AN ANALYSIS OF TRAUMATIC RUPTURE OF THE AORTA IN SIDE IMPACT SLED TESTS

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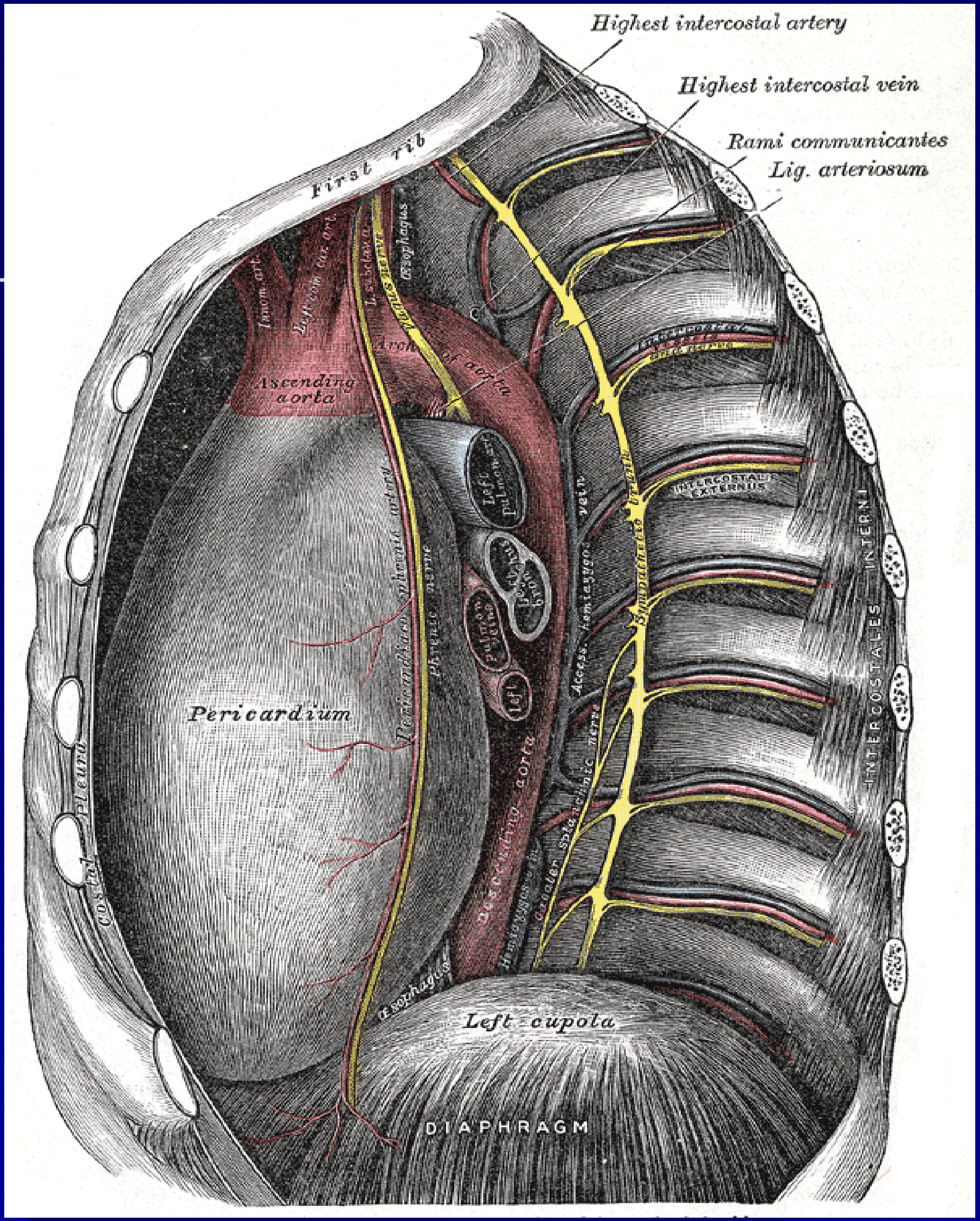
Anatomy



Highest intercostal artery
Highest intercostal vein
Rami communicantes
Lig. arteriosum
First rib
Ascending aorta
Arch of aorta
Pericardium
Left cupola
DIAPHRAGM
INTERCOSTALES INTERNI
Costal pleura
Descending aorta

Traumatic Rupture of the Aorta (TRA)

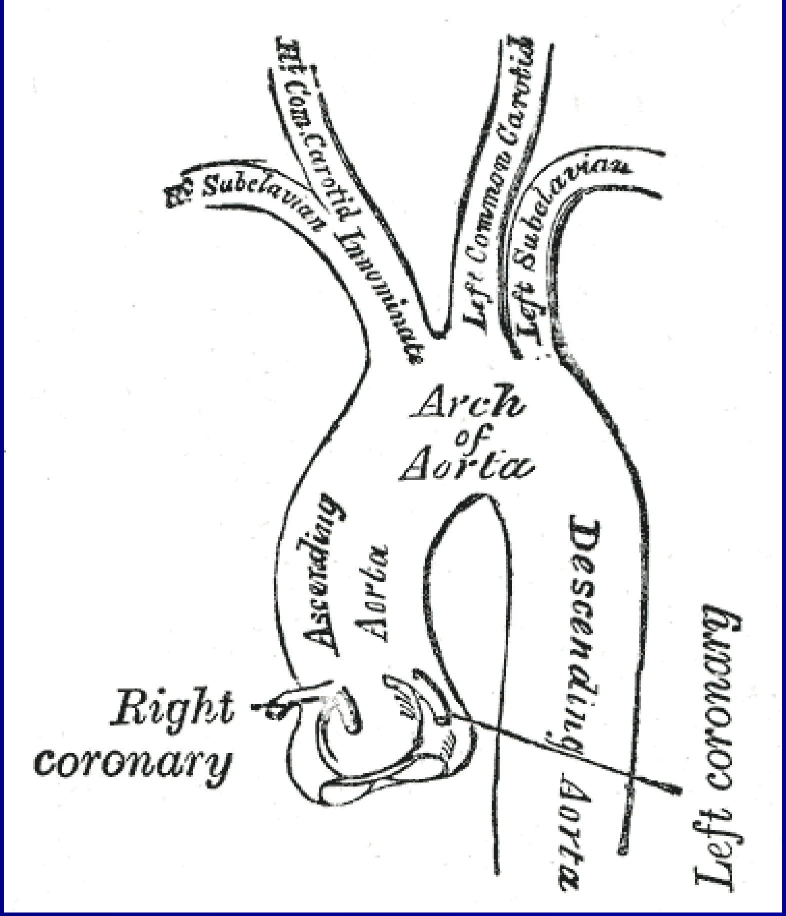
- **It has been estimated that 7500-8000 cases of TRA occur each year.** ***(Jackson, 1984; Mattox, 1989)***
- **Found in 21% of autopsies of traffic accident victims.** ***Katyal et al (1997)***
- **Responsible for 10-25% of traffic fatalities.**
  Viano (1983), Newman and Rastogi (1984)
- **70-90% of victims of TRA die at the scene.**
  Hunt et al (1996)

