Aortic Injury Analysis in Near Side Impacts

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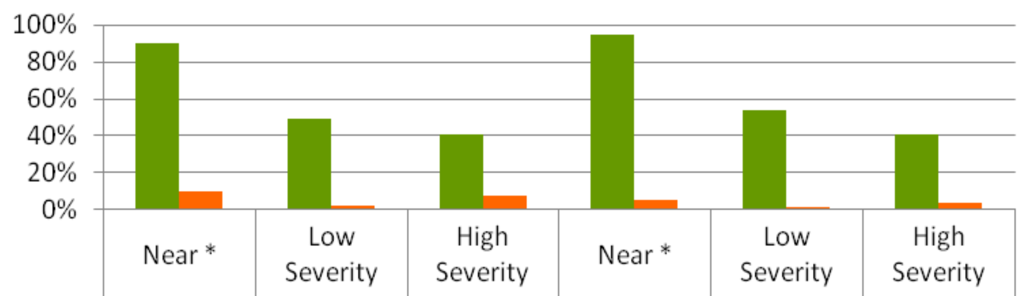
Introduction

Introduction

- Motor vehicle crashes remain a leading cause of death among the younger population between the ages of 4 -34
- Among the top ten causes of death for all age groups
- 42,000 fatalities per year
- 2.9 million people injured per year
- $230.6 billion per year on additional cost to society
- 26 percent of AIS 3+ severity crashes are side-impact crashes
- Blunt trauma can cause partial or total rupture of the aorta resulting in excessive blood loss and possible death.
- Motor vehicle collisions are responsible for most cases of aortic injury in the United States (Burkhart, et al., 2001).

Introduction – Motor Vehicle Aortic Injury Statistics

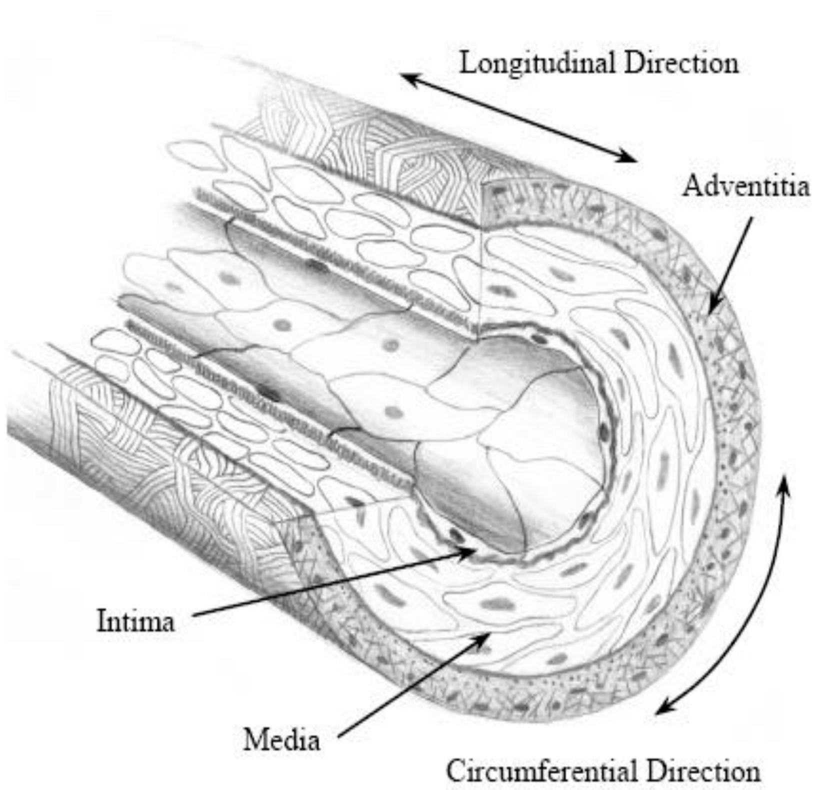
- Aortic Injury accounts for (5–16%) of motor vehicle deaths.
- Aortic Injury fatality rate is very high (92%).
- Most of the Aortic Injuries that occur in low severity crashes could be survivable if recognized and treated in time.



