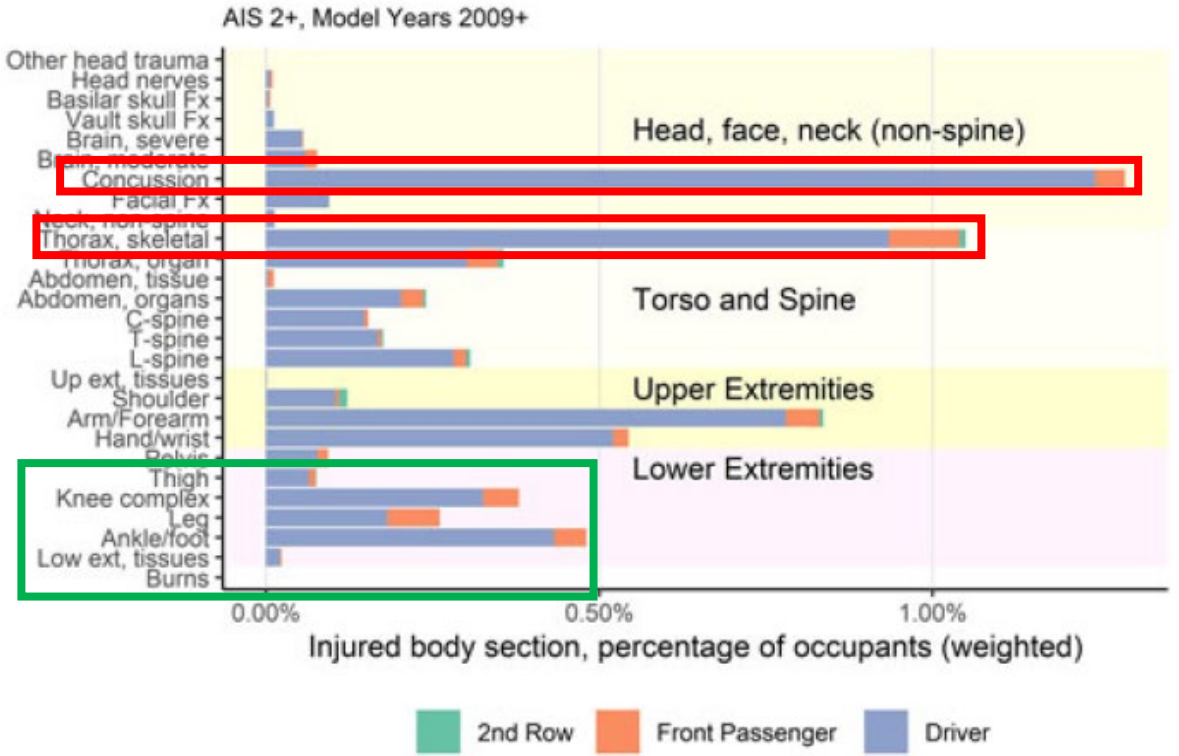
**Risk of AIS 2+ injuries by body region (based on average values)**

AIS2+ risk for 5th female and 50th male




## Forman et al. 2019:

**Risk of AIS 2+ injuries by body region**

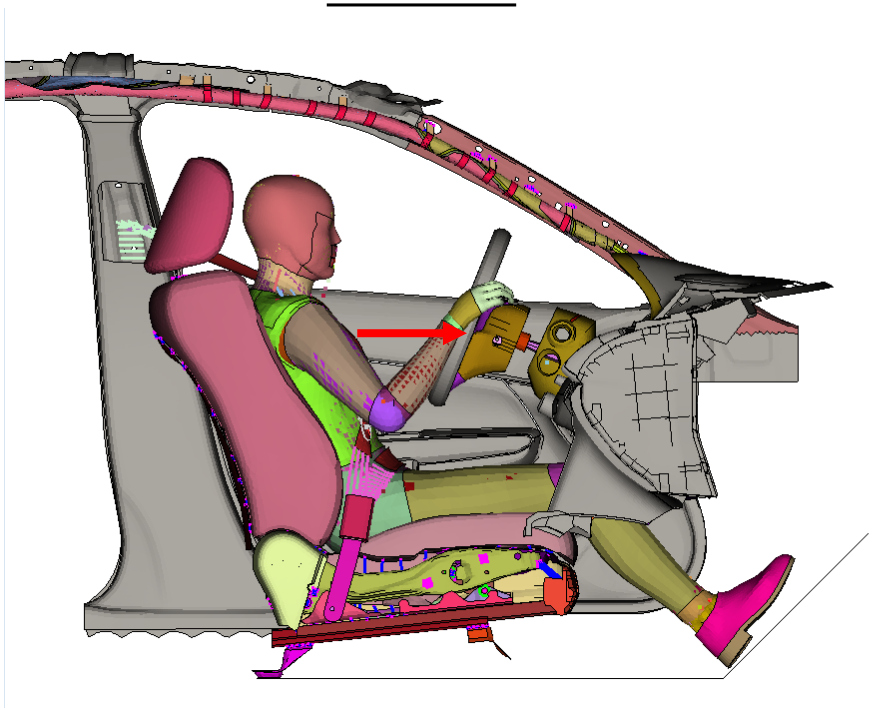


# Possible reason for the injury risk differences



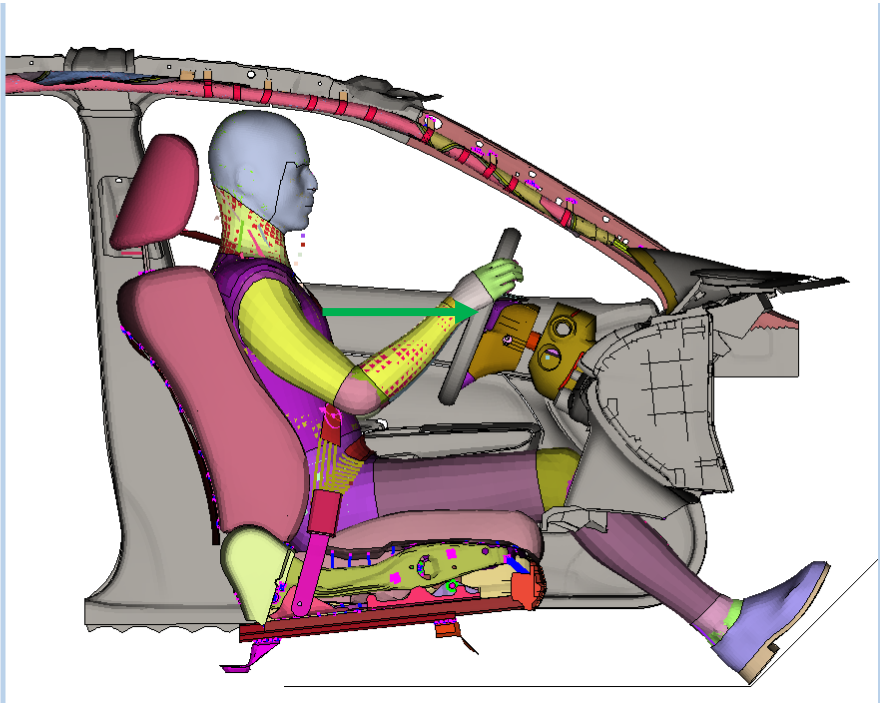
*Seating position and human model size difference*

**5th female**



Chest to steering hub distance = 226 mm

**50th male**



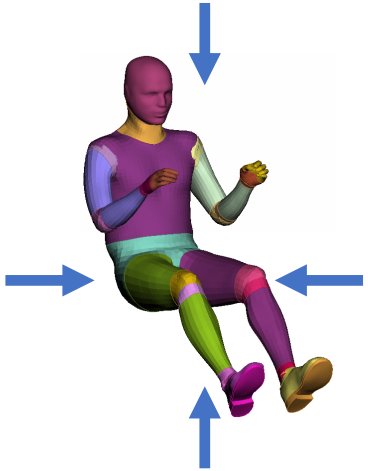
Chest to steering hub distance = 301 mm

*5th female sits closer to the steering wheel as compared to the 50th male*

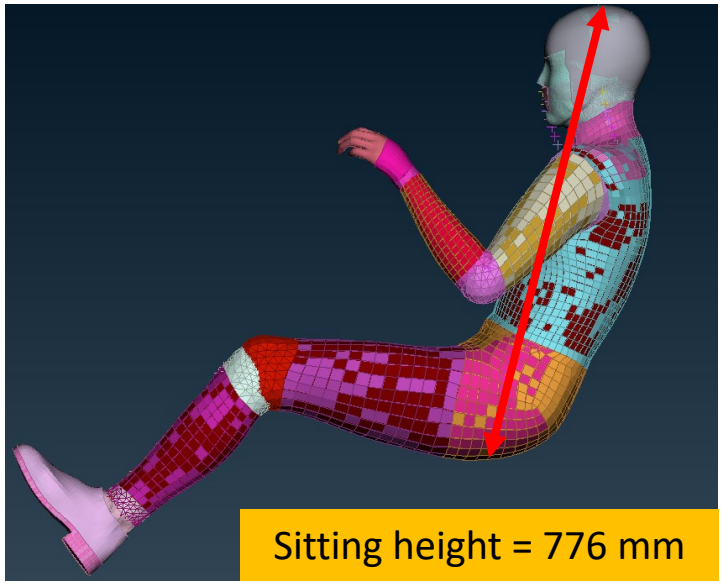
# 5th scaled GHBMC model



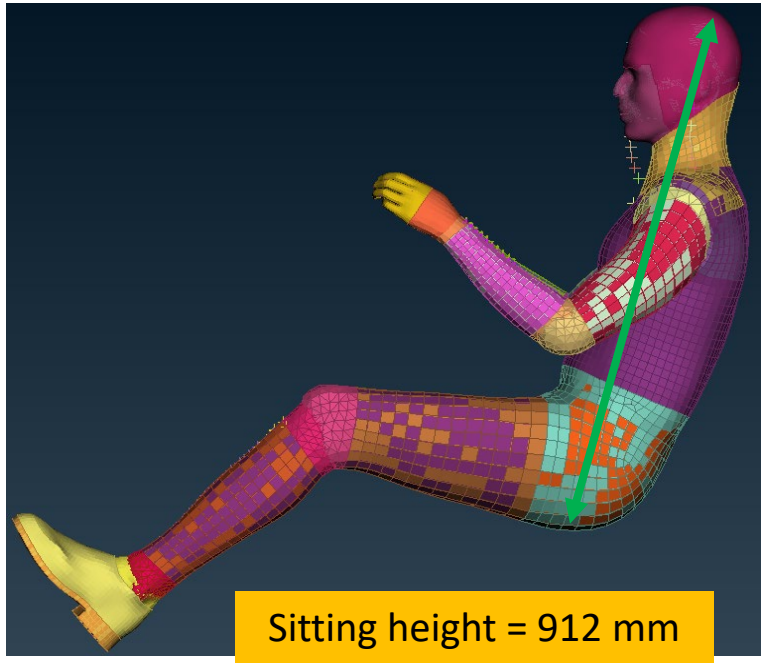
We scaled the 50th male model to 5th female sitting height.