Various Injury Mechanisms Proposed

- Traction or shear forces between mobile points of the vessel and points of fixation.
- Direct compression over the vertebral column.
- Sudden increases in intraluminal pressure.

Aortic Isthmus

- **The peri-isthmic region is the site of most aortic lacerations.** ***Viano et al (1983), Katyal et al (1997).***
- **The aortic isthmus is a region just distal to the left subclavian artery and ligamentum arteriosum.**



TRA in Side Impact

- J Steps, 2003 PhD Thesis, NASS-CDS 1995-2001 data
  - There were 15,000 aortic injuries
  - Near side impacts represented 15% of total crashes, but 28% of aortic injury cases.
  - Near side impacts had twice rate the of aortic injuries as frontal impacts in vehicle-to-vehicle crashes.

TRA in Side Impact

- Aortic injuries have typically not occurred in cadaver side impact tests.
- 5 cases of aortic laceration occurred in 17 side impact tests run at WSU in 1989-92.

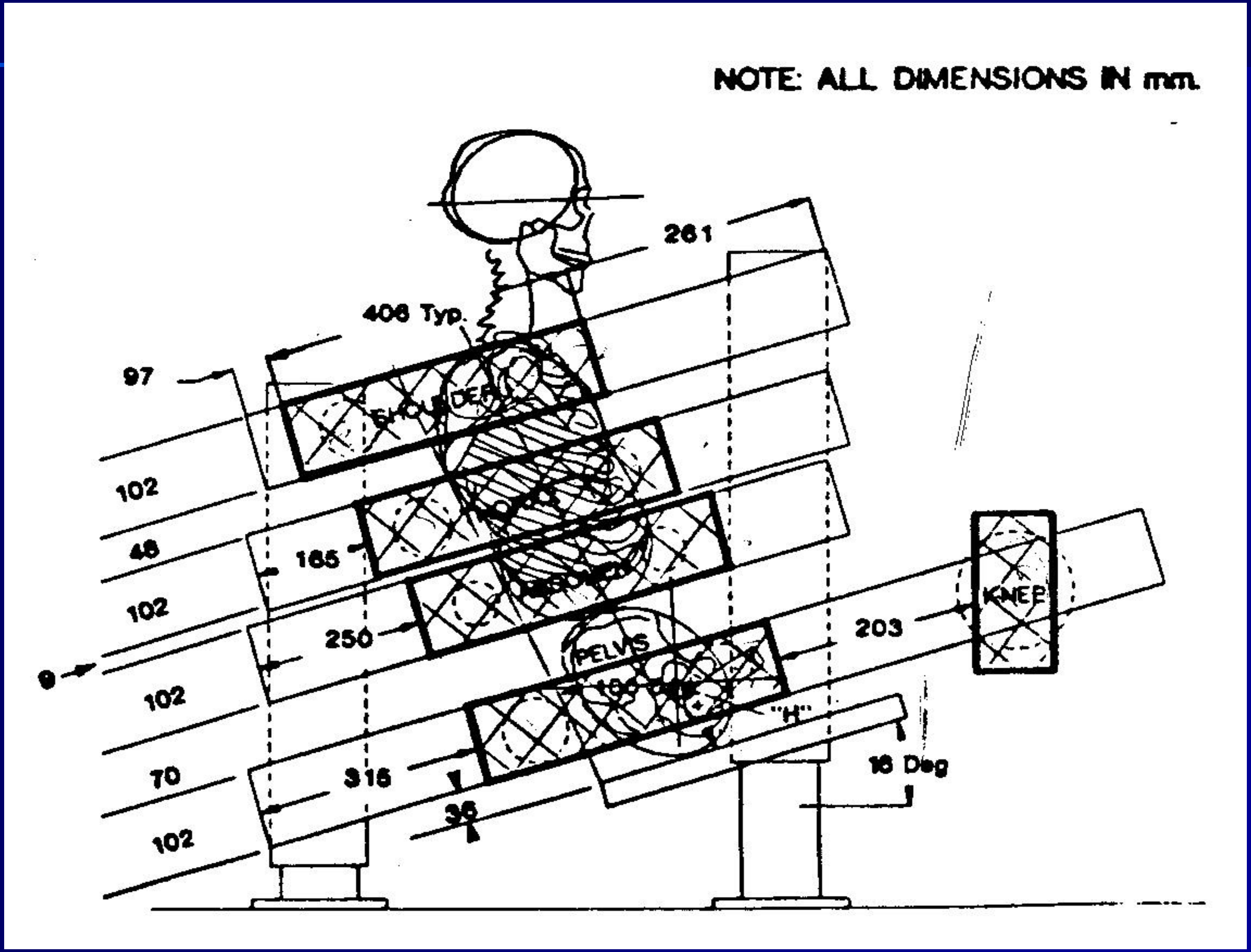
PURPOSE OF CURRENT STUDY

- To analyze retrospectively the data from these tests and determine if any single or multiple factors predicted aortic injury.

