Investigation of Traumatic Rupture of the Aorta (TRA) Using Simulated Real-World Accidents Involving Aortic Injuries

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Traumatic Rupture of the Aorta (TRA)

- Second most common cause of death (Sauaia et al. 1995)
- 70 % TRA from motor vehicle crashes (MVC) (Burkhart et al. 2001)
- 45% frontal, 22.5% side impact MVC (McGwin et al. 2003)
- Rate of TRA in near-side impact was found to be twice that in frontal MVC (Steps 2003)
- Elderly occupant, higher delta-v, higher crush increase risk of TRA (Steps 2003)

TRA – FE Modeling

- Shah et al. (2001)
  - FE thorax model, pendulum impact from number of directions, high stress in peri-isthmic region
- Shah et al. (2004)
  - Whole-body model with integration of component models
- Shah et al. (2005)
  - Feasibility of simulating real-world accidents for investigating TRA using FE

TRA - Summary

- MVC is a major cause of TRA
- Retrospective studies and laboratory experiments have yielded limited information
- FE simulations of real-world MVC will provide insight for designing future experiments aimed at elucidating the mechanisms of TRA

Simulation of real-world accidents that involve aortic injury to occupants, and to analyze stress and strain within the aorta

Methods

- Four real-world aortic injury cases obtained from NASS database
- Case selection criteria
  - **Gender: male**
  - **Height: 170-180 cm**
  - **Weight: 68-82 kg**
  - **Crush deformation (<70 cm)**
  - **Delta-V (<50 km/hr)**
  - **No catastrophic deformation**

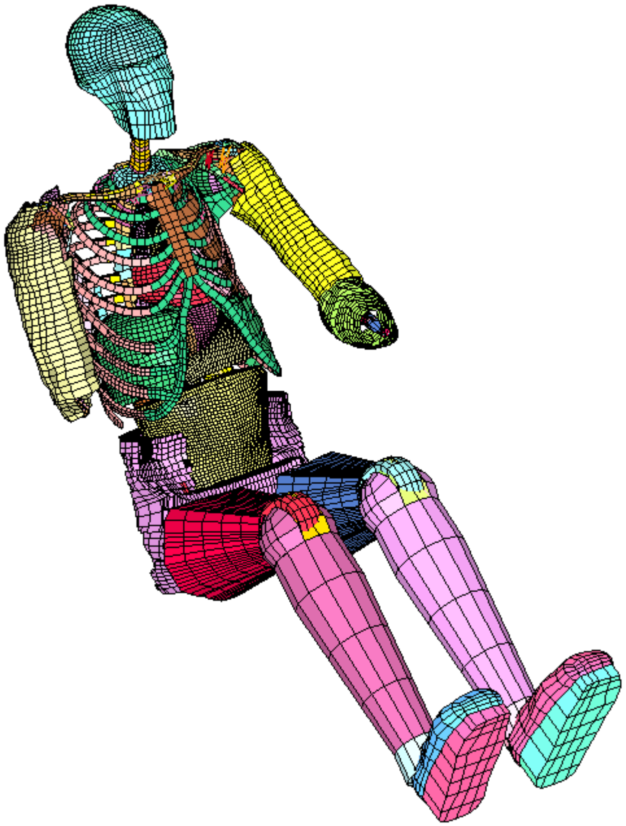
Methods

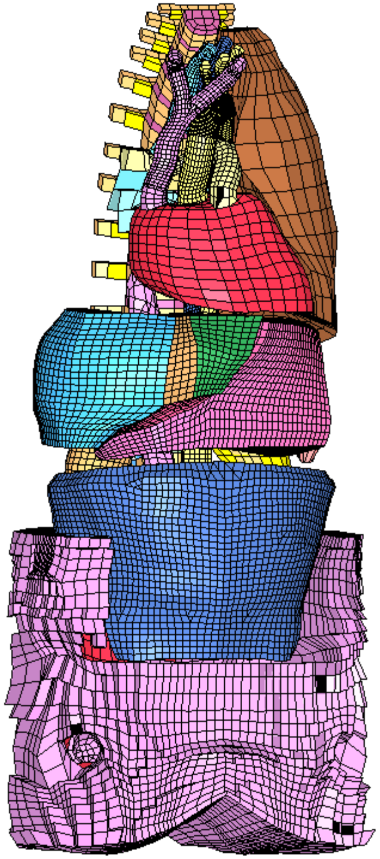
- Phase 1
  - Car-to-car simulation
  - Kinematics of selected structures recorded and saved for phase 2 simulation
- Phase 2
  - Application of previously recorded kinematics of structures
  - Occupant interaction with selected vehicle interior structures

Methods

- FE vehicle models from NCAC
- Case vehicle or POV not available: used closest dimensional representation
- Scaled, mass adjusted at CG
- Occupant model Wayne State whole-body human FE model

Whole-body Human FE Model





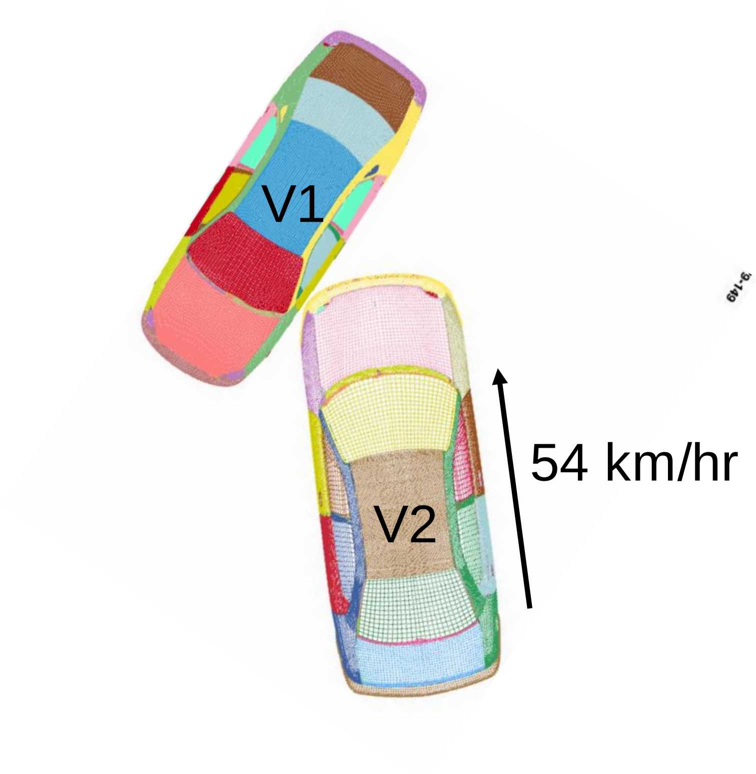
Side Impact (S1)