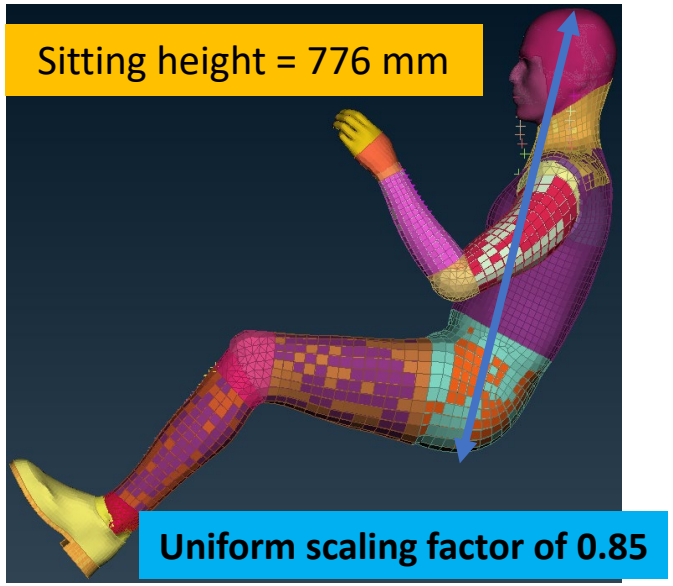
5th female (5th original)




50th male




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

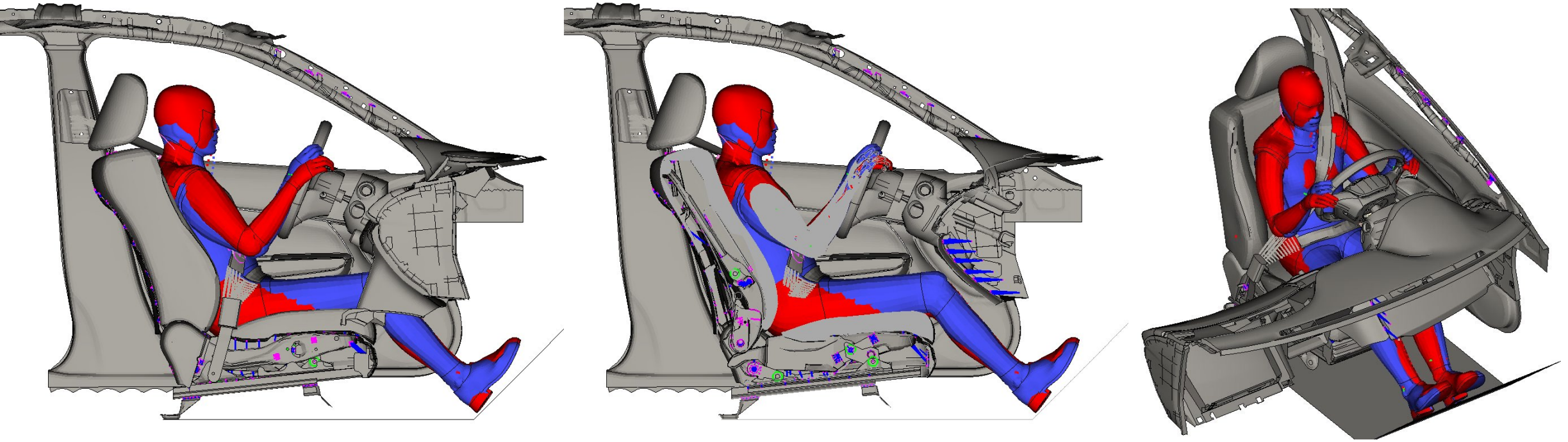


# Seating Position comparison: 5th female & 5th scaled



Overlay: 5th female & 5th scaled models (Seating Positions)

***DOE study: (paired tests) for 5th scaled model***



5th female

5th scaled

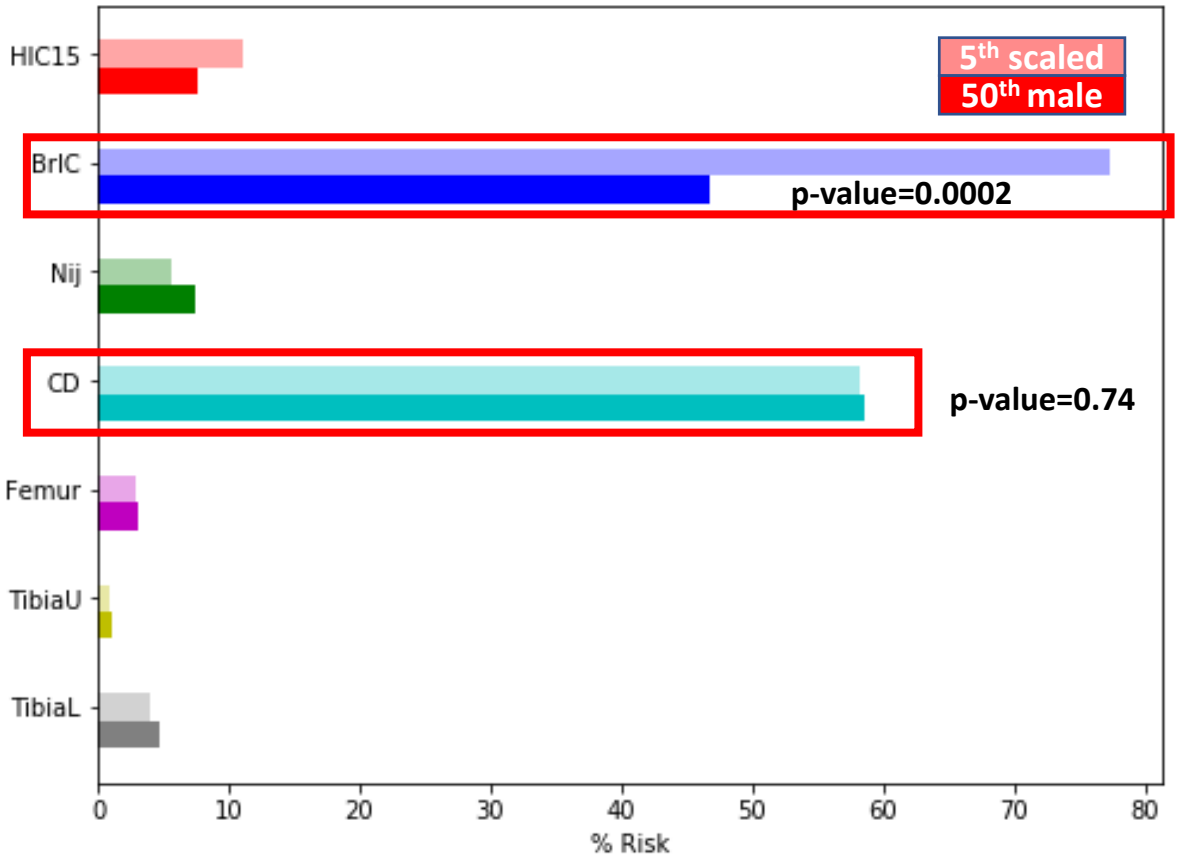
# Injury Risks: 5th scaled and 50th male



## 5th scaled and 50th male

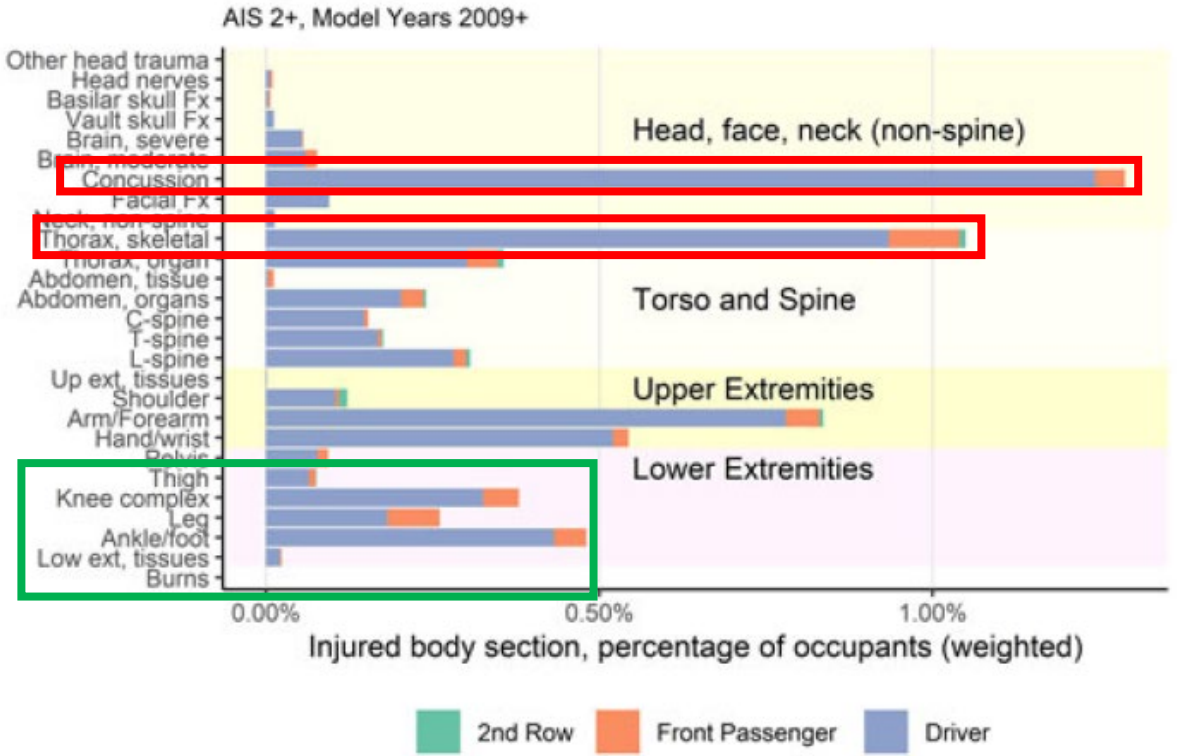
**Risk of AIS 2+ injuries by body region (based on average values)**

AIS2+ risk for 5th scaled and 50th male




## Forman et al. 2019:

**Risk of AIS 2+ injuries by body region**



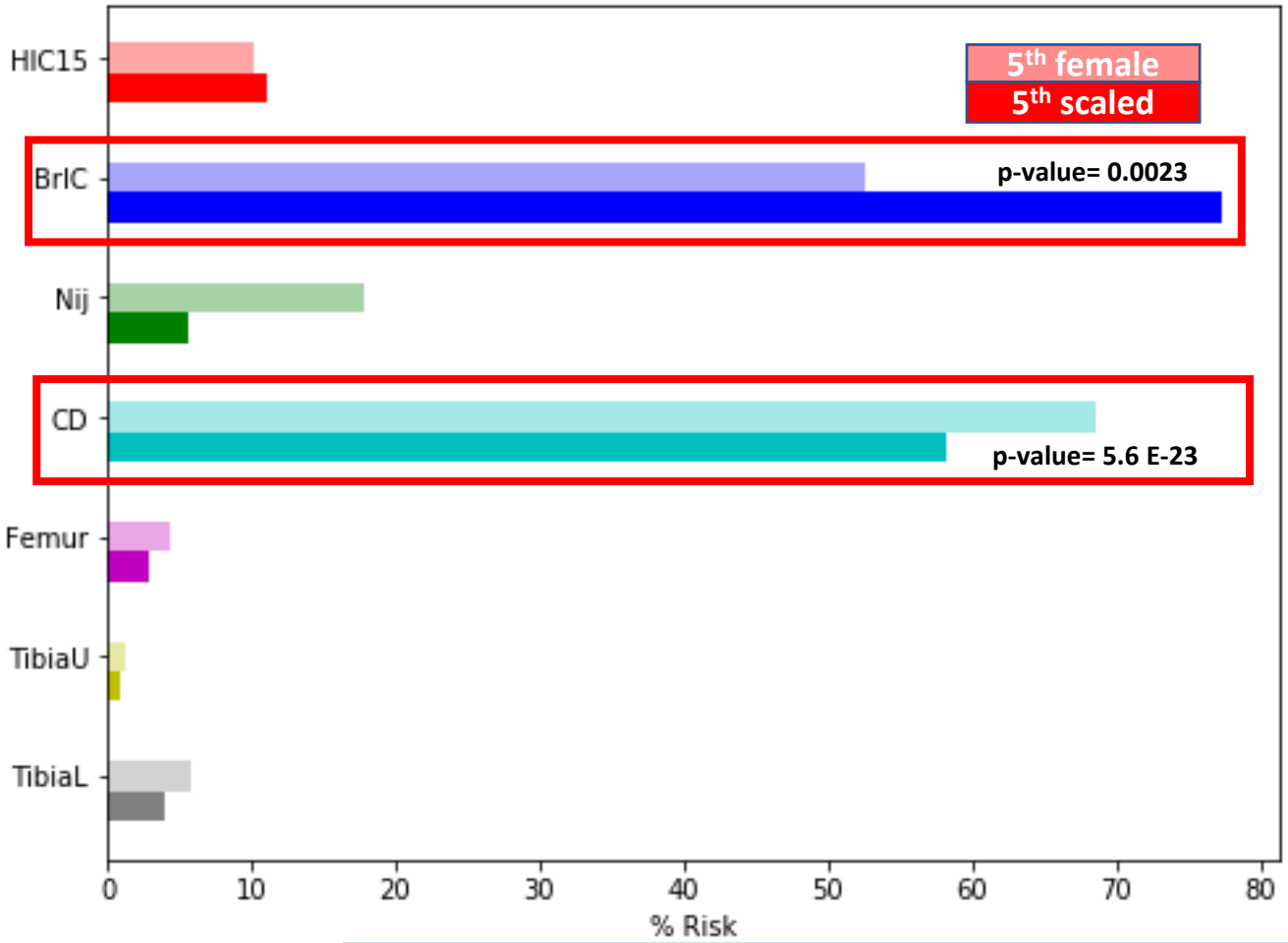
# Injury Risks: 5th female and 5th scaled