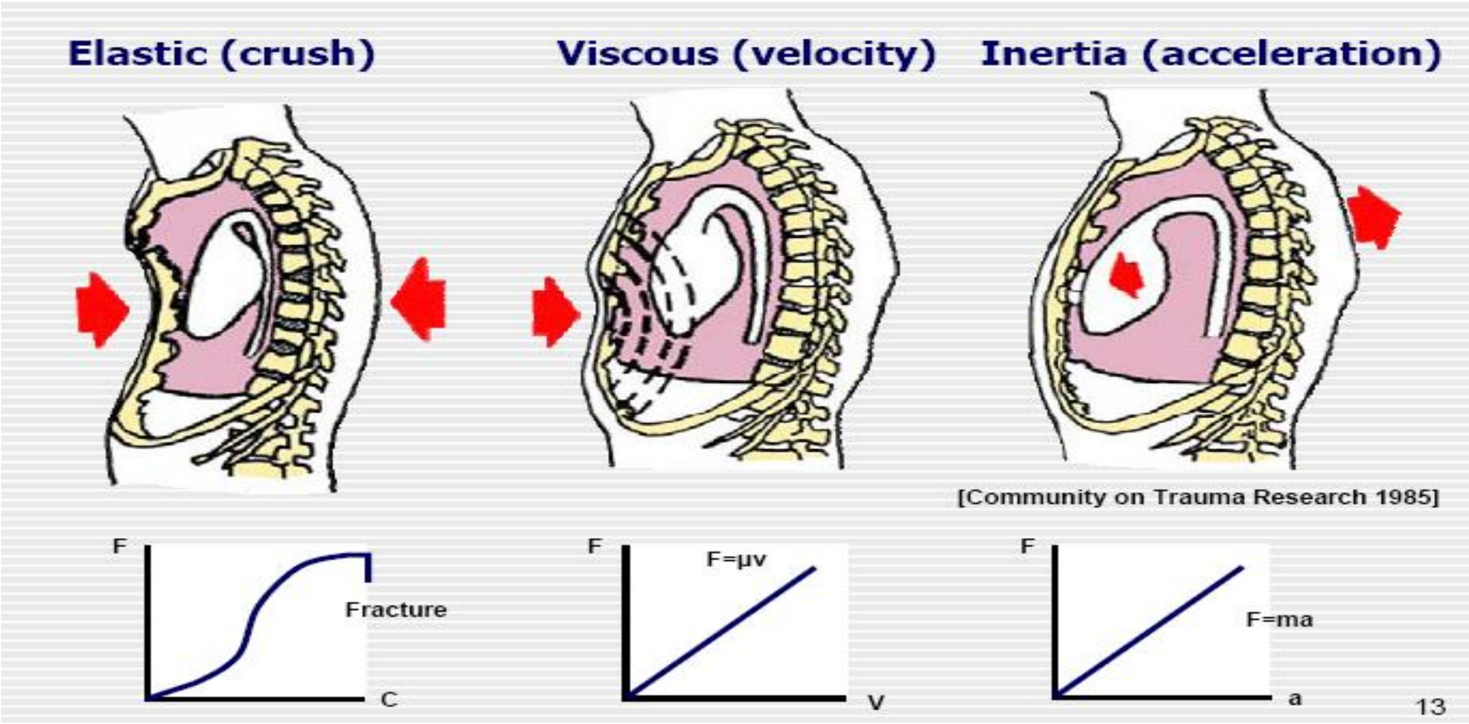
	UNWEIGHTED			WEIGHTED		
	Near *	Low Severity	High Severity	Near *	Low Severity	High Severity
Near Side Impacts (No AI)	90%	49%	41%	95%	54%	41%
Near Side Impacts (AI)	10%	2%	8%	5%	1%	4%

Frequency of AIS 3+ Injuries by Crash Severity??
Weighted and Unweighted Data

Anatomy of Aorta



Mechanisms of injury



- The three most common mechanisms of injury proposed is chest compression, viscous response and inertia

Goal and Approach

Goals and Approach

- Goal
  - Explore the inertial effect of the heart as a factor of the injury mechanisms of aortic rupture using multidisciplinary methods and previous research studies to reproduce environments conducive to aortic injury.

- Approach
  - Examine previous research studies
  - Analysis of real world accident data
  - Computer modeling of Vehicle tests with 2001 Taurus NCAC FE Model
  - Computer modeling of Cadaver sled tests
  - Spring mass model to study inertia effect on Z direction

Previous Research Studies

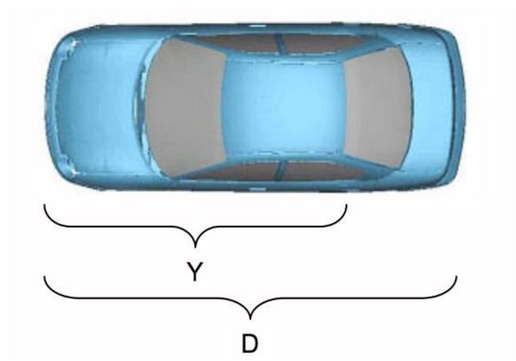
Previous Research Studies (cont)

- **Viano (1983) and Katyal et al.(1997) and Shah (2001)**
  - Aortic injuries appear primarily in the peri-isthums region
- **Parmley (1958)**
  - Automobile crashes account for the majority of TRA
- **Bertrand (2008)**
  - Near and far side-impacts (2.4% incidence)
  - Frontal impacts (1.1 % incidence).

Previous Research Studies

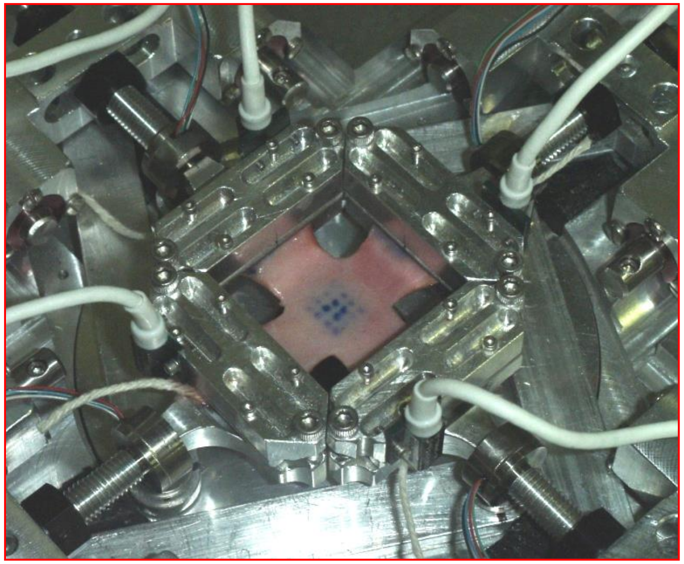
- Viano and Lau (1986) - Pendulum
  - 14 cadavers – no aortic injuries
  - Defined Viscous Criterion and tolerance levels
- Cavanaugh (1990-2005) - Side impact sled test (Only tests with Aortic Injury)
  - 17 cadavers only 5 with aortic tears
  - Extensive damage to cadavers
  - Identified combination of [VC]max & T12Z as best predictor of aortic injury
- **Steps (2004) – Real World Analysis and Simulations**
  - Age, Delta-V and intrusion as predictors
  - Rib fracture common but not necessary
  - Y –Damage of vehicle presented higher loading.