Methodology

Instrumentation	Location and axes
Accelerometers	Head- 3,2,2,2 Shoulder - X, Y, Z Up sternum- X, Y Lower sternum- X, Y T1- X, Y, Z T12- X, Y, Z S1- X, Y, Z Rib4 Y (right and left) Rib8 Y (right and left)
Barrier load cells	Shoulder 1, 2 Thorax 1, 2 Abdomen 1, 2 Pelvis 1, 2 Knee
Photo targets	Upper sternum, lower sternum T1, T5, T12 Sacrum, right iliac crest Rib 4 (Right) Rib 8 (Right) Medial and lateral ends of the clavicle Acromion and spine of the scapula Acromion of the right scapula

SAE No. 933127



Cadaver Pressurization

- A solution of India ink and normal saline was pumped into the thoracic vascular system from a pressurized tank that was fastened to the sled.
- The arterial system was pressurized to 100 mm Hg and the venous system to 50 mm Hg just before impact.

Film Analysis

- 16 m high speed film
  (frame rate ~ 500/sec).
- Deflection of struck side half thorax measured.
- T5 target or sternum targets on chest.

Data Processing

- Analog data was filtered at 1000 Hz (SAE channel class).
- Digitized at 8000-10000 Hz.
- Data quality checks were performed and any unusable data is labeled “NA” in the paper.
- Before filtering, the baseline was zeroed for the first 300 points before the cadaver made contact with the barrier.
- The acceleration data and sidewall force data were digitally filtered with a 300 Hz Butterworth Filter. (Corresponds to SAE CFC 180 Hz filter, SAE J211).

Normalizing

- Data were normalized using the equal stress-equal velocity scaling procedure outlined by the Eppinger et al. (1984).

Lamda= (standard mass/subject mass) $^{1/3}$

- Normalized force =(force x lamda ^{2})
- Normalized acceleration = (accel/lamda)
- Normalized deflection= (deflection x lamda)
- Normalized time = (time x lamda)

Logistic Regression Analysis

- $P = 1/(1+\exp(-\text{alpha} - \text{beta}_i * x_n))$
- Where:
  - P is the probability of aortic injury.
  - Alpha is the intercept and beta_i are the coefficients for each independent variable.
  - x_n are the independent response variables.

Logistic Regression Analysis

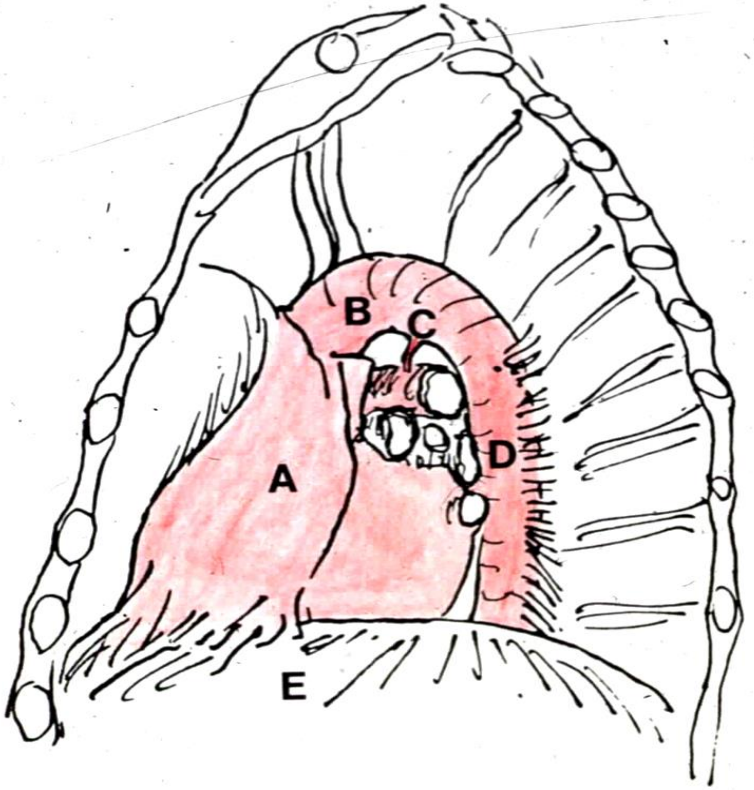
- Aortic injury AIS 4 and 5 assigned a value of 1.
- No aortic injury assigned a value of 0.

RESPONSE VARIABLES IN LOGIST ANALYSIS
CHEST ACCELERATIONS
T1-X
T1-Y
T1-Z
T12-X
T12-Y
T12-Z
R4-LEFT
R8-LEFT
R4-RIGHT
R8-RIGHT
U.STERN-X
L.STERN-X
ASA 10 at T12
BARRIER FORCES
SHOULDER
THORAX
SHOULD+THORAX
Cmax, VCmax (Film Analysis)
Cmax
VCmax

RESULTS

Run No.	AGE, SEX	Pelvic Offset (CM)	Impact Speed (m/s)	PAD Depth (cm)	kPa	Aorta AIS
SIC01	60 M	15.2	8.9	None		0
SIC02	64 F	15.2	9.1	None		4
SIC03	37 M	15.2	10.5	None		5
SIC04	69 M	0	9.1	None		0
SIC05	67 M	0	6.7	None		0
SIC06	60 M	0	9.0	None		0
SIC07	66 M	0	6.7	None		0
SIC08	64 F	0	6.6	None		5
SIC09	61 M	0	9.2	7.6	152	5
SIC10	60 M	0	8.7	15.2	55	0
SIC11	54 F	0	8.9	10.2	55	0
SIC12	68 F	0	8.9	10.2	131	5
SIC13	62 M	0	8.3	10.2	55	0
SIC14	72 M	0	9.4	10.2	90	0
SIC15	43 F	0	8.9	10.2	55	0
SIC16	58 F	0	8.9	7.6	103	0
SIC17	65 M	0	8.9	15.2	55	0