## 5th female and 5th scaled

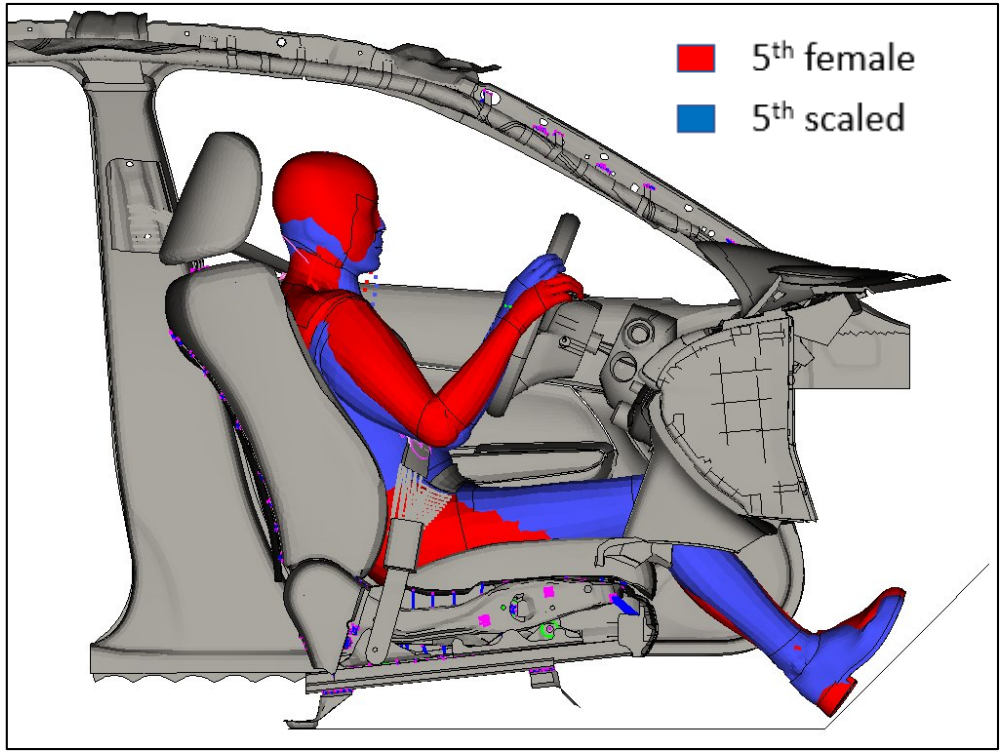
**Risk of AIS 2+ injuries by body region (based on average values)**

*AIS2+ risk for 5th female and 5th scaled*




Seating position and model size

***Seating positions of 5th female and 5th scaled***



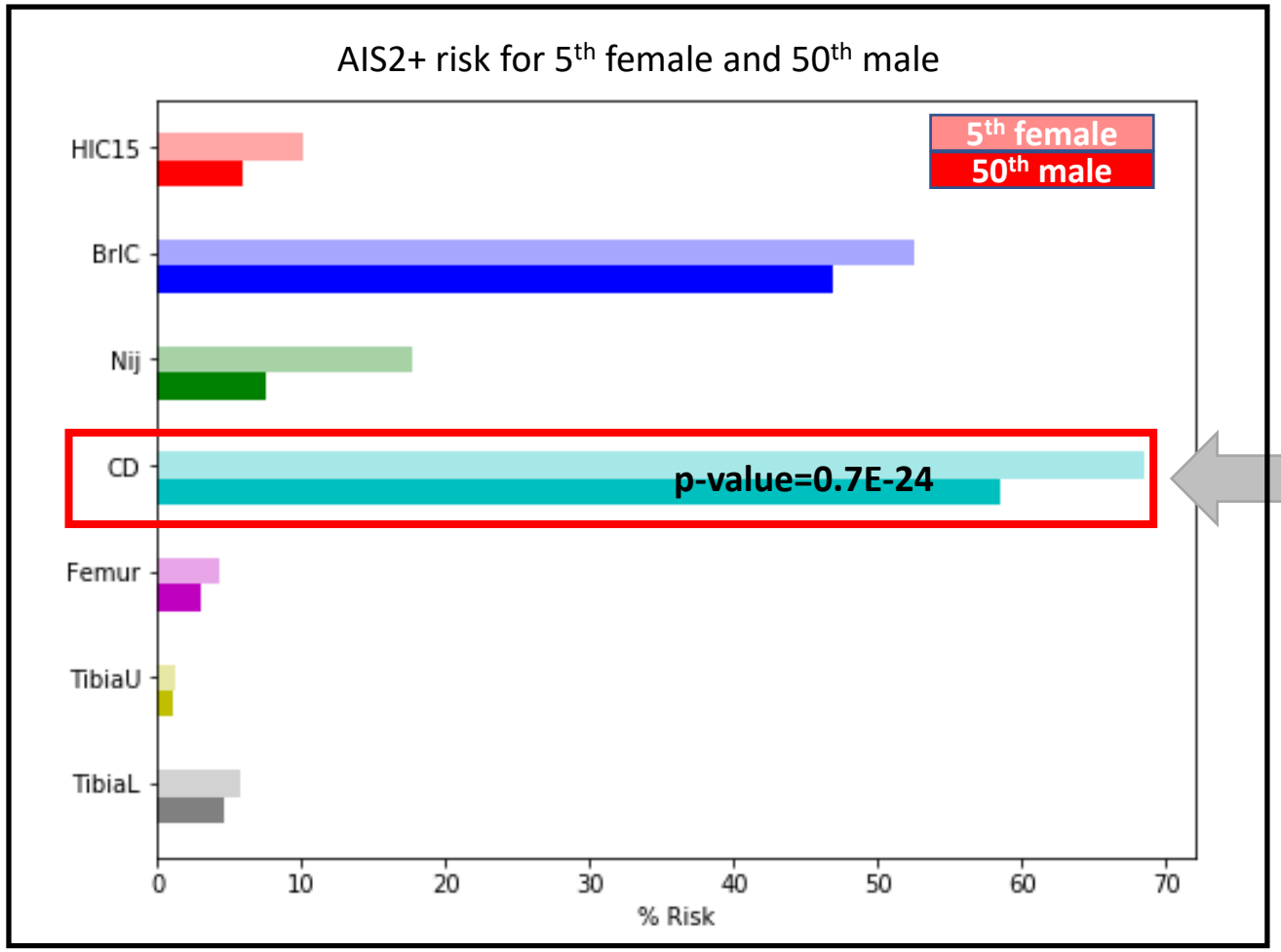

Different injury risks between 5th female and 5th scaled model

# Injury Risks: 5th female and 50th male



## 5th female and 50th male

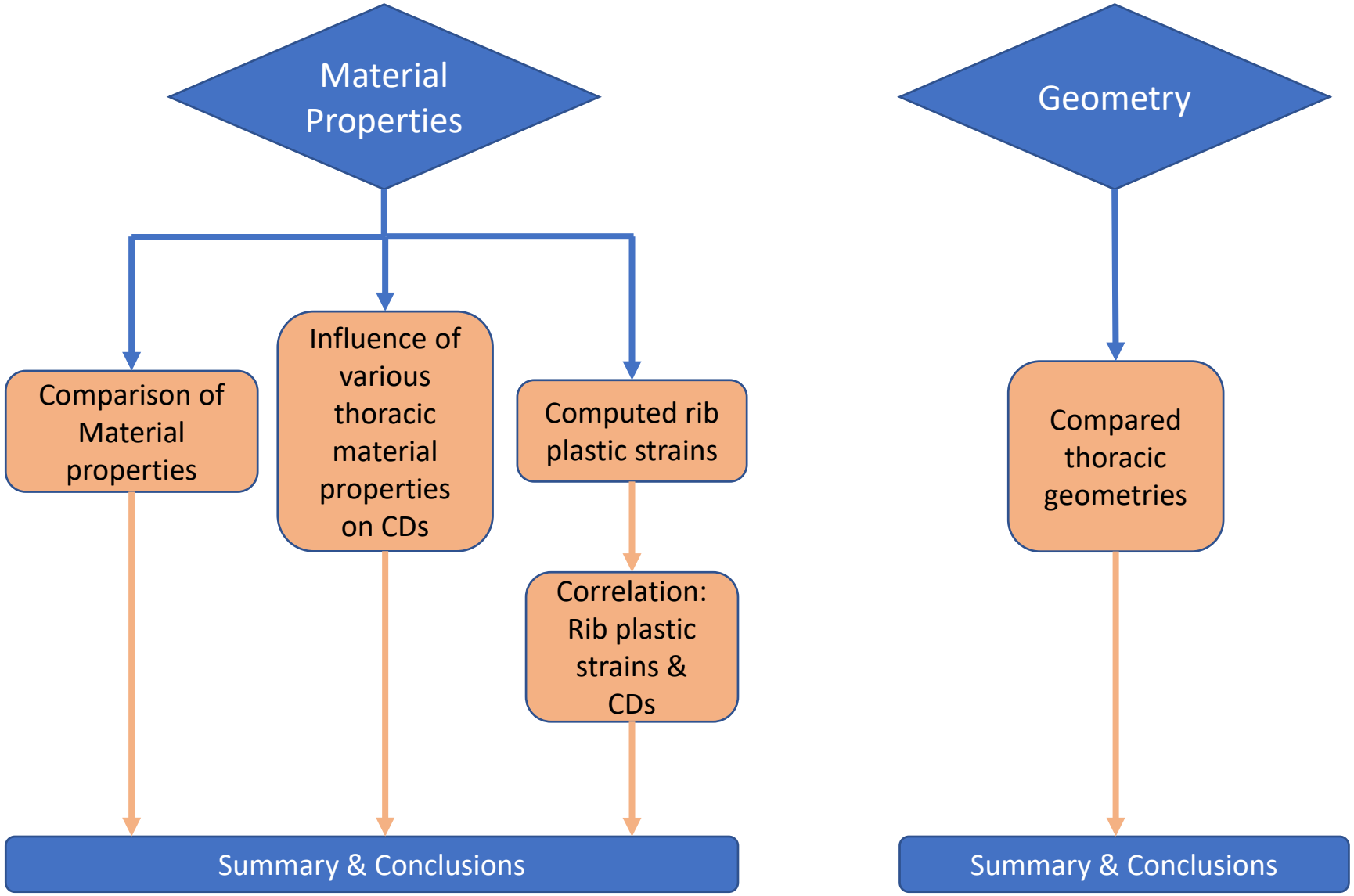
**Risk of AIS 2+ injuries by body region (based on average values)**




Significant difference

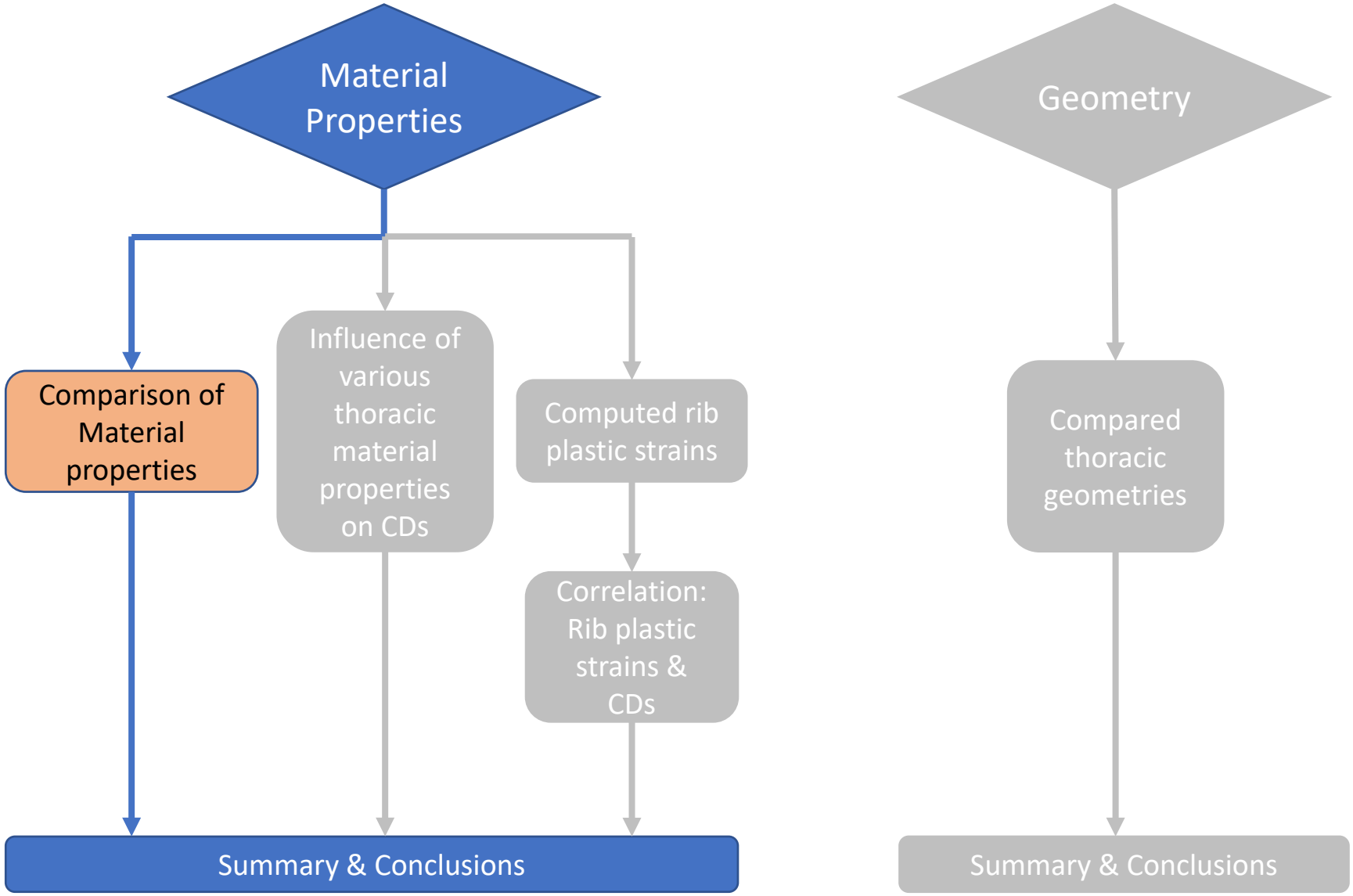
# Study for evaluating differences in chest deflections