ADD VIDEO OF CADAVER TEST AND NOTE THAT YOU WILL BE SIMULATING THEM

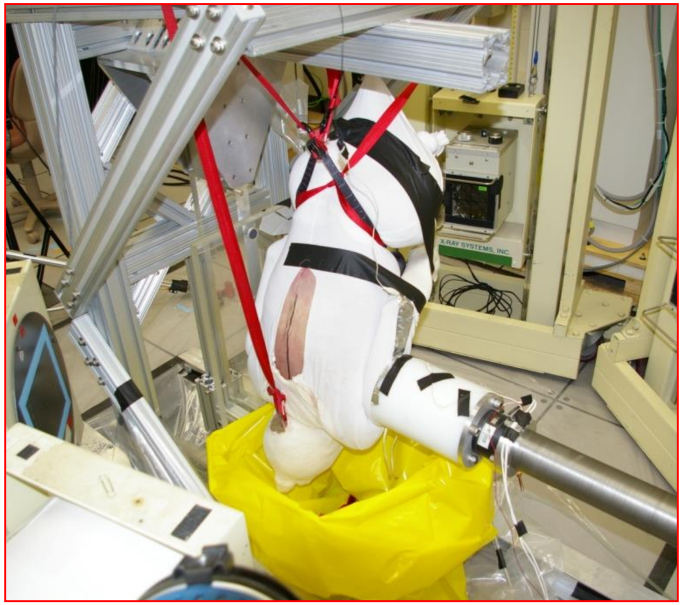


Previous Research Studies

- **Shah (2007) – High speed biaxial tissue testing machine**
  - Mechanical Properties of Aorta - Stress-Strain response



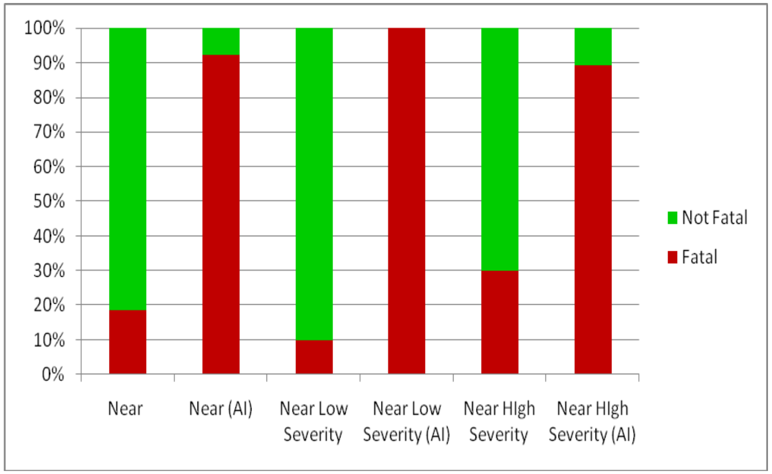
- **Hardy (2007) – Inverted impactor tests**
  - 8 cadavers, 7 with aortic injuries.
  - Position and orientation of the heart controlled by having an inverted and angled cadaver.
  - Hardened arteries have a greater risk of damage to the aorta .



Real World Data Analysis

Real World Data Analysis

- Low Severity Cases – Delta V =< 30 Kph
- The following criterion is followed to select the appropriate cases for the study:
  - All data and results use un-weighted and weighted data.
  - The data set was built using only vehicle-to-vehicle near-side-impacts.
  - Rollover cases were excluded.
  - Only cases with AIS 3+ injuries were included.
  - Passengers eleven years old or older
  - Front passengers
  - Passenger cars
  - Cases with one event were included in the data set to isolate the side-impact effects.
- High Fatality rates
- Rib Fractures are common



Real World Data Analysis (cont.)

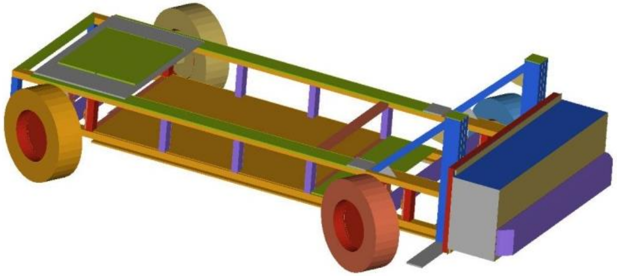
- Analysis on:
  - Occupant Factors : weight, height, age, gender
  - Crash Factors: belt usage, PDOF, damage pattern, damage extent

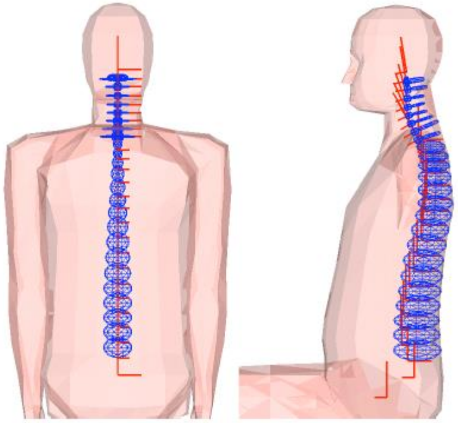
- Statistically Significant Variables (logistic regression)
  - Age
  - Delta-V
  - Intrusion
  - Damage Location/Pattern

Computer Modeling

Computer Models

- Software
  - LS-DYNA
  - MADYMO
- NCAC FE Models
  - 2001 Taurus
  - NHTSA MDB
  - IIHS MDB
- TNO Model
  - Human Facet Model
- Used Prescribe Structural Motion (PSM)



