Thoracic Response Corridors of Small Female PMHS in Simplified Frontal and Side Impacts

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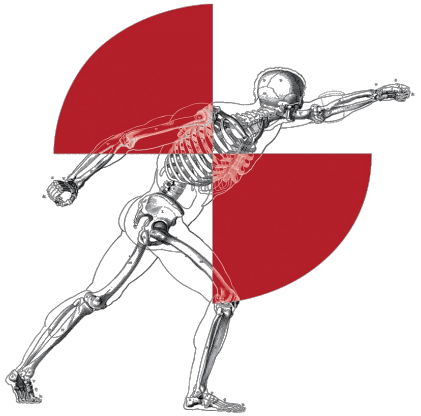
NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

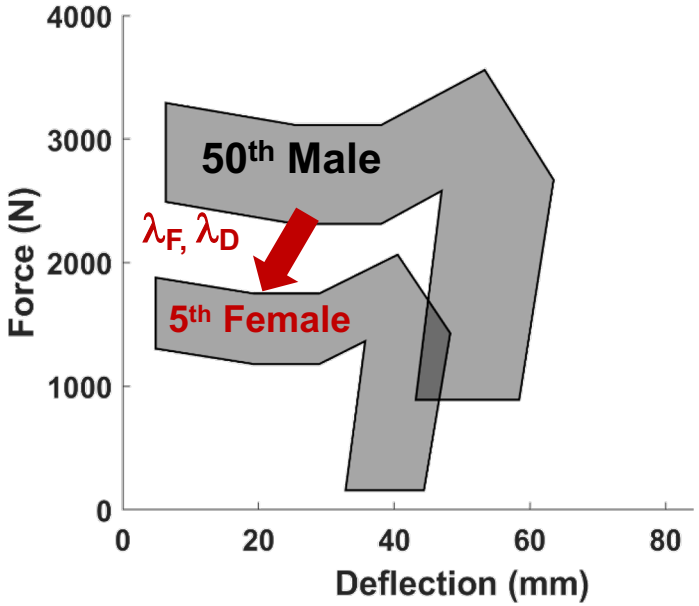


Content Warning

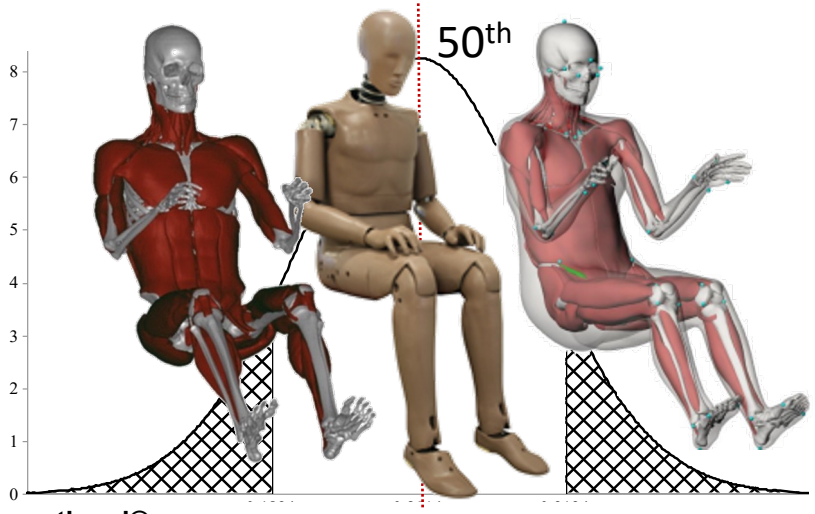
The following slides include cadaveric images that are graphic and may be considered disturbing to some viewers

Introduction

- Thoracic injuries frequent in MVCs
  - Females may be at greater risk of thoracic injuries than males in MVCs [Parenteau et al 2013, Forman et al 2019]
- Large body of work on thoracic response has focused on mid-size male



Mid-size Male



- Limited availability of female biomechanical data for the thorax
  - Requires scaling

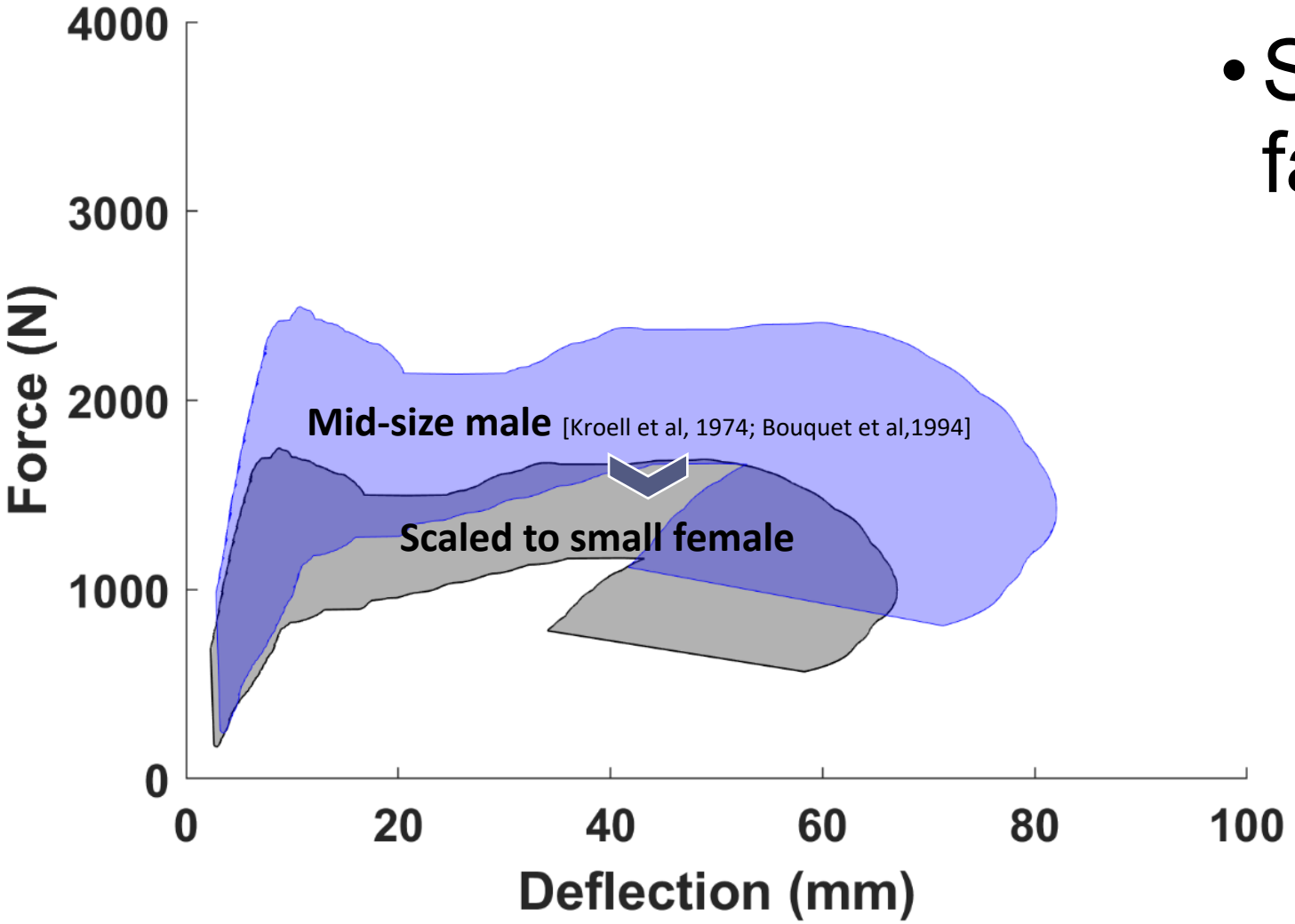
Objective

- Generate biomechanical thoracic response corridors for ***small female PMHS*** in simplified impacts
  - Evaluate scaled corridors used for female ATD & HBM development

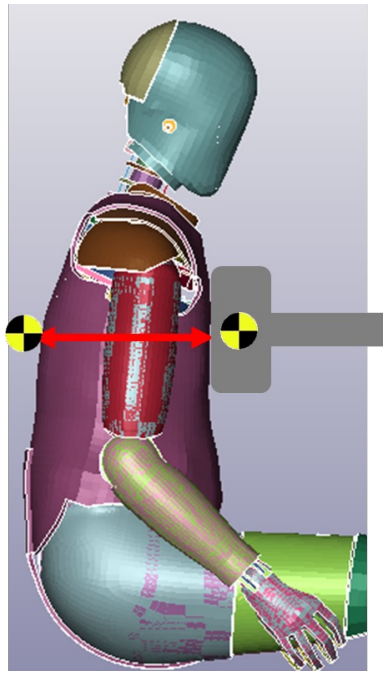
- Frontal impact
- Side impacts
  - Lateral
  - Oblique

FRONTAL IMPACT

Frontal Scaled Corridors

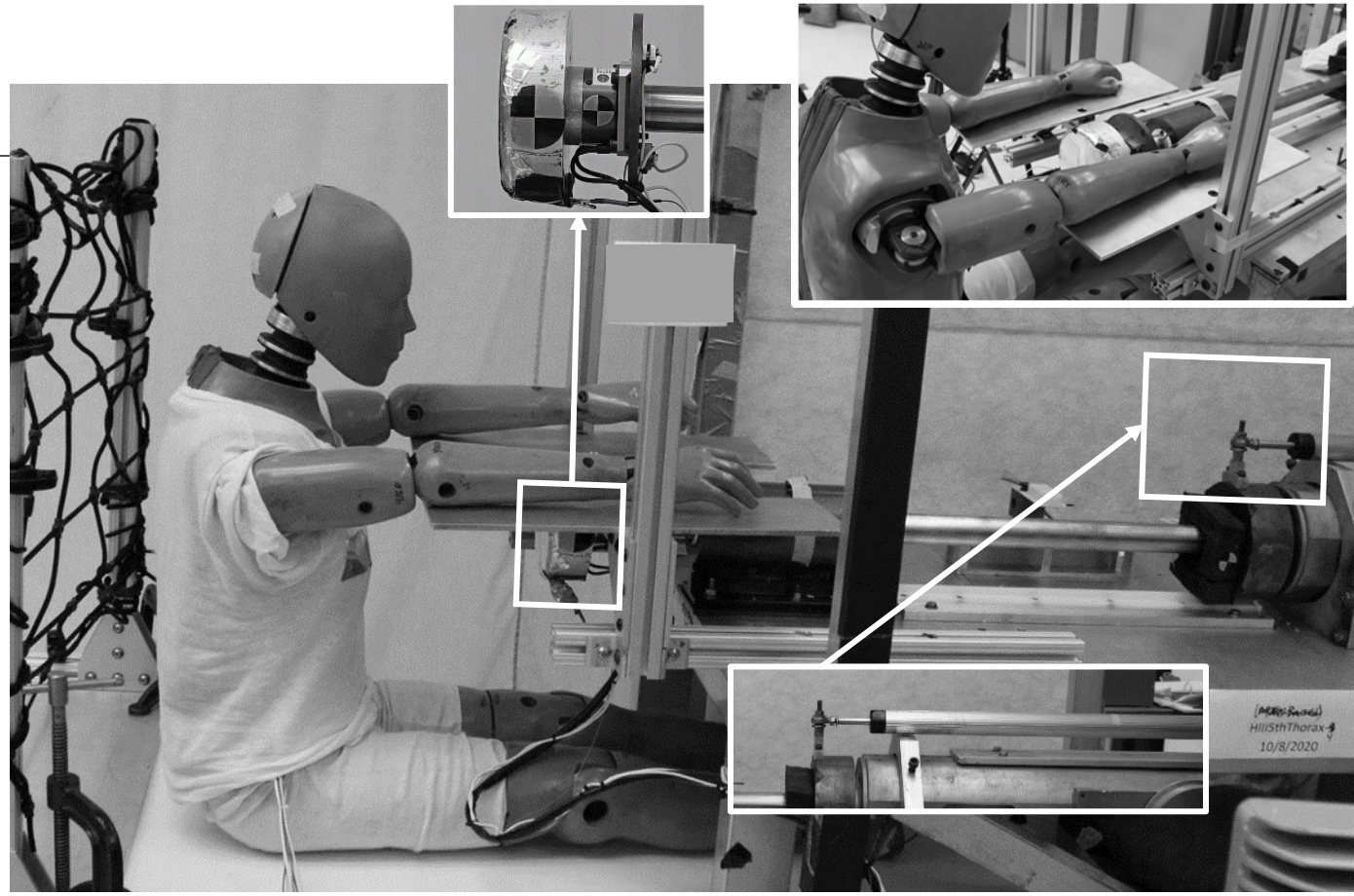


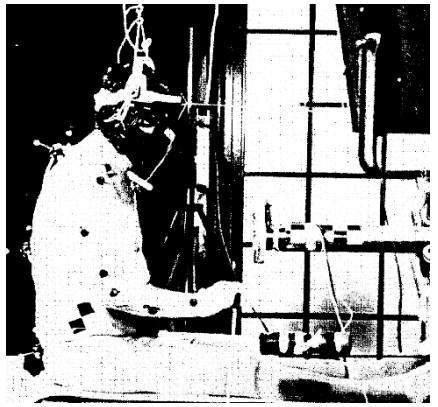
- Small female scaling factors based on:
  - Mertz et al 1989
    - Lee et al 2020, Wang et al 2018



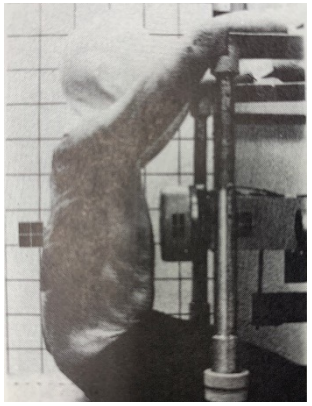
Frontal Experiment

- Impact force
  - Inertially compensated 6 axis load cell data
  - 152mm, 14kg impactor
- External deflection
  - Same as Kroell[1971,1974] and Bouquet[1994] studies
    - Spinal displacement minus impactor displacement

