Measurement of Aortic Injuries In Lower Severity Near-side Impacts

Paper Number 11-0265

The George Washington University
and
The William Lehman Injury Research Center (WLIRC)
and
Wayne State University

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Bottom Line

- Aortic injuries in lower severity near-side crashes are a serious problem not recognized by NASS or by cadaver tests
  - Field detection of aortic injuries is difficult
  - High fatality rate when present
- Existing IIHS side impact test is good for evaluating aortic injury risk
- Best Injury measures – (T12Z and V*Cmax)
- Testing for aortic injury may require
  - a better side impact dummy
  - different injury criteria

Doctorial Dissertations and Master's Theses

- **Steps, J.A**., (2003), Crash characteristics indicative of aortic injury in near side vehicle-to- vehicle crashes. *Doctoral Dissertation*, The George Washington University, April, 2003.
- **Shah, C.S.** (2007) Investigation of traumatic rupture of the aorta (TRA) by obtaining aorta material and failure properties and simulating real-world aortic injury crashes using the whole-body finite element (FE) human model. *Doctorial Dissertation*, Mechanical Engineering, Wayne State University, Detroit, Michigan.
- **Echemendia, C**., (2008) Inertia effects of the heart as a factor in aortic injuries in near-side impacts, *Master's Thesis*, The George Washington University, December, 2008.

Award Winning Stapp Paper

Hardy, WN; Shah, CS; Mason, MJ; Kopacz, JM; Yang, KH; King, AI; Van Ee, CA; Bishop, JL; Banglmaier, RF; Bey, MJ; Morgan, RM; Digges, KH (2008) Mechanisms of Traumatic Rupture of the Aorta and Associated Peri-isthmic Motion and Deformation. Stapp Car Crash Journal, 52:233-265.

Other Publications

- **Augenstein, J, Digges, K., Steps, J., Higuchi, K., and Ato., T**. (2003) Crash attributes that influence aortic injuries in near-side crashes. Paper 232, Proceedings of the ESV Conference, May, 2003.
- **Shah, C.S., Maddali, M., Mungikar, S.A., Beillas, P., Hardy, W.N., Yang, K.H., Bedewi, P.G., Digges, K., and Augenstein, J.** (2005) Analysis of a real-world crash using finite element modeling to examine traumatic rupture of the aorta. SAE Technical Paper No. 2005-01-1293. Society of Automotive Engineers, Warrendale, PA.
- **Mason, M.J., Shah, C.S., Maddali, M., Yang, K.H., Hardy, W.N., Van Ee, C.A., Digges, K.** (2005) A new device for high-speed biaxial tissue testing: application to traumatic rupture of the aorta. Transactions of the Society of Automotive Engineers, Paper No. 2005-01-0741.

Other Publications

- **Cavanaugh, J.M., Koh, S.W., Kaledhonkar, S.L., and Hardy, W.N.** (2005) An analysis of traumatic rupture of the aorta in side impact sled tests. SAE Technical Paper No. 2005-01-0304. Society of Automotive Engineers,
- **Hardy, W.N., Shah, C.S., Kopacz, J.M., Yang, K.H., Van Ee, C.A., Morgan, R., and Digges, K.** (2006) Study of potential mechanisms of traumatic rupture of the aorta using in situ experiments. Stapp Car Crash Journal, 50:247-
- **Shah, C.S., Hardy, W.N., Mason, M.J., Yang, K.H., Van Ee, C.A., Morgan, R., and Digges, K.** (2006) Dynamic biaxial tissue properties of the human cadaver aorta. Stapp Car Crash Journal, 50:217-245.

Other Publications

- **Zhao, A. Pericevic I, Digges, K., Kan, C., Moatamedi, M., Augenstein J.,** (2006) FE modeling of the orthotropic and three-layer human thoracic aorta. The 2006 ASME Pressure Vessels and Piping/ICPVT-11 Conference, Vancouver, British Columbia, Canada, July 23-27, 2006
- **Alonso, B., Digges, K., and Morgan, R**. (2007) Far-side vehicle simulations with MADYMO. SAE 2007-01-0378, April 2007.
- **Shah, C., Hardy, W., Yang, K., Van C., Morgan, R., and Digges, K.** (2007) Investigation of traumatic rupture of the aorta (TRA) by simulating real-world accidents. 2007 Conference of the International Research Council on Biomechanics of Injury, pp. 349-359.

