4-Point Thoracic Injury Criteria Development for THOR

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FRIENDLY REMINDER

All material and information presented are the current opinions of the authors only, and **DO NOT** reflect the viewpoints of NHTSA.

Outline

- Evolution and description of the THOR
- Research aims and objectives
- Overview of methodological approaches in describing risk factors associated with thoracic rib injury
  - Finite Element (FE) Modeling
  - THOR sled test configurations
  - Matched cadaveric tests
  - Statistical analyses
- Summary and current status

THOR Test Device for Human Occupant Restraint

UVA THOR Task-work

1992

TAD-50M

2001

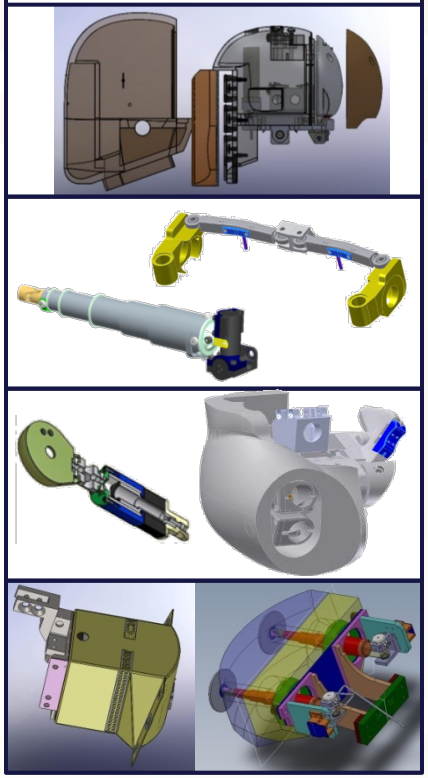
THOR Alpha

2005

THOR-NT

2009-2012

Mod Kit

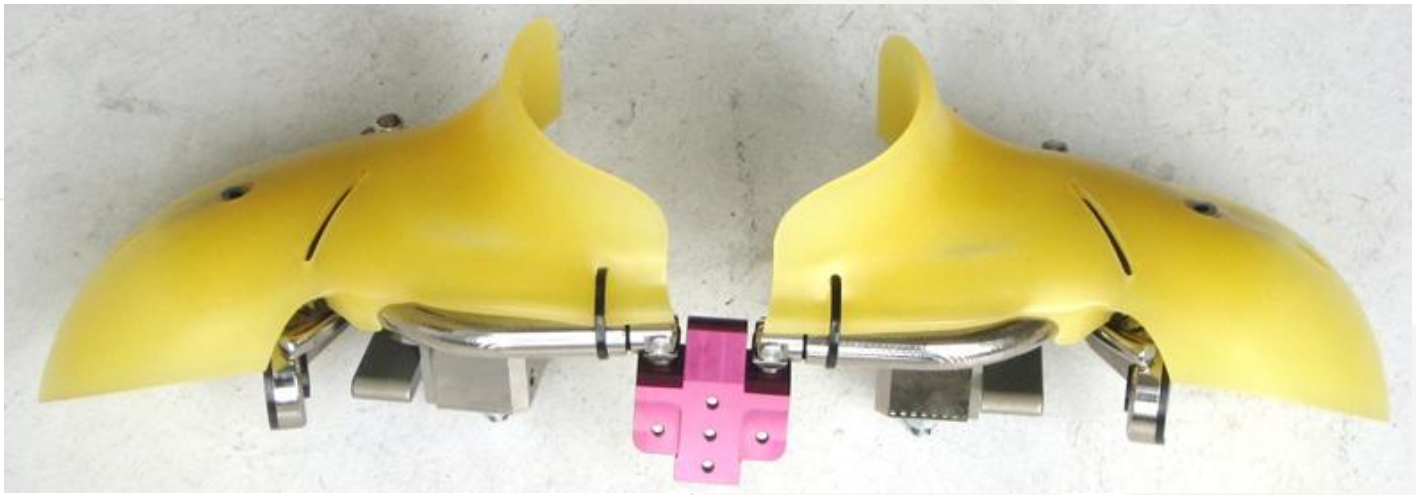


2013

THOR Evaluation

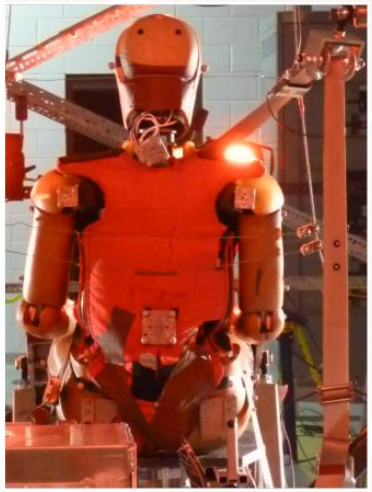
THOR Mod-Kit with SD3 Shoulder Evaluation