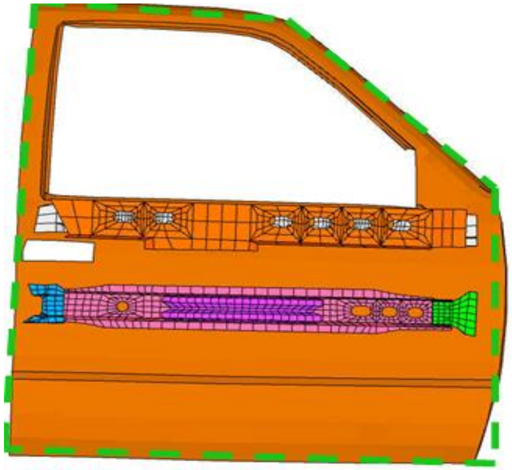


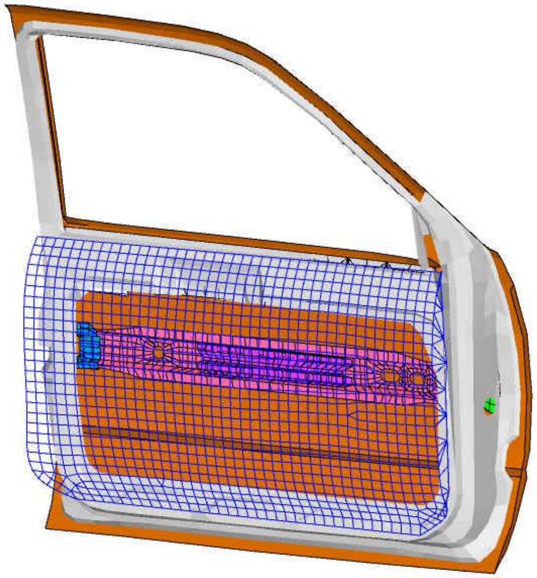
TNO'S Human Facet Model

- Cadavers
  - Poor repeatability because of age, sex weight and height variations
  - Older subjects with more plaque in the arteries
  - Ethical issues prevent this practice from being more popular
  - Post mortem changes
    - Physical properties of tissue change after death
    - Lack of muscle tone in the cadaver which may change the posture of the subject
    - Response to acceleration and the location of the internal organs change due to gravity
- Dummies
  - No ethical or repeatability problems but biofidelity is not precise
- Human Facet Model
  - Better biofidelity over the EuroSID2 (Steps, 2004)
  - Multidirectional responses not only lateral
  - Validated for far-side crashes (Alonso, 2004) by duplicating cadaver test performed by Fildes (Fildes, et al., 2002)

Prescribed Structural Motion

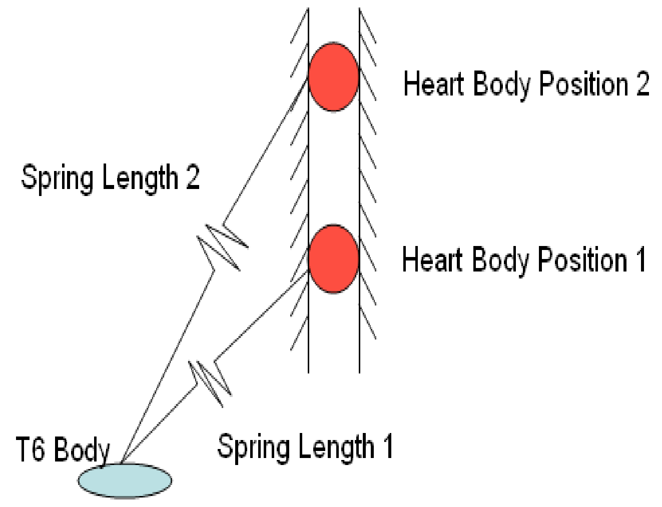
- Advantages
  - PSM helps input the velocity and intrusion profile to interact with the occupant model.
  - Shorter computation time
- Methodology
  - Outer door panel, inner door panel and door trim are main PSM boundaries
  - Nodal time histories from the LS-DYNA results
  - Outer door panel is totally prescribed
  - Only outer edge of the inner door panel and trim are prescribed
  - Critical structural parts are not totally prescribed
  - Contacts are specified between the door layers

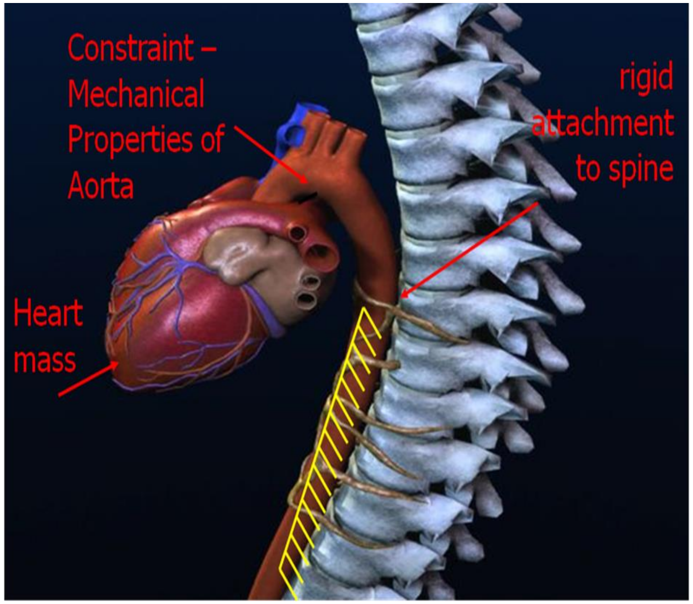




Spring Mass Model

- Spring Mass Model was added to represent the heart-aorta in TNO's Human Facet Model.
- Heart body and T6 Body were represented by Rigid Bodies.
- The spring with the mechanical properties of the aorta represents the aorta
- Bracket Joint represents the rigid attachment of the aorta to the spine
- Translational Joint represents the degree of freedom given to the heart (upward direction)