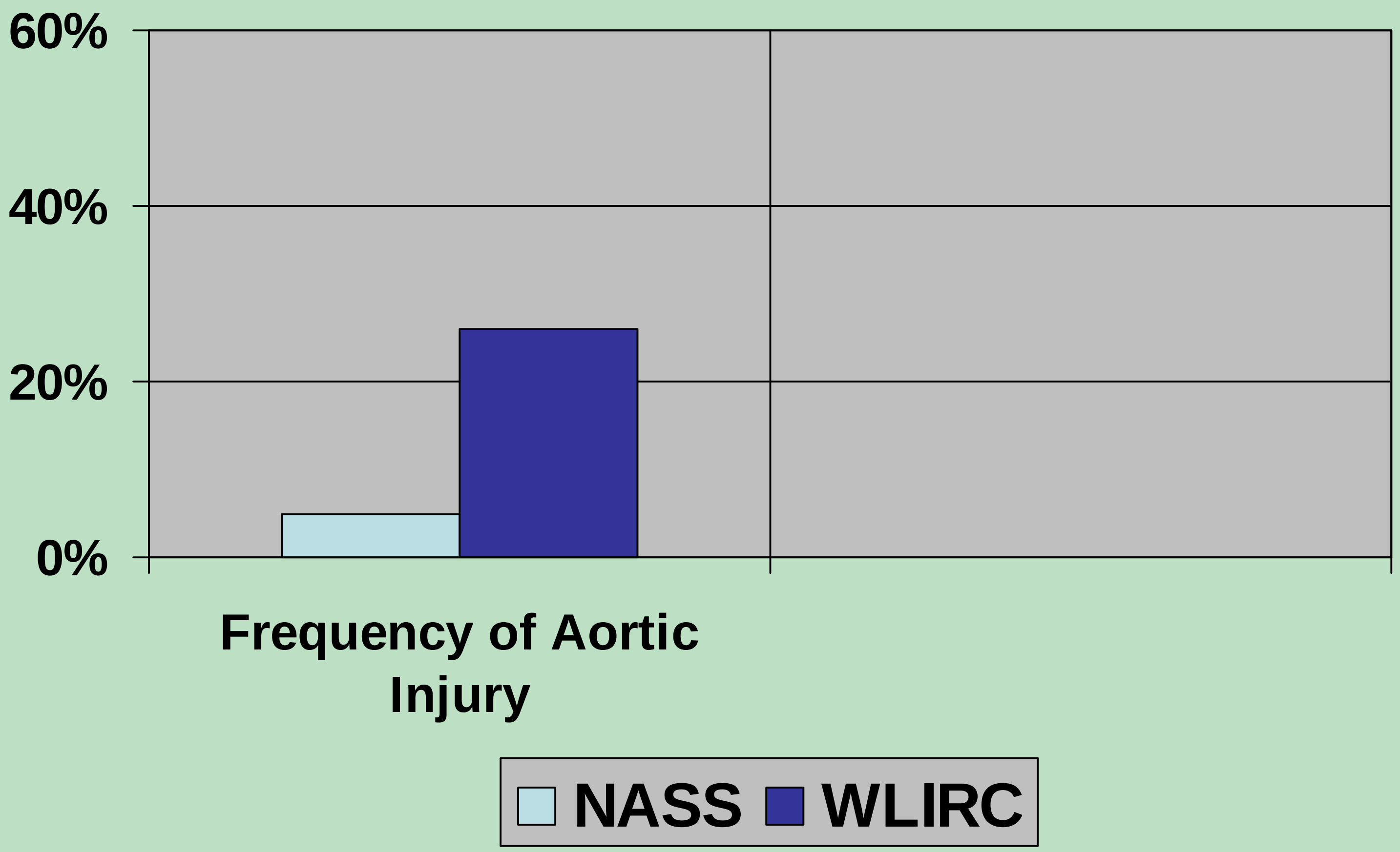
Research Objectives

- Define Crash Characteristics Causing Aortic Injury
- Determine Aortic Injury Mechanisms
- Recommend Injury Criteria
- Recommend Critical Test Procedures and Test Dummies

Research Objectives

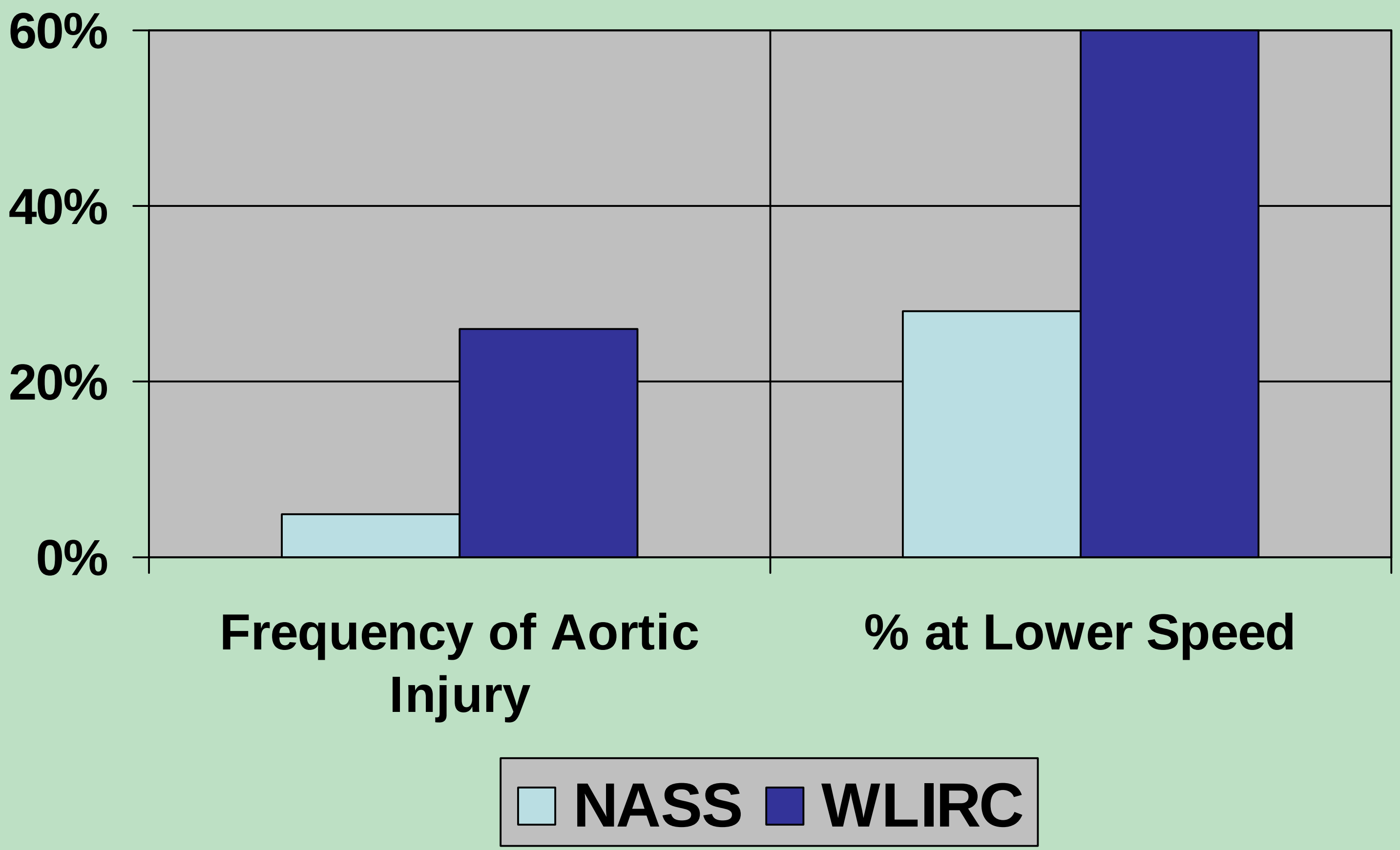
- Define Crash Characteristics Causing Aortic Injury
  - Data Sources:
    - NASS
    - William Lehman Injury Research Center (WLIRC) (A CIREN Center during the initial research period)