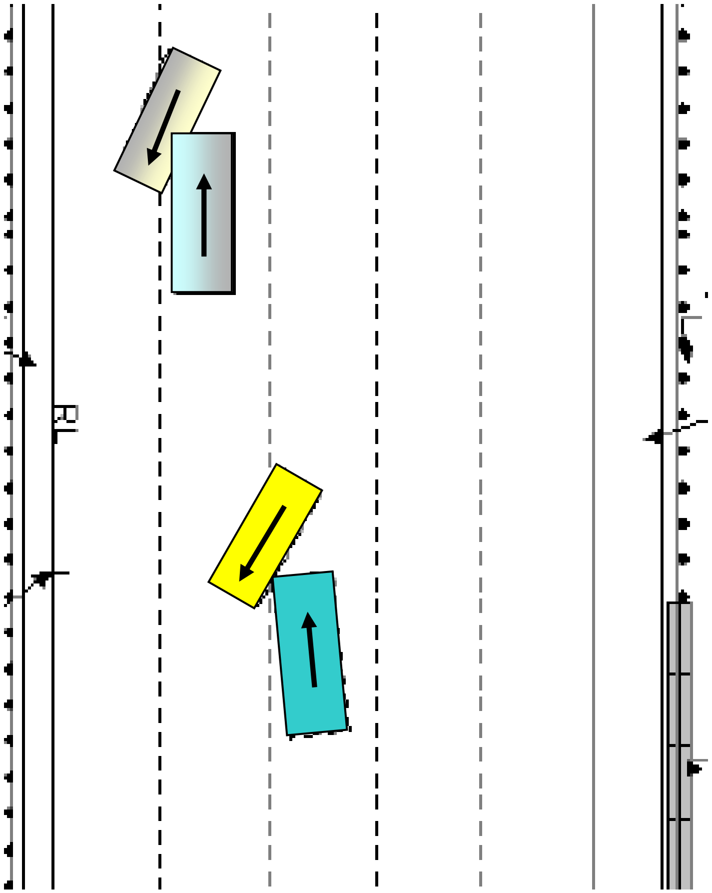
V1 Occupant

Male, 28 , 180 cm, 68 kg

No restraints, Airbag deployed

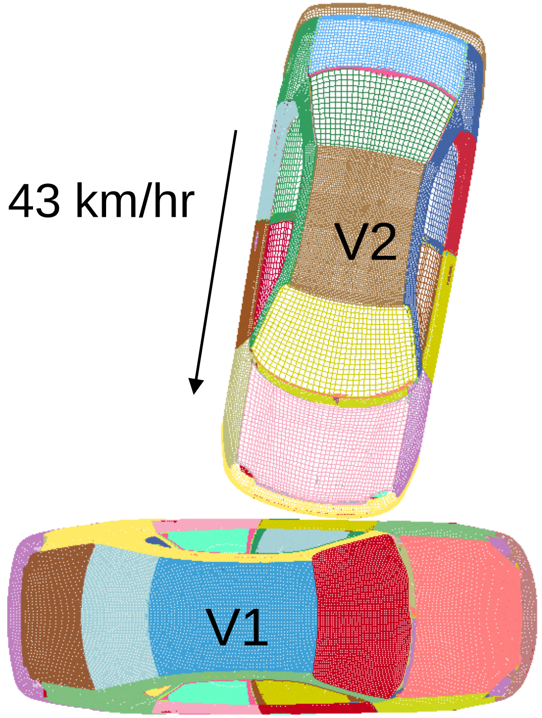
AIS 5 aortic injury

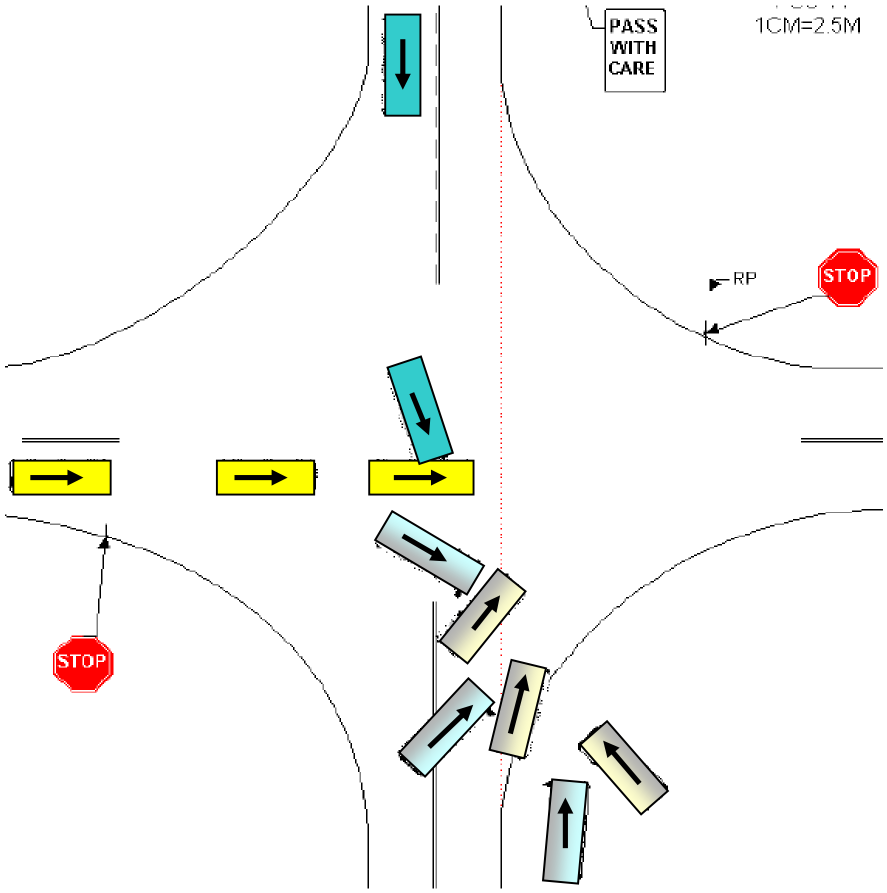




Side Impact (S2)

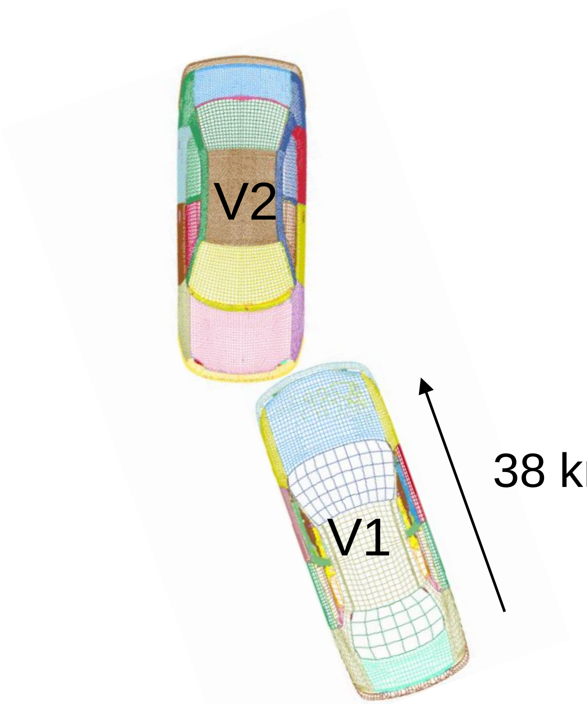