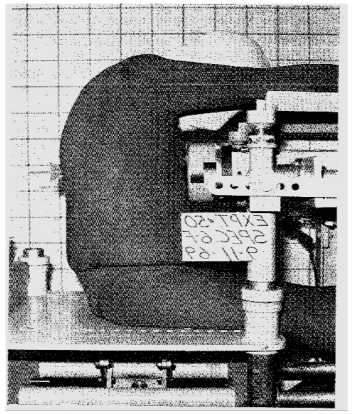




Bouquet et al 1994



Kroell et al 1974



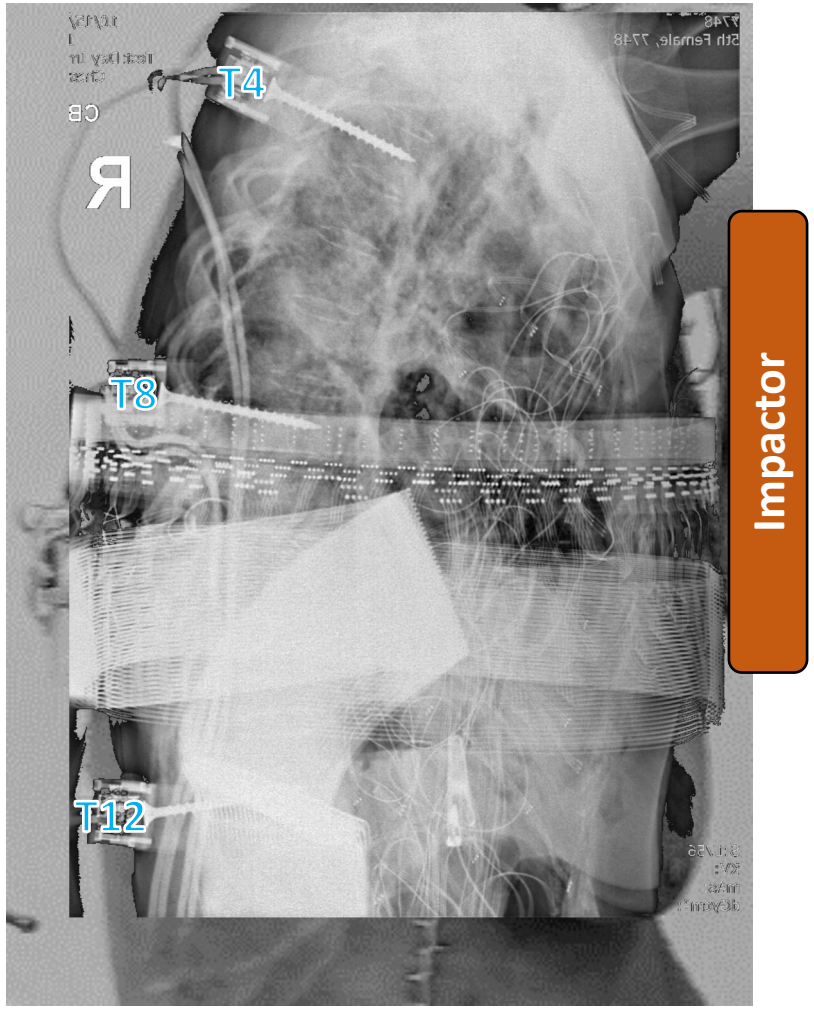
Nahum et al 1970, Kroell et al 1971,1974

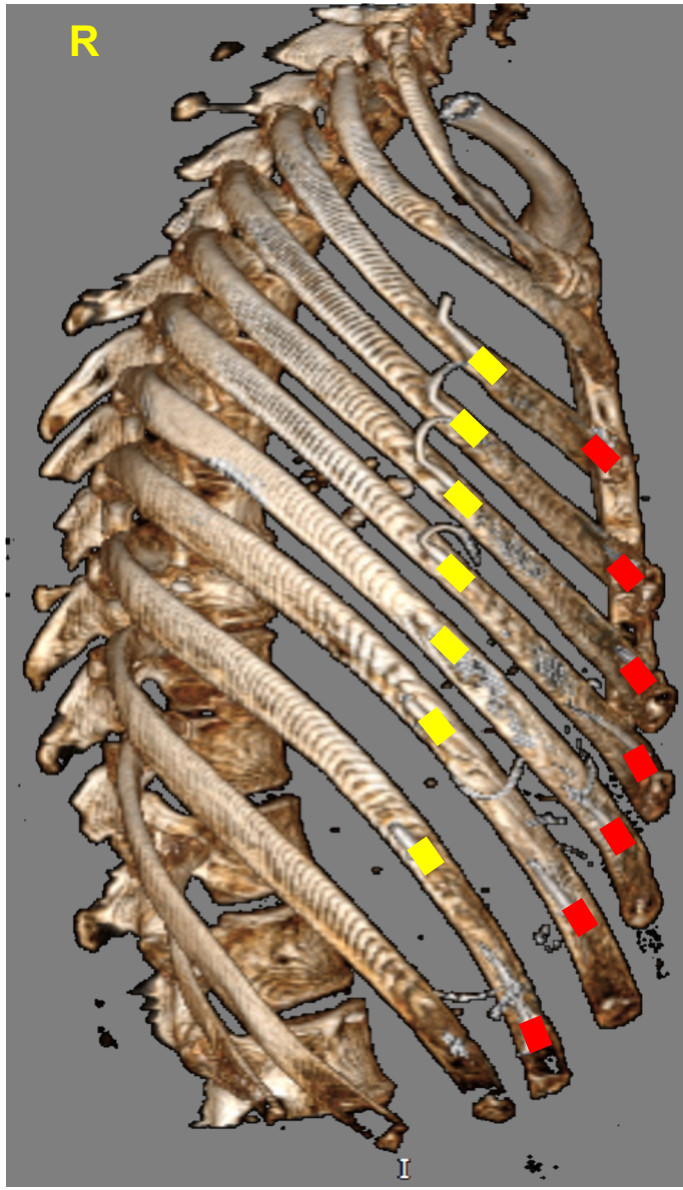
Frontal Experiment

- Instrumentation
  - Strain gages
    - Ribs 3-9
  - 6DXs
    - T4, T8, T12
  - Chestband
- Impact location
  - 4th intercostal space

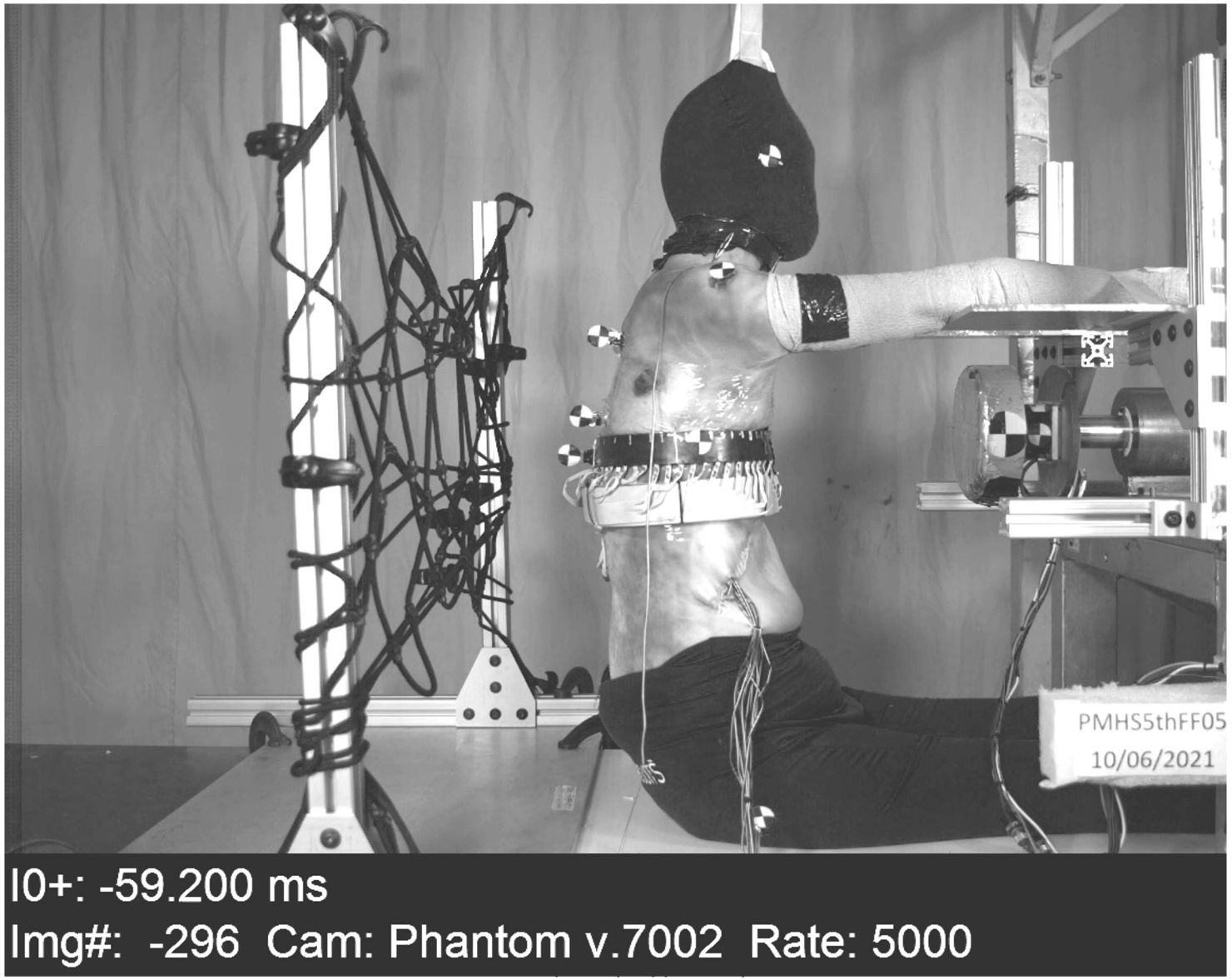
    [Nahum et al 1970, Kroell et al 1971]
- Low speed (4.3m/s) to avoid injury

  [Neathery 1974, Lebarbe & Petit 2012]





Frontal Experiment



Frontal PMHS

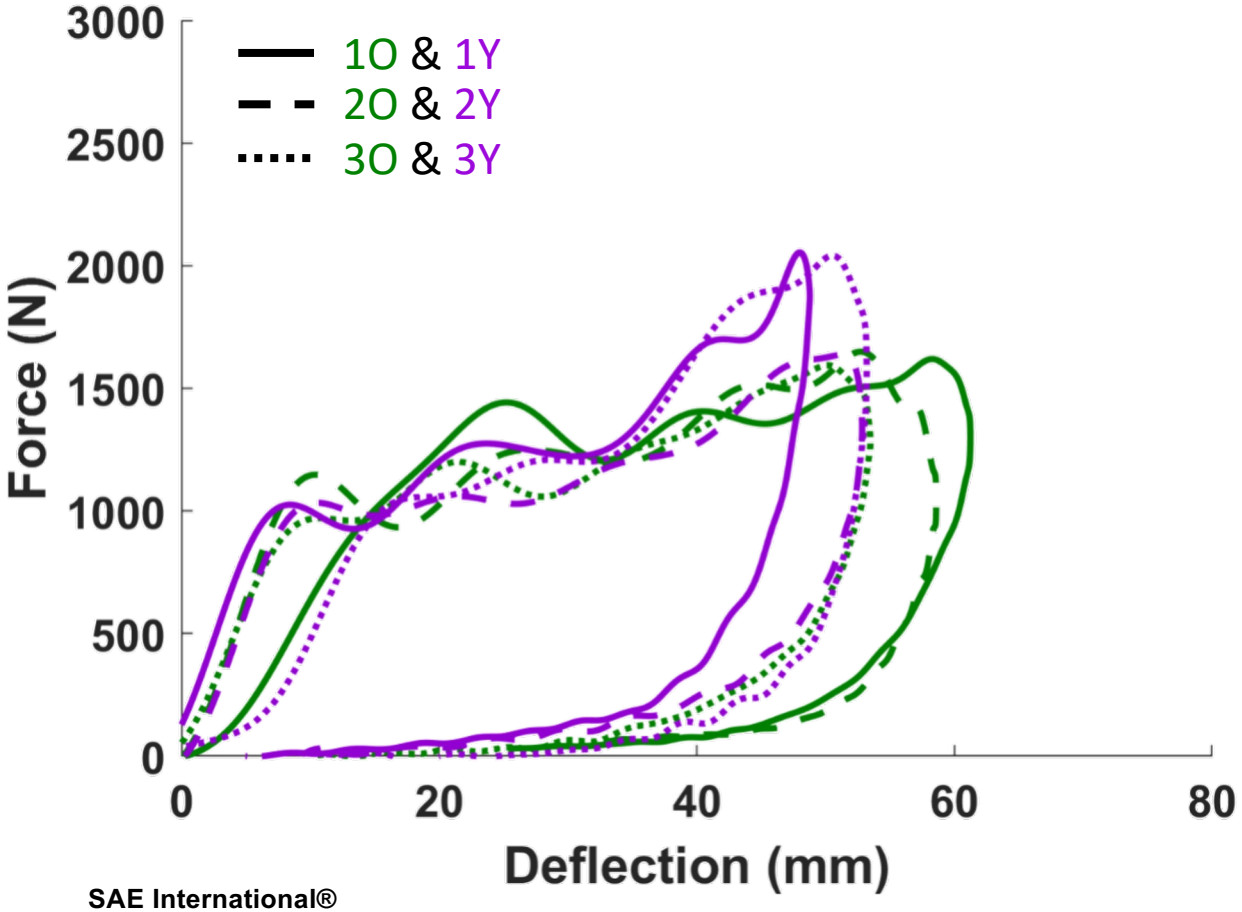
- N=6 small females
  - 3 Older
  - 3 Younger
- Each PMHS impacted once

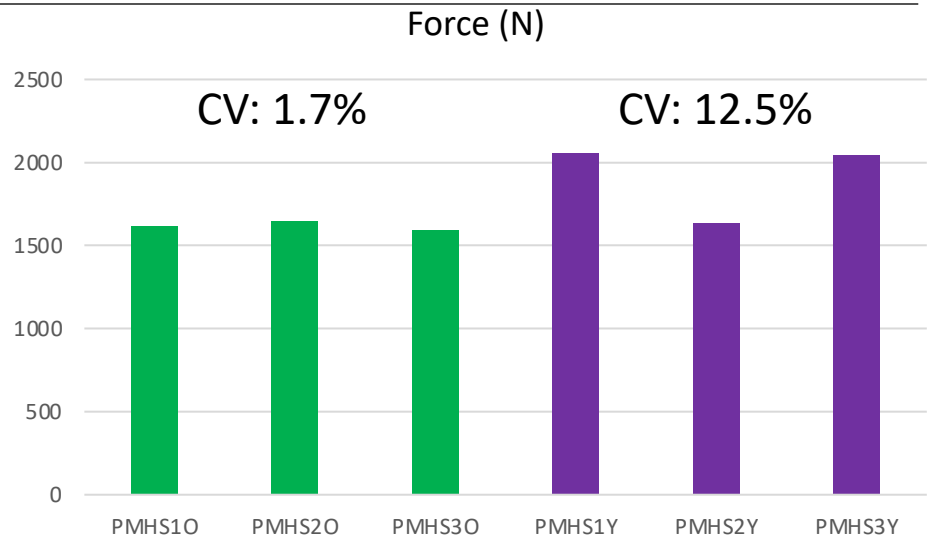
ID	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Chest depth (cm)
PMHS1O	67	157.5	55.3	22	18.5
PMHS2O	89	158.8	52.6	21	20.0
PMHS3O	75	151.1	46.3	20	20.5
Mean	**77**	**155.8**	**51.4**	**21**	**19.7**
PMHS1Y	31	152.4	46.7	20	18.2
PMHS2Y	51	160.3	45.4	18	15.5
PMHS3Y	50	159.6	38.0	15	13.6
Mean	**44**	**157.4**	**43.4**	**17.5**	**15.8**
*5th Female Target	-	151.3	46.7	20	18.7