Aortic Injury Rates in Near-side Crashes



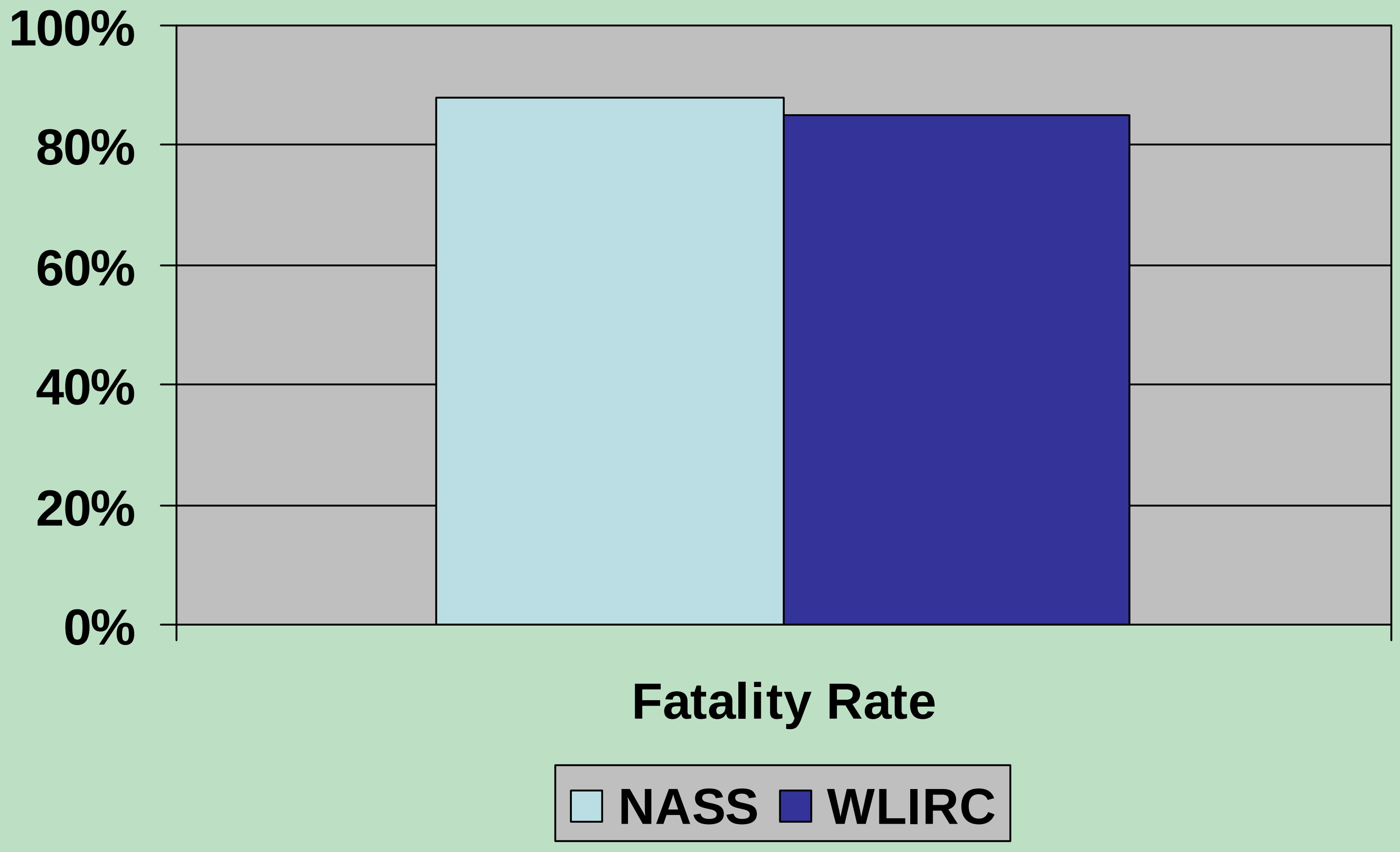
Steps Dissertation, 2003

Aortic Injury Rates in Near-side Crashes



Steps Dissertation, 2003

Fatality Rate for Aortic Injuries in Near-side Crashes



Steps Dissertation, 2003

Why Study Aortic Injuries?

Observations:

– NASS is missing the aortic injuries in lower severity crashes

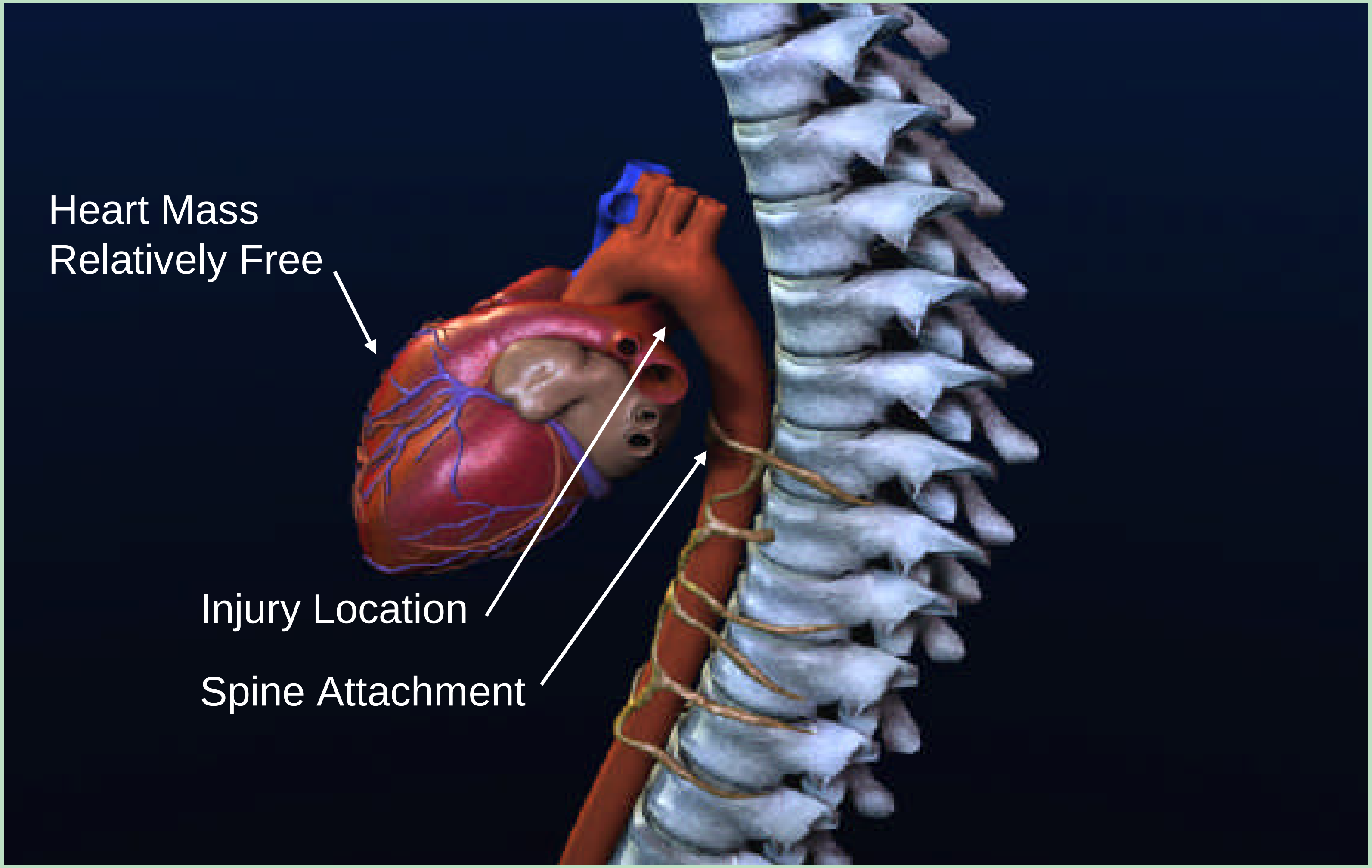
– Incorrect assessment of aortic injuries may result