June 2012



SD3 Test Results:

Acceptable durability, biofidelity, effect on ribcage deformation



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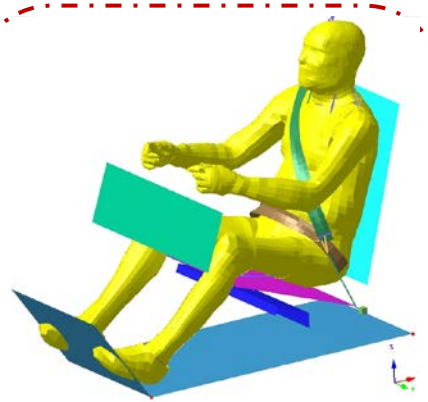
Aims & Objective

- ***Overall Goal***
  - To develop a thoracic injury criterion for THOR that takes advantage of THOR's multi-point, 3D chest instrumentation
  - To develop a chest injury risk function *methodology* for belt and airbag loading in frontal collisions for THOR

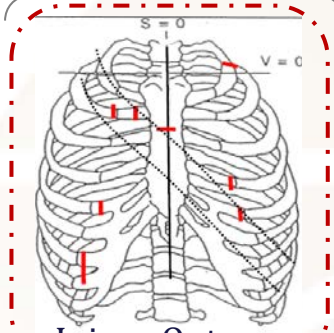
Development of Injury Risk Function

PMHS Sled Tests

FE modeling



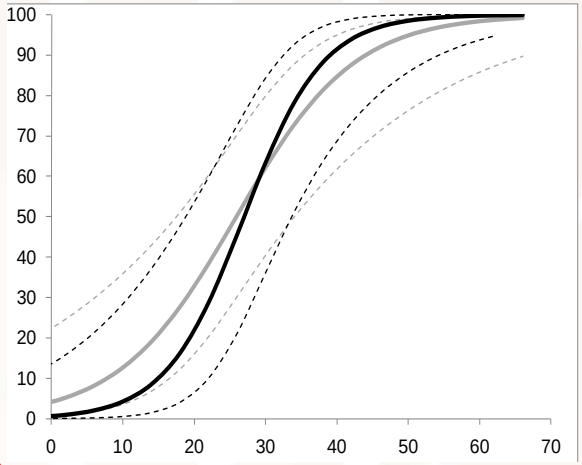
FE used to investigate injury mechanism and identify relevant injury criteria



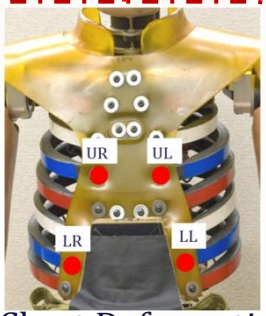
Injury Outcome

Utilize knowledge from FE, predictors from THOR and injury outcome from PMHS

Develop Injury Risk Functions



Matched THOR Sled Tests

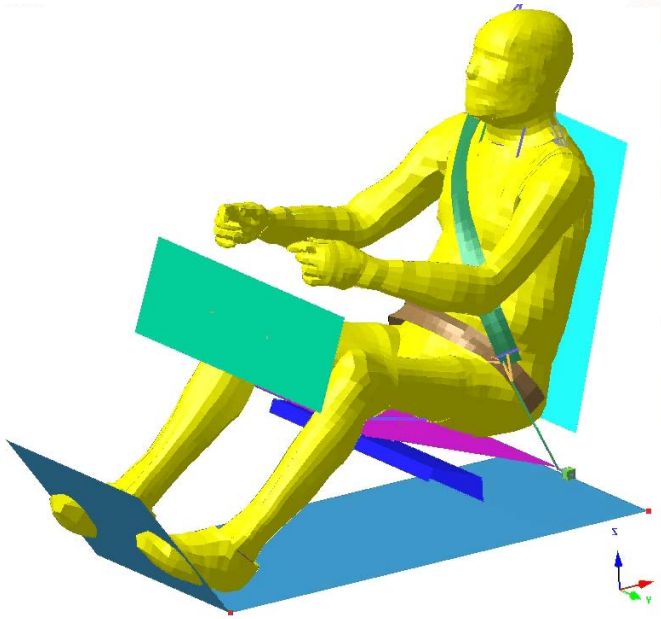


Chest Deformation (from IRTRACCs)