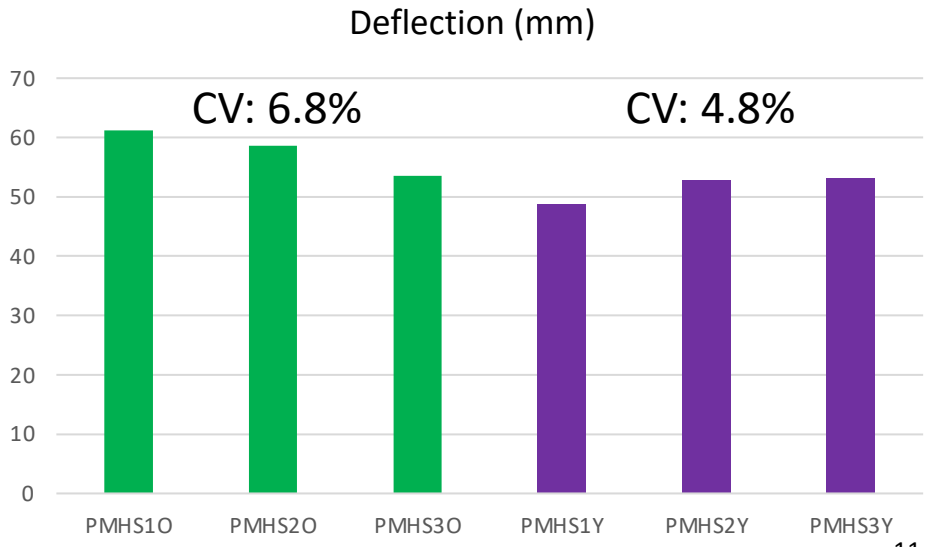
*Mertz et al. 2001

Frontal F-D

Small Female PMHS Y
Small Female PMHS O

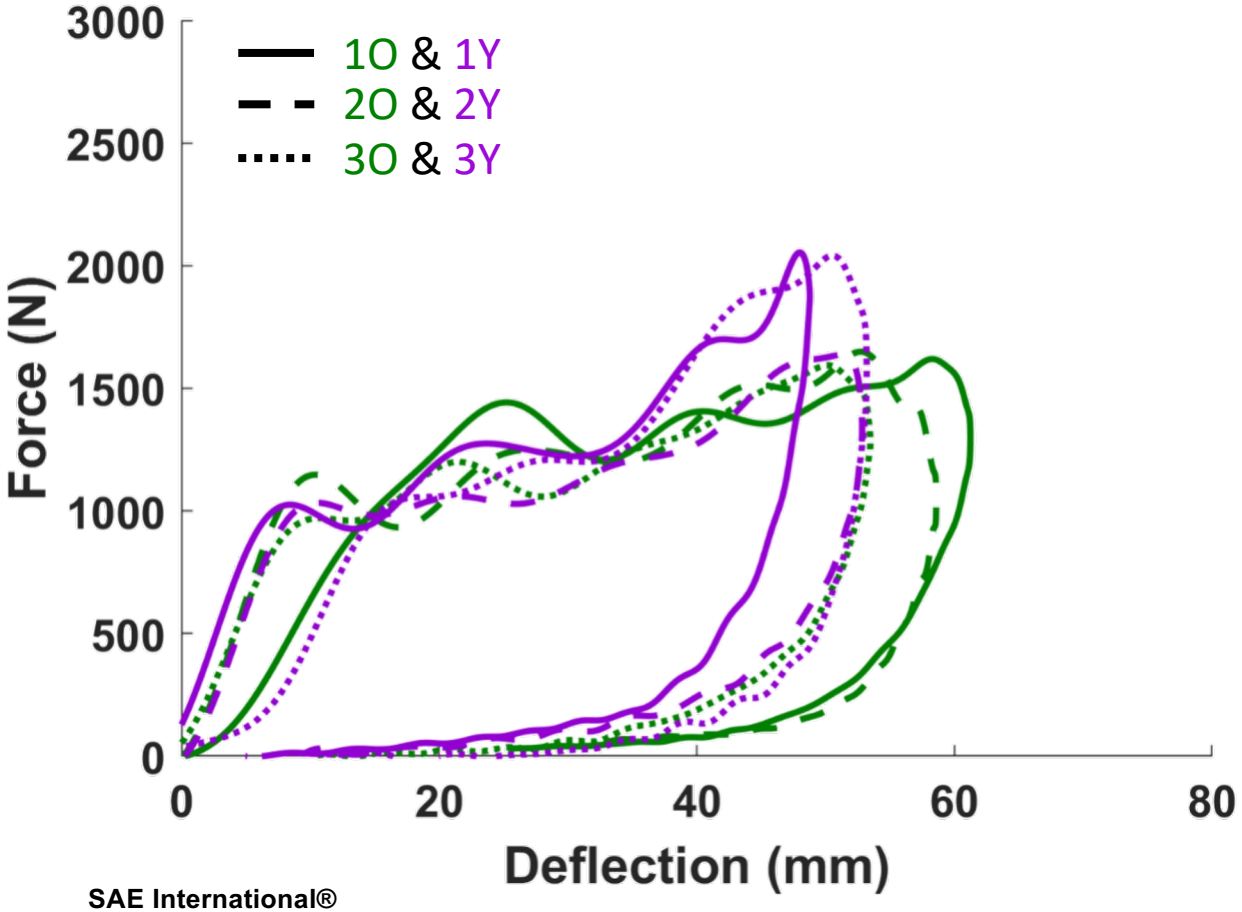


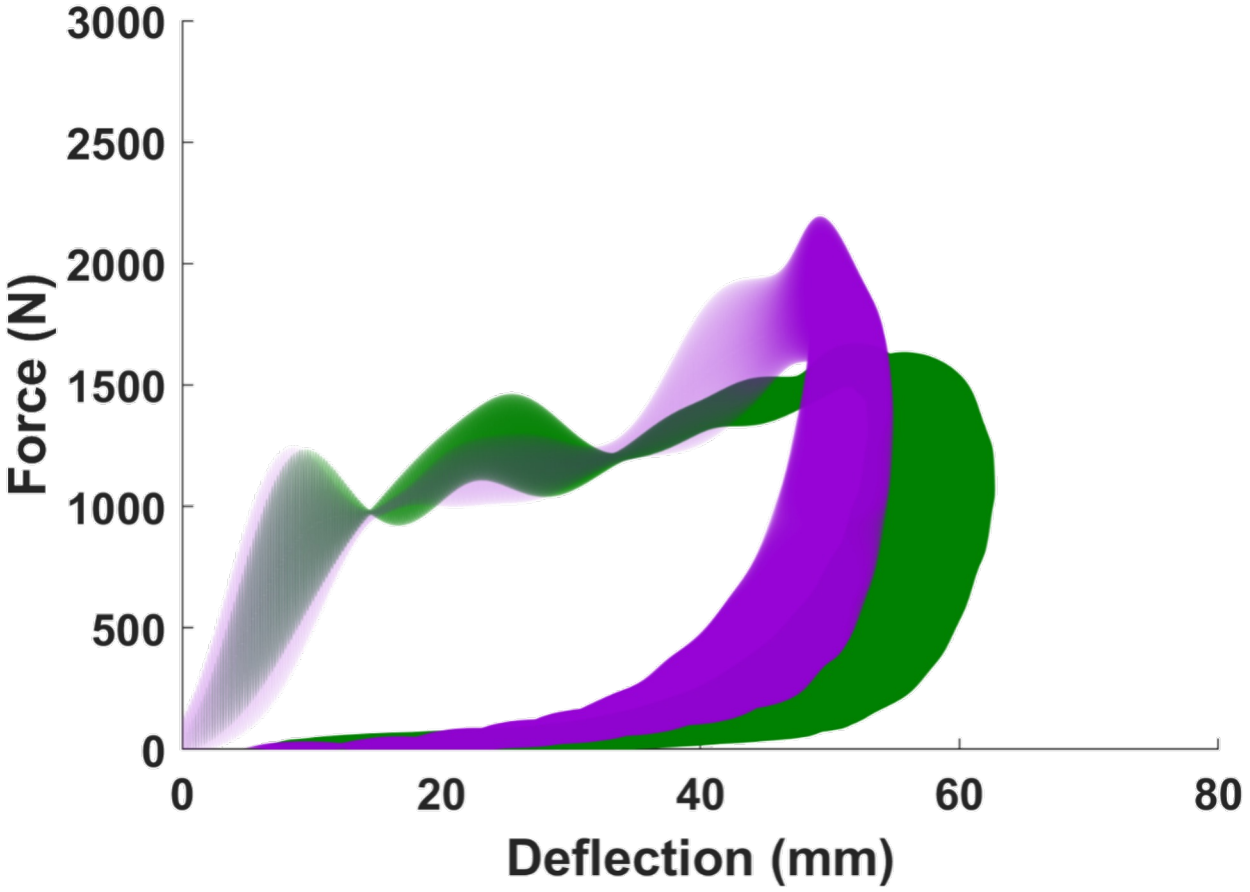




Frontal F-D Corridors

Small Female PMHS Y
Small Female PMHS O

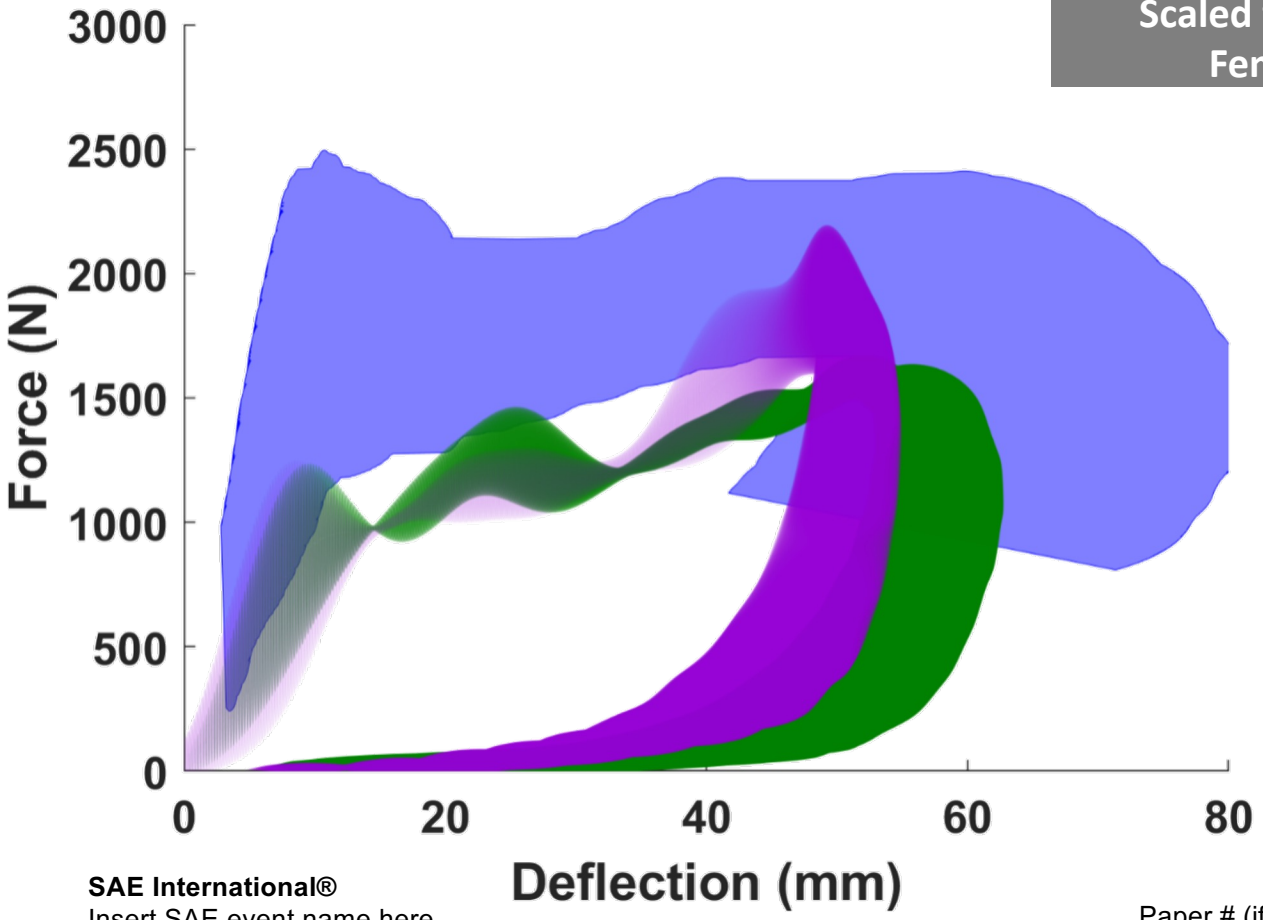


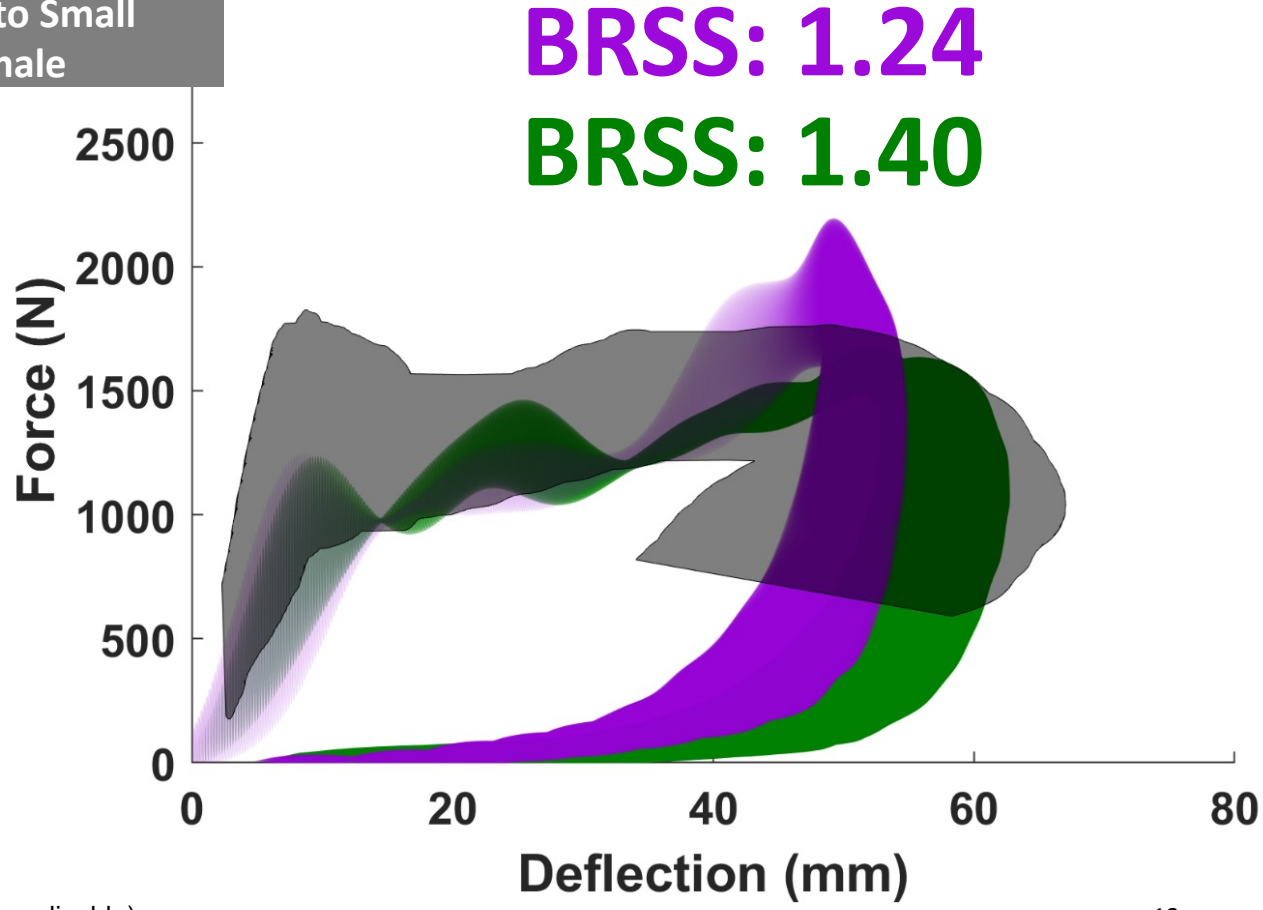


Frontal F-D Corridors

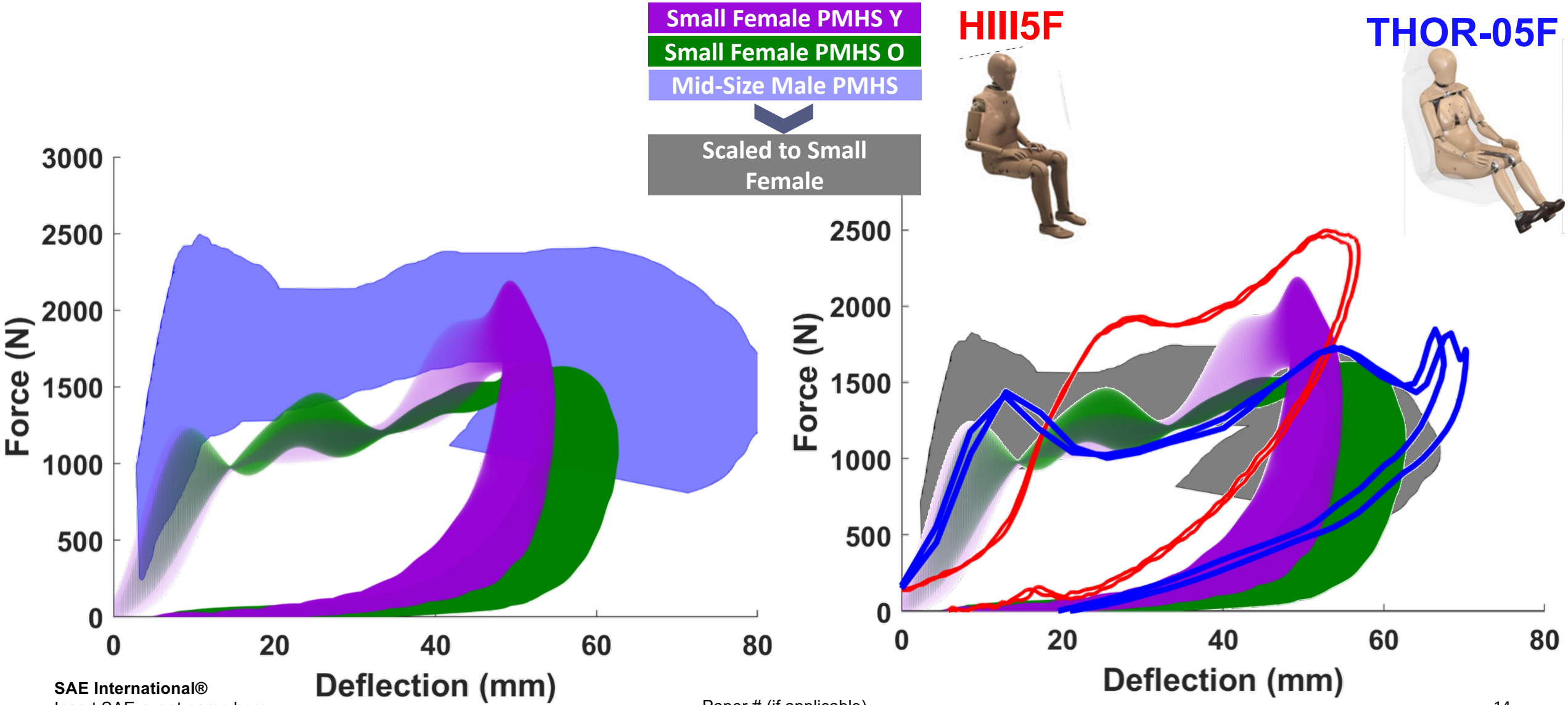
Small Female PMHS Y
Small Female PMHS O
Mid-Size Male PMHS
Scaled to Small Female

BioRank System Score (BRSS)[Kang et al 2021]
-Avg of F-t and D-t BRSS
-BRSS <2 indicates good agreement



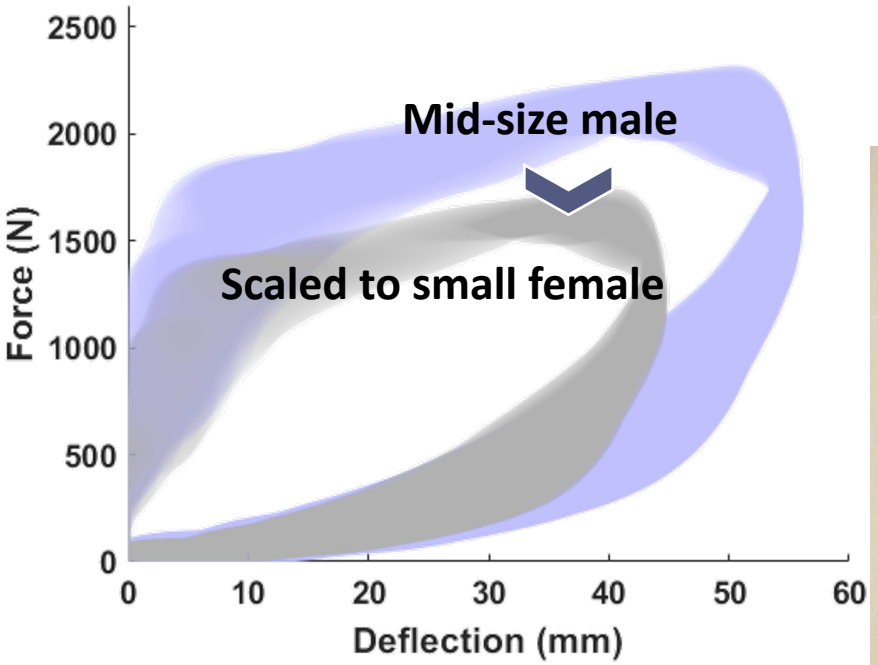


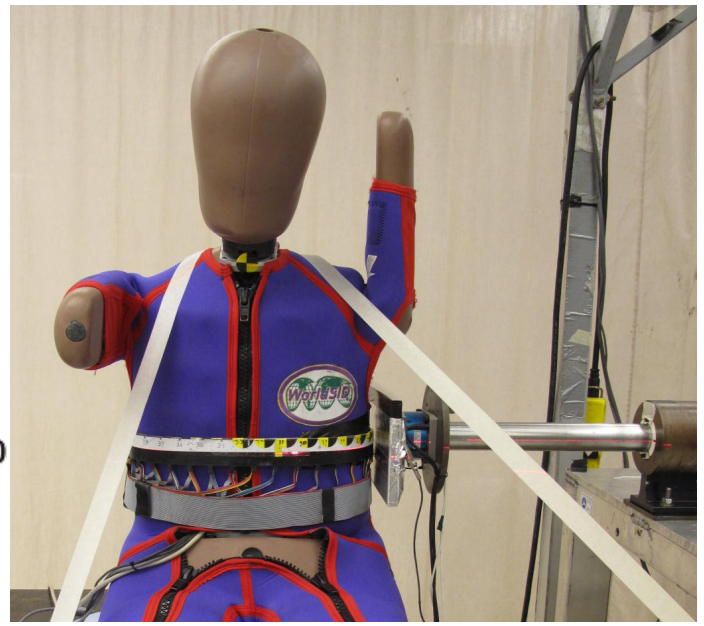
Frontal ATD Biofidelity



SIDE IMPACT

Side Scaled Corridors