– Aortic injuries carry a very high fatality rate

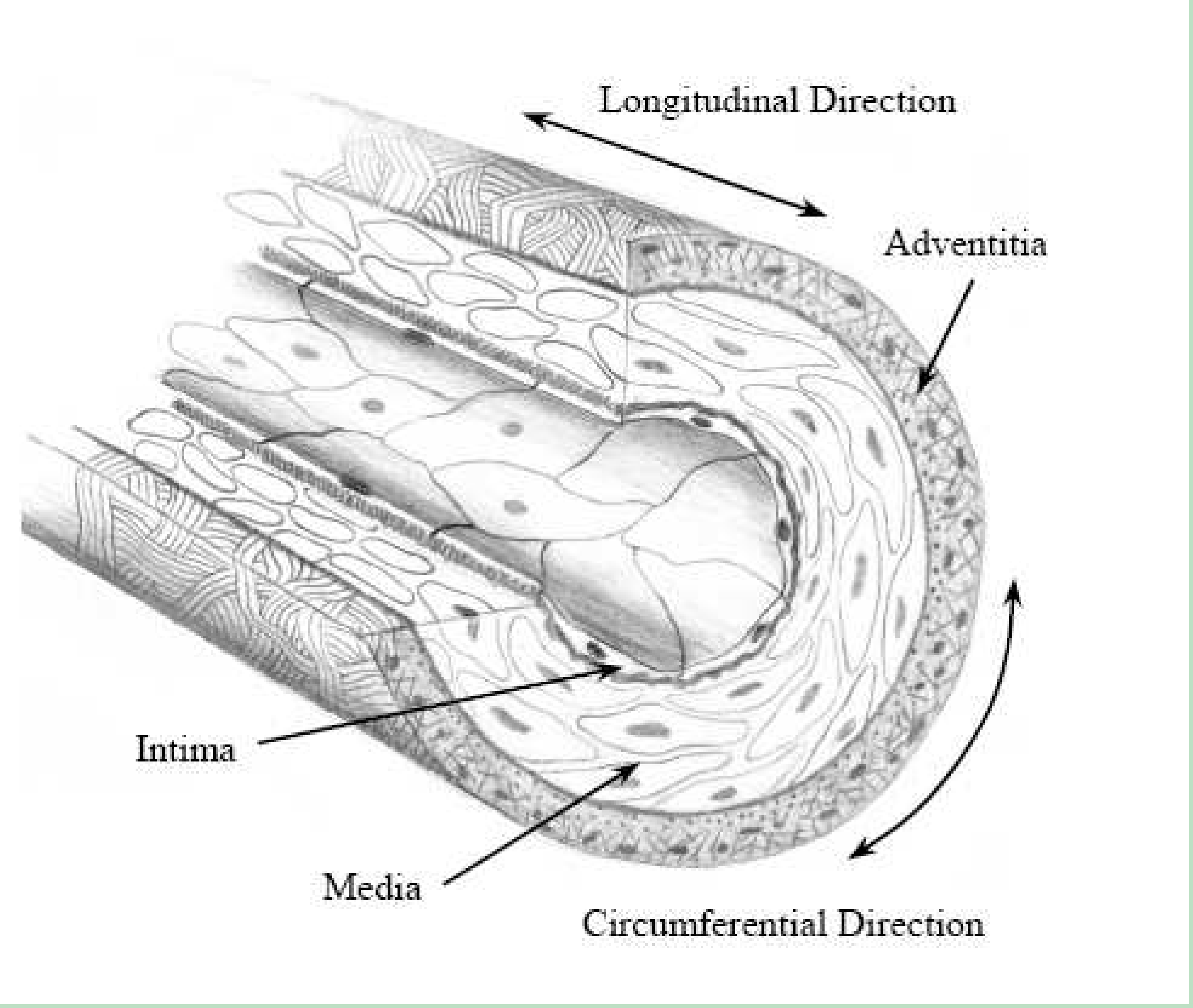
WLIRC Observations
Aortic Injuries

- 49% did not die at the scene
- Of the 51% transported to the medical centers 70% survived for over 1hr.
- More than 50% of those transported, died
- Survivors suffered no long term impairment
- Normal physiological indicators frequently give no indication of potentially fatal aortic injuries

Constraints on the Aorta

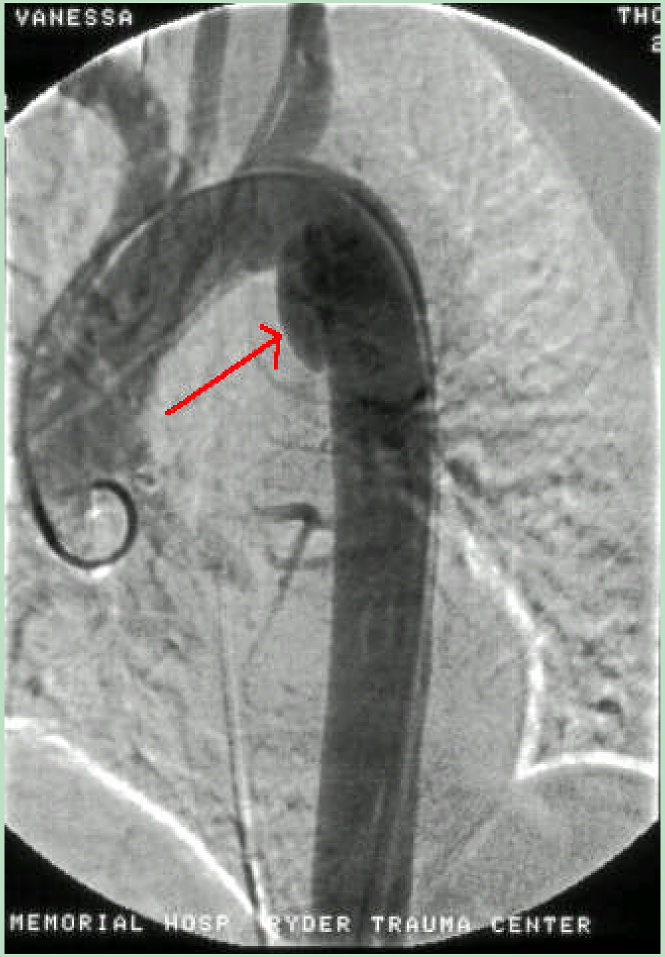


Composition of the Aorta



Significance of AIS 4+ Aortic Injury

- Occur in low severity near-side crashes
- Frequently occult (no physiological cues)
- Frequently fatal
- Usually complete recovery when successfully treated



Typical Cases with Aortic Injuries

Cases from the William Lehman Injury Research Center (WLIRC)

14 MPH - FATALITY

- Driver, 62 Y/O Male
- 68” Tall; 174 Lbs
- 10 O’clock
- 13” Max Crush
- Injuries:
  - AIS-6 Aorta
  - AIS-5 Rib/Lung
  - AIS-4 Lower X
- Alert on Scene

Case Vehicle - 1990 Lexus 250
Bullet Vehicle - 1983 Olds Cutlass

Case 96-008S

21 MPH CRASH - FATALITY

- Driver
- 27 Y/O Male
- 69” Tall; 164 Lbs
- 11 O’clock
- 19” Max Crush
- Injuries:
  - AIS-6 Aorta
  - No Serious Rib Fx

Case Vehicle - 1985 Nissan Sentra
Bullet Vehicle- 1987 Dodge Caravan

Case 97-024S

19 MPH - NON FATAL

- Driver 49 Y/O Female
- 67” Tall; 240 Lbs.
- 10 O’clock
- 20” Max Crush
- Injuries:

    AIS-5 Aorta

    AIS-4 Rib
- Alert on Scene

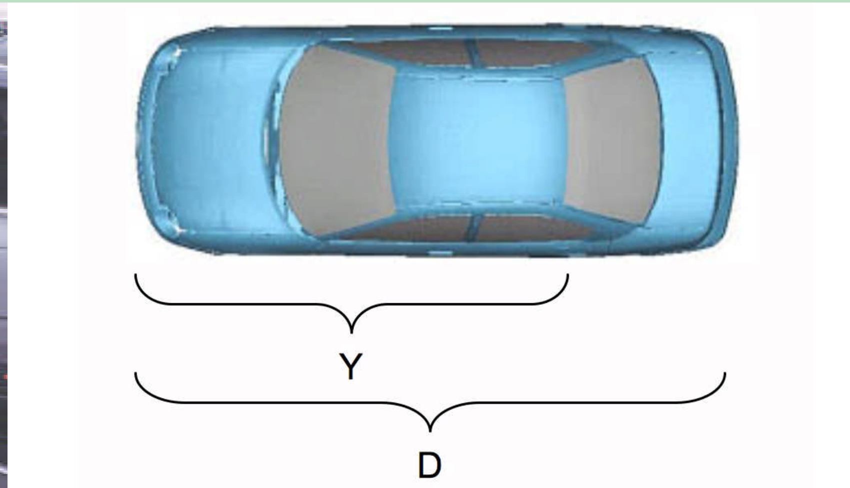
Case Vehicle -1987 Buick Park Ave.
Bullet Vehicle-1992 Lincoln Continental

Case 97-003S

Results of CIREN Case Analysis

Significant Variables in Near Side Crashes:

1. **Intrusion**
2. **Age**
3. **Y and D Damage Pattern**



Typical Vehicle Damage

Y Damage Location

Y-Damage Crash Test

Conducted May 8, 2003
By GW University, NCAC
At FHWA Test Facility
McLean Va.

Y- Damage Test

Chevy S-10 Pickup into Ford Taurus at 30 mph

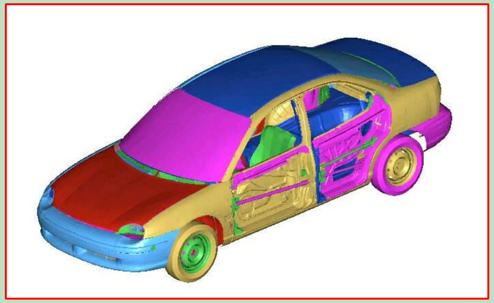
Y Damage Crash and Test

Real Crash With Aortic Injury

Y- Damage Crash Test

Crash Reconstruction

Steps Dissertation, 2003



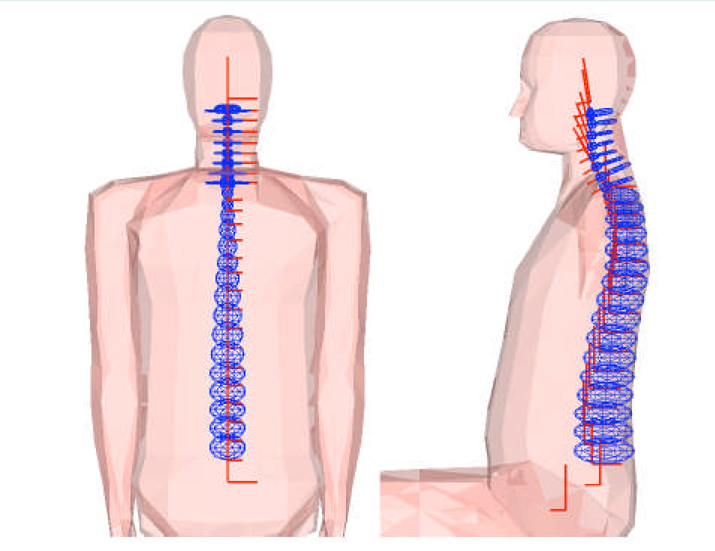
FEM Vehicle Model

214/SINCAP

Y-Damage

Purpose: Determine Differences in Acceleration and Intrusion Time History

Model Response to Y-Damage Pattern



MADYMO
Human
Model

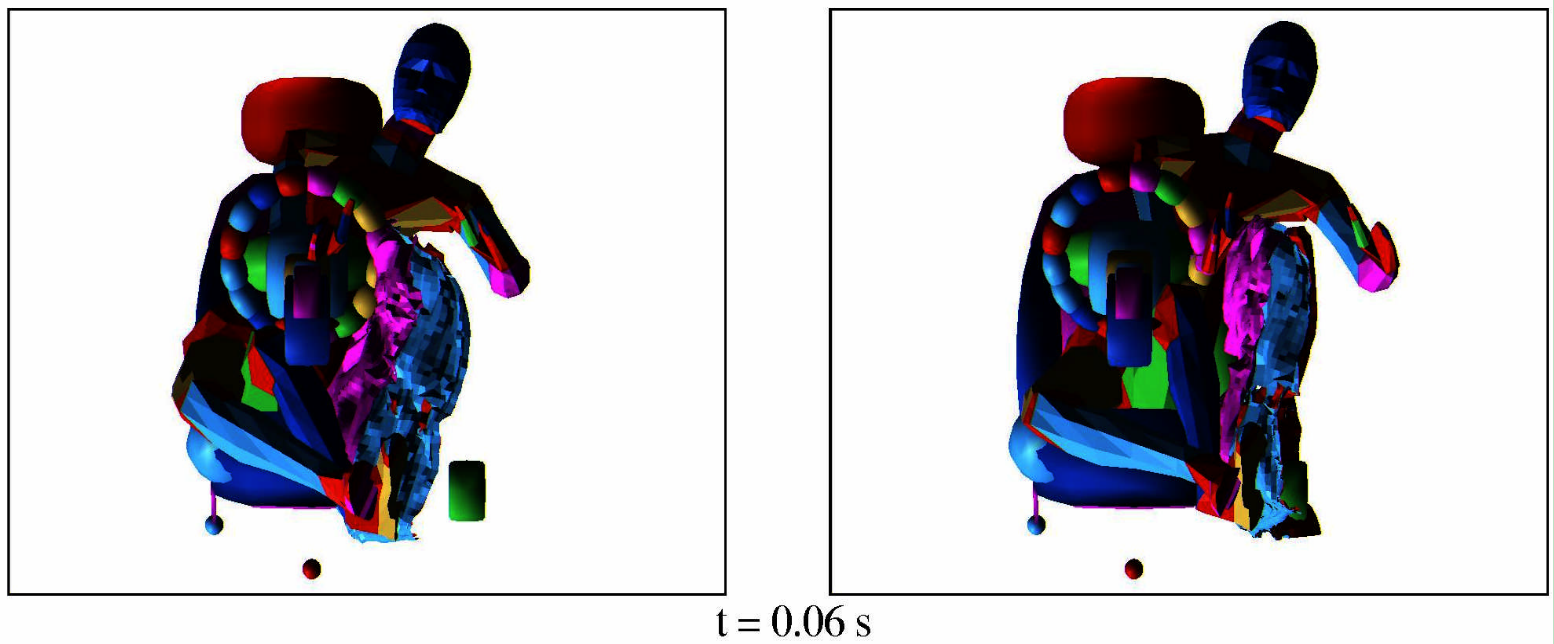
•**Thorax is impacted by a force component from the front**
•**Head z acceleration increased – more spinal stretching**

MADYMO *Human Facet* Model Response

Y-Damage has:

Greater **head excursion and z spinal acceleration**;

Chest compressed in both the **x and y direction**



SINCAP Y-Damage

Unable to observe a difference using *MADYMO dummy models*!