V1 Occupant
Male, 58, 155 cm, 68 kg
Lap belt, No airbag
AIS 4 aortic injury, fatal

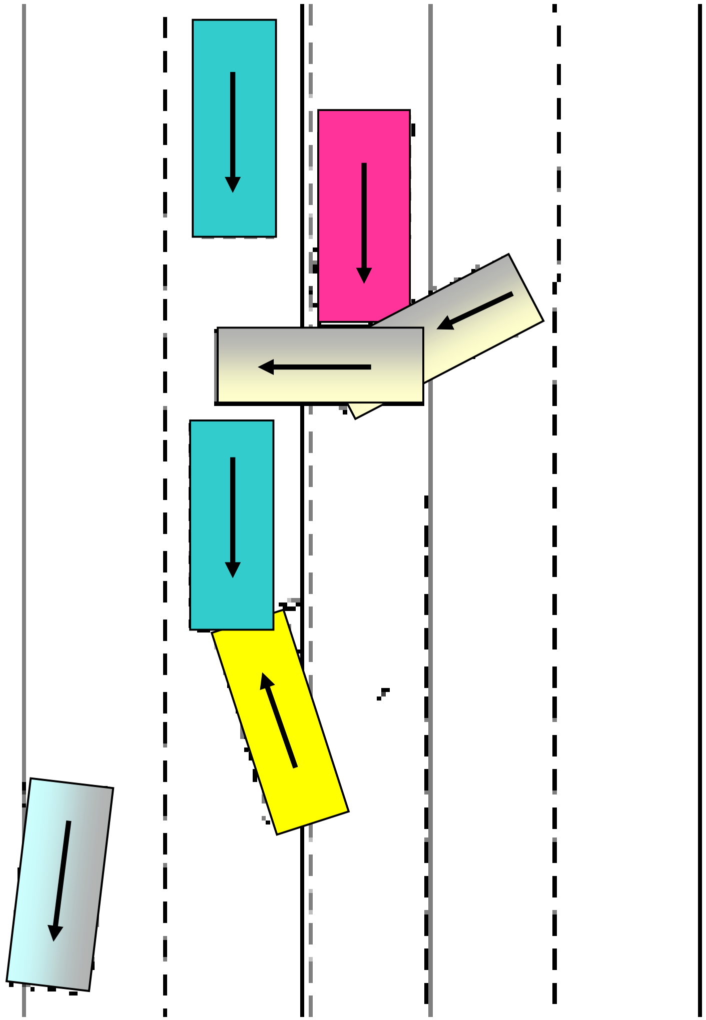




Frontal Impact (F1)

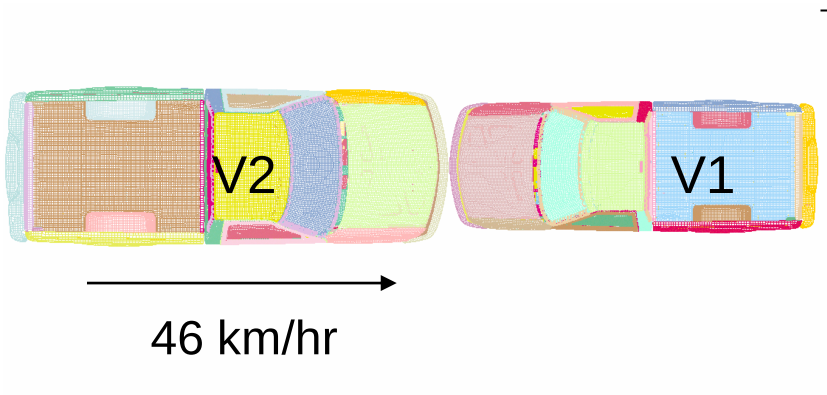
V1 Occupant
Male, 43, 175 cm, 71 kg
No restraints, no airbag
AIS 4 aortic injury, fatal