Test No.	AIS Aorta	Aortic Injury	Site of Injury and Comments
UNPADDED PELVIC OFFSET 9 m/s			
SIC02	4	1 cm intimal tear	Just below the ligamentum arteriosum
UNPADDED PELVIC OFFSET 10.5 m/s			
SIC03	5	1.5 cm complete transverse tear	Just below the level of ligamentum arteriosum
UNPADDED 6.7 m/s			
SIC08	5	1 cm complete transverse tear of thoracic aorta	In an area of marked atherosclerosis just distal to left subclavaian artery and ligamentum arteriosum
3 INCH STIFF PAD 9 m/s			
SIC09	5	1 cm complete transverse tear	Just distal to left subclavian artery and ligamentum arteriosum
4 INCH STIFF PAD 9 m/s			
SIC12	5	1.5 cm complete transverse tear	Just distal to left subclavian artery and ligamentum arteriosum



A. HEART IN PERICARDIAL SAC.

B. AORTIC ARCH.

C. LIGAMENTUM ARTERIOSUM.

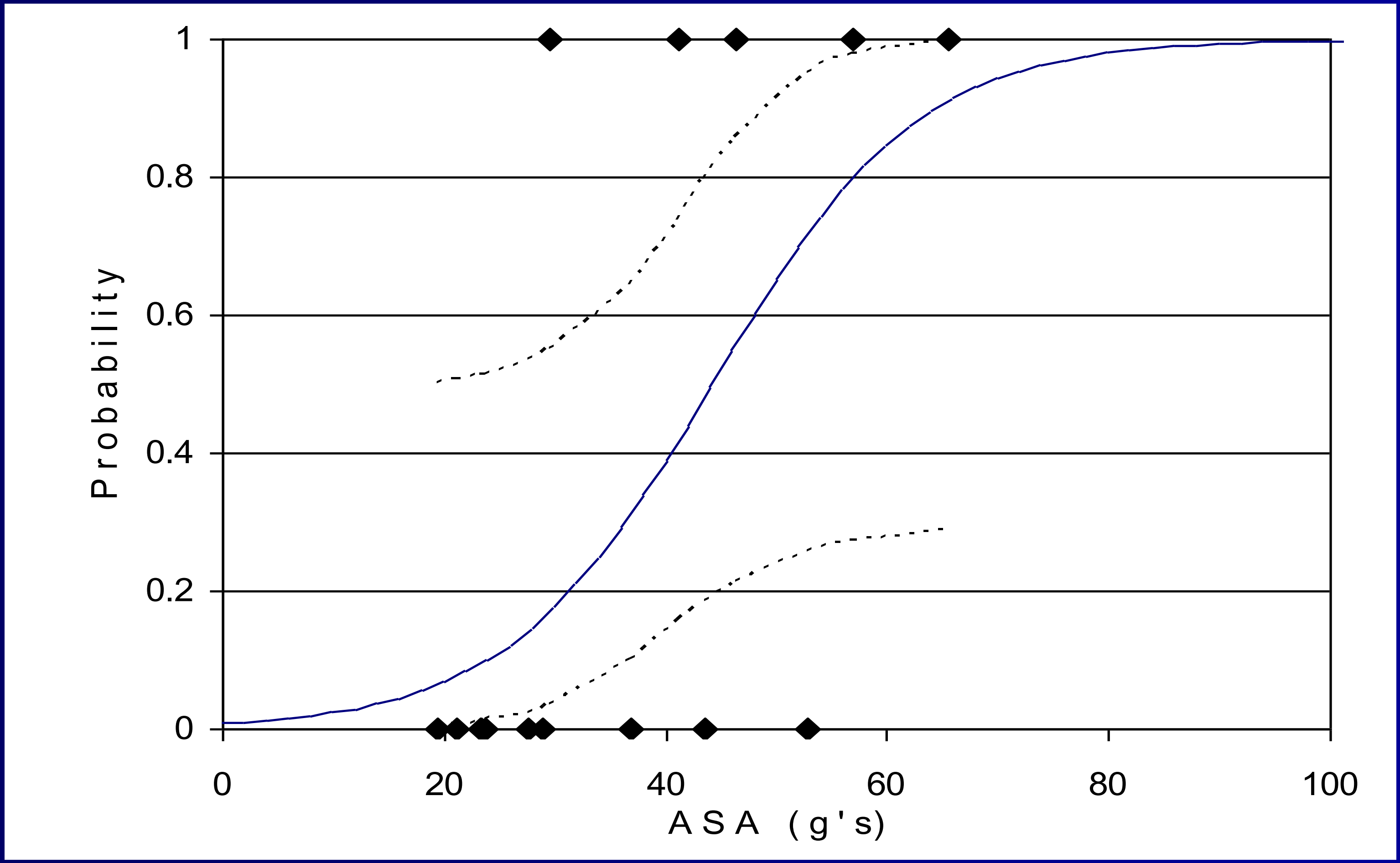
D. DESCENDING THORACIC AORTA TIED DOWN TO POSTERIOR CHEST WALL WITH FASCIA

E. DIAPHRAGM.

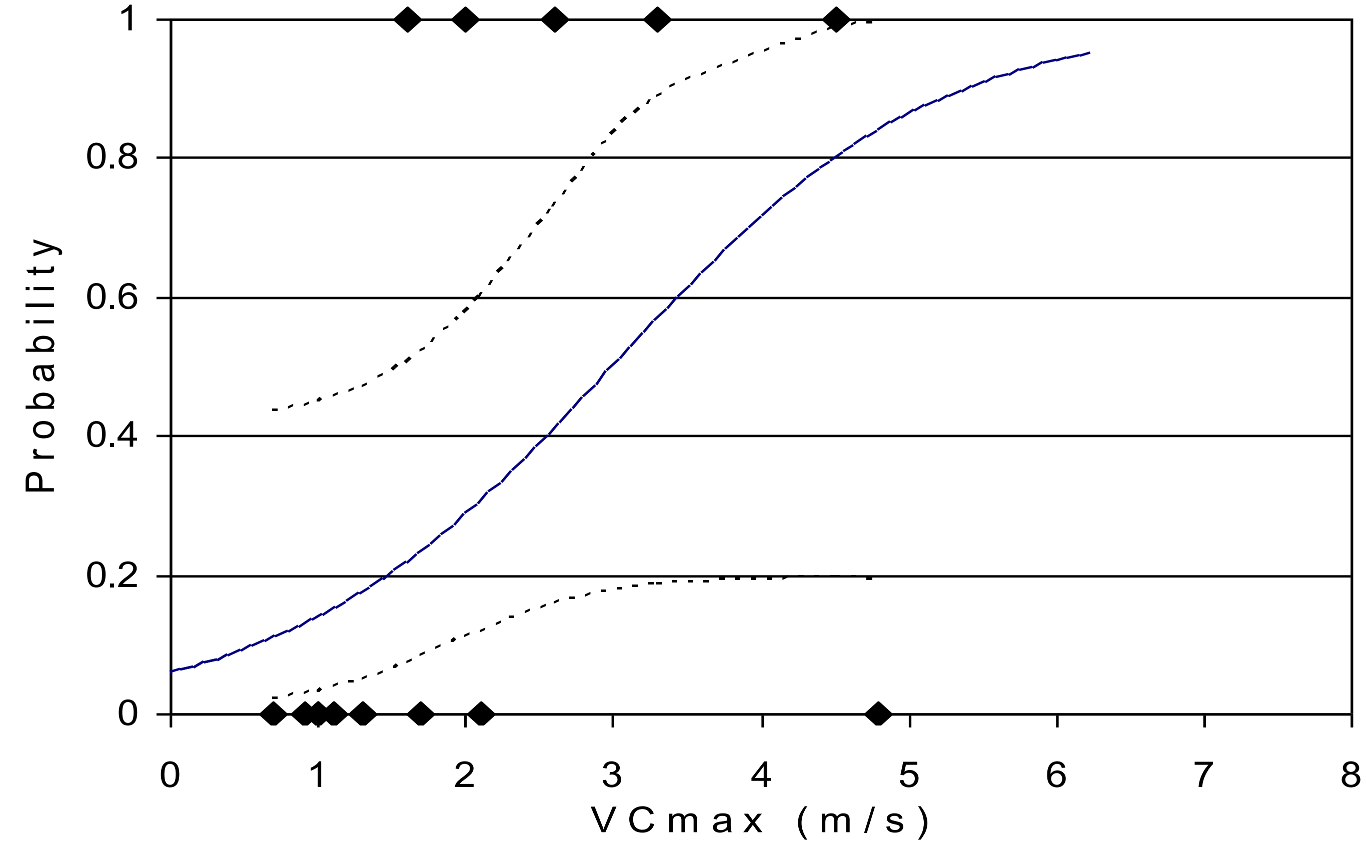
Logistic Regression Single Variables

Response variable	Chi square	P value
R8-RIGHT	5.166	0.0230
ASA10 at T12	5.216	0.0224
VCmax	3.959	0.0466