An improved spine is needed in the model

Aortic Injury in Cadaver Tests

- NHTSA database of cadavers in side impacts
  - 137 tests
  - 5 with aortic injuries
  - All 5 were at WSU in Cavanaugh's project for CDC to evaluate padding stiffness and door offset at the hip region.

Wayne State University
Cavanaugh CDC Cadaver Tests

- 17 Tests Conducted with and without pelvis offset
- 5 Produced Aortic Tears

- Heidelberg-type sled
- Pressurized aorta

Aortic Injury Predictors –

Cavanaugh Analysis of Cadaver Tests

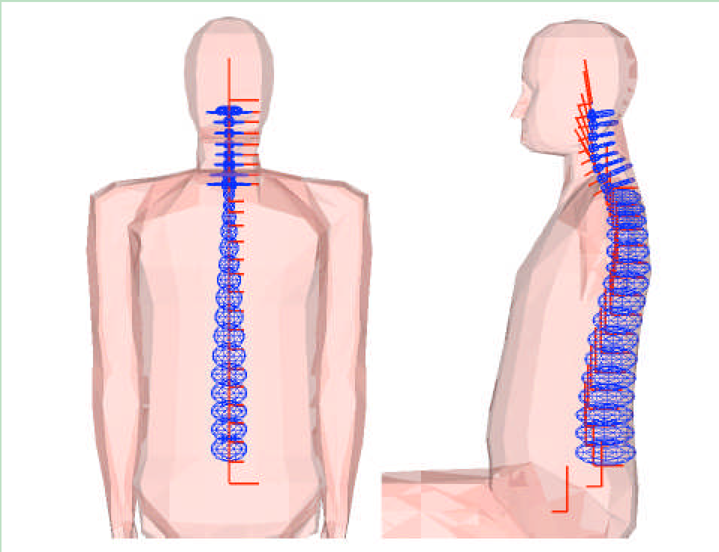
ASA – Average Spinal Acceleration

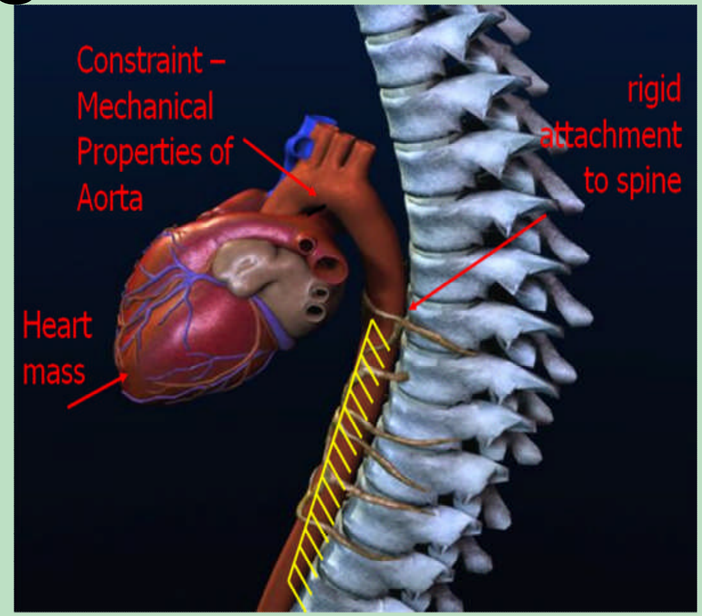
(T12Z, V*C) combination are best predictors

T12Z – Max Spinal Vertical Acceleration at T12
UpsX – Max Upper Sternum X Displacement

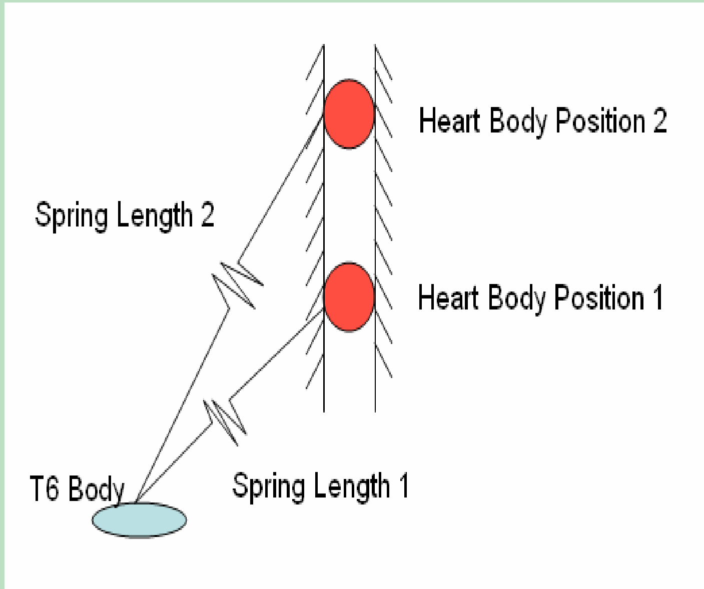
Variable or Combination	**k1**	**k2**	**k3**	**Chi-square**	**P value**
ASA 10 at T12				5.216	0.0224
Cmax				2.329	0.127
VCmax				3.959	0.0466
k1*T12Z~k2*ASA~k3	0.0426	0.2123	-12.03	8.985	**0.0027**
k1 *T12Z~k2*Cmax~k3	0.0236	0.3666	-20.97	8.438	**0.0037**
k1*T12Z~k2*VCmax~k3	0.0294	4.6622	-10.452	9.76	**0.0018**
k1*UpsX~k2*ASA~k3	0.0964	0.1889	-16.168	8.405	**0.0037**