# Study for evaluating differences in chest deflections



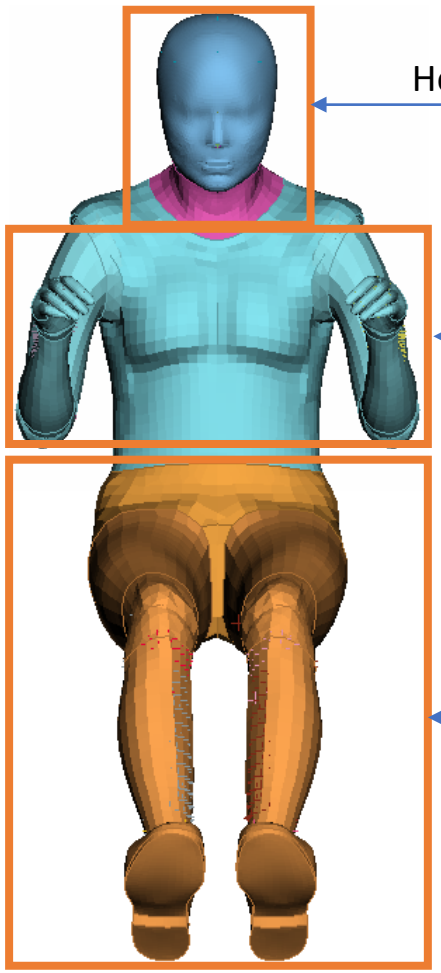


# Comparison of materials : 5th female and 50th male FE models



**5th female**

**50th male (or 5th scaled)**



Head and Neck

Same materials

Head and Neck

Thorax and arms

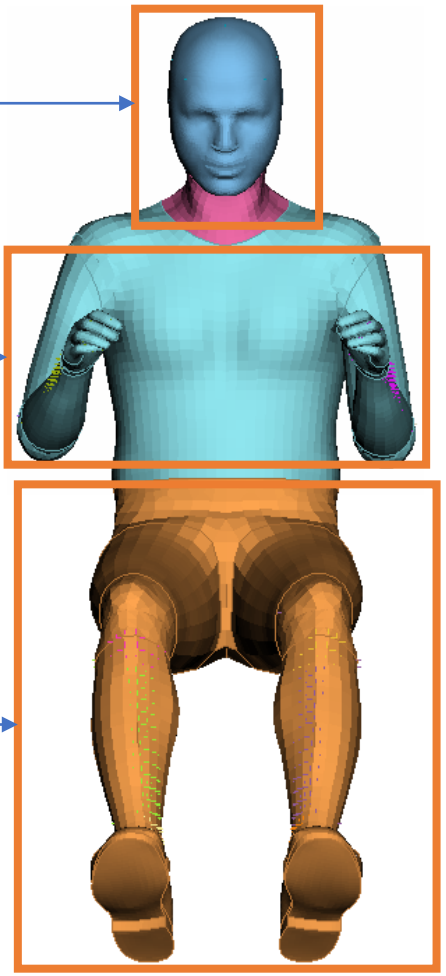
Same materials

Thorax and arms

Pelvis and lower extremities

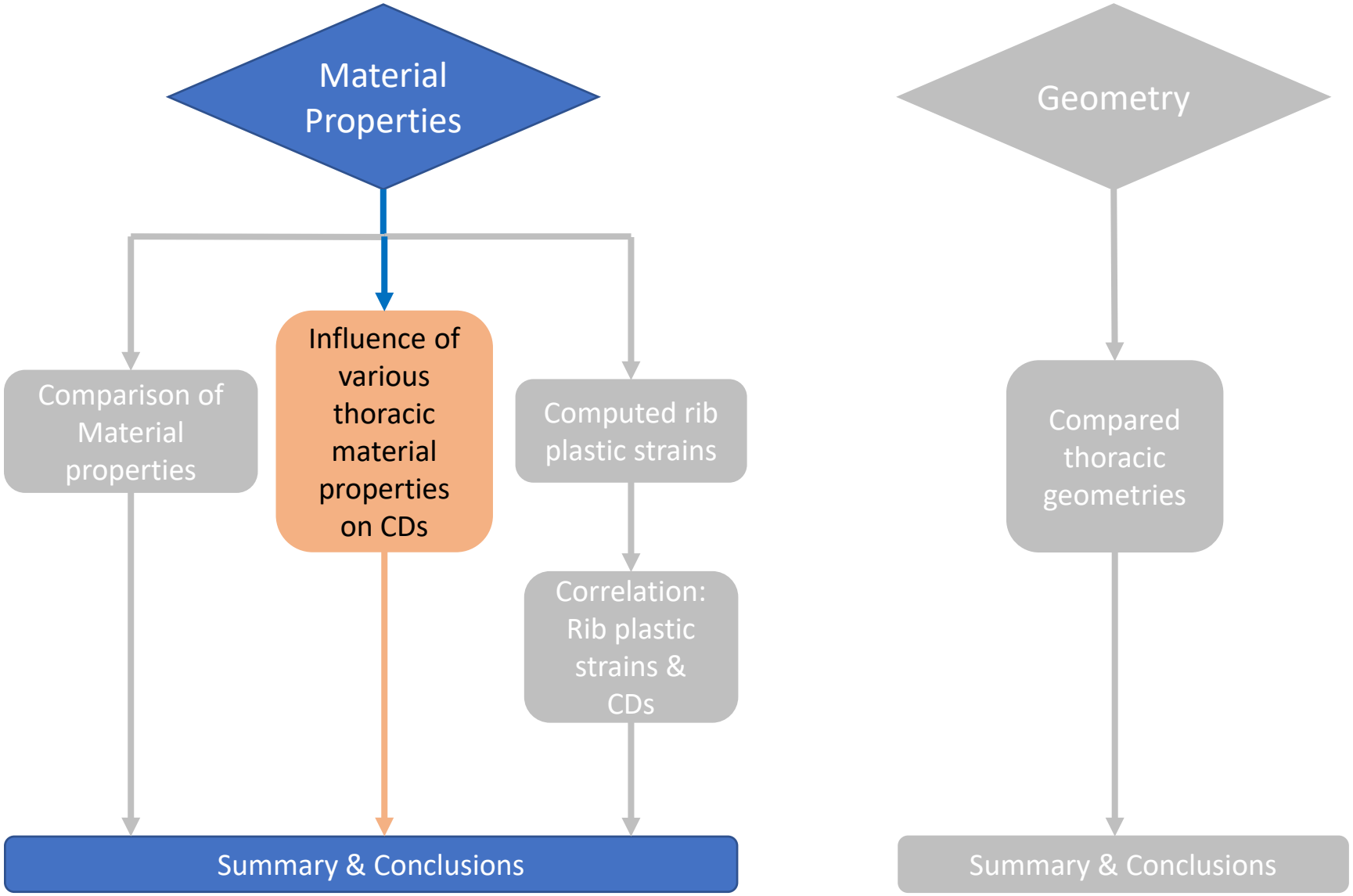
Same materials

Pelvis and lower extremities



# Study for evaluating differences in chest deflections

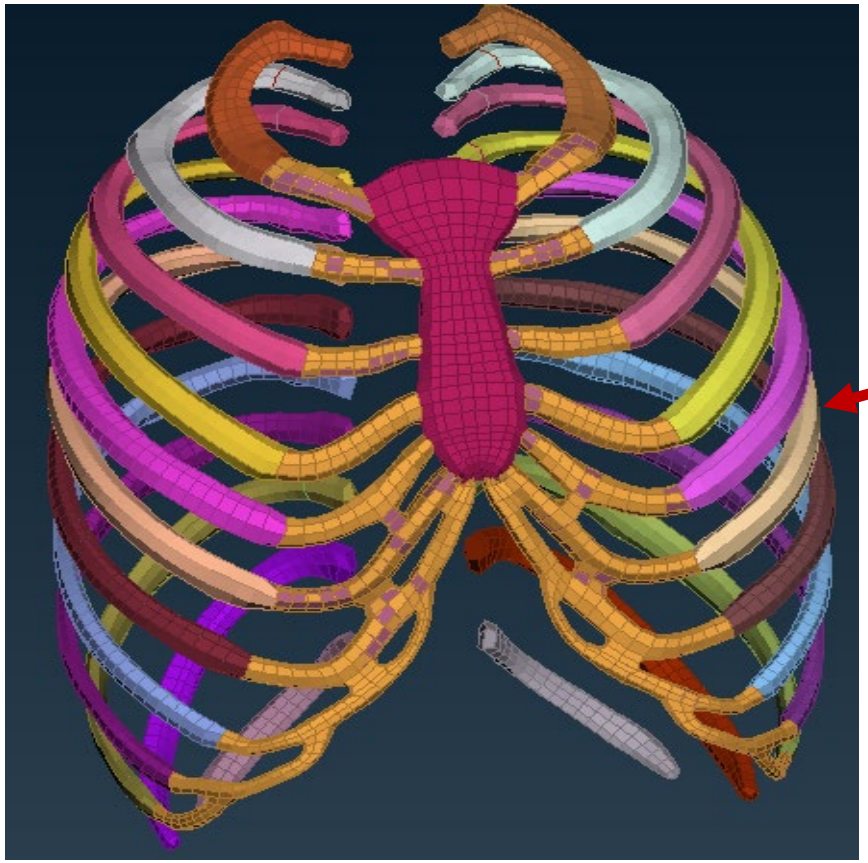




# Material properties study



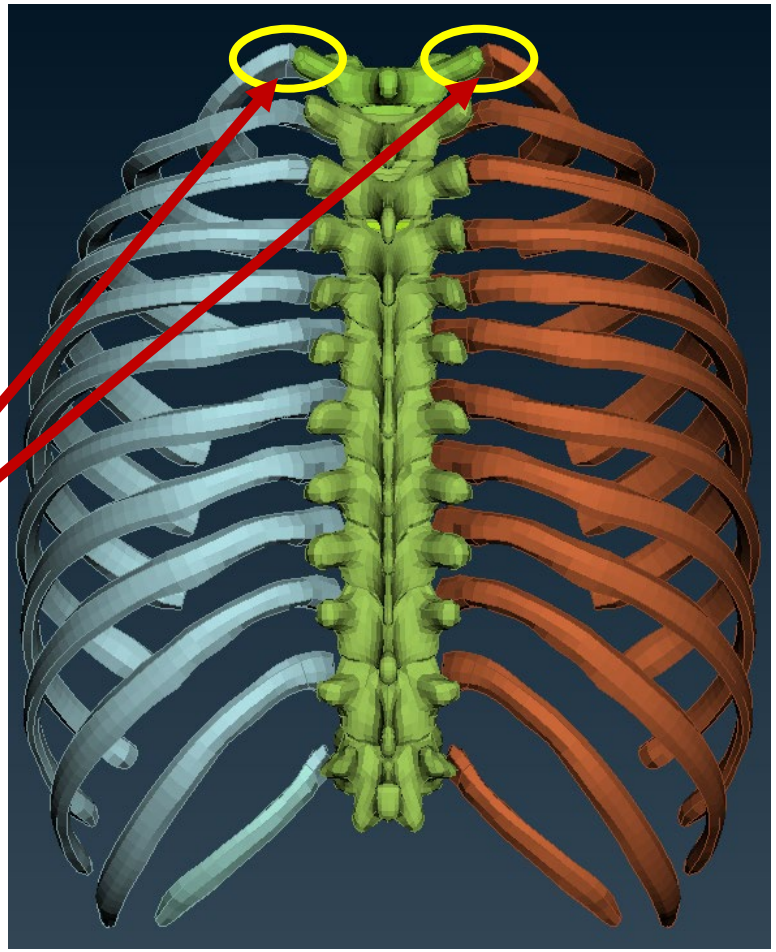
Thoracic material property modifications: 5th female, 50th male, and 5th scaled models