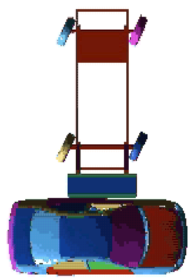




Computer Modeling of Vehicle-to-Vehicle Side Impacts

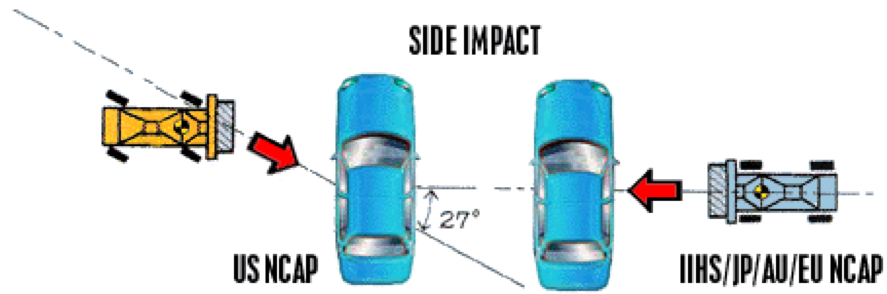
Side Impact Configurations

	NCAP	NCAP Y-Damage	IIHS
Impact Velocity	61.95 Km/h (38.5mph)	61.95Km/h (38.5mph)	50 Km/h (31.06mph)
Impact Angle	270	270	270
Crab Angle	27	27	0
Moving Deformable Barrier	NHTSA	NHTSA	IIHS
Impact Location	Middle of Vehicle	Front of Vehicle	Middle of Vehicle