FE Modeling

FE Modeling

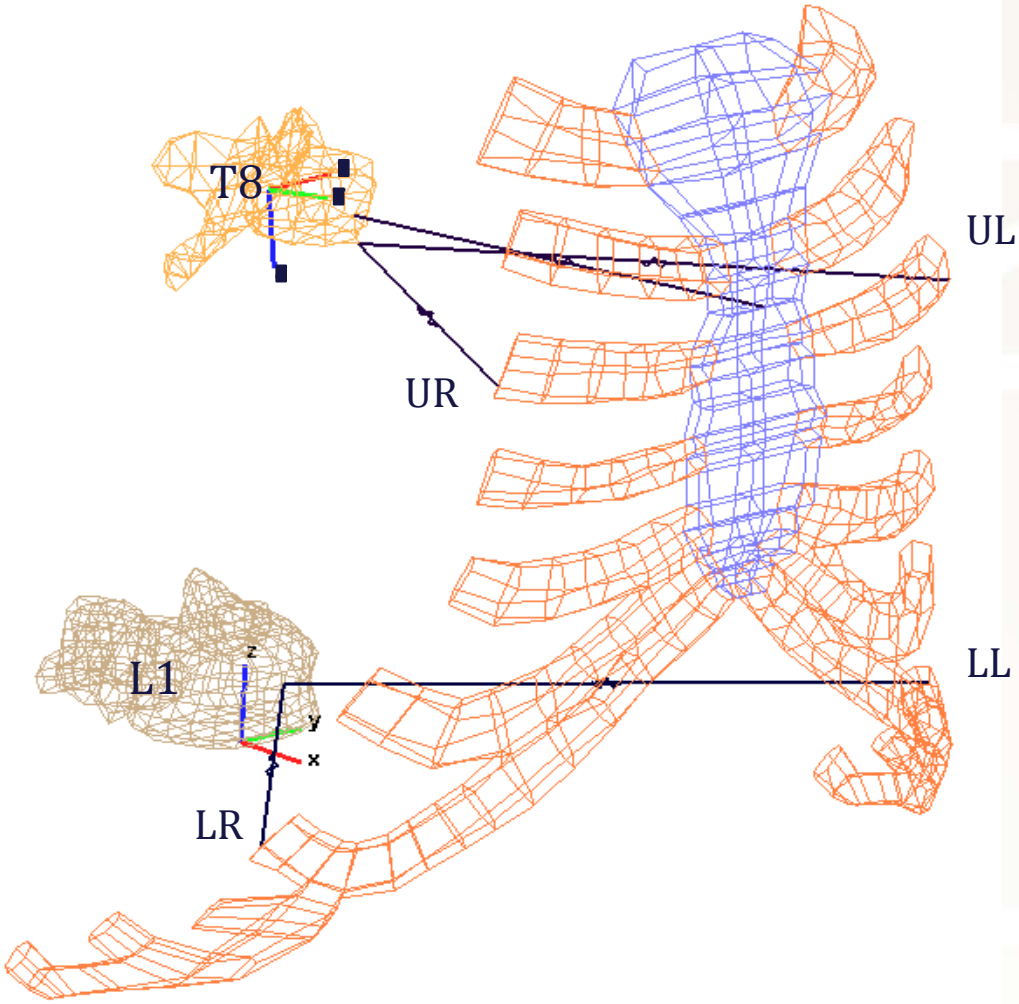
- Goal: Study relation between multi-point chest deflection measurement and rib fracture risk
- Human body model (HUMOS)
- Sled test simulations (Song et al. 2009, Bose et al. 2010)



Test Condition			Sim #
Sled (Belt only)	Sled 40 km/h	3pt Belt, 6 kN FL	6
	Sled 45 km/h	3pt Belt, 6 kN FL	7
	Sled 50 km/h	3pt Belt, 6 kN FL	8
Sled (Belt + AB)	Sled 40 km/h	3pt Belt + AB, 4kN FL	9
	Sled 50 km/h	3pt Belt + AB, 4kN FL	10
	Sled 60 km/h	3pt Belt + AB, 4kN FL	11
Sled (AB only)	Sled 40 km/h	AB only	12
	Sled 45 km/h	AB only	13
	Sled 60 km/h	AB only	14