Thorax (skeletal) components

Material properties modified by +-25%

Costovertebral joint properties modified by +-25%



Costovertebral joints

# Material properties study



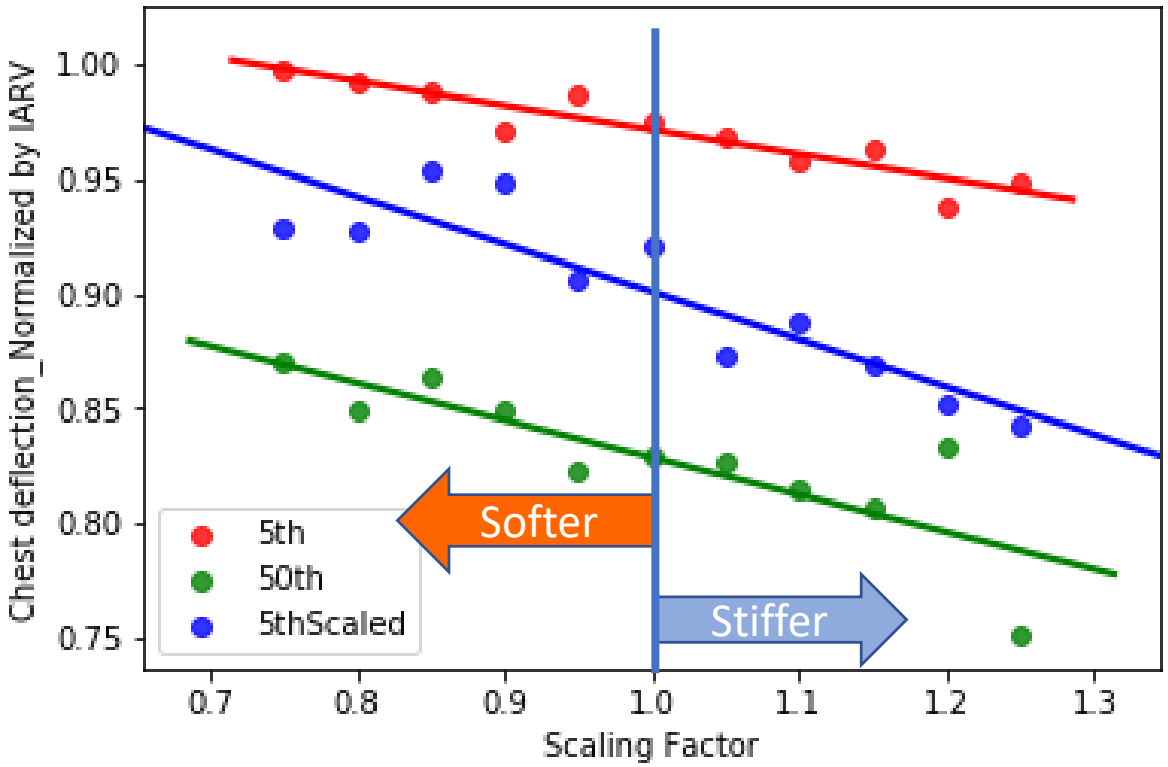
**Mini DOE study: parameters**

| Parameters | Range |
|---|---|
| Thorax material and joints properties | 0.75 to 1.25 |
| PDOF | -20, 0, +20 |
| Other parameters | Fixed to baseline values |

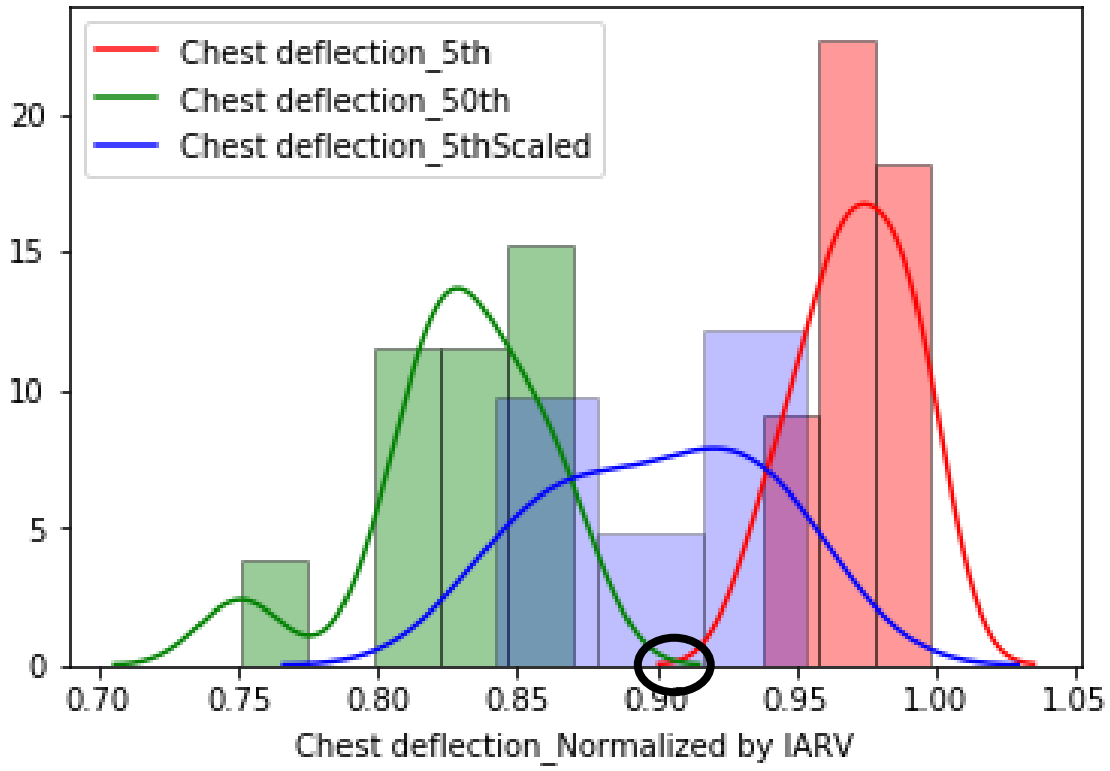
# Material properties study

## CD comparison: 5th female, 50th male, and 5th scaled models

*CD normalized by IARVs vs scaling factor*



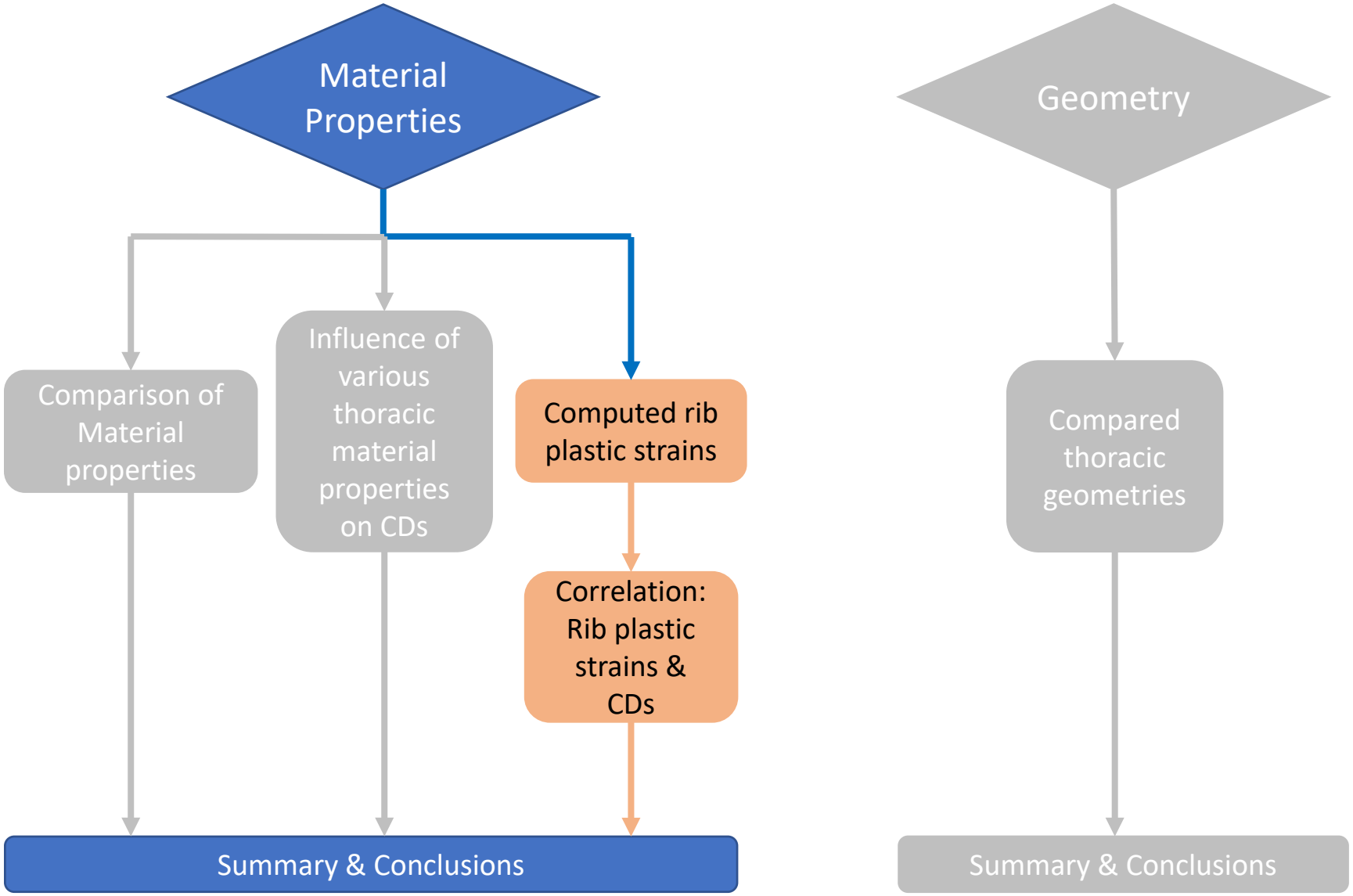

*Distribution: CD normalized by IARVs*




- 5th scaled chest deflections overlap with 50th male and 5th female model chest deflections
- No significant overlap between 5th female and 50th male chest deflections

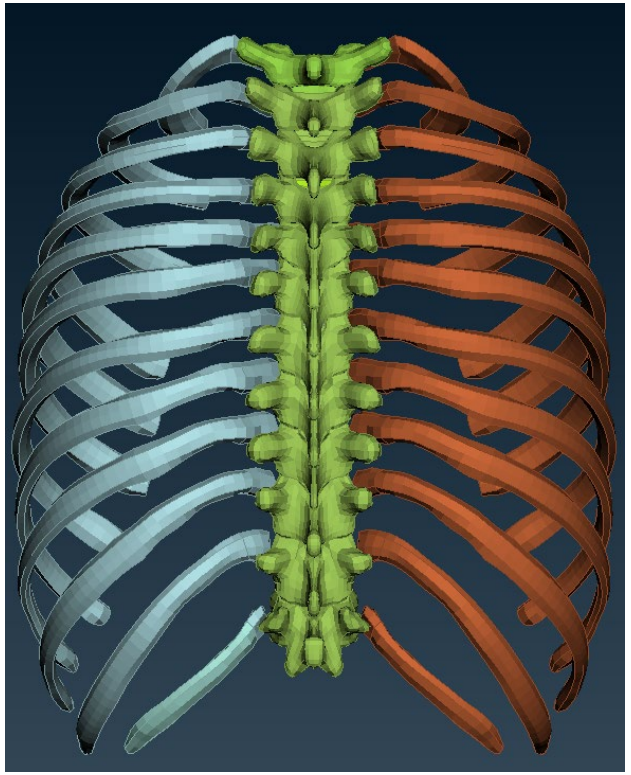
# Study for evaluating differences in chest deflections





# Method for computing rib plastic strains



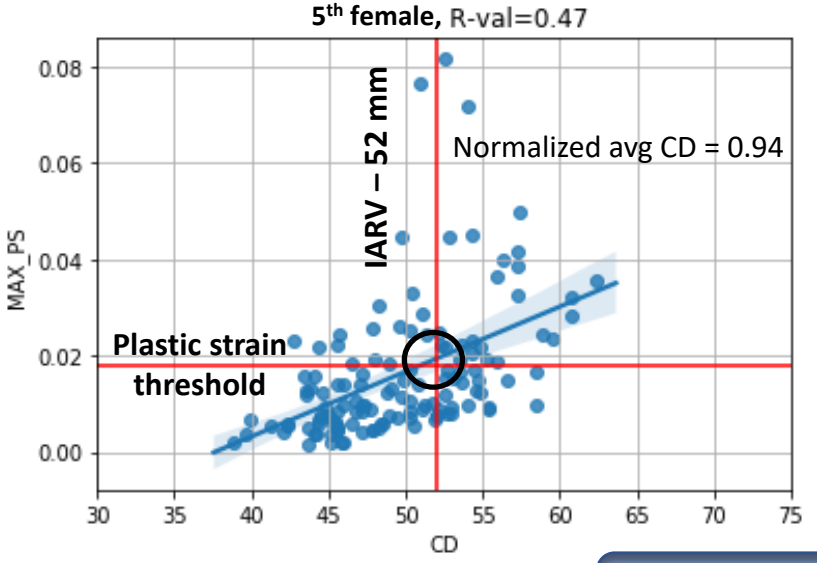


- Plastic strains were collected for each rib element
- Fractured rib = one element crossing plastic strain threshold (0.018)
- AIS1 = 1 rib fracture, AIS2 = 2 rib fractures, AIS3 = 3+ rib fractures