NCAP

NCAPYDAM

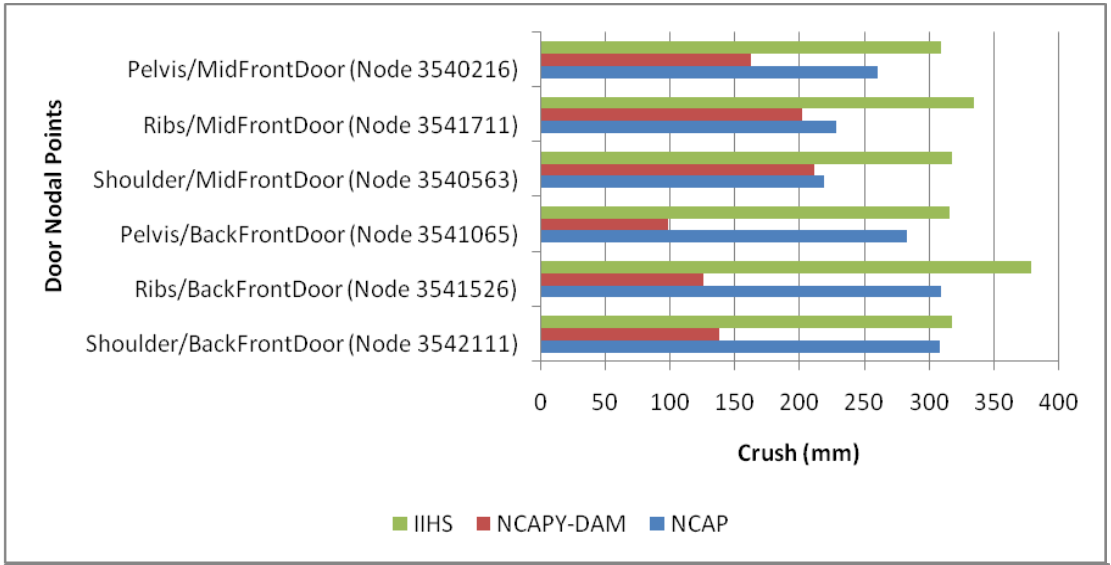


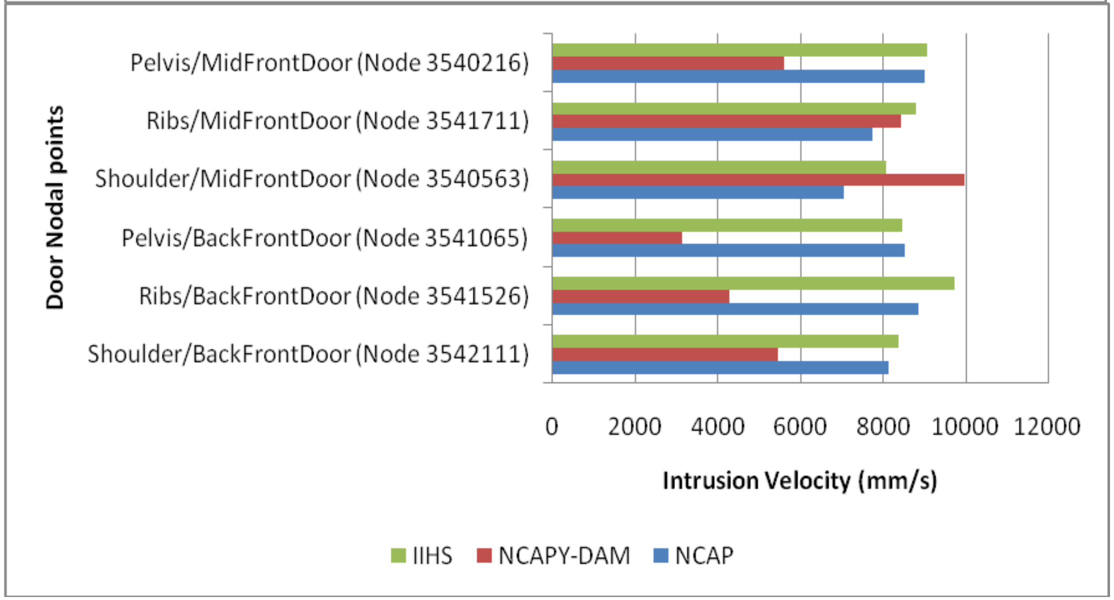
NCAP

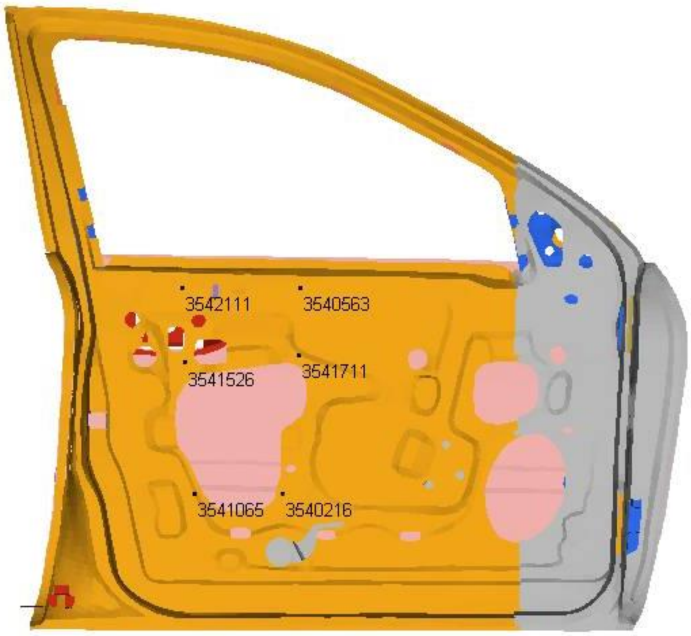
NCAP -Y

IIHS

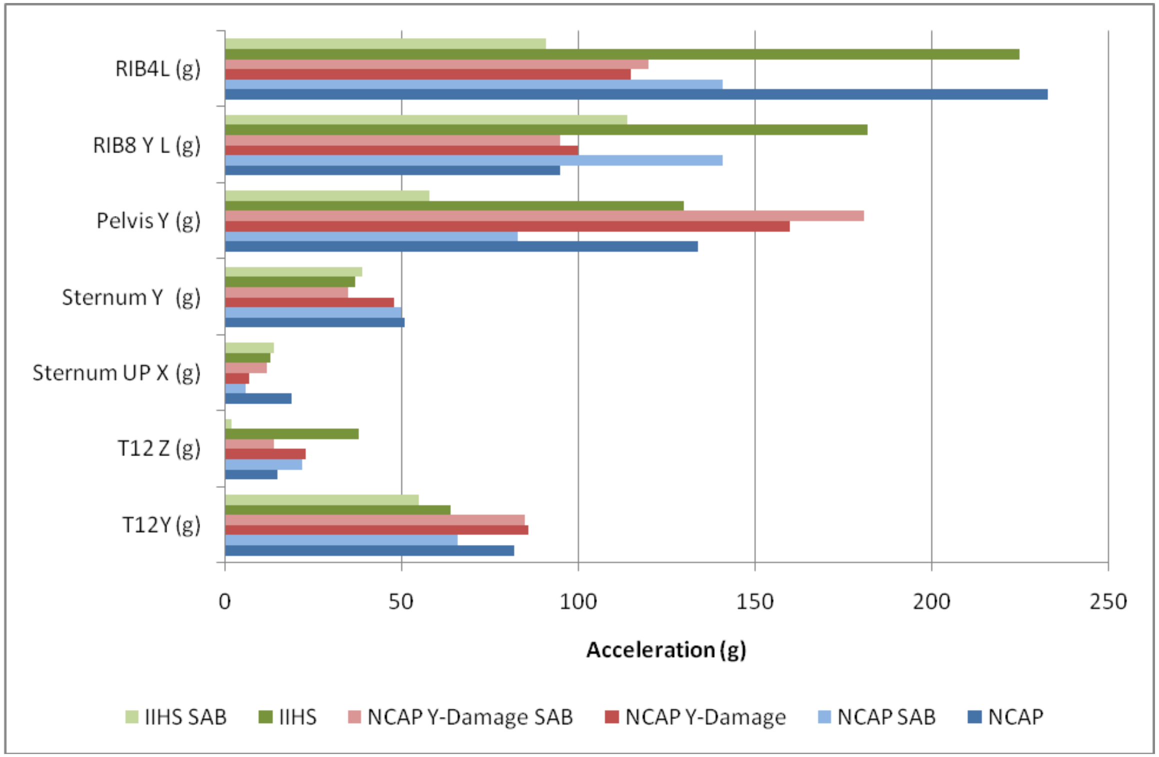
Door Crush and Intrusion Velocity







Peak Accelerations – Side Impact



• Understanding the crash environment and interior contacts that cause injury to humans is essential to identify the causes of such serious and/or fatal injuries in lateral impacts.
• Use of Airbags show decrease in accelerations in most cases
•Higher loads on the pelvis on NCAY Y-Damage
•NCAP with SAB Higher Rib8 YL Acceleration than without SAB

Results – Side Impact

- IIHS - Highest [VC]Max and CMax with values reaching 2.973 m/s and 72%.
- NCAP vs. NCAPY-Damage - NCAPY-Damage higher values of [VC]Max
- IIHS – T12Z and [VC]Max Prob. = 98%
  T12Z and Cmax Prob. = 100%
- NCAP Y-Damage – T12Z and [VC]Max Prob. = 75%
  T12Z and Cmax Prob. = 48%
- NCAP W/SAB – higher [VC]Max and Cmax than without SAB
- NCAP Y-Damage and IIHS the use of airbags lowered the [VC]Max and Cmax
- IIHS has highest relative elongation 0.132 (Failure limit 0.175)
- NCAPY-Damage second highest relative elongation 0.108