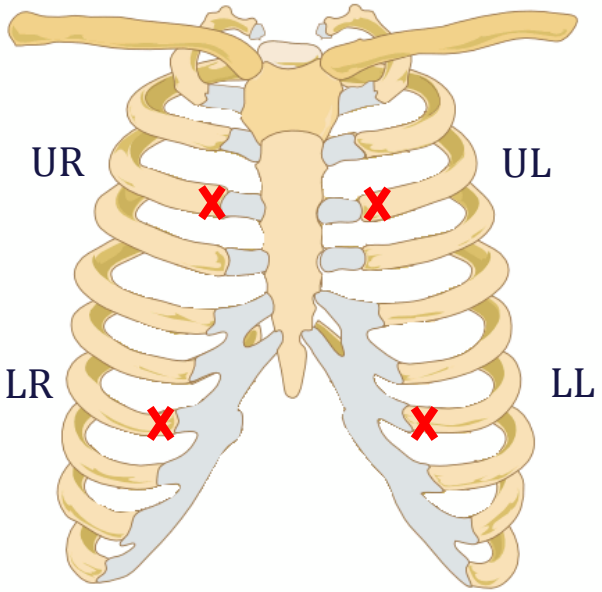
FE Modeling

- **Chest deflection measures**



3rd and 7th rib deflection along A-P direction

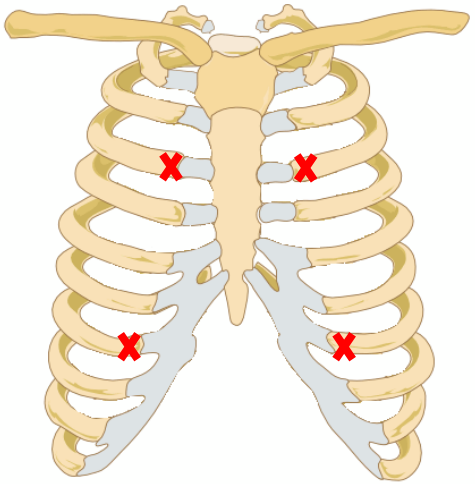
Resolved into X, Y, Z components (and resultant)