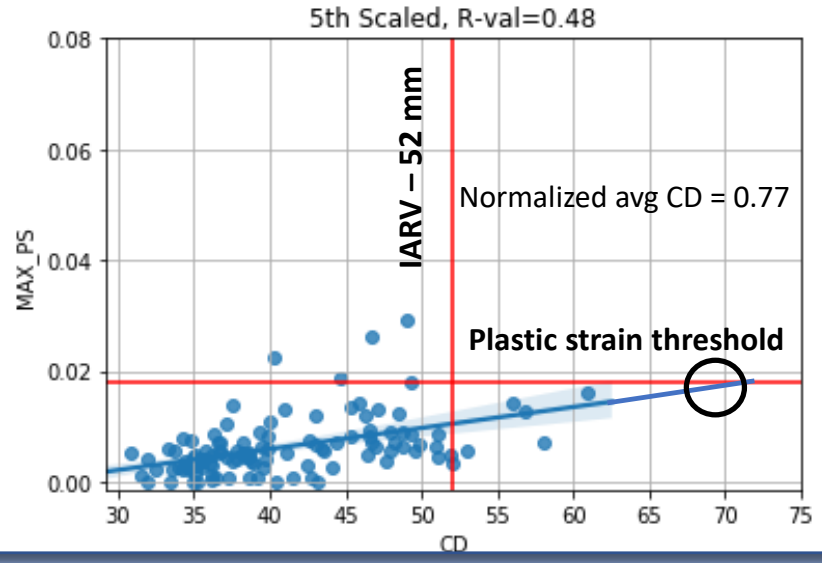
# Correlation and risk plots



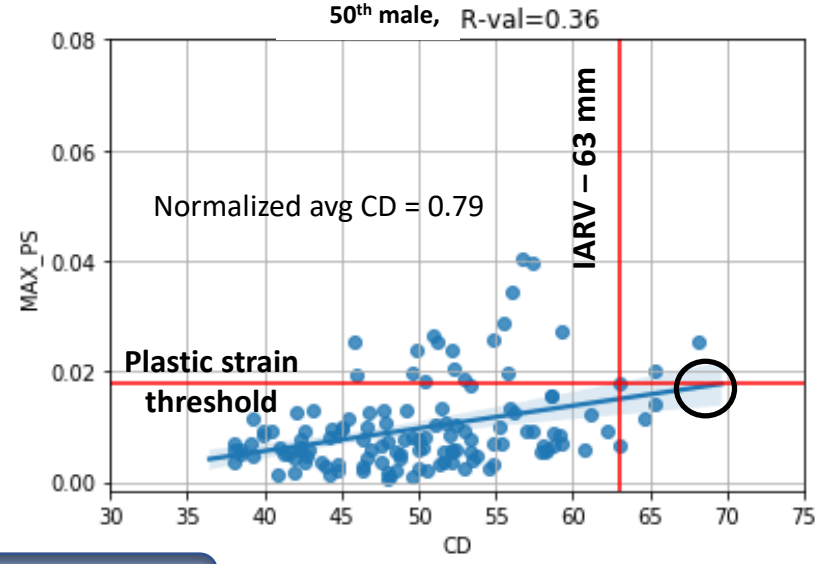
## 5th female



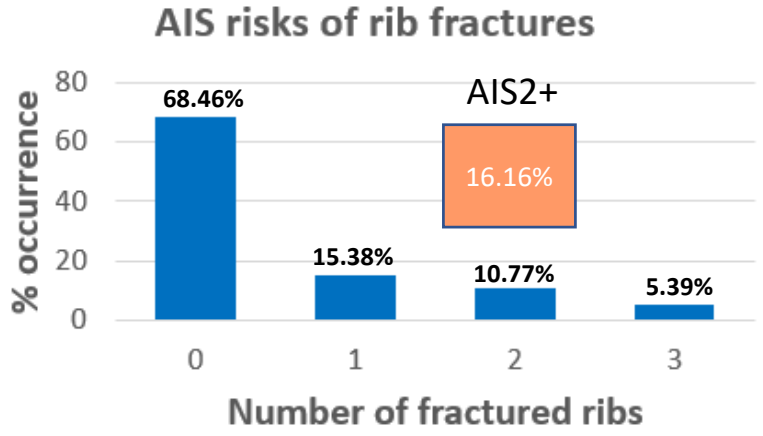

## 5th scaled

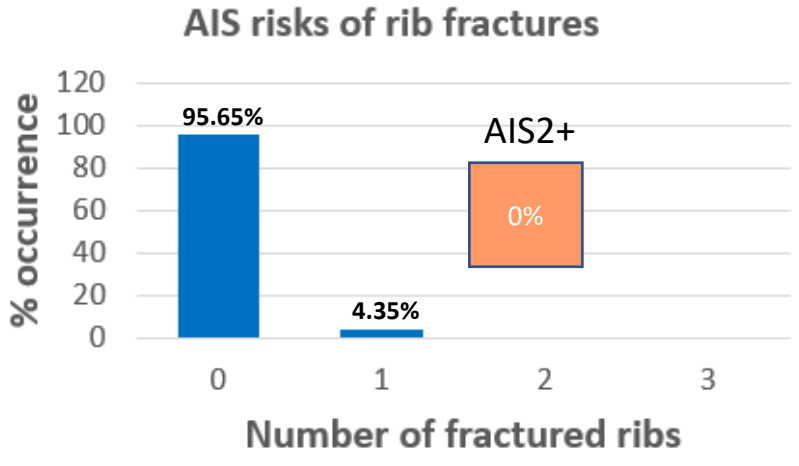


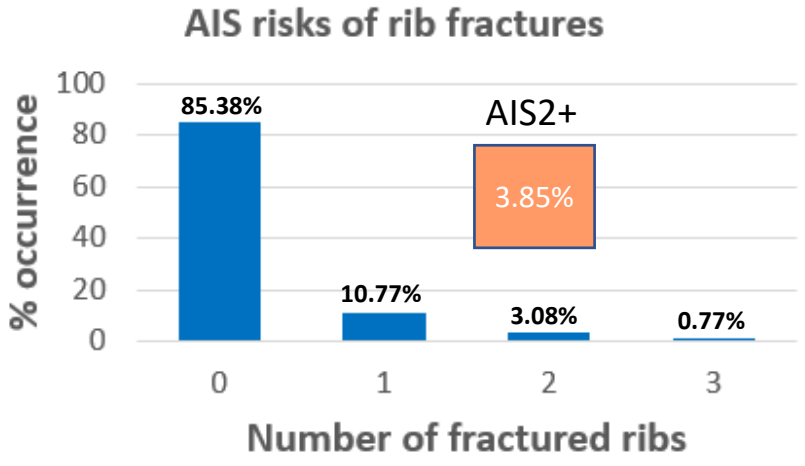

## 50th male




Chest Deflections do predict rib fractures in our study!