Results – Side Impact

- Comparison of Injury Severity of different tests based on VC
  - IIHS - Highest [VC]Max
  - NCAP vs. NCAPY-Damage - NCAPY-Damage higher values of [VC]Max
- Comparison of Injury Risks of different tests based on T12Z & VC
  - IIHS – Prob. = 98%
  - NCAP Y-Damage –Prob. = 75%
  - NCAP - Prob. = 48%
- Comparison of Side Air Bags in different tests
  - NCAP W/SAB – higher [VC]Max than without SAB
  - NCAP Y-Damage and IIHS the use of airbags lowered the [VC]Max
- Comparison of Spring Elongation in different tests
  - IIHS has highest relative elongation 0.132 (Failure limit 0.175)
  - NCAPY-Damage second highest relative elongation 0.108

Injury Response – Side Impact

Parameter	Units	NCAP	NCAP SAB	NCAP YDam	NCAP YDam SAB	IIHS	IIHS SAB
[VC]Max LR8 (m/s)	m/s	1.358	1.922	0.673	1.165	2.973	1.933
[VC]Max LR4 (m/s)	m/s	1.630	2.550	2.270	1.200	1.095	1.923
CMax LR8		39%	54%	27%	44%	72%	57%
CMax LR4		54%	58%	55%	47%	42%	51%
K1*T12Z+K2*[VC]MaxRL8+K3		-3.694	-0.848	-6.638	-4.618	4.516	-1.389
K1*T12Z+K2*[VC]MaxRL4+K3		-2.425	2.082	0.808	-4.455	-4.237	-1.435
K1*T12Z+K2*CMaxRL8+K3		-6.289	-0.658	-10.558	-4.675	6.312	0.139
K1*T12Z+K2*CMaxRL4+K3		-0.852	0.949	-0.183	-3.282	-4.503	-2.108
P (T12Z&[VC]MaxRL8)		4%	74%	0%	3%	98%	83%
P(T12Z&[VC]MaxRL4)		11%	15%	75%	2%	3%	84%
P(T12Z&CMaxRL8)		0%	41%	0%	2%	100%	52%
P(T12Z&CMaxRL4)		35%	75%	48%	4%	1%	12%
T12 Z	(g)	15	22	23	14	38	2
Sternum UP X	(g)	-19	-6	-7	-12	-13	-14
Pelvis Y	(g)	-134	-83	-160	-181	-130	-58
T12Y	(g)	-82	-66	-86	-85	-64	-55
Sternum Y	(g)	-51	-50	-48	-35	-37	-39
RIB8 Y L	(g)	-95	-141	-100	-95	-182	-114
RIB4L	(g)	-233	-141	-115	-120	-225	-91
TTI = 0.5 (Rib8y+T12y)	(g)	-89	-103	-93	-90	-123	-84
TTI = 0.5 (Rib4y+T12y)	(g)	-158	-103	-100	-103	-144	-73
TTI(average)= 0.5 (((Rib4y+Rib8y)/2)+T12y)	(g)	-123	-103	-97	-96	-134	-79
Relative Elongation		0.036	-0.050	0.110	0.108	0.132	0.064
Percentage Elongation (Failure @0.175)		21%	-29%	63%	62%	76%	37%

Computer Modeling of Sled Tests (Cavanaugh Cadaver Tests)

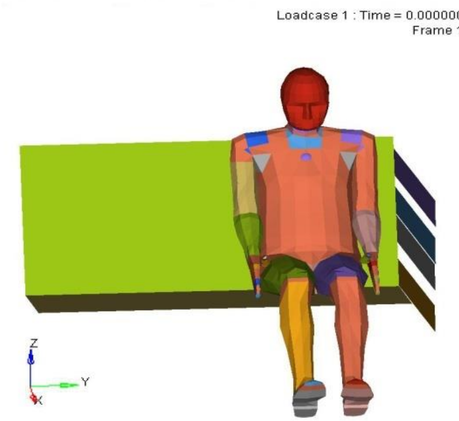
Computer Modeling Sled Tests

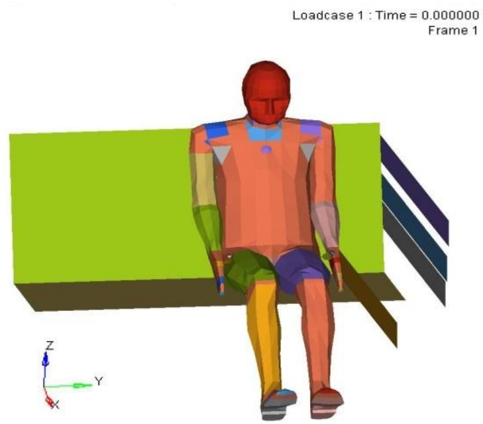
- Cadaver Sled testing studies performed by Cavanaugh, examined the response of the human body to side-impacts.
- Horizontally accelerated sled with rigid seat fixture
- Used as a reference to continue the study of aortic injury through modeling.
- Human Facet Model and a rigid seat sled model were used to model Cavanaugh's test environment using MADYMO
- Parameters studied by Cavanaugh such as: Lower Spine (T12Z, T12Y), Upper Sternum (SternumUpX, SternumUPY), Pelvis (PelvisY) and Upper and lower Ribs Accelerations, [VC]Max and CMax were used in the Human Facet Model simulations for the analysis
- Sled test with and without a six inch pelivc offset.