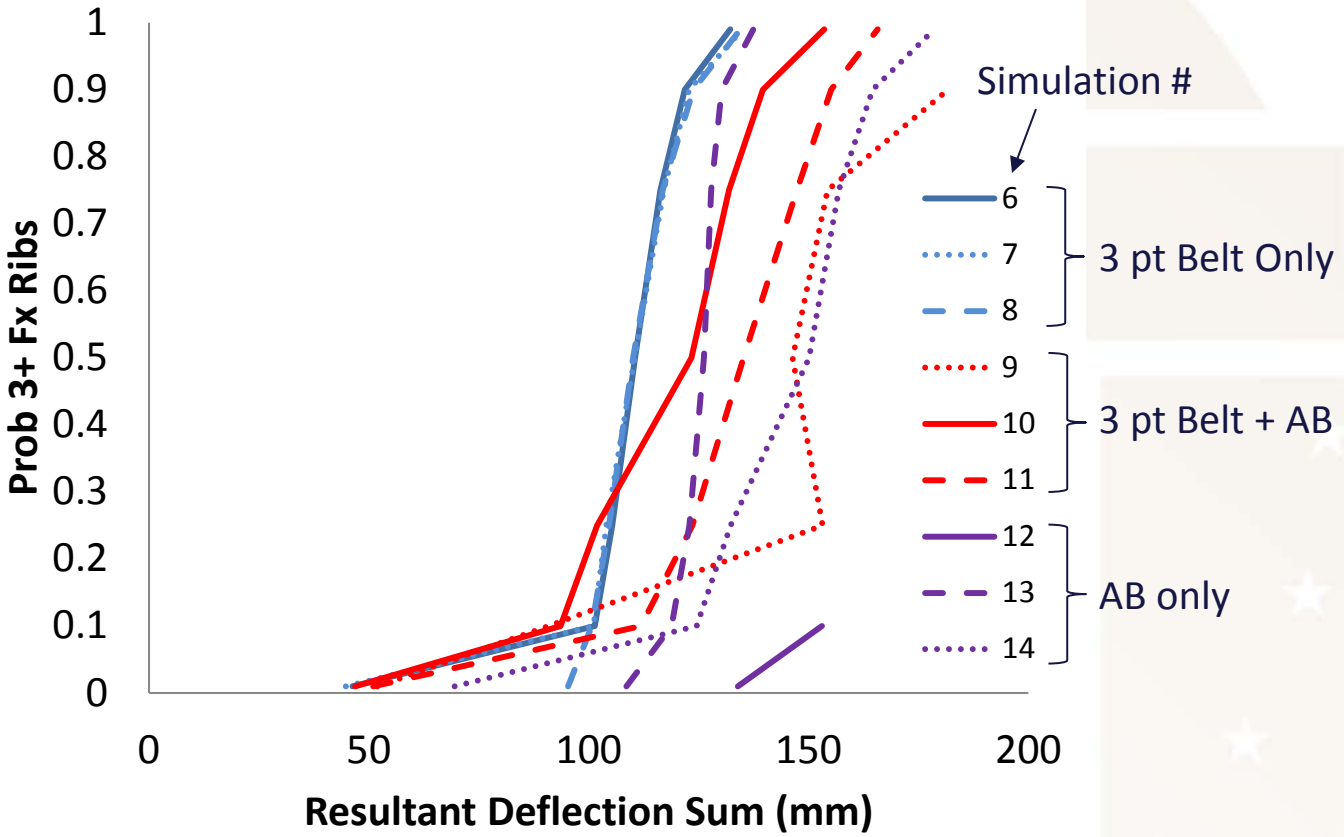


FE Modeling

- ***Analysis of whole ribcage***

Probability of 3+ fractured ribs based on rib strain (*Forman et al., 2012 AAAM*)





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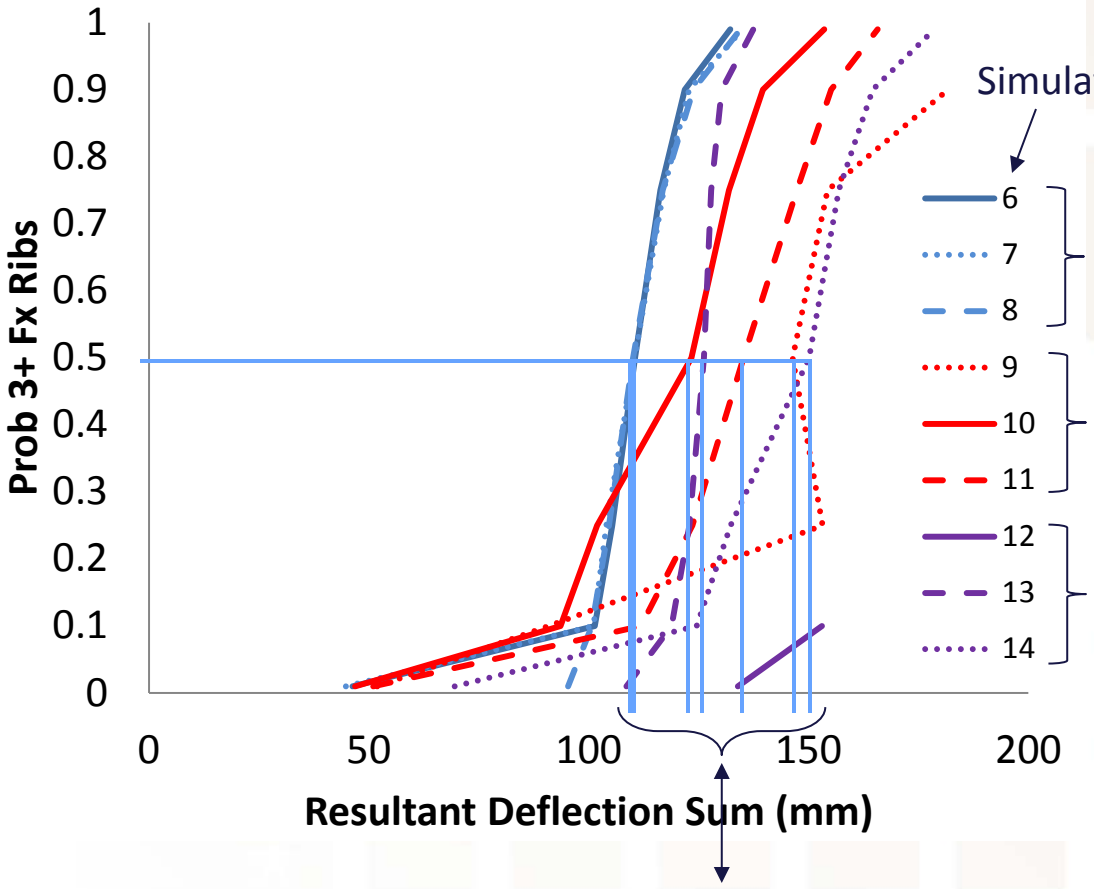
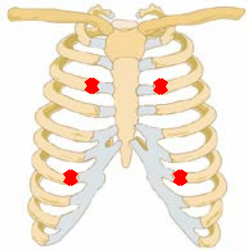