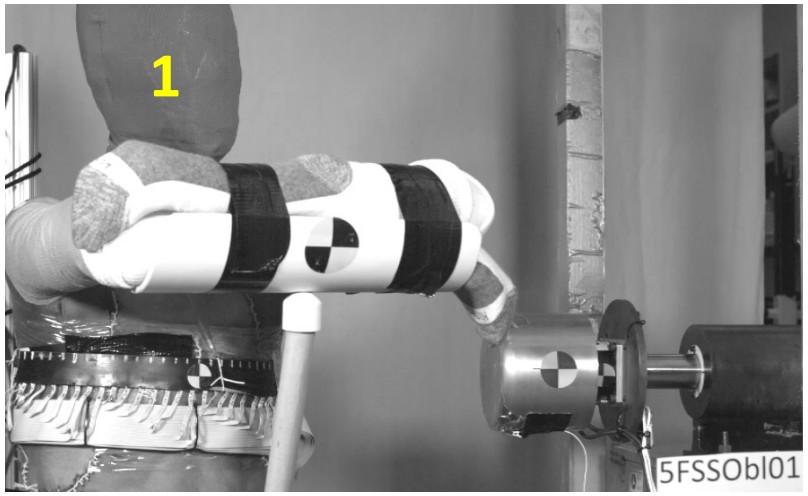


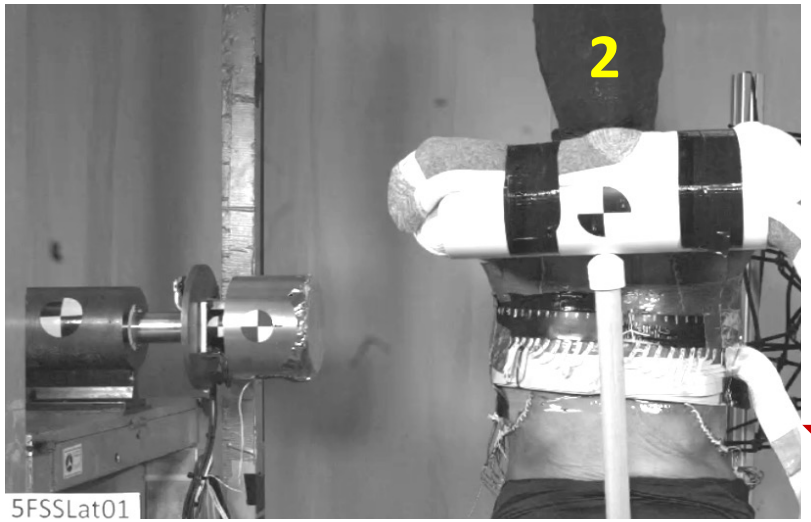


- WorldSID-05F biofidelity evaluation
  - New normalization [Donnelly et al 2017] and corridor construction techniques applied to mid-size male PMHS
  - Scaled corridor to small female
    - Based on Mertz 1989
      - Lee et al 2017, 2020
    - Coming soon!

Side Test Matrix

Shaw et al 2006
Rhule et al 2011

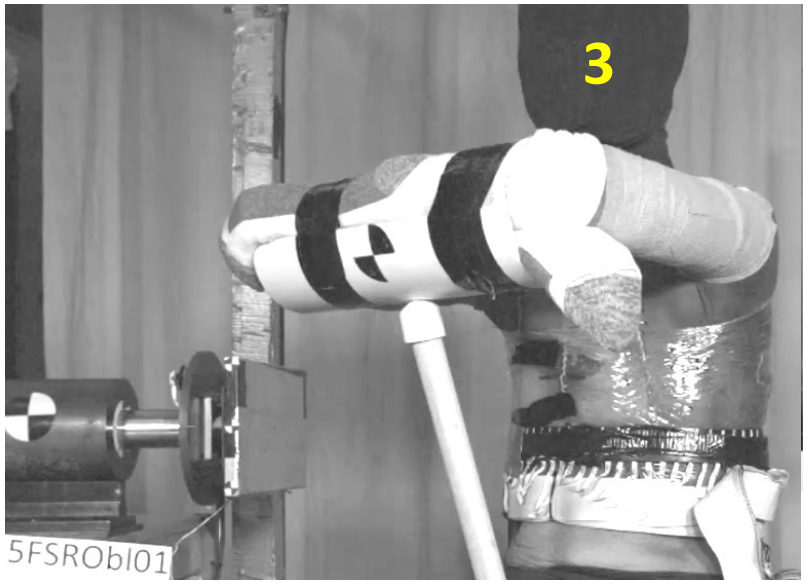


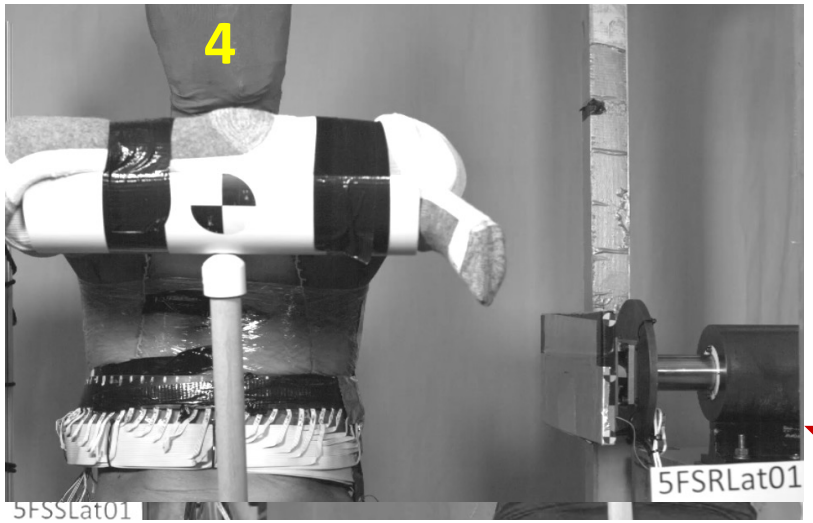


Test	Impact Direction	Impactor Face	Impact Velocity (m/s)	Impact Side	Impact Level
-1- Shaw	Oblique 60°	Circle	2.5	Left	4th IC space
-2- Shaw	Lateral 90°	Circle	2.5	Right	4th IC space
-3- Rhule	Oblique 60°	Rectangle	4.5	Right	Xiphoid
-4- Rhule	Lateral 90°	Rectangle	4.5	Left	Xiphoid