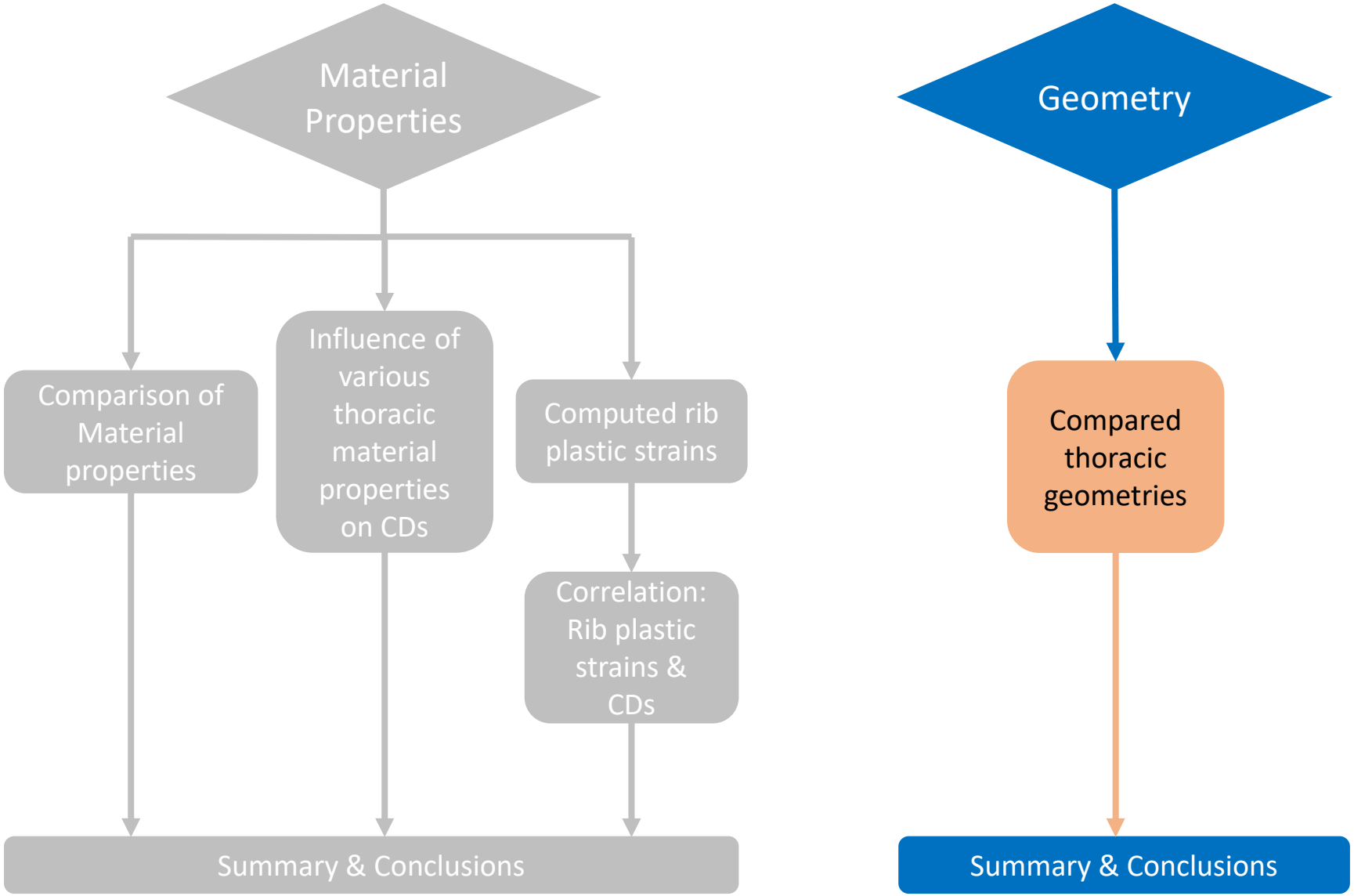


# Study for evaluating differences in chest deflections



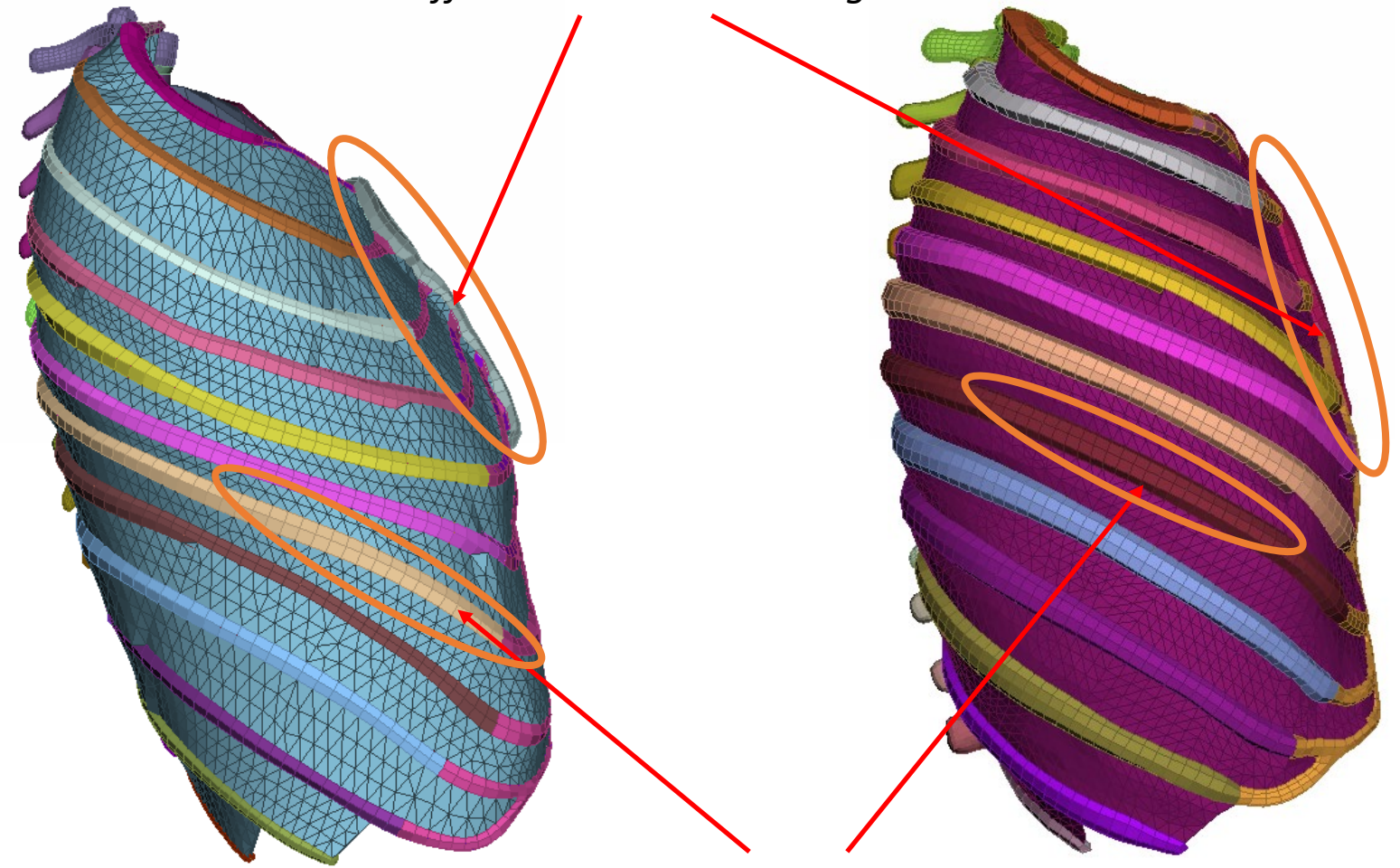


# Differences in thoracic geometry

5th female

50th male

*Differences in sternum angles*



*Differences in rib angles*

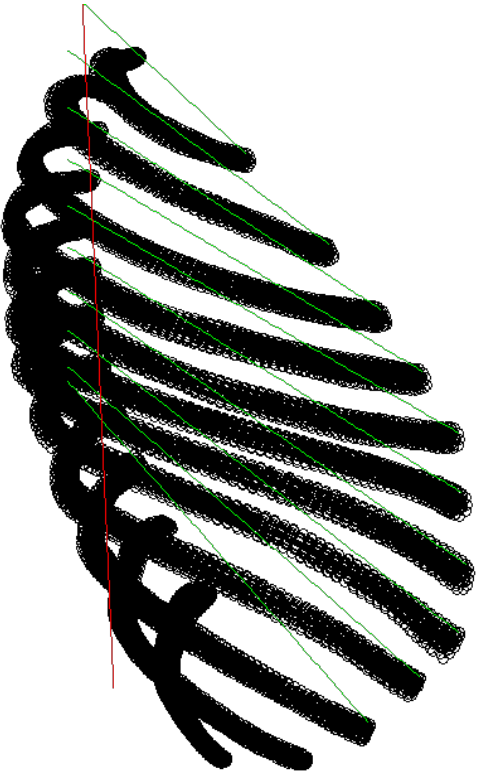
Both of these GHBMC models have been built by scanning one individual

**Question:** Is 5th female GHBMC thoracic geometry similar to average 5th female thoracic geometry?

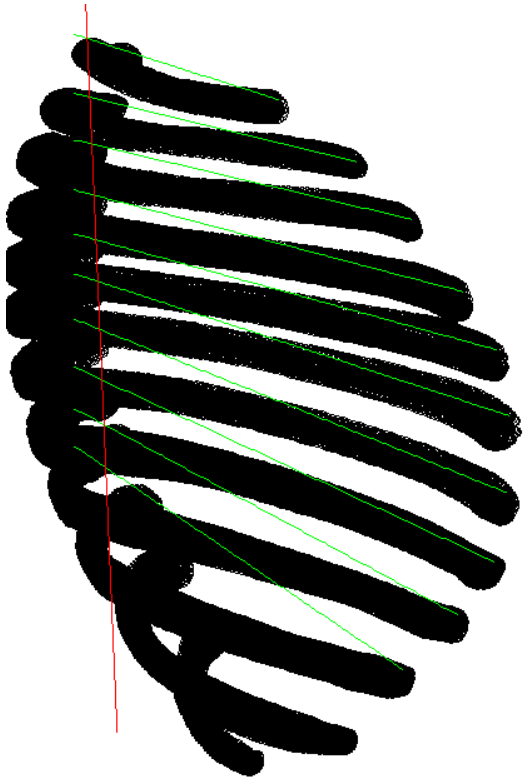
# Thoracic geometry comparison



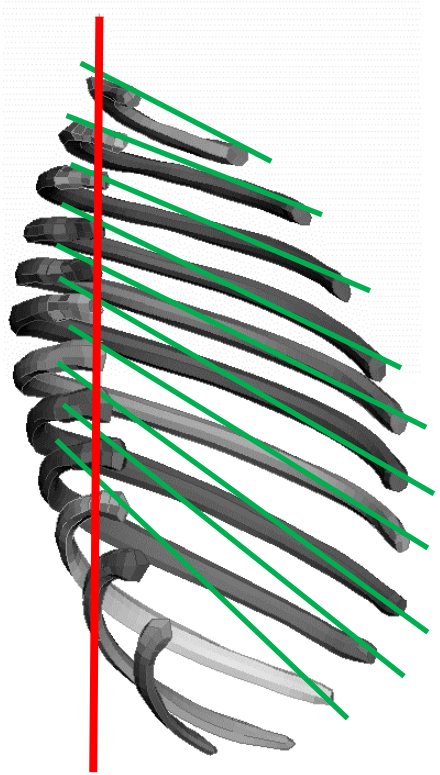
*5th female GHBMC*



*5th female (average)*



*5th scaled (or 50th male) GHBMC*



Comparable rib angles

| Rib # | Rib Angles | | |
|---|---|---|---|
| | 5th female GHBMC | 5th female: average (F05 45YO) | 5th scaled (or 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 |

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

1] What is the average geometry?

2] How does the deviation from average geometry affect the chest injuries?

# Sensitivity analysis

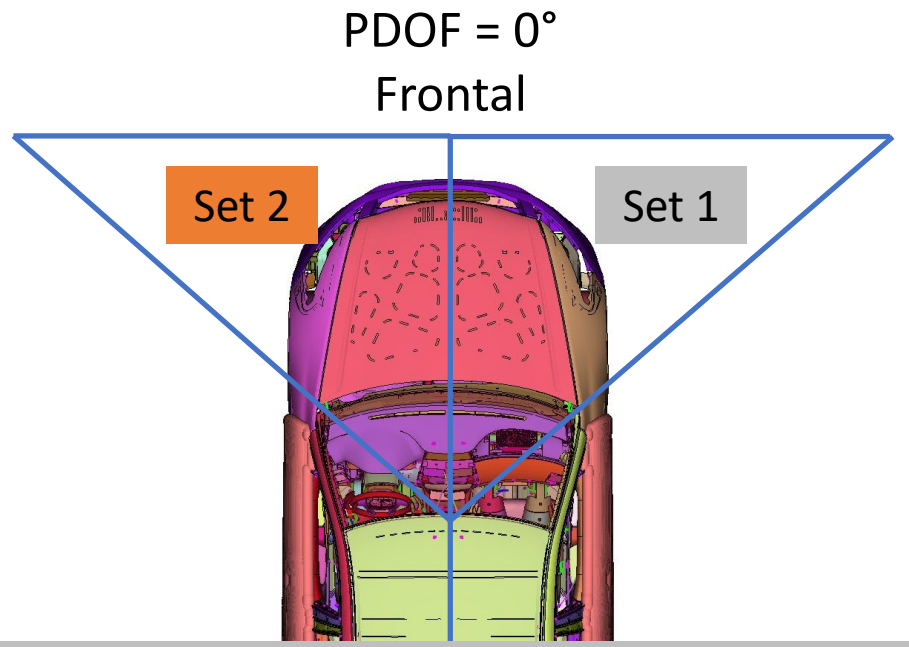


Sensitivity analysis

Crash and restraints parameters affecting chest deflections

Summary & Conclusions

## PDOF range for DOE study




To clearly see the trends for far side and near side we split the PDOF range in to two sets

# Important parameters for CD: PDOF (0° to +30°)

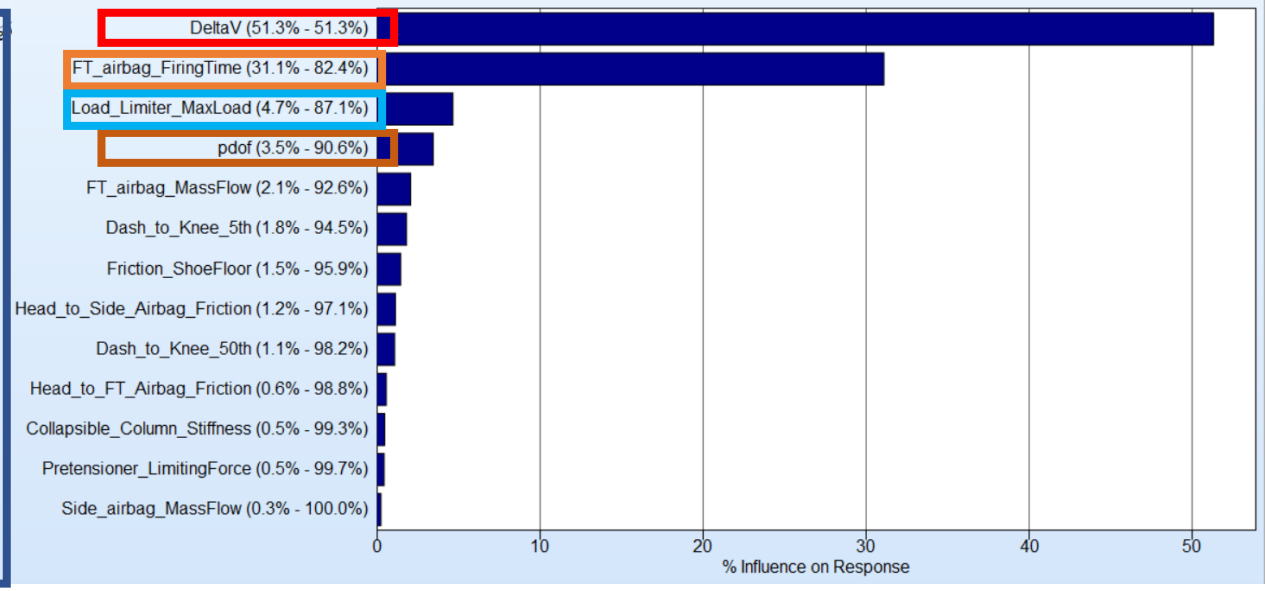
## Correlation matrix & Sensitivity

*5th female*

### Correlation matrix – chest deflections

| Variables | Collapsible_Column_Stiffness | Dash_to_Knee_50th | Dash_to_Knee_5th | DeltaV | FT_airbag_FiringTime | FT_airbag_MassFlow | Friction_ShoeFloor | Head_to_FT_Airbag_Friction | Head_to_Side_Airbag_Friction | Load_Limiter_MaxLoad | Pretensioner_LimitingForce | Side_airbag_MassFlow | pdof | ChestDe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Collapsible_Column_Stiffness | | -0.26 | -0.09 | -0.09 | -0.08 | 0.01 | -0.01 | -0.09 | -0.10 | 0.03 | 0.03 | 0.03 | 0.10 | -0.01 |
| Dash_to_Knee_50th | | | 0.01 | 0.16 | -0.00 | 0.01 | 0.01 | 0.06 | -0.08 | 0.02 | -0.10 | -0.18 | -0.11 | 0.07 |
| Dash_to_Knee_5th | | | | -0.08 | -0.01 | 0.21 | 0.09 | 0.02 | 0.03 | -0.03 | 0.12 | 0.21 | 0.04 | 0.09 |
| DeltaV | | | | | -0.15 | -0.10 | -0.04 | 0.03 | 0.10 | 0.02 | -0.11 | 0.01 | -0.12 | 0.69 |
| FT_airbag_FiringTime | | | | | | -0.24 | 0.10 | 0.13 | 0.13 | -0.25 | -0.07 | 0.08 | 0.04 | 0.27 |
| FT_airbag_MassFlow | | | | | | | -0.01 | 0.03 | -0.08 | -0.11 | 0.06 | 0.14 | 0.02 | -0.01 |
| Friction_ShoeFloor | | | | | | | | 0.15 | 0.16 | -0.05 | 0.07 | 0.15 | -0.11 | 0.12 |
| Head_to_FT_Airbag_Friction | | | | | | | | | -0.14 | 0.01 | 0.04 | 0.16 | -0.05 | 0.04 |
| Head_to_Side_Airbag_Friction | | | | | | | | | | -0.07 | -0.14 | 0.05 | -0.05 | 0.03 |
| Load_Limiter_MaxLoad | | | | | | | | | | | 0.25 | -0.16 | -0.25 | 0.16 |
| Pretensioner_LimitingForce | | | | | | | | | | | | -0.08 | 0.07 | 0.04 |
| Side_airbag_MassFlow | | | | | | | | | | | | | 0.18 | 0.05 |
| pdof | | | | | | | | | | | | | | -0.28 |