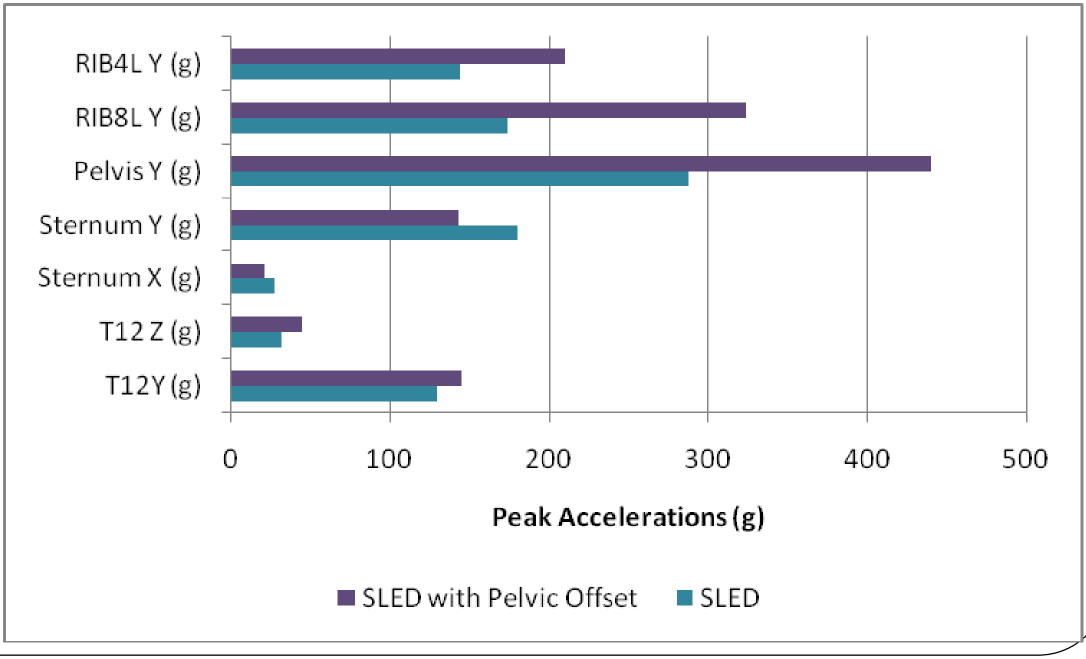
Computer Modeling Sled Tests

- Cavanaugh's test @ approximately 9 m/s
- MADYMO simulations @ 12m/s to reach the T12Z accelerations, Chest Compressions and Viscous Criterion in Cavanaugh's study.
- The differences in the acceleration, compression and VC differences between the model and cadavers can be attributed to:
  - Older cadavers and cadavers of different heights, body shapes and weights factors that are not well represented in the simulations.
  - Hardened arteries, usually present in older individuals, are more vulnerable to aortic tears (Hardy, et al., 2008).
  - Rib fracture was present in all cadavers.
- However, we can focus on the differences between the model with and without pelvic offset to make an assessment on this environmental condition.

Peak Accelerations – Sled Tests







Results – Sled Tests

- T12Z higher values on the pelvic offset test
- The non-offset sled test shows a 0.0153 relative elongation, while the offset-sled test has a 0.1946.
- Consistent with the Cavanaugh sled test results where he was able to reproduce aortic injury with offset sled tests better than with non-offset ones.
- The offset causes a greater inertial component in the positive Z-direction than the non-offset test.
- We can see a correlation between the T12Z component and the longitudinal elongation of the aorta.
- Offset Tests - T12Z and [VC]Max Probability = 111%

Injury Response – Sled tests

	Units	SLED	SLED with Pelvic Offset
[VC]Max R8 Res	m/s	1.6090	2.2129
[VC]Max R4 Res	m/s	0.4536	1.6704
CMax R8 Res		43%	45%
CMax R4 Res		21%	40%
P(T12Z&[VC]maxResR8)		14%	76%
P(T12Z&[VC]maxResR4)		0%	23%
P(T12Z&CMaxResR8)		1%	3%
P(T12&CMaxResR4)		0%	0%
T12 Z	(g)	32.02	44.46
Sternum UP X	(g)	27.02	20.50
Pelvis Y	(g)	287.36	440.62
T12Y	(g)	129.61	144.80
Sternum Y	(g)	180.08	142.76
RIB8L(Lower)	(g)	173.25	323.56
RIB4L (Upper)	(g)	143.98	209.65
TTI = 0.5 (Rib8y+T12y)	(g)	151.43	234.18
TTI = 0.5 (Rib4y+T12y)	(g)	136.79	177.23
Relative Elongation		0.0153	0.1946
Percentage Failure		9%	111%

Conclusions

Conclusions and Contributions

- Results conclude that the inertia effect is a possible factor in the injury mechanisms of aortic rupture.
- This stretching of the aorta as the result of inertia effect of the heart is present in the side-impact environments that were simulated.
- The aortic stretch is more severe in the higher severity cases and the Y-Damage pattern of the vehicle-to-vehicle simulations.
- It was also more severe in the pelvic offset sled tests, conforming to the previous cadaver research results from Cavanaugh
- Highest intrusion velocities in NCAP Y-Damage test at the Shoulder/MidFDoor location. This suggests that the loading in some areas of the door could be more severe in the Y-Damage configuration than in any of the other two configurations explored in this study.

Future Studies

- The Y-Damage pattern is not currently being addressed in current U.S. regulations even though Y-Damage pattern is the most common in real-world cases.
- This study opens the likelihood of inertia on the Z (upward) direction is a possible injury mechanism that should be studied in conjunction with Chest Compression.
- The ability to study the interaction between the Chest Compression and the inertial effect can be crucial in the development of an appropriate dummy and an associated injury criterion for aortic ruptures.

References