Side Test Matrix

Shaw et al 2006
Rhule et al 2011





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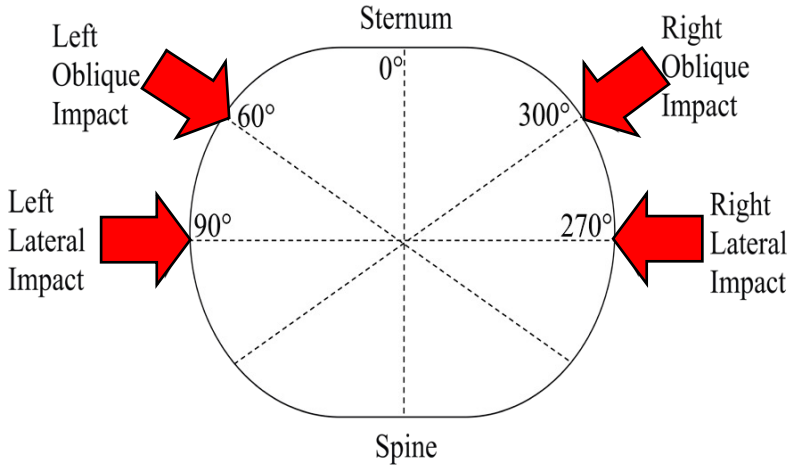
-1- Shaw	Oblique 60°	Circle	2.5	Left	4th IC space
-2- Shaw	Lateral 90°	Circle	2.5	Right	4th IC space
-3- Rhule	Oblique 60°	Rectangle	4.5	Right	Xiphoid
-4- Rhule	Lateral 90°	Rectangle	4.5	Left	Xiphoid

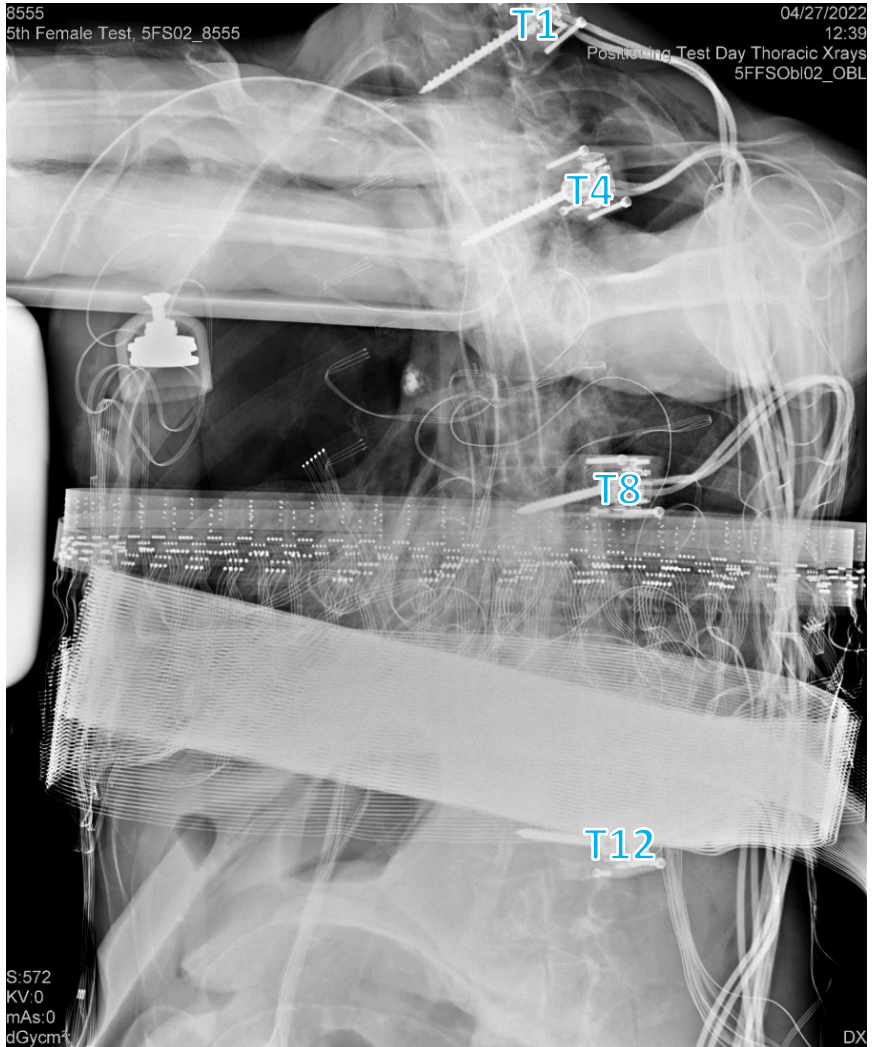
Side Experiment

- Instrumentation
  - Strain gages
    - Ribs 3-9
  - 6DXs
    - T1, T4, T8, T12
  - Chestband @ impact location

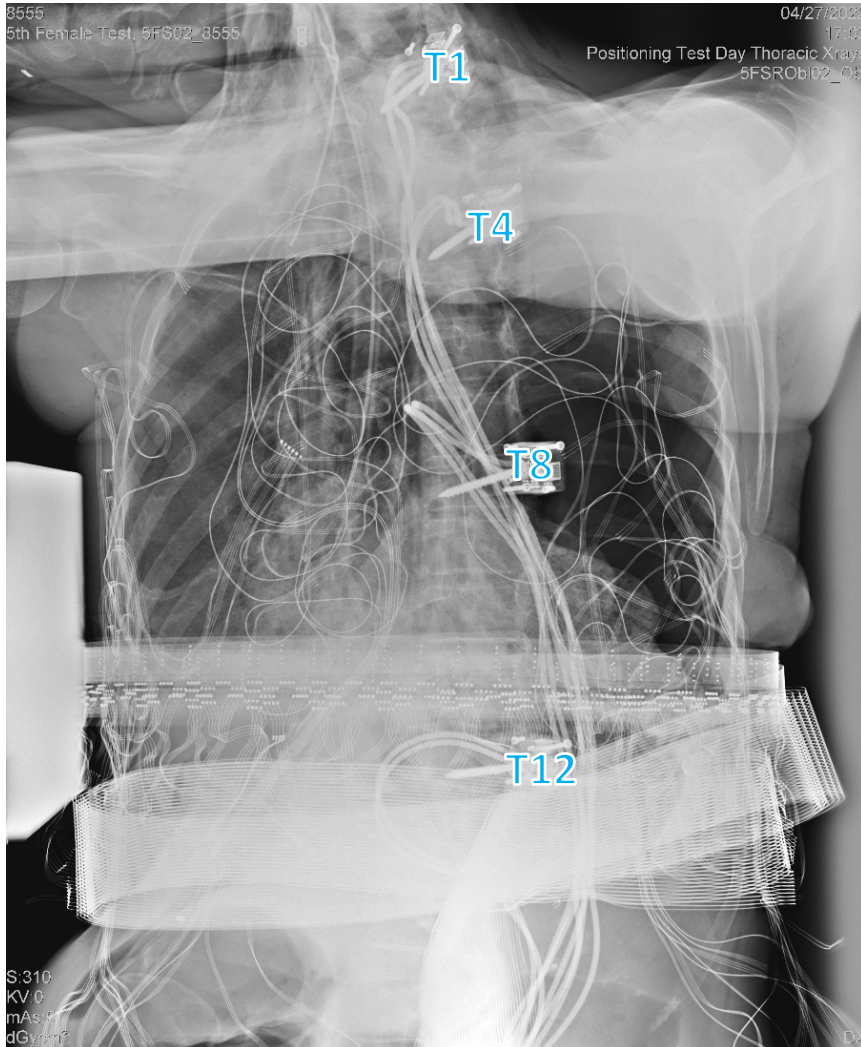


SAE International®
Insert SAE event name here

Shaw et al 2006

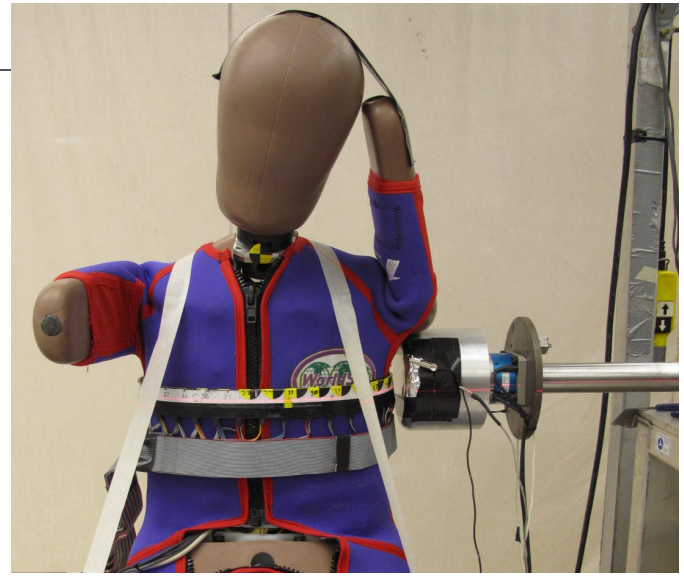


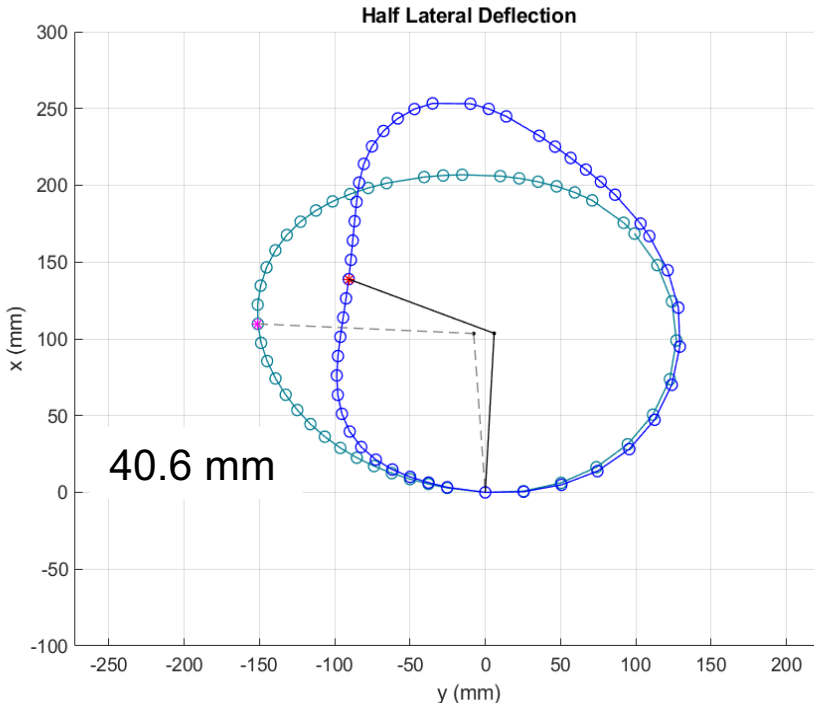
Rhule et al 2011



Force and Deflection Measurements

- Impact force
  - Inertially compensated 6 axis load cell data
  - 14 kg impactor
    - Shaw: 125mm
    - Rhule: 125 x 275mm
- External deflection
  - Chest band





Side PMHS

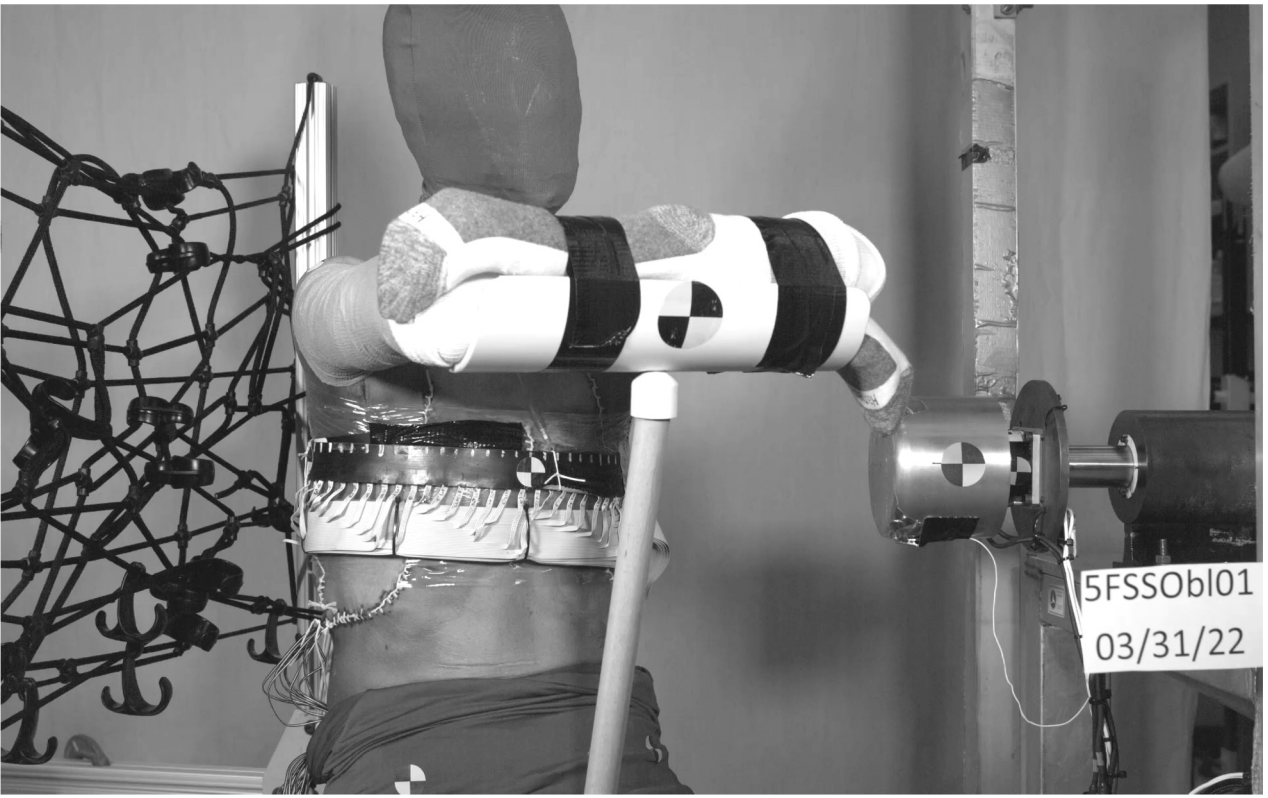
- N=3 small females in each condition
  - Each impacted once in each of 4 conditions

ID	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Chest Breadth (cm)	Chest Circumference (cm)
PMHS 1	53	170.0	48.5	17	28.3	82.0
PMHS 2	69	157.0	44.2	18	24.3	77.3
PMHS 3	63	170.0	51.3	18	26.7	81.6
PMHS 4	68	152.9	43.1	18	24.1	77.9
Mean	**63.5**	**162.5**	**46.8**	**17.7**	**25.9**	**79.7**
***5th Female Target**	**-**	**151.3**	**46.7**	**20**	**26.0**	**79.2**