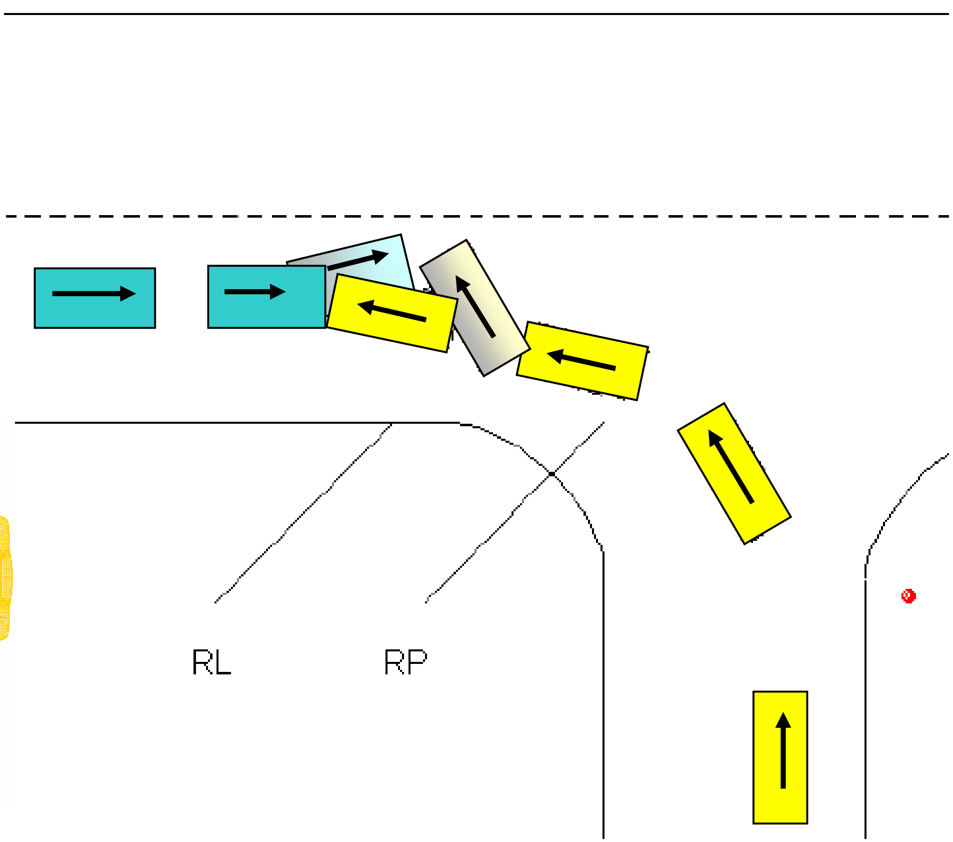




Frontal Impact (F2)

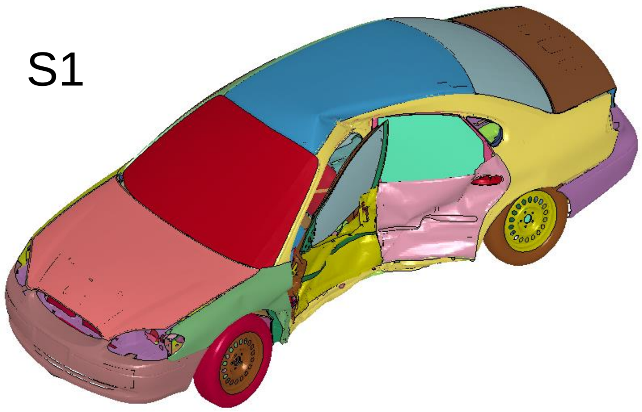
V1 Occupant
Male, 37, 175 cm, 73 kg
No restraints, no airbag
AIS 5 aortic laceration