ASA



VCmax

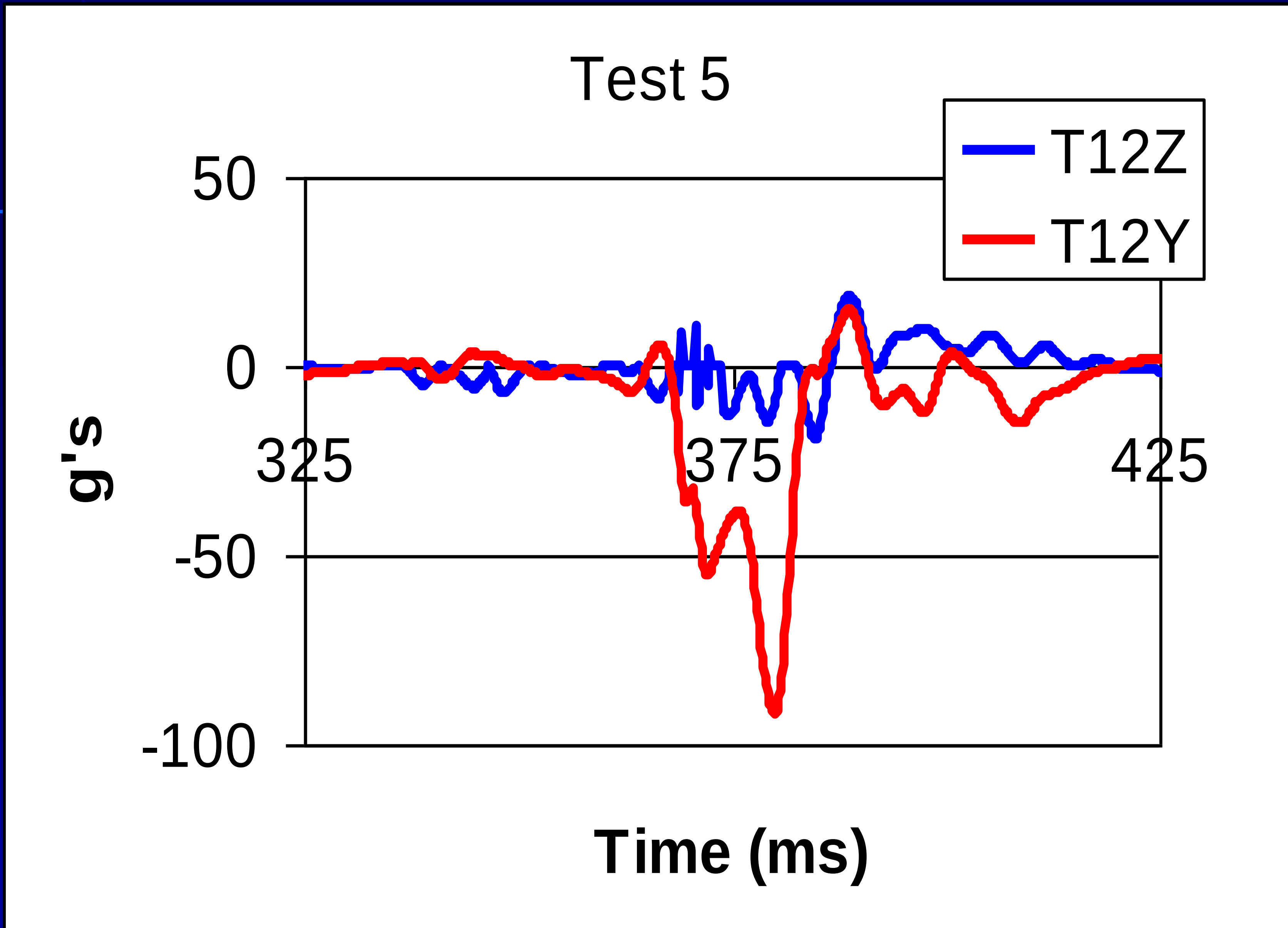


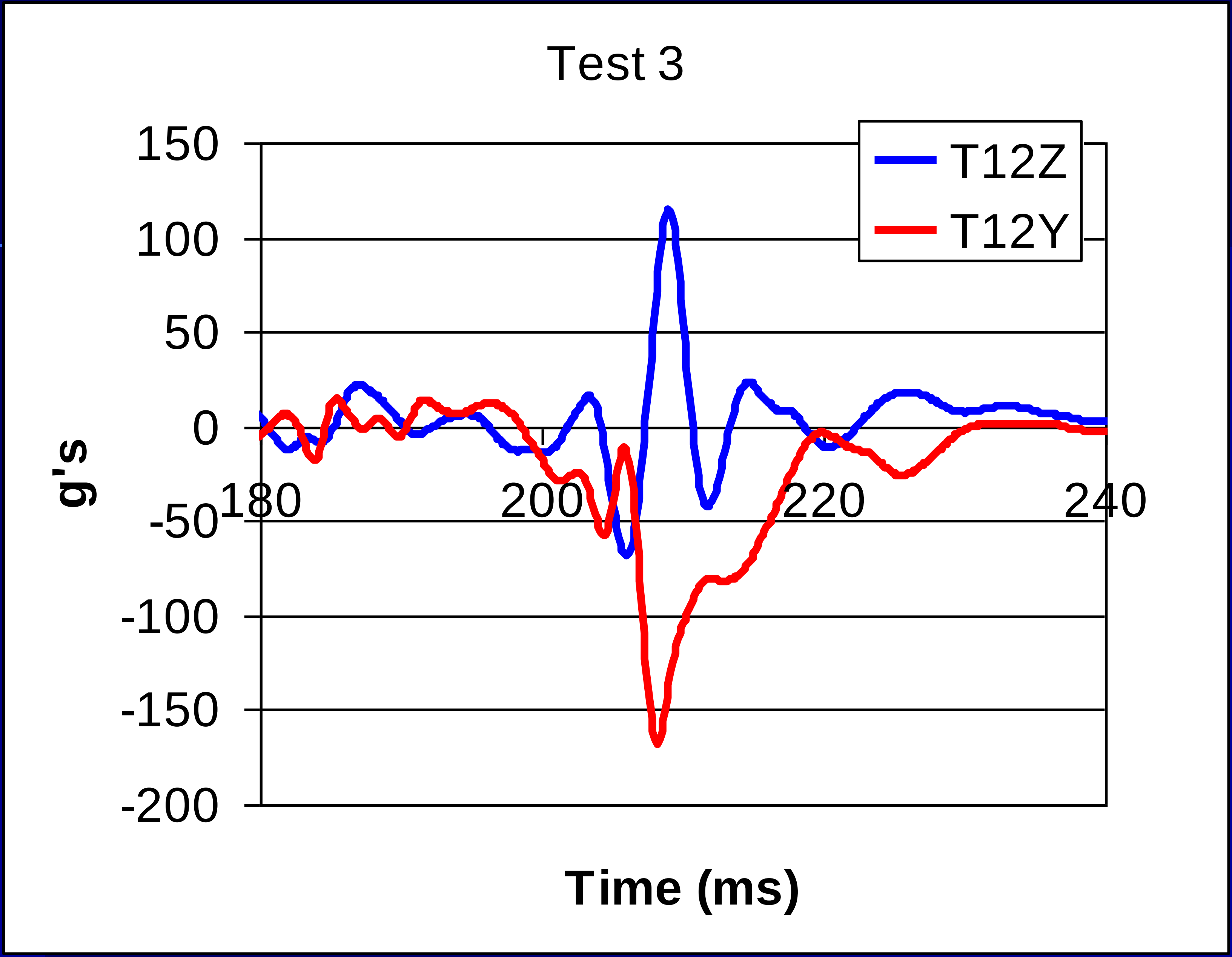
Linear Combination Analysis

Combination	k1	k2	k3	Chi-square	P value
k1*Age+k2*R8r+k3	0.3454	0.0416	-28.0385	7.057	0.0079
k1*T12Z+k2*ASA+k3	0.0426	0.2123	-12.0304	8.985	0.0027
k1*T12Z+k2*Cmax+k3	0.0236	0.3666	-20.9704	8.438	0.0037
k1*T12Z+k2*VCmax+k3	0.0294	4.6622	-10.4518	9.760	0.0018
k1*UpsX+k2*ASA+k3	0.0964	0.1889	-16.1679	8.405	0.0037

Peak T12-Z (filtered, normalized)