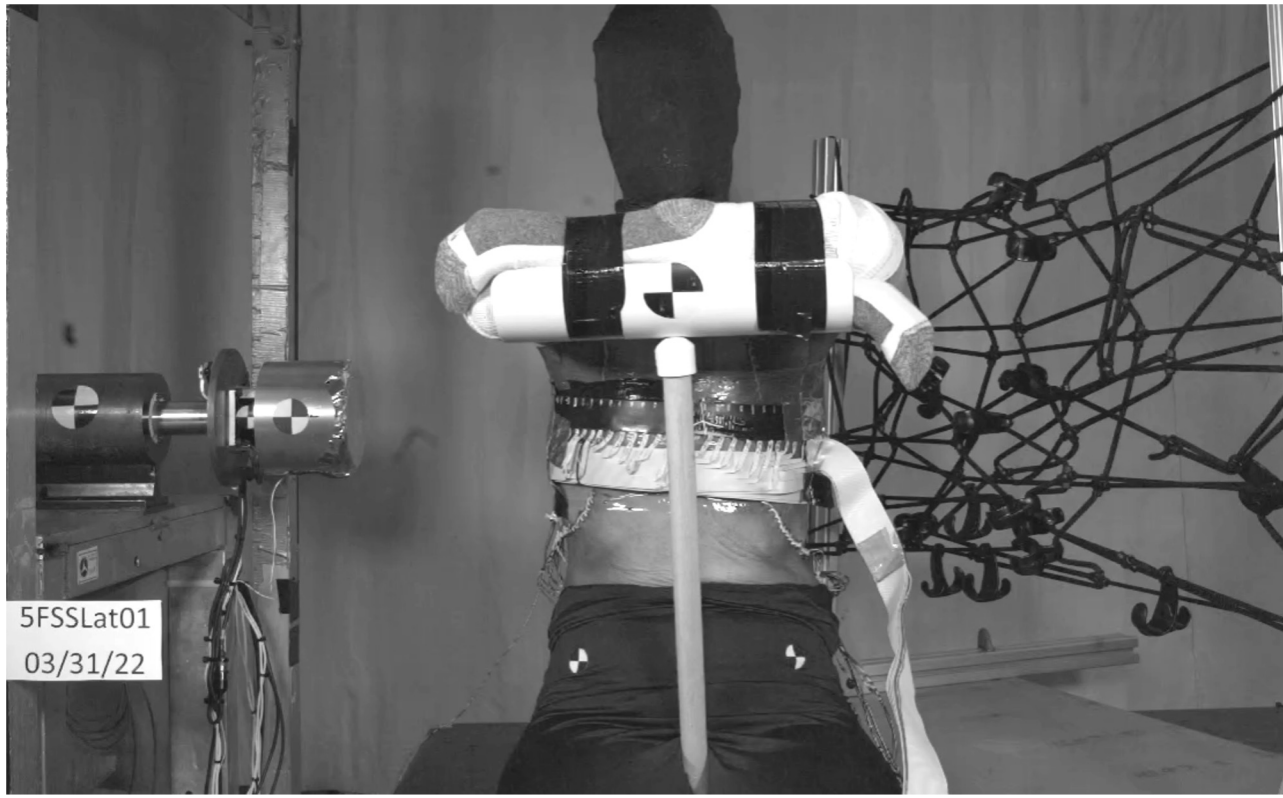
*Mertz et al. 2001

Side Experiment - Shaw

Oblique



Lateral

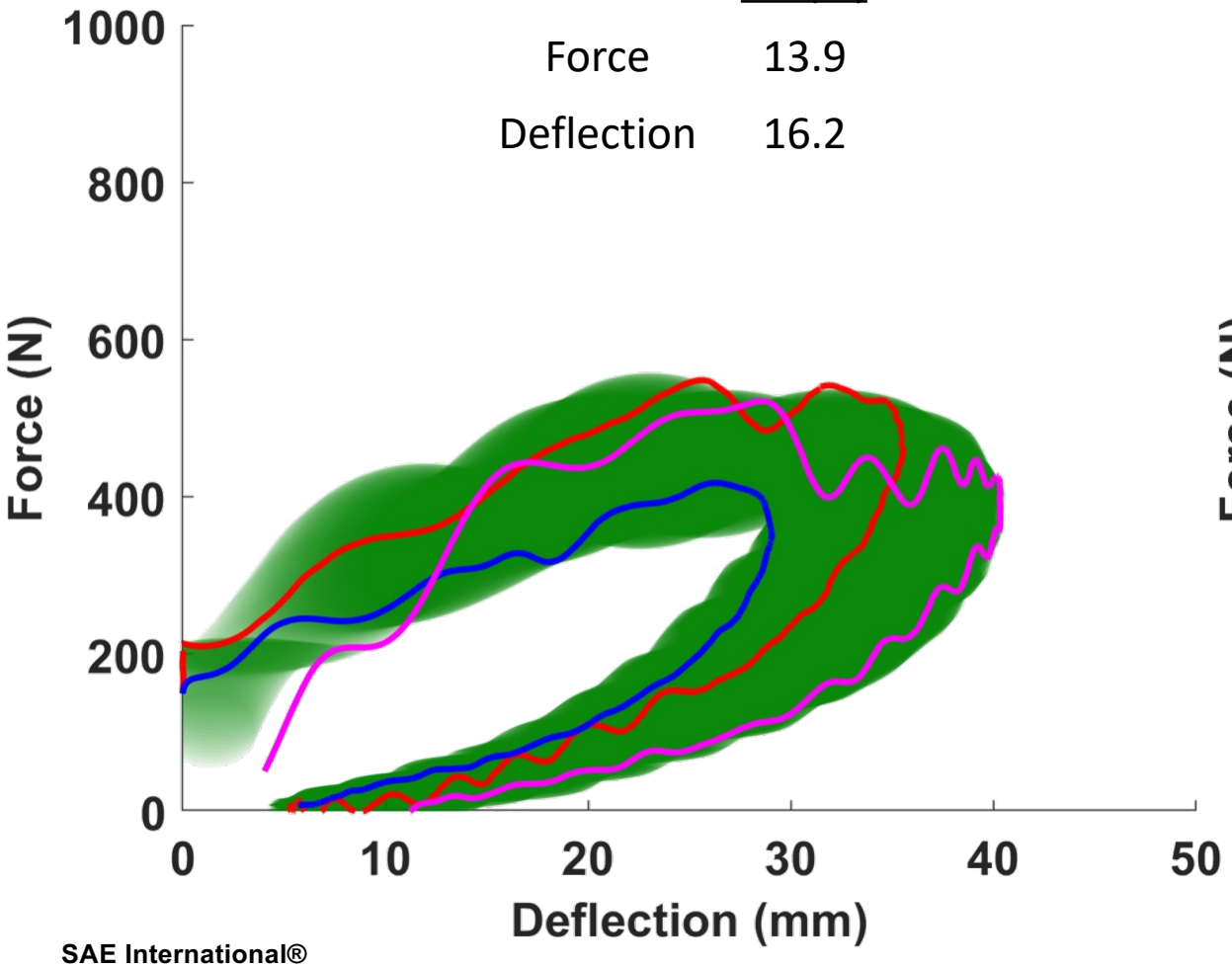


Side F-D Corridors - Shaw

Small Female PMHS

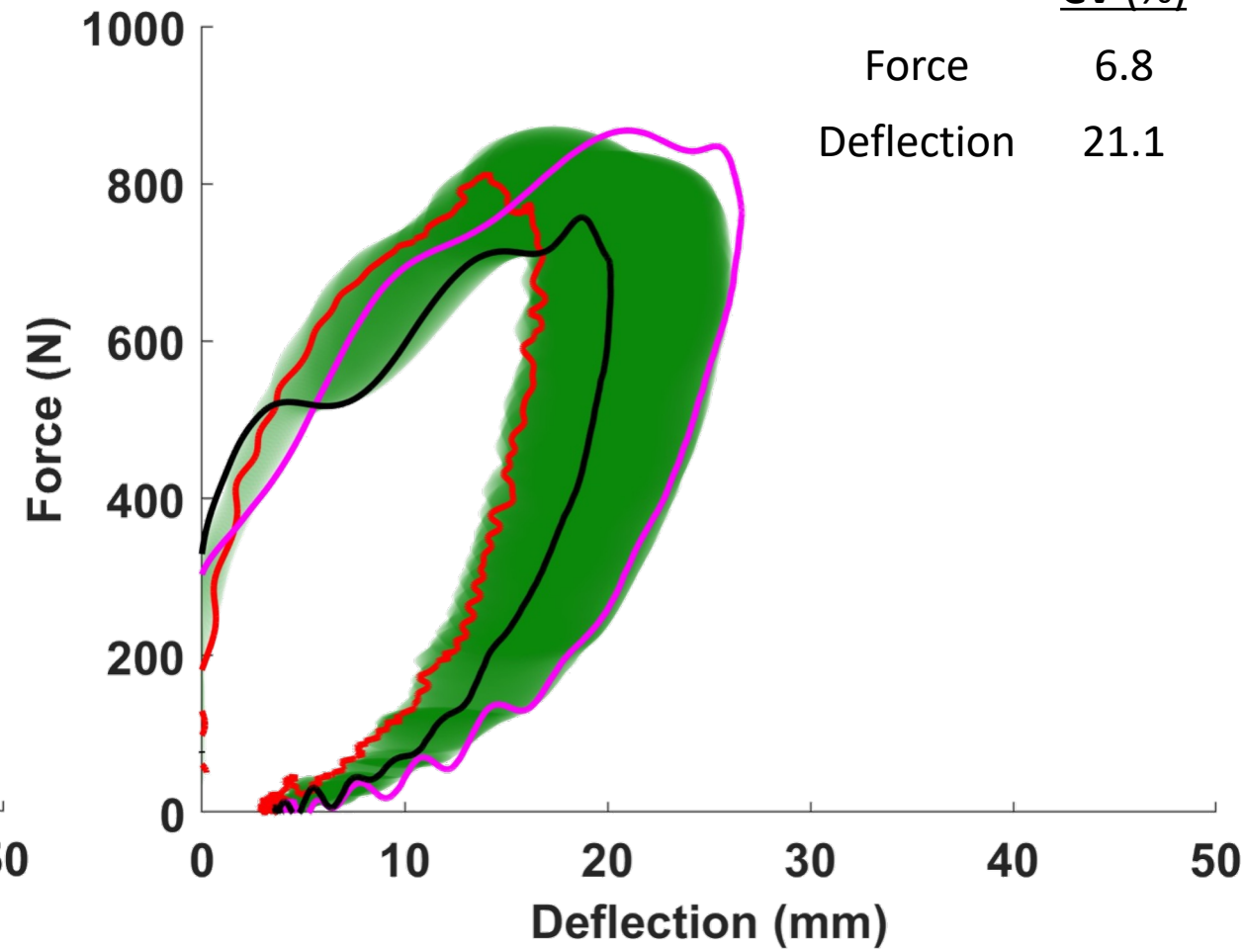
Oblique

	CV (%)
Force	13.9
Deflection	16.2



Lateral

	CV (%)
Force	6.8
Deflection	21.1



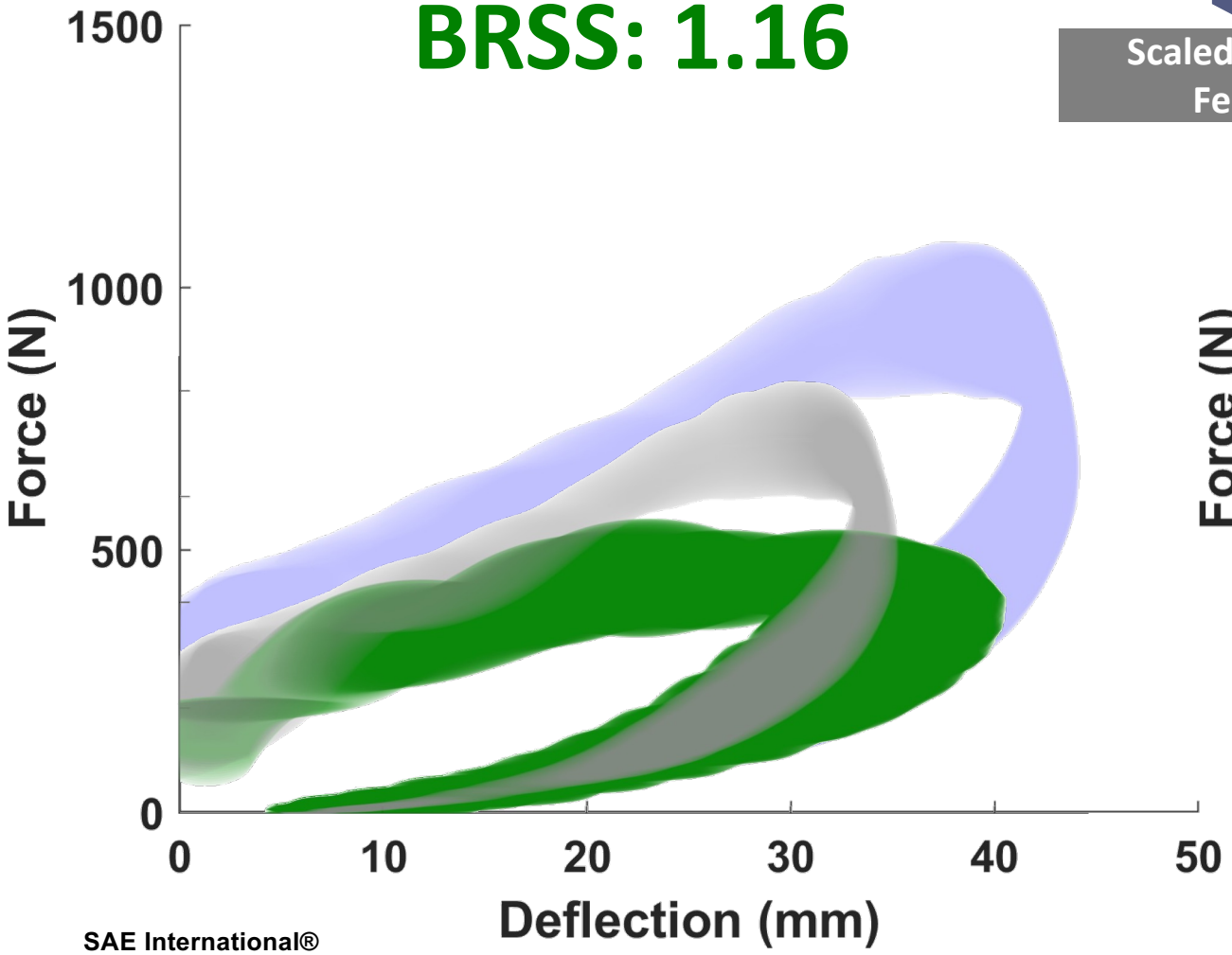
BioRank System Score (BRSS)[Kang et al 2021]
-BRSS <2 indicates good agreement