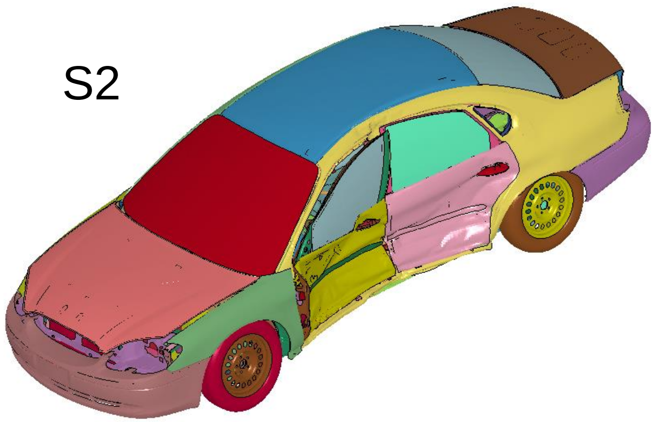


Results – Phase 1

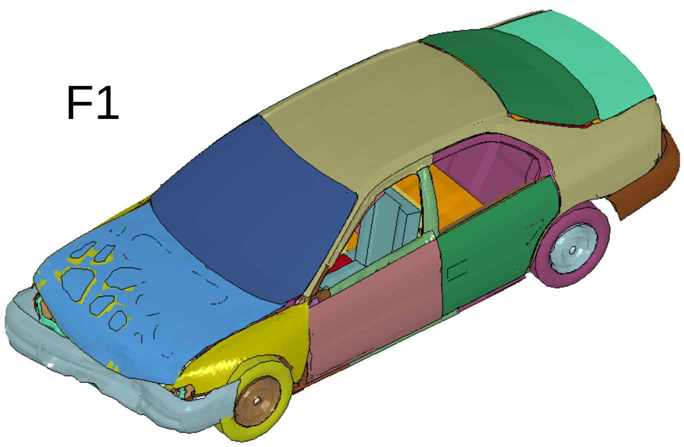
S1



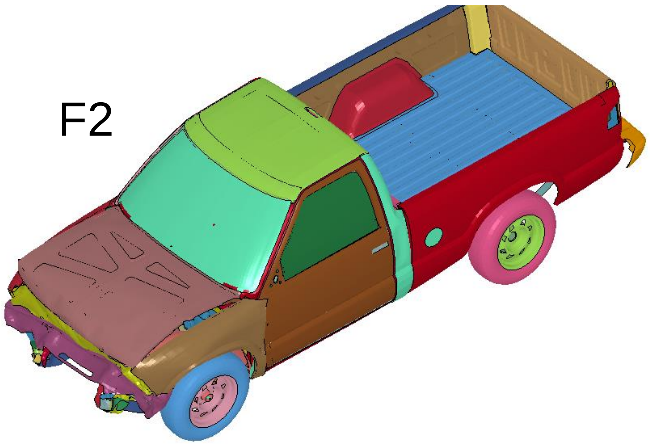
S2



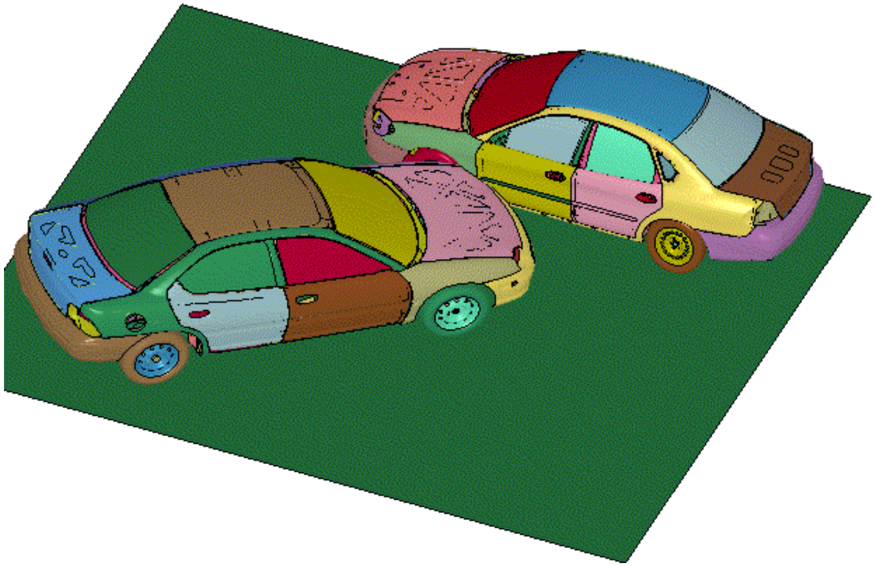
F1

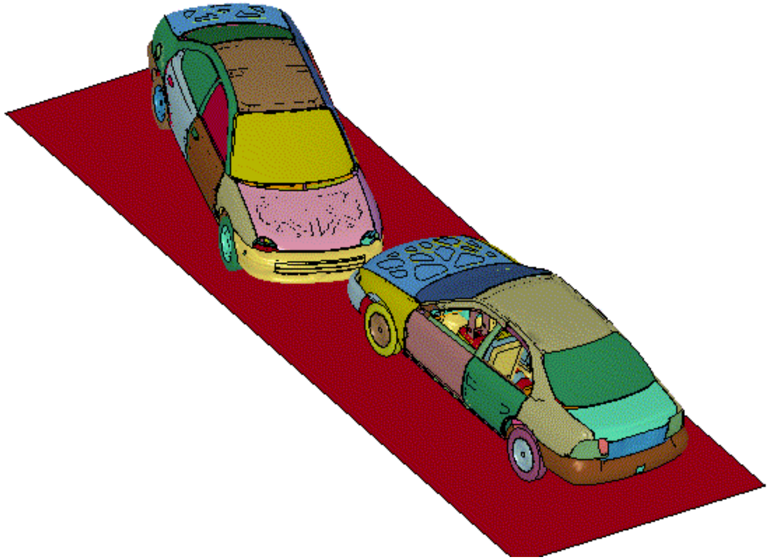


F2



Results – Phase 1

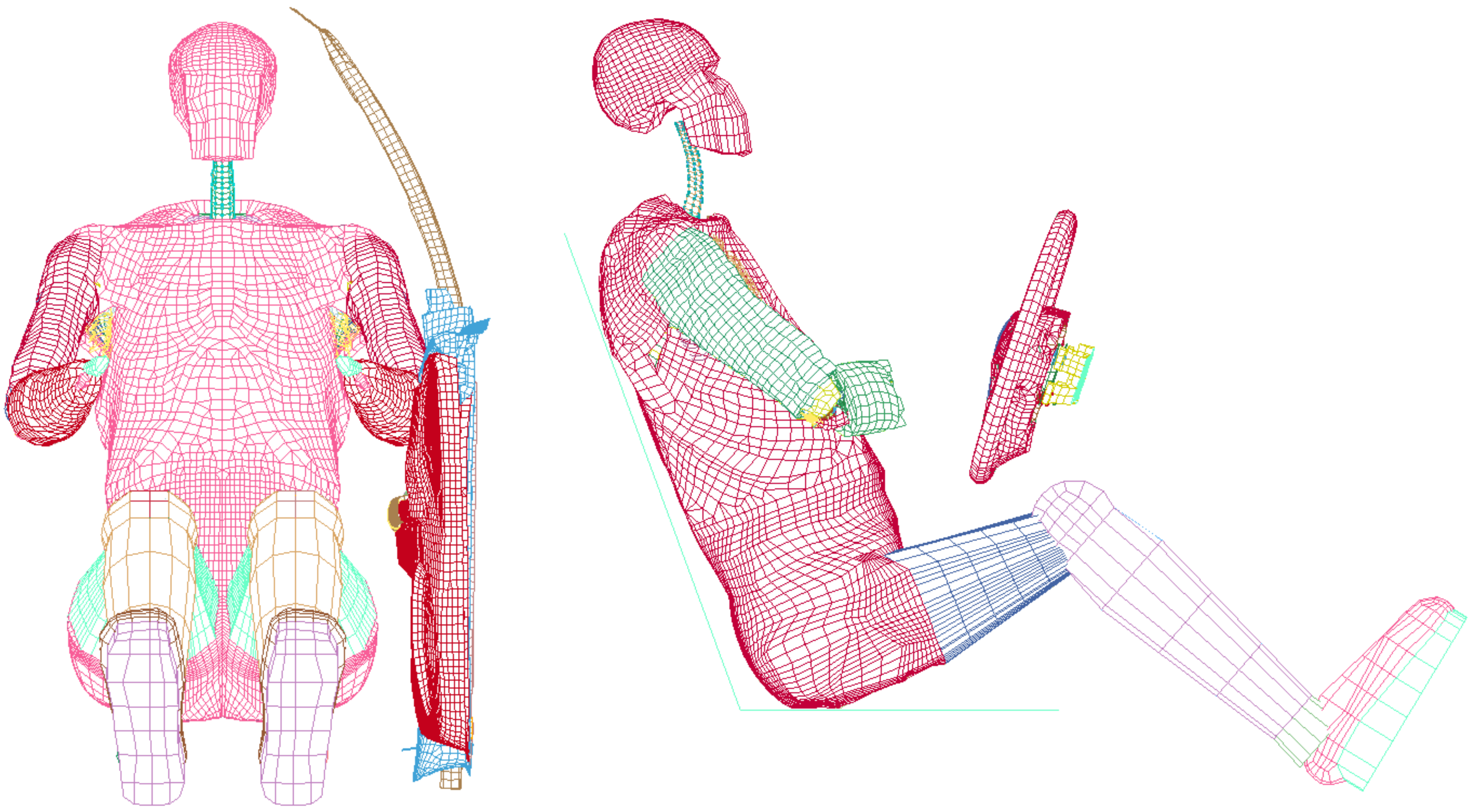




Results – Phase 1 (CDC)

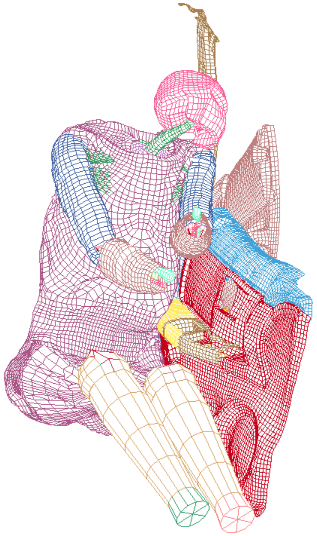
	S1		S2		F1		F2	
	Actual	FE	Actual	FE	Actual	FE	Actual	FE
C1	**0**	*	**160**	*	**650**	**571**	**690**	**580**
C2	**400**	**334**	**700**	**380**	**670**	**546**	**590**	**520**
C3	**600**	**525**	**370**	**448**	**520**	**448**	**630**	**553**
C4	**300**	**265**	**450**	**382**	**310**	**352**	**660**	**574**
C5	**60**	*	**140**	*	**110**	**131**	**530**	**485**
C6	**0**	*	**0**	*	**0**	**0**	**580**	**493**
Avg. Δ (%)		-9.7		-3.0		-2.4		-15.3