### Sensitivity, Radial Basis Function Network (RBF)



# Important parameters for CD: PDOF (0° to +30°)

***Sensitivity***

| 5th female | 5th scaled | 50th male |
|---|---|---|
| Delta V (51%) | Delta V (61%) | PDOF (42%) |
| Firing time (31%) | PDOF (15%) | Delta V (29%) |
| Load limiter (5%) | Firing time (14%) | Load limiter (13%) |
| PDOF (4%) | Dash to knee 5th (3%) | Steering column stiffness(6%) |

# Important parameters for CD: PDOF (-30° to 0°)

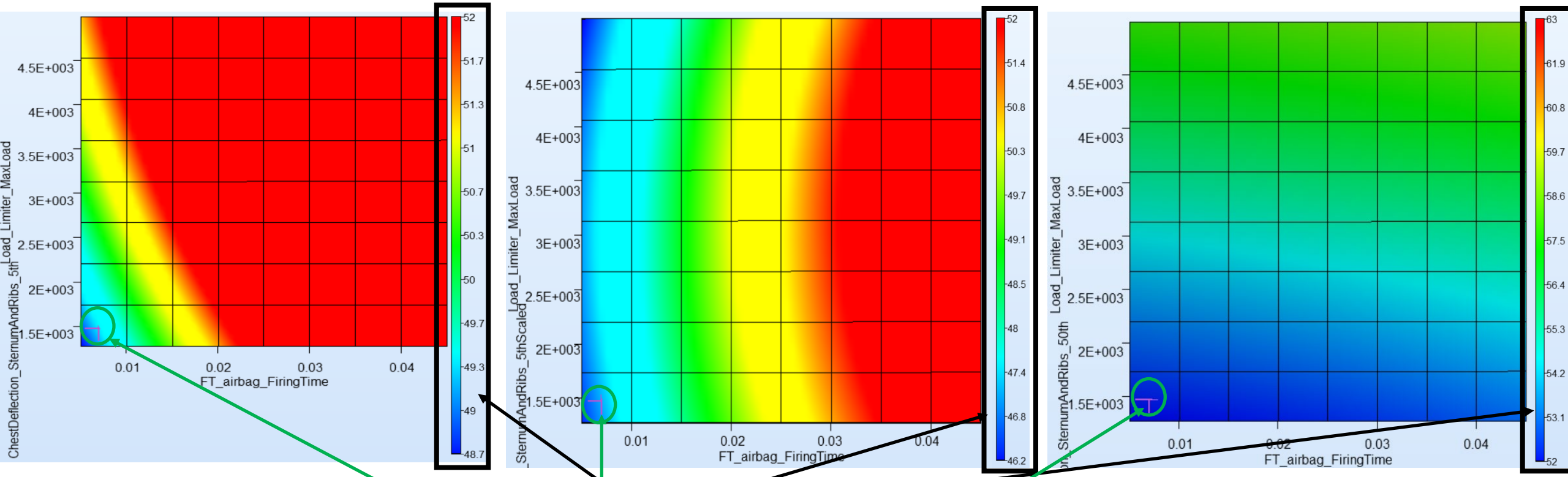
| 5th female | 5th scaled | 50th male |
|---|---|---|
| Delta V (42%) | Delta V (43%) | Delta V (41%) |
| Firing time (36%) | PDOF (27%) | Load limiter (24%) |
| Load limiter (9%) | Firing time (20%) | PDOF (20%) |
| Dash to knee 5th (5%) | Load limiter (3%) | Side airbag mass flow rate (10%) |

# Metamodels: Chest Deflection (@PDOF = 0°, DeltaV= 33 mph)

5th female

5th scaled

50th male

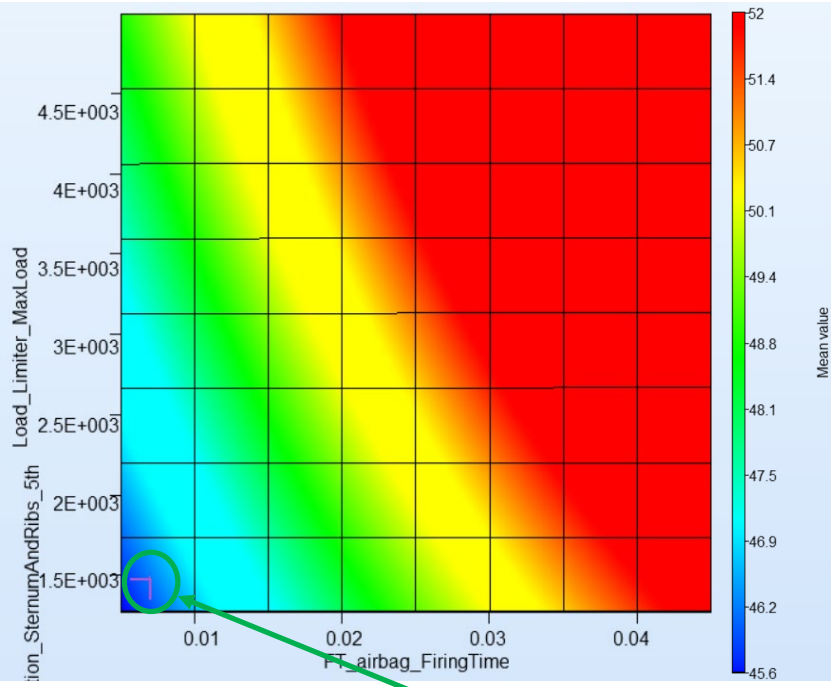



Chest deflections

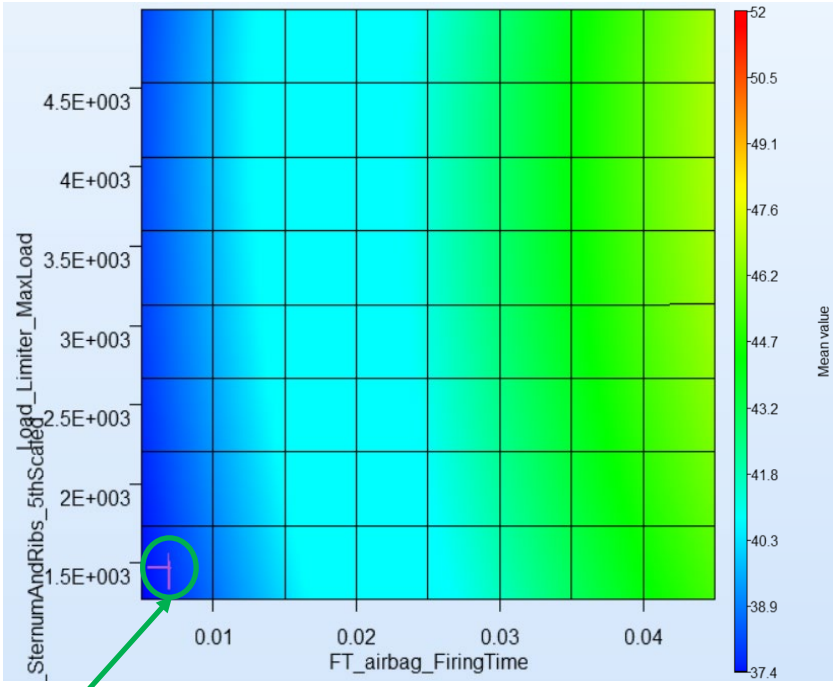
Controlling firing time and load limiter yield lower chest deflections

# Metamodels: Chest Deflection (@PDOF = +30° DeltaV= 33 mph)

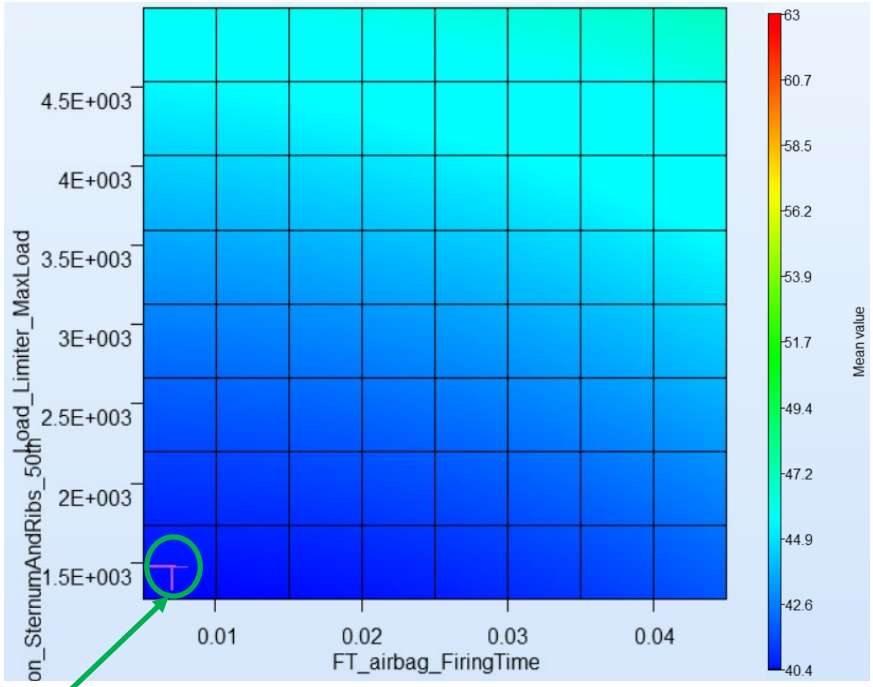
5th female




5th scaled




50th male



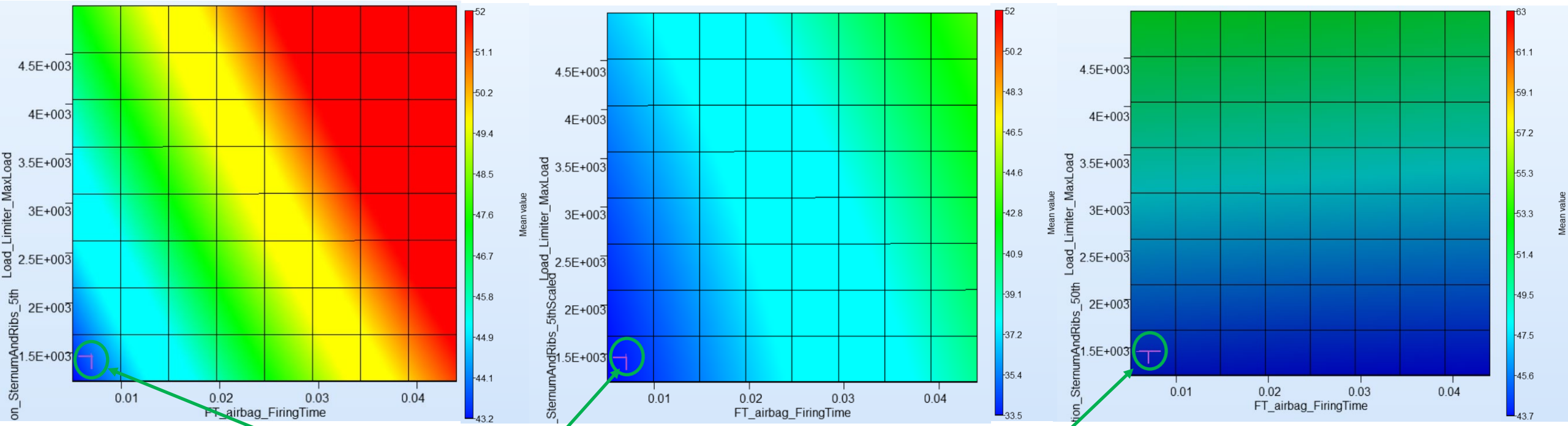

Chest deflections are well below IARVs when firing time and load limiter is controlled.

# Metamodels: Chest Deflection (@PDOF = -30° DeltaV= 33 mph)

5th female

5th scaled

50th male




Chest deflections are well below IARVs when firing time and load limiter is controlled.

# Limitations



- One model each ($5^{th}$ female and $50^{th}$ male) represents the field.
- $5^{th}$ female is not an average female.
- One car represents the field and the fleet (although some adjustments were made in the DOE study).
- The range of DeltaV, PDOF, and other parameters in DOE study may not be same as that of field and fleet.
- Optimization study to minimize all injury metrics (not just CD) has not yet been carried out.
- Etc.

# Conclusions



- The simulation study indicates that 5$^{th}$ female may be at higher injury risks across all body regions when compared to 50$^{th}$ male.
- Chest and brain had the highest risk of injuries for both female and male.
- The seating position and model size may not be the cause of different injury risks between males and females.
- Thoracic geometric differences may contribute to injury risk differences between males and females.
- Chest deflections may be reduced for females and males by controlling the firing time and load limiter.

# Thank you

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