Side F-D Corridors - Shaw

Small Female PMHS
Mid-Size Male PMHS
Scaled to Small Female

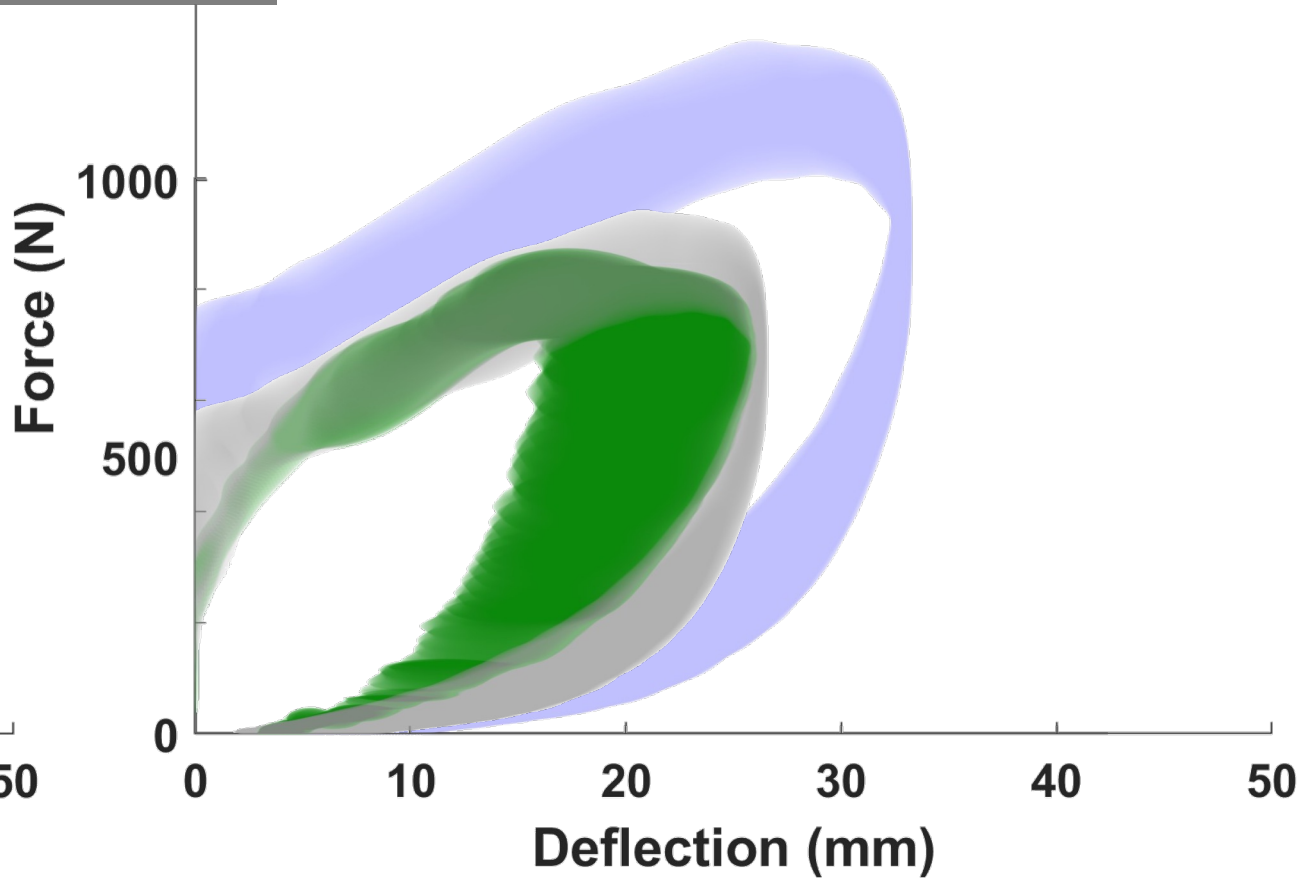
Oblique

BRSS: 1.16

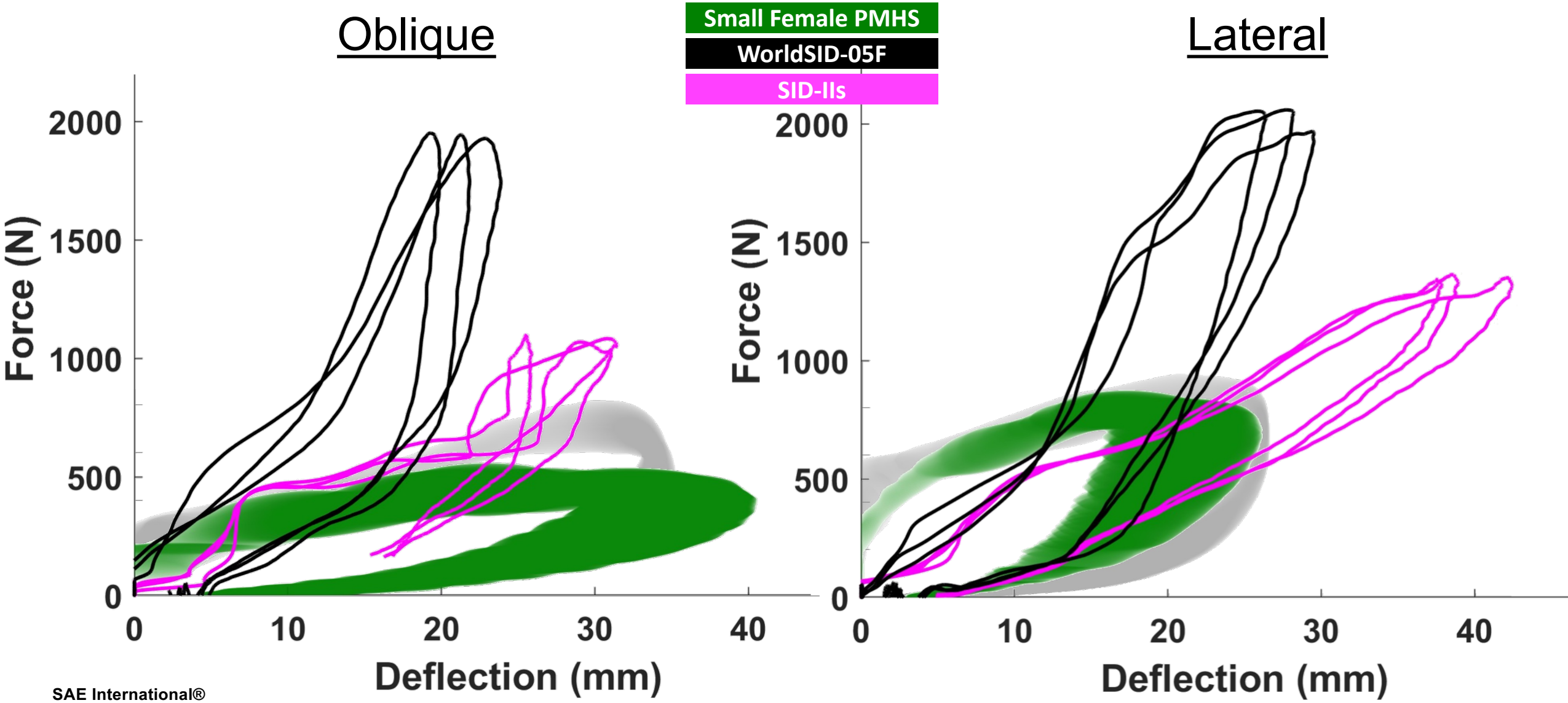


Lateral

BRSS: 1.09



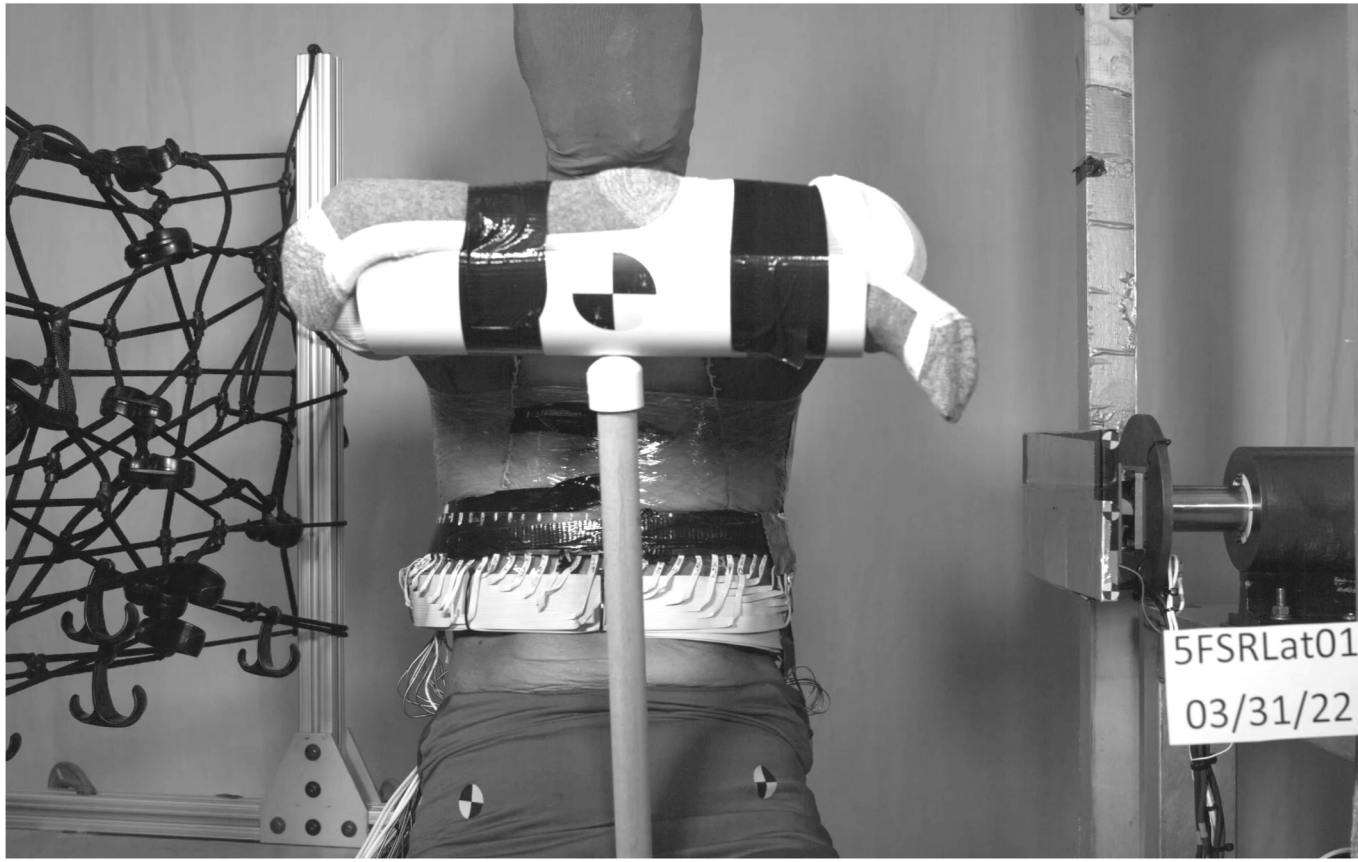
Side ATD Biofidelity - Shaw



Side Experiment - Rhule

Oblique

Lateral

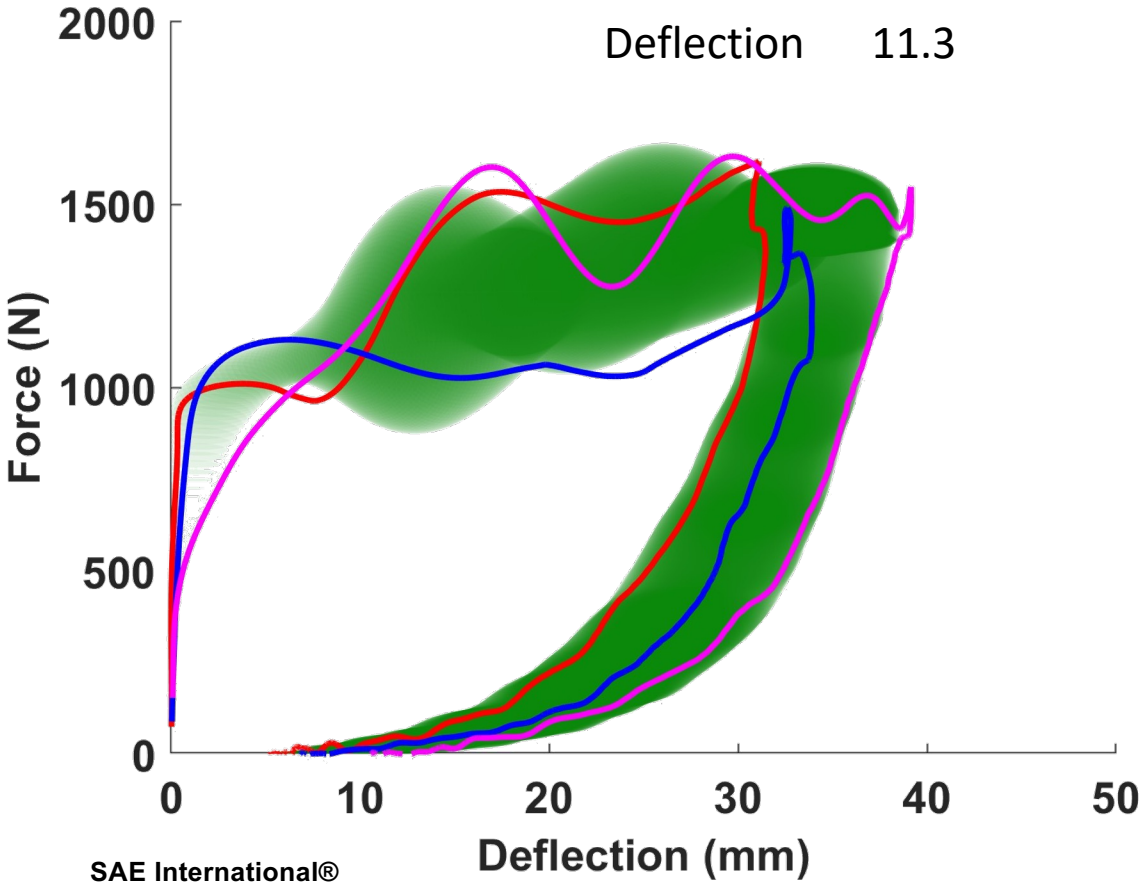


Side F-D - Rhule

Small Female PMHS

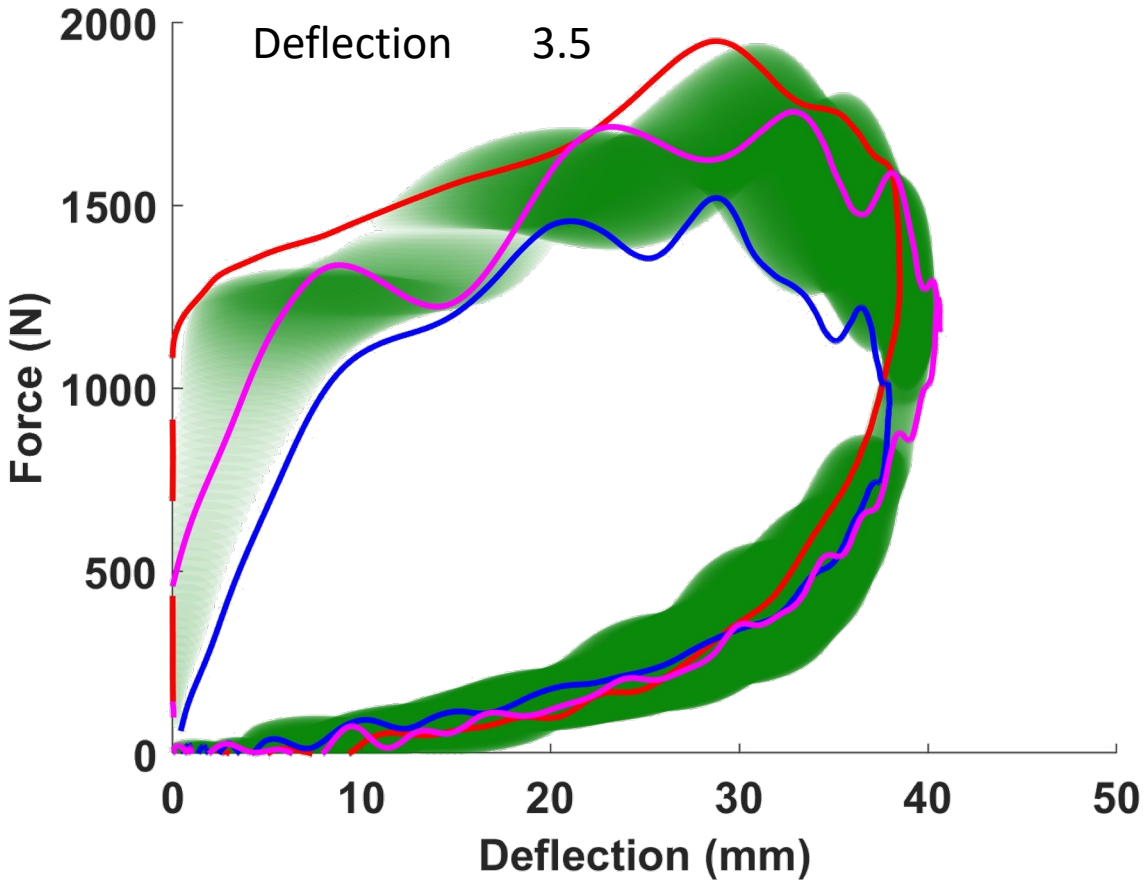
Oblique

	CV (%)
Force	4.9
Deflection	11.3



Lateral

	CV (%)
Force	12.3
Deflection	3.5



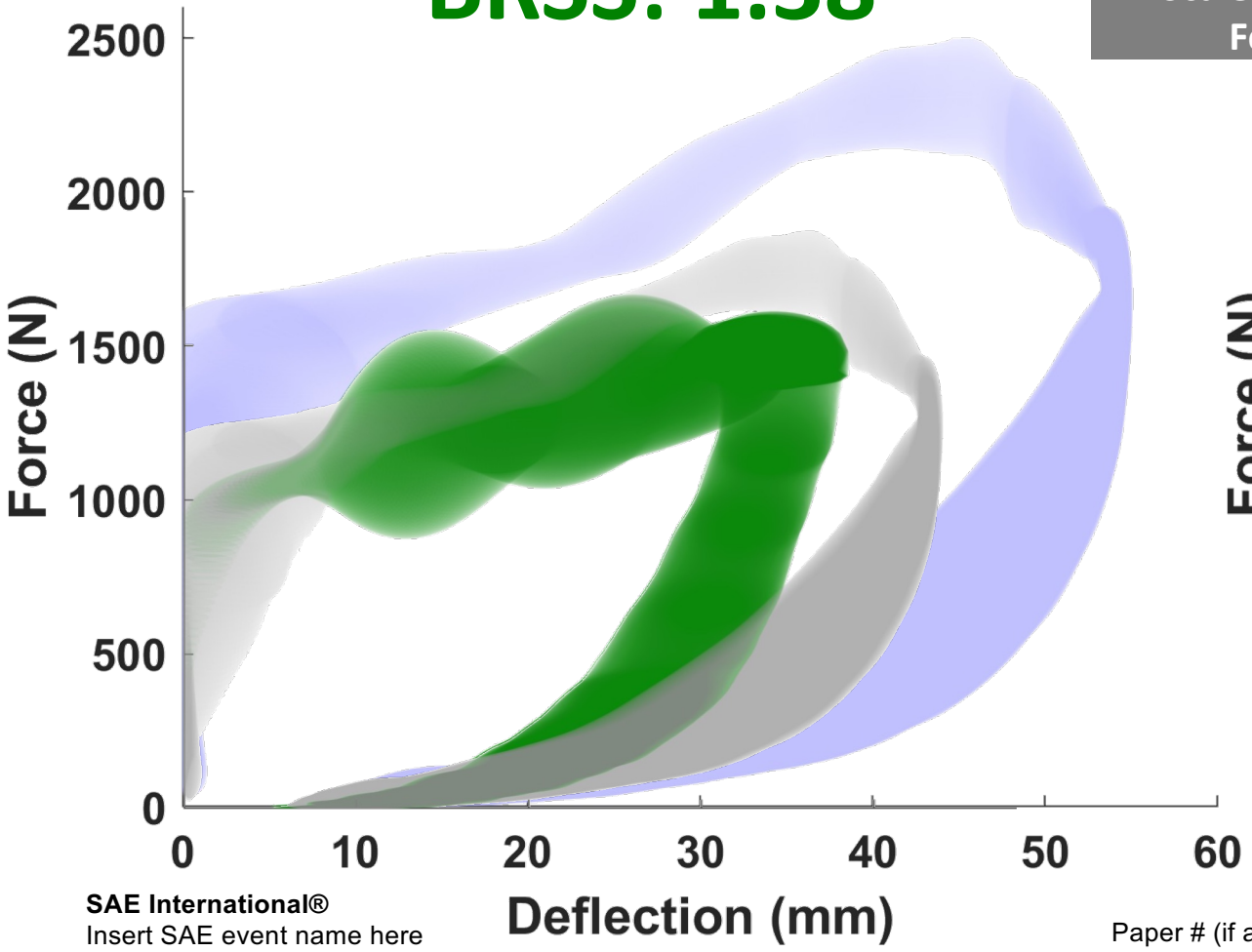
BioRank System Score (BRSS)[Kang et al 2021]
-BRSS <2 indicates good agreement

Side F-D Corridors - Rhule

Small Female PMHS
Mid-Size Male PMHS
Scaled to Small Female

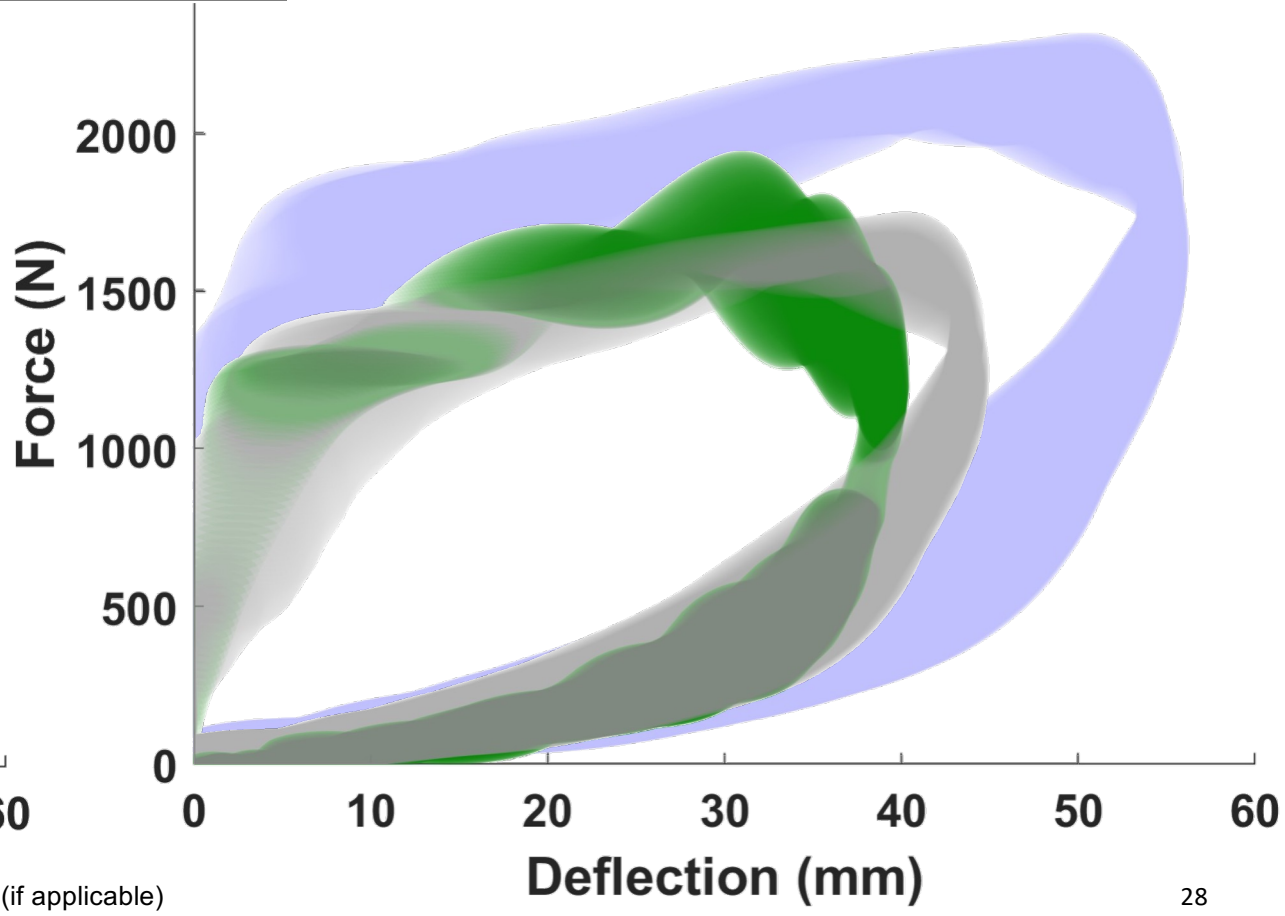
Oblique

BRSS: 1.38

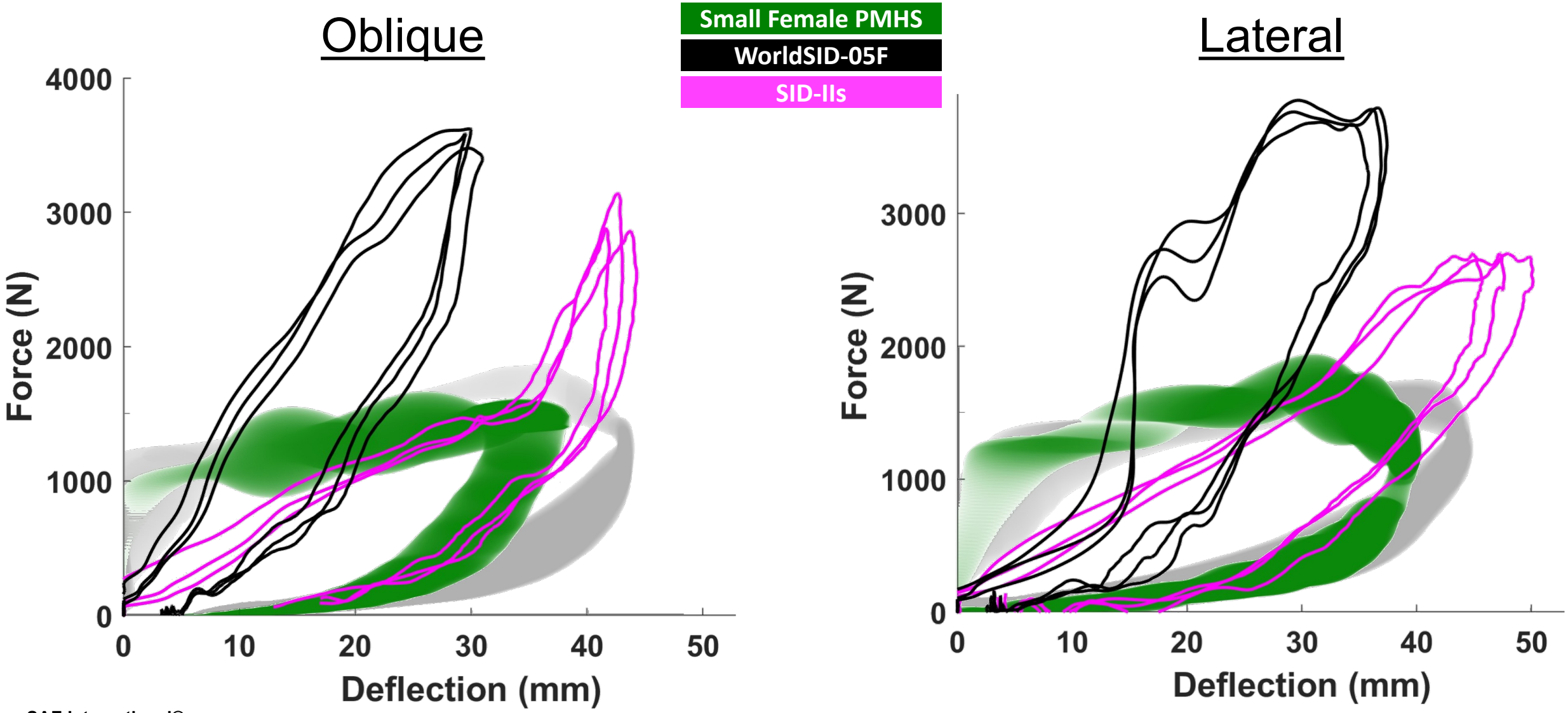


Lateral

BRSS: 0.57



Side ATD Biofidelity - Rhule



Summary & Conclusions

- Small female PMHS thoracic response corridors in simplified impacts
  - Frontal
    - Older and younger PMHS
  - Side
    - Lateral and oblique conditions