P_{50} Coefficient of Variation

$$CV50 = SD_{P50} / Mean_{P50}$$

FE Modeling



- ***Analysis of whole ribcage***

Independent Variable	CV50
X-Deflections	
Deflection sum	0.356
Max deflection	0.190
Combined X Deflection	0.178
Resultant Deflections	
Deflection sum	0.127
Max deflection	0.144
Combined Res. Deflection	0.110

- Resultant generally produces more consistent risk prediction
- Most consistent multi-point predictor:
  - Combined Resultant Deflection (11% P_{50} coefficient of variation)

THOR
Sled Tests

Testing Conditions

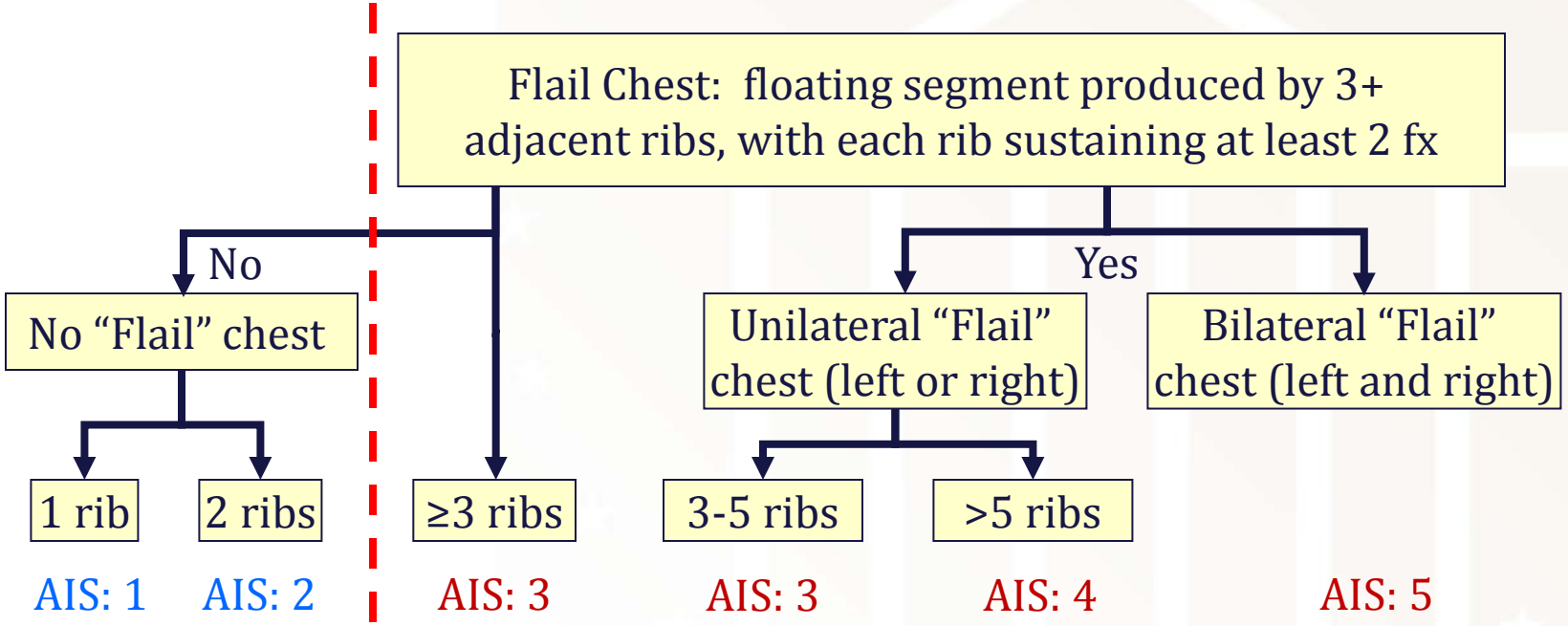
- Tests with THOR dummy matched to 38 ***frontal impact*** cadaver sled tests performed at UVA
  - Variations on position, restraint type, Delta-V, and buck