Echemendia's Spring Mass Model

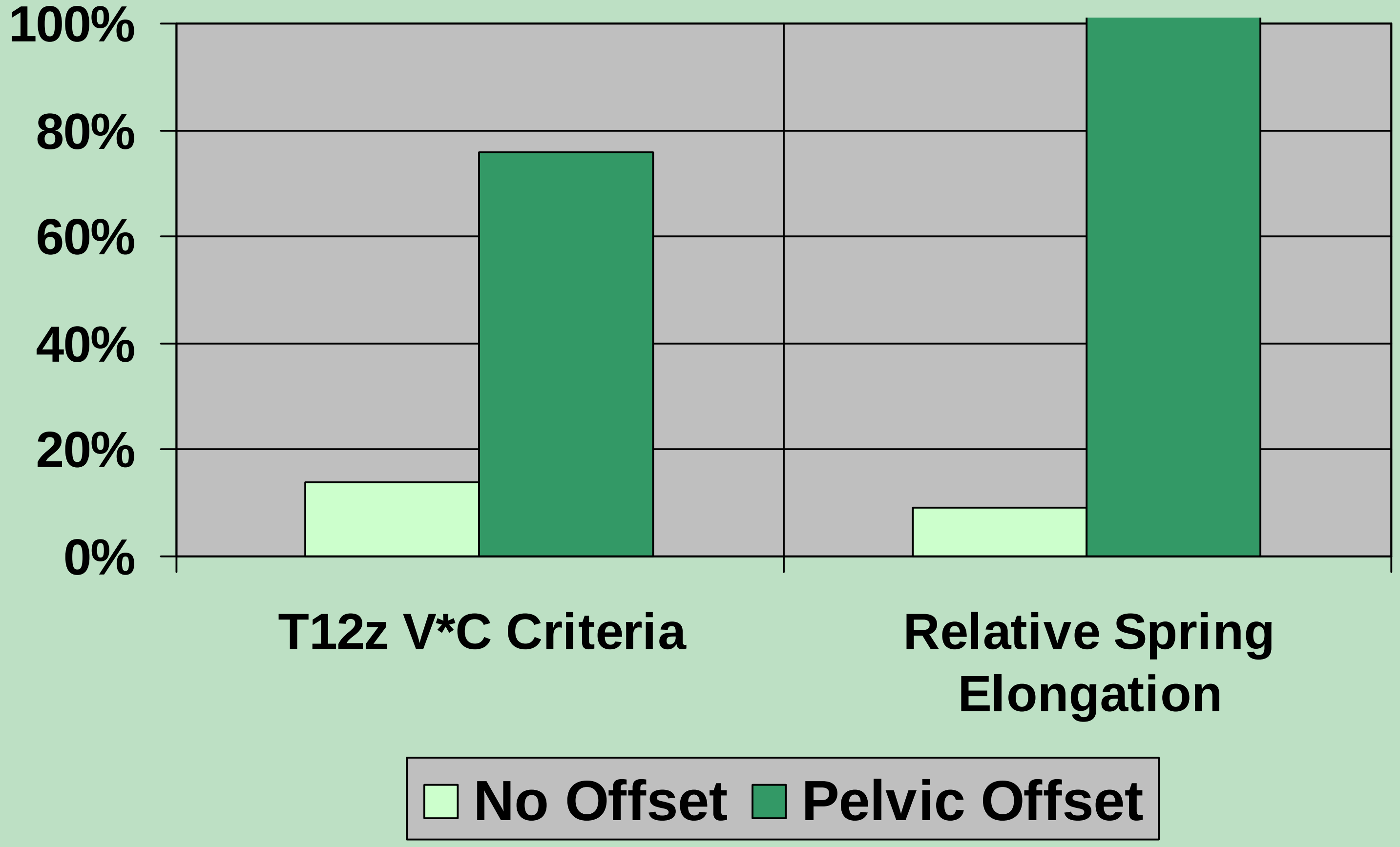




- Spring Mass Model was added to represent the heart-aorta in TNO's Human Facet Model..
- The spring with the mechanical properties of the aorta