- Scaled corridors → good agreement in all conditions
  - Current safety tools typically optimized to scaled corridors

- Female biomechanical data are valuable
  - Improvements to scaling techniques and interpretation of ATD data
  - Improvements to HBMs

Limitations & Future work

- Simplified impacts
  - Future work will focus on more realistic loading scenarios
- Small sample sizes
- Multiple side impacts to PMHS
- Small female data not normalized
  - 50M side data were renormalized and scaled
- Breast tissue removal
  - Focus on skeletal response
  - No scaled corridors accounted for breast tissue
  - Future work will explore the effects of breast tissue on thoracic response and injury

Acknowledgements

Anatomical Donors of…

THE OHIO STATE UNIVERSITY

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TRC Transportation Research Center Inc.

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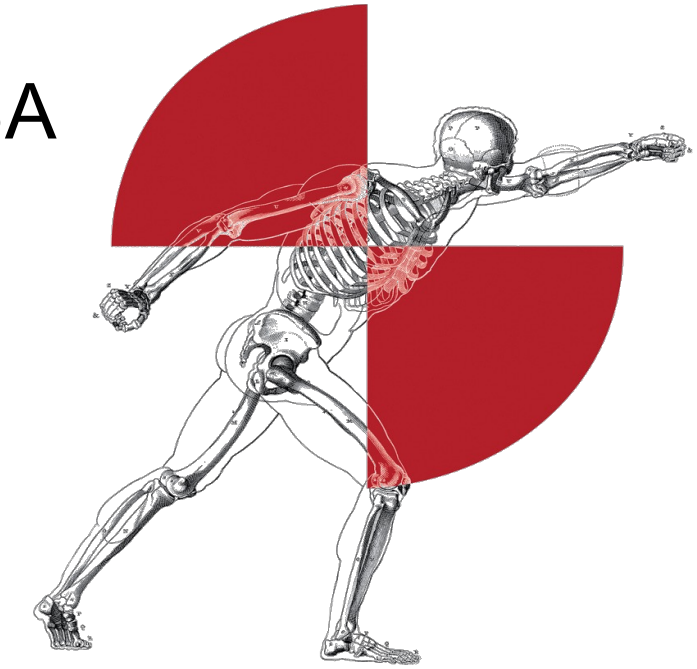

Thoracic Response Corridors of Small Female PMHS in Simplified Frontal and Side Impacts

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