Phase 2 Setup



Results – Phase 2

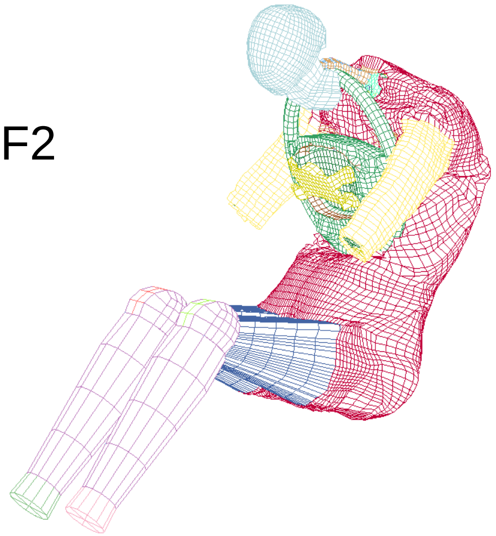
S1



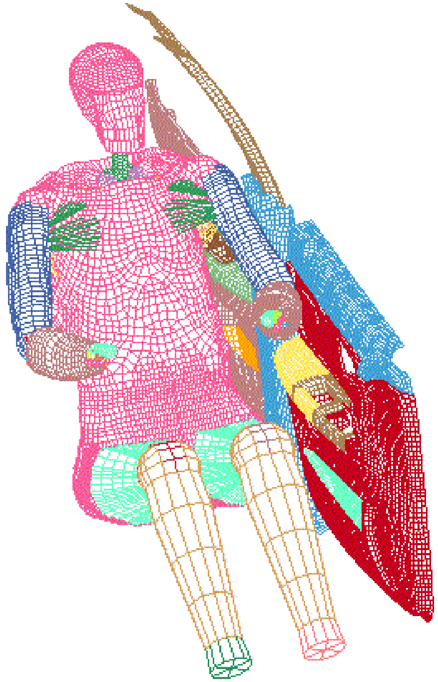
S2

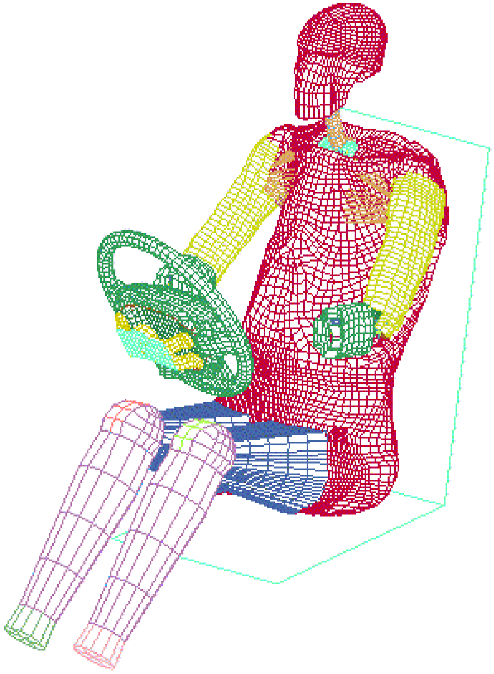
F1

F2

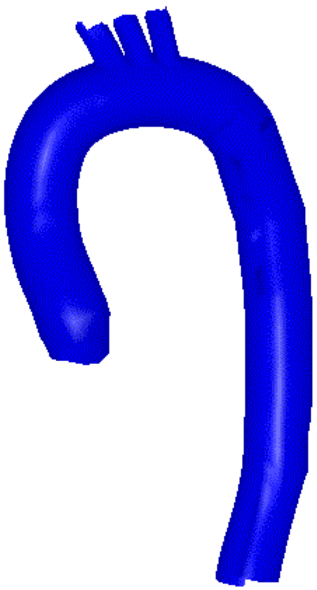


Results – Phase 2

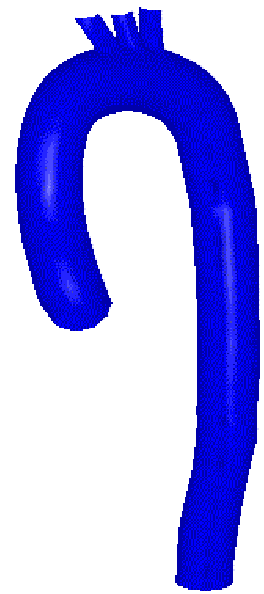




Results – Phase 2

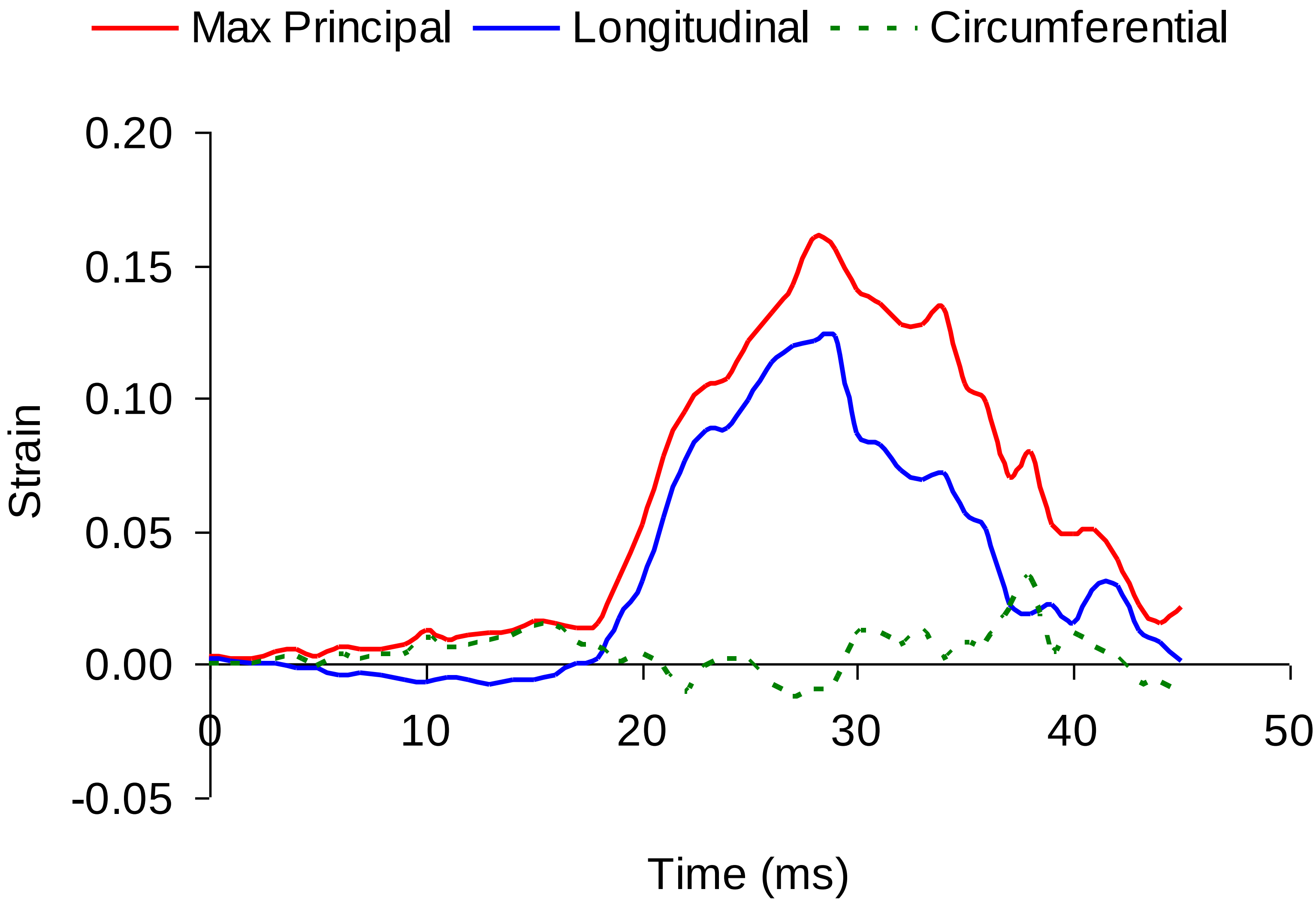


Side Impact

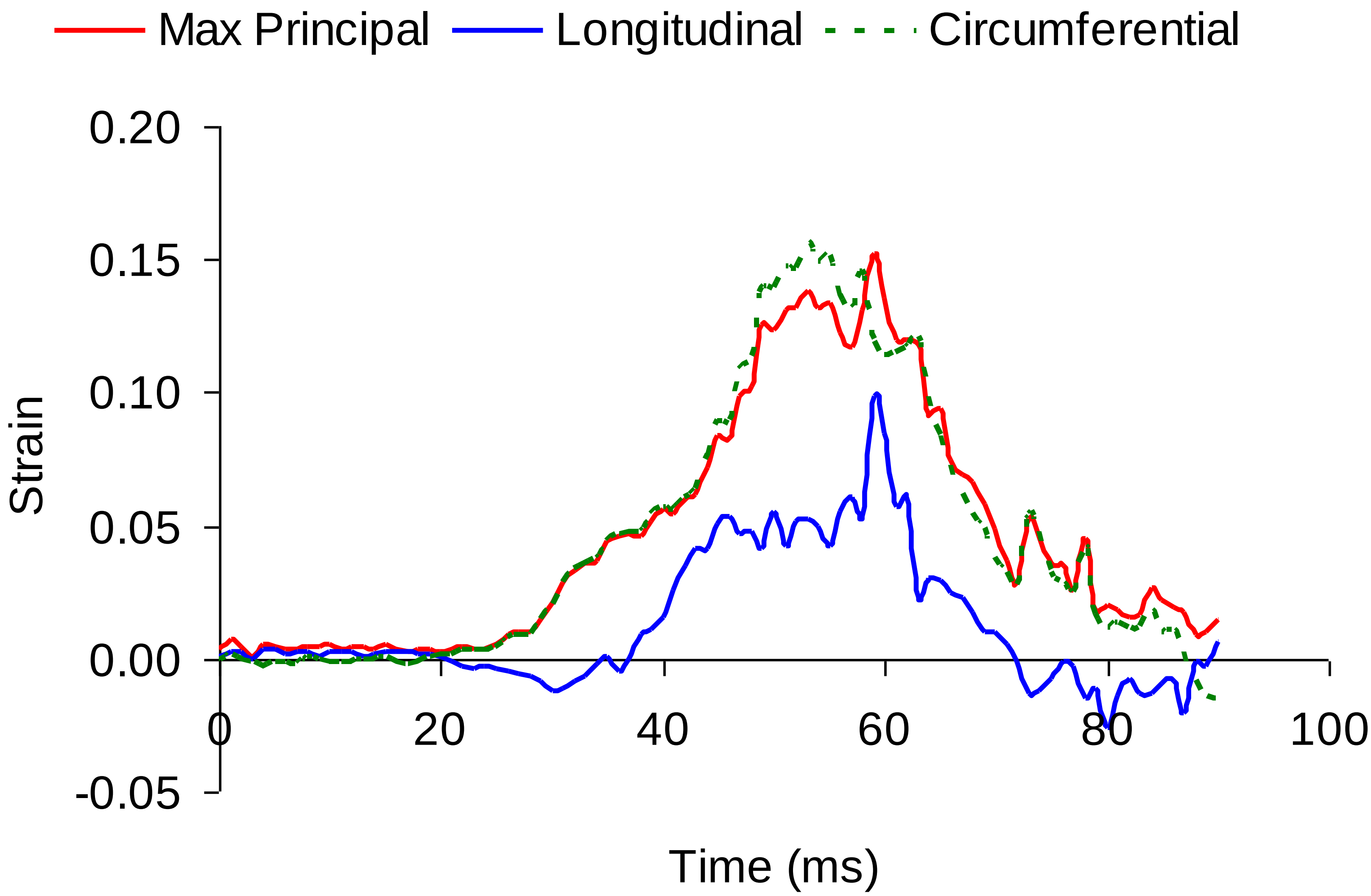


Frontal Impact

Results – Phase 2 (Side)



Results – Phase 2 (Frontal)



Results – Aorta Stress & Strain

	S1	S2	F1	F2	Threshold (Shah et al. 2005)
Long. True Stress (MPa)	**1.28**	**1.03**	**0.93**	**1.58**	**1.31~2.31**
Max. Prin. Strain (%)	**16**	**15.3**	**7.2**	**15.2**	**26.5~41.4**
Long. Lag. Strain (%)	**12.3**	**12.3**	**5.9**	**9.9**	**18.6~33.4**

Discussion

- Four real world aortic injury cases simulated
- No exact vehicle models available (not first order limitation)
- Vehicle model structural issues (front end)
- Occupant position and posture
- Global validations of whole-body human FE model

Discussion

- No autopsy data available for direct comparison
- Peri-isthmic region weaker (Lundevall 1964) and clinically vulnerable (Katyal et al. 1997)
- Parietal pleura, pericardium, central tendon present, no tissue connecting pericardium to sternum
- Linear elastic aorta with E from Shah et al. (2005)
- Additional efforts of Madalli et al. (2005) and Shah et al. (2005, 2006)

Conclusions

- TRA study using FE simulations will help design future experiments
- High stress and strain observed in peri-isthmic region for near-side impact
- High stress and strain in isthmus and junction of arch and ascending aorta for frontal impact
- Substantial work needed to locally validate FE model and aorta kinematics

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THANKS!