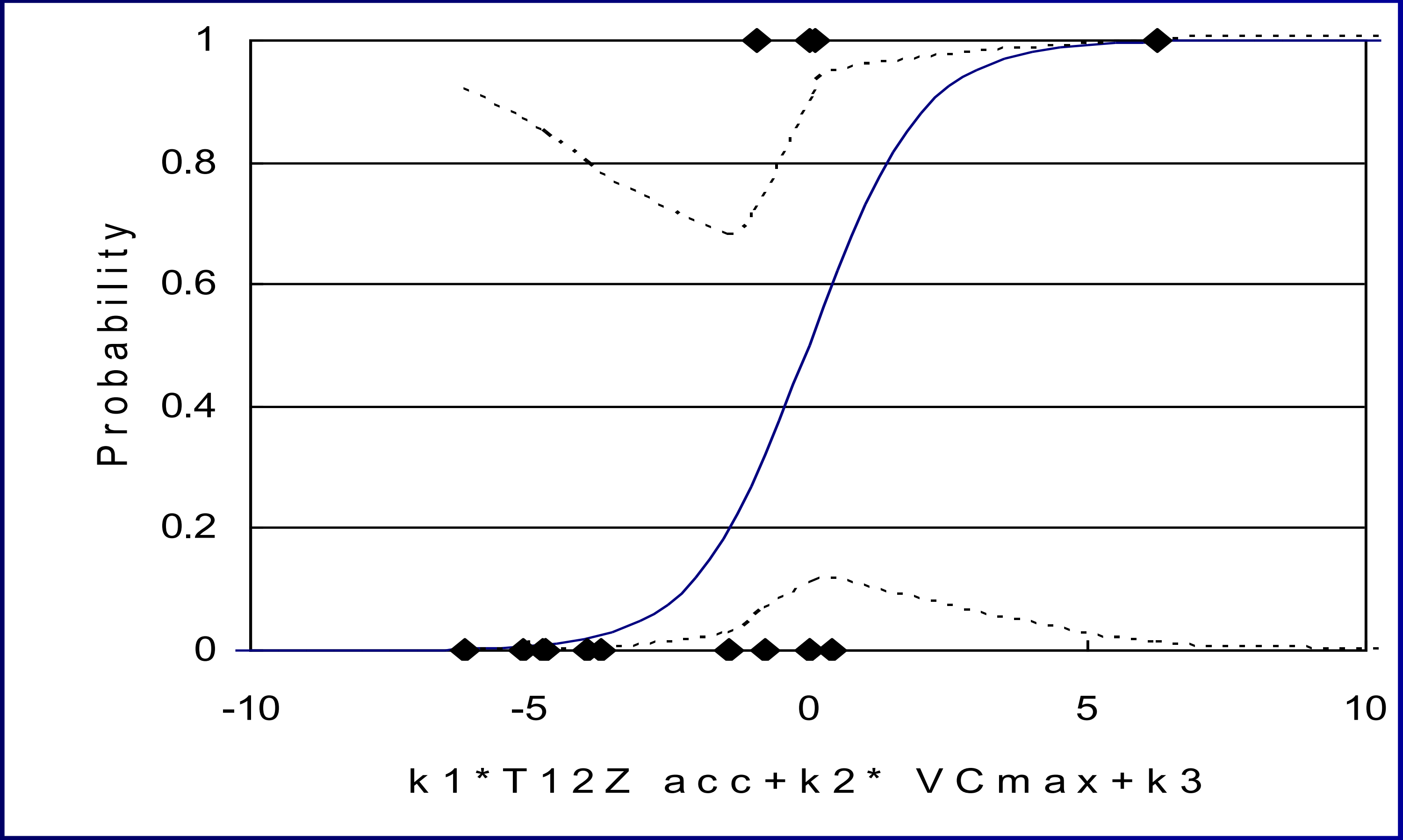
- Avg 68.1 g's in aortic injury cases
- Avg 41.7 g's in non-injury cases


Test 5
T12Z
T12Y
50
0
-50
-100
325
375
425
g's
Time (ms)