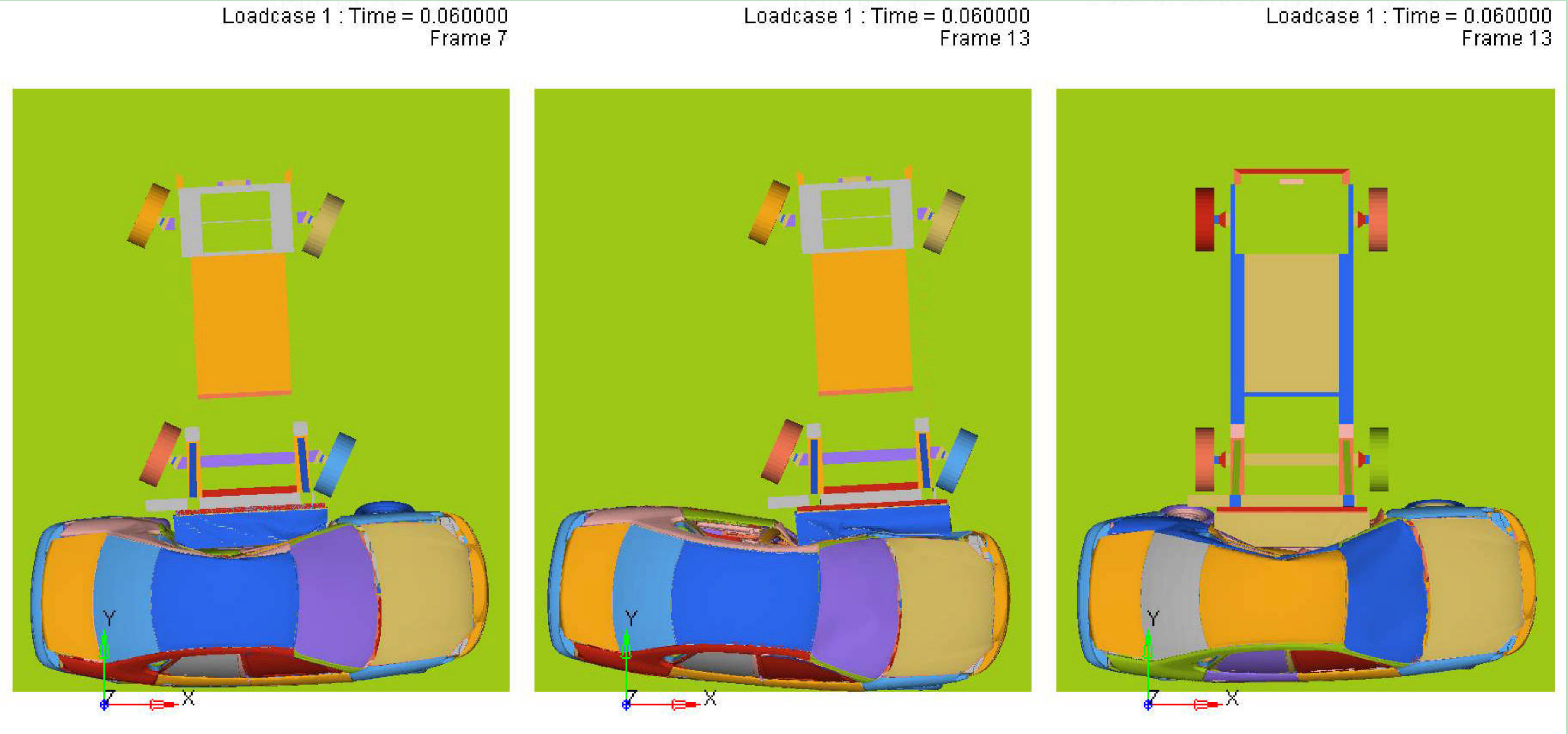


Human Model Simulations of Cavanaugh's of Cadaver Tests



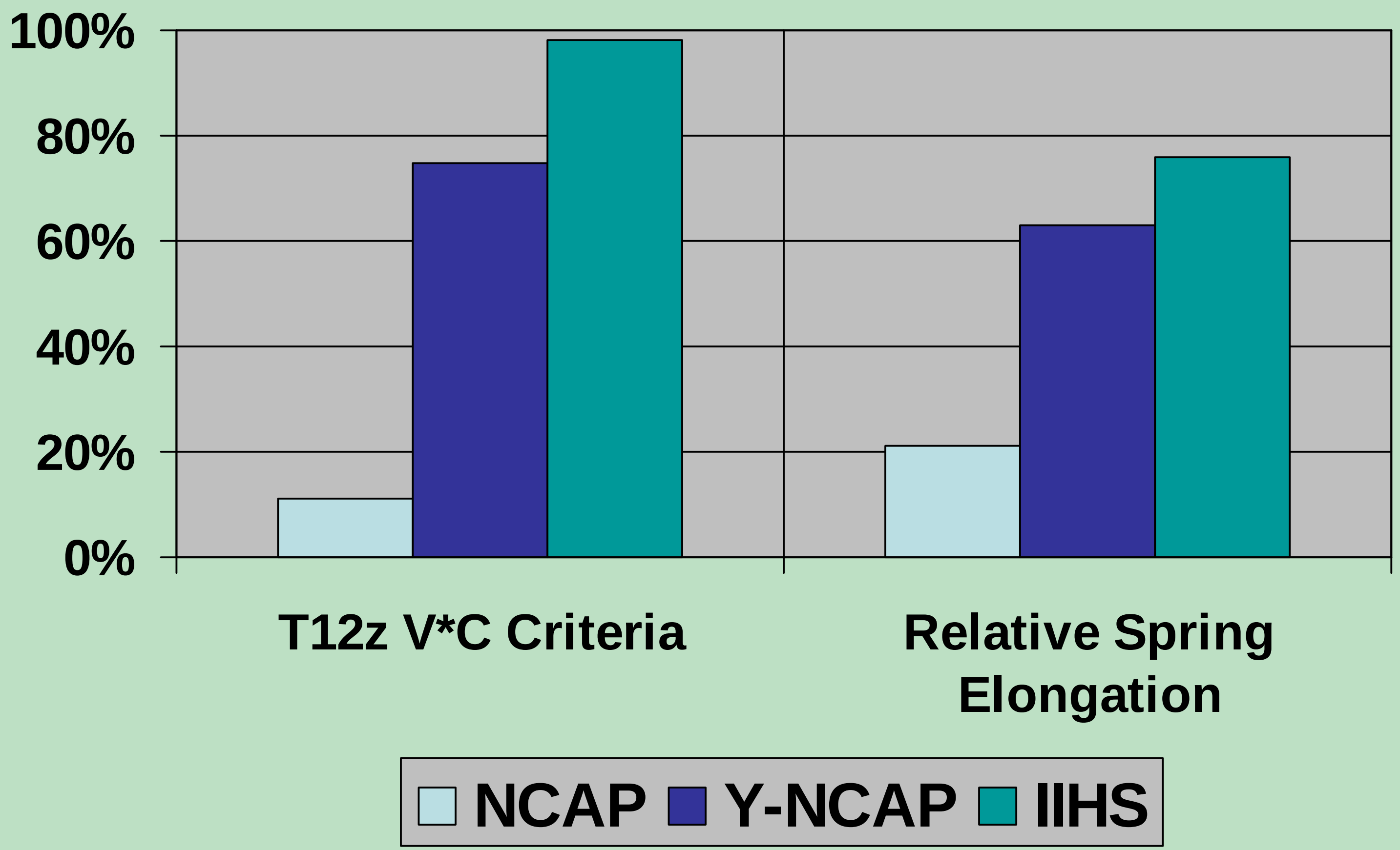
Echemendia Thesis, 2008

FEM Crash Simulations and Human Model Simulations



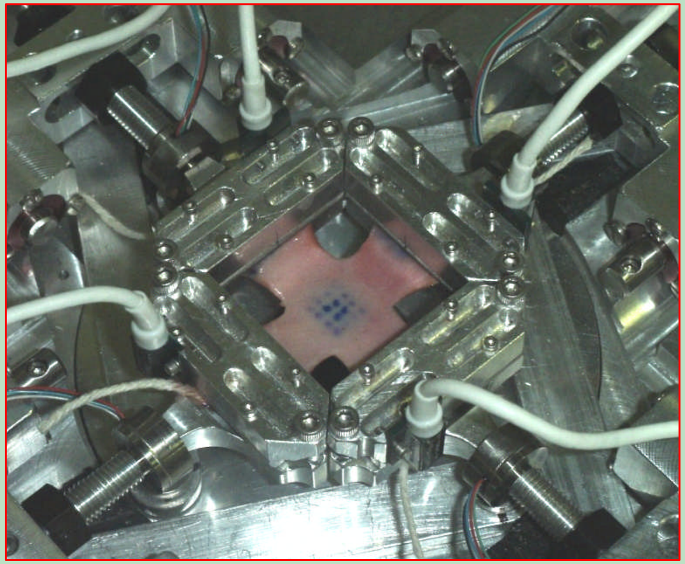
NCAP Y-NCAP IIHS

Human Model Simulations of Alternative Crash Tests



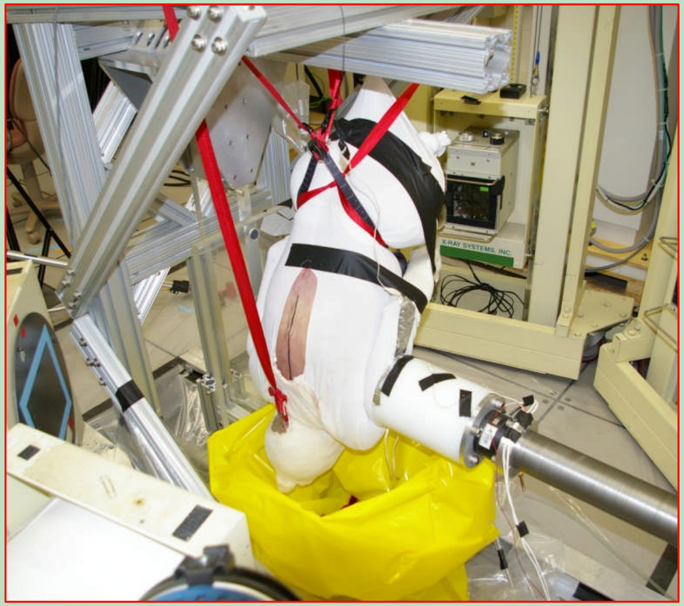
Echemendia Thesis, 2008

Wayne State Studies Supported by GW



Shah (2007) – High speed biaxial tissue testing machine

- Mechanical Properties of Aorta - Stress-Strain response



- **Hardy (2007) – Inverted cadaver impacted**
  - 8 cadavers, 7 with aortic injuries.
  - 3 side impact tests – all with aortic injuries
  - Position of the heart controlled by inverting the cadaver
  - High speed X-ray captured motion

Conclusions – Hardy and Shah

- Longitudinal stretch of the aorta is central to aortic injury
- Spinal Z-acceleration may cause longitudinal stretch of the aorta
- Anterior sternum displacement may be important to aortic injury
  - sternum displacement causes the aorta to move away from the spine during side impacts

Implications of Injury Measures

- A dummy may need a more biofidelic chest to measure sternum displacement
- Spinal biofidelity is needed to accurately reproduce the spinal z acceleration

Observations

- Pelvic offset loading increased the risk of aortic injury in cadaver tests
- The flexibility of the dummy spine is an important factor in accurately detecting crash environments that produce aortic injury
- The IIHS test with an improved side impact dummy should predict aortic injuries

Acknowledgements

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