Occupant Position	Buck	Restraint	FL nominal	Delta V	PMHS Info Average Age	PMHS Info Age Range	N
Front Driver	Gold Standard Driver	3 point standard belt	--	10	62.7	59-69	3
			--	40	62.7	59-69	3
Front Passenger	97 Ford Taurus	3 point belt with FL + AB	4000	48	63.8	57-72	4
		Lap belt with AB	--	48	52.0	40-70	2
		3 point standard belt with AB	--	48	61.0	55-69	3
		3 point standard belt	--	29	44.0	39-49	3
			--	38	44.0	44	1
	Gold Standard 1	3 point standard belt	--	40	54.0	37-76	8
	Gold Standard 2	3 point belt with custom FL	3000	30	62.5	59-66	2
Rear Passenger	04 Ford Taurus	3 point standard belt	--	48	55.0	51-57	3
		3 point belt with FL + PT	3000/4400	48	69.3	67-72	3
		3 point belt with FL + PT + belt bag	2500	48	60.3	40-72	3

THOR
Injury Risk Function Development

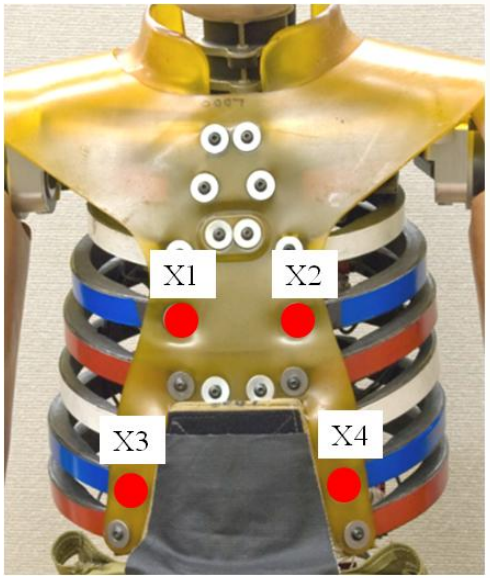
Outcome of Interest – Rib Fracture

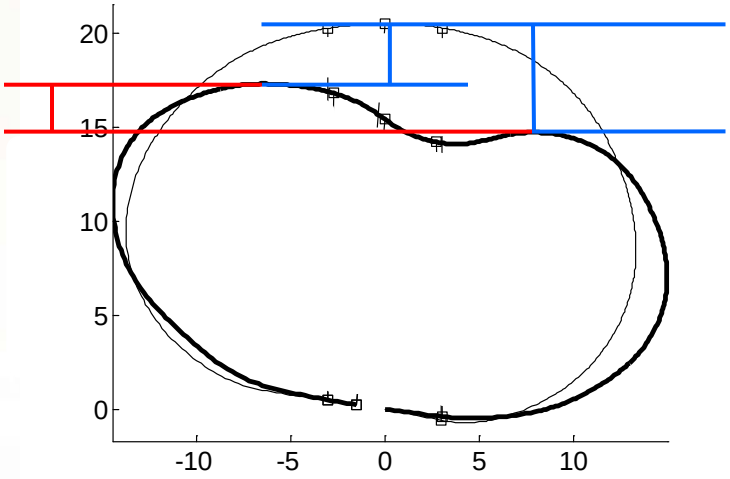
- Dependent variable: – Thoracic rib fx, AIS 3+ severity
  - Dichotomous term, using AIS 2005 ('08 update) coding definitions
  - Includes costal cartilage



Primary Independent Variables

- Chest deflection (*X, d, and resultant deflections*)
  - Total upper max deflection
  - Total lower max deflection
  - Total max deflection
  - EU's THORAX dc metric
  - Upper max L/R difference
  - Lower max L/R difference
  - Max peak deflection
  - UV_A deflection score *(via principal components)*





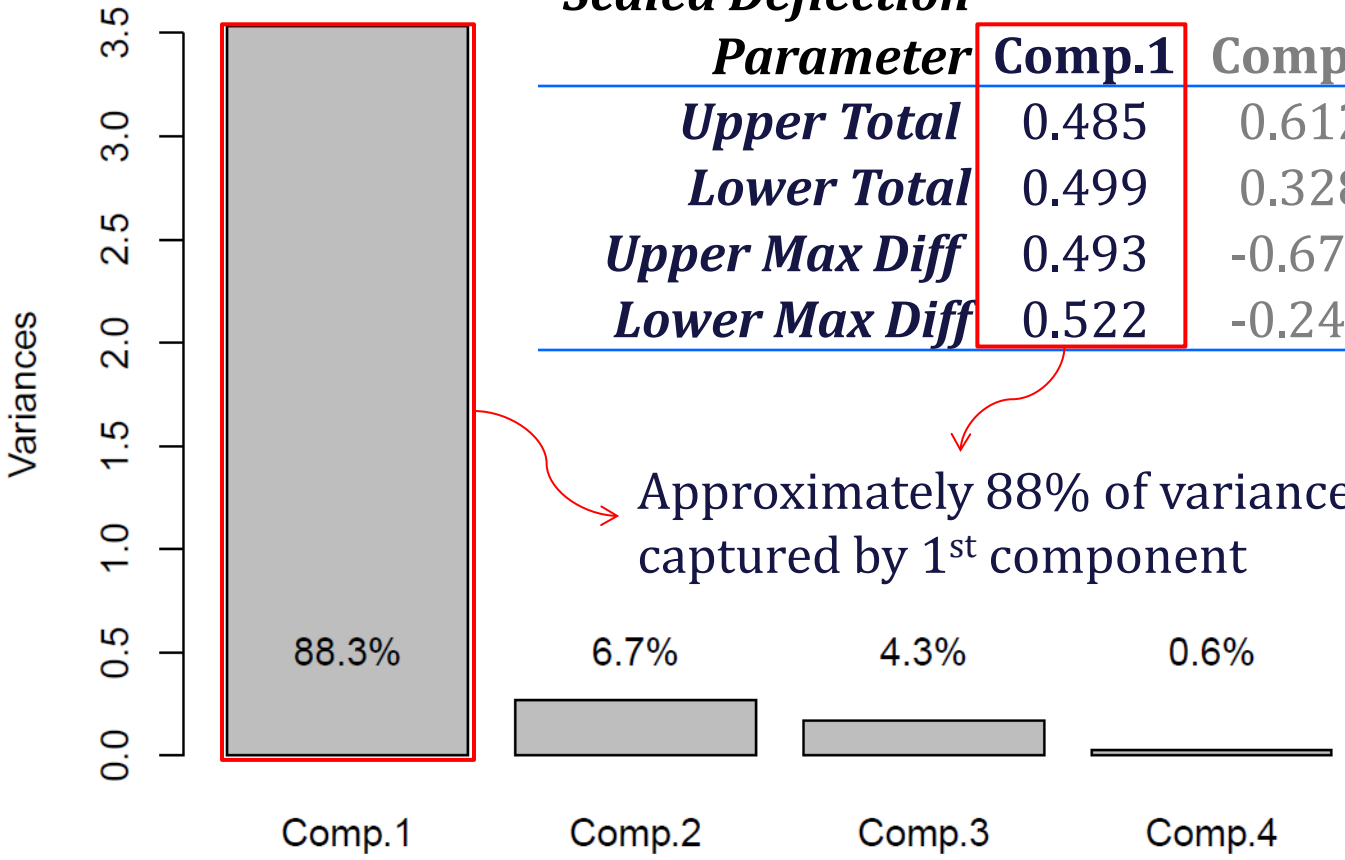
Principal Component Analysis (PCA)

- A variable reduction procedure
  - Reduce the dimensionality of the observed deflection patterns
    - Develop a smaller number of derived variables (called principal components) that will account for most of the variation in the observed deflections
  - Linear combination of weighted input variables
  - Prevents issues of collinearity
- Resulting score can be used as a predictor variable in subsequent analyses

PCA Weighting Results

- Results suggest a relatively equally-weighted combination of the components

Scaled Deflection Parameter	Comp.1	Comp.2	Comp.3	Comp.4
Upper Total	0.485	0.612	-0.624	-0.026
Lower Total	0.499	0.328	0.724	-0.346
Upper Max Diff	0.493	-0.678	-0.261	-0.479
Lower Max Diff	0.522	-0.246	0.135	0.806



Approximately 88% of variance captured by 1st component

Statistical Modeling

- Outcome
  - AIS 3+ (AIS 2005)
- Chest deflection measures (*X, d, and resultant)*
  - Total upper deflection
  - Total lower deflection
  - Total max deflection
  - EU's THORAX dc metric
  - Upper max difference
  - Lower max difference
  - Max peak deflection
  - UVA deflection score
- Modeling Strategies
  - Logistic regression
  - Parametric survival analysis
    - Accelerated failure time with Weibull distribution that accounts for repeated measures
  - Univariate and age-adjusted

Outcomes

- Methodological approach for:
  - Better understanding and describing rib strain and patterns of deflection within THOR dummy
  - Statistical analyses for maximizing the utility of PMHS and dummy data
- Injury risk function that can be applied to frontal crash testing conditions
  - *With appropriate restraint configurations*
- Risk curve generation and interpretation
- Comparisons to previously published risk functions
- Research report
  - Findings are currently under review by NHTSA

Questions?