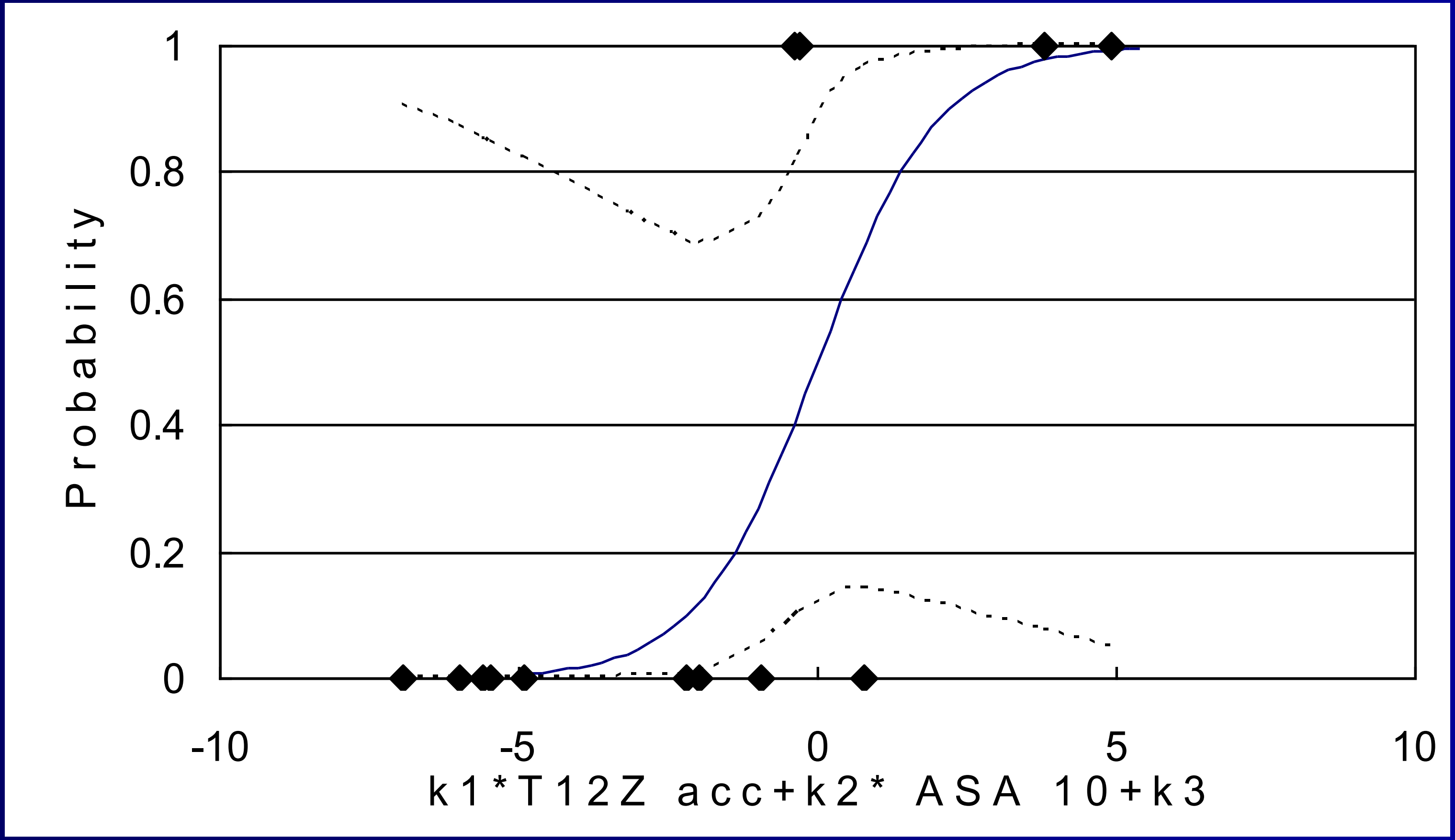


Test 3
T12Z
T12Y
150
100
50
0
-50
-100
-150
-200
180
200
220
240
g's
Time (ms)

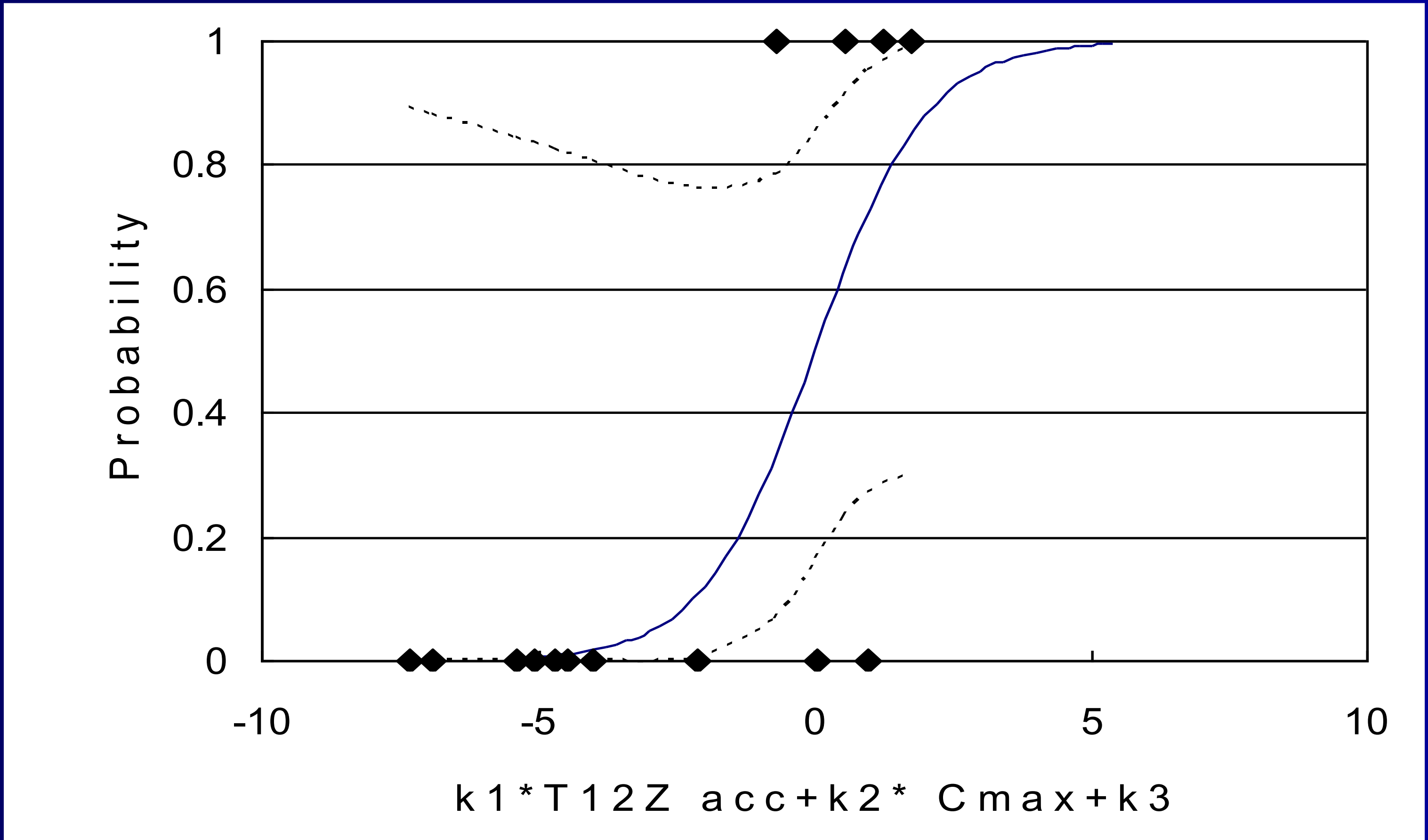
T12z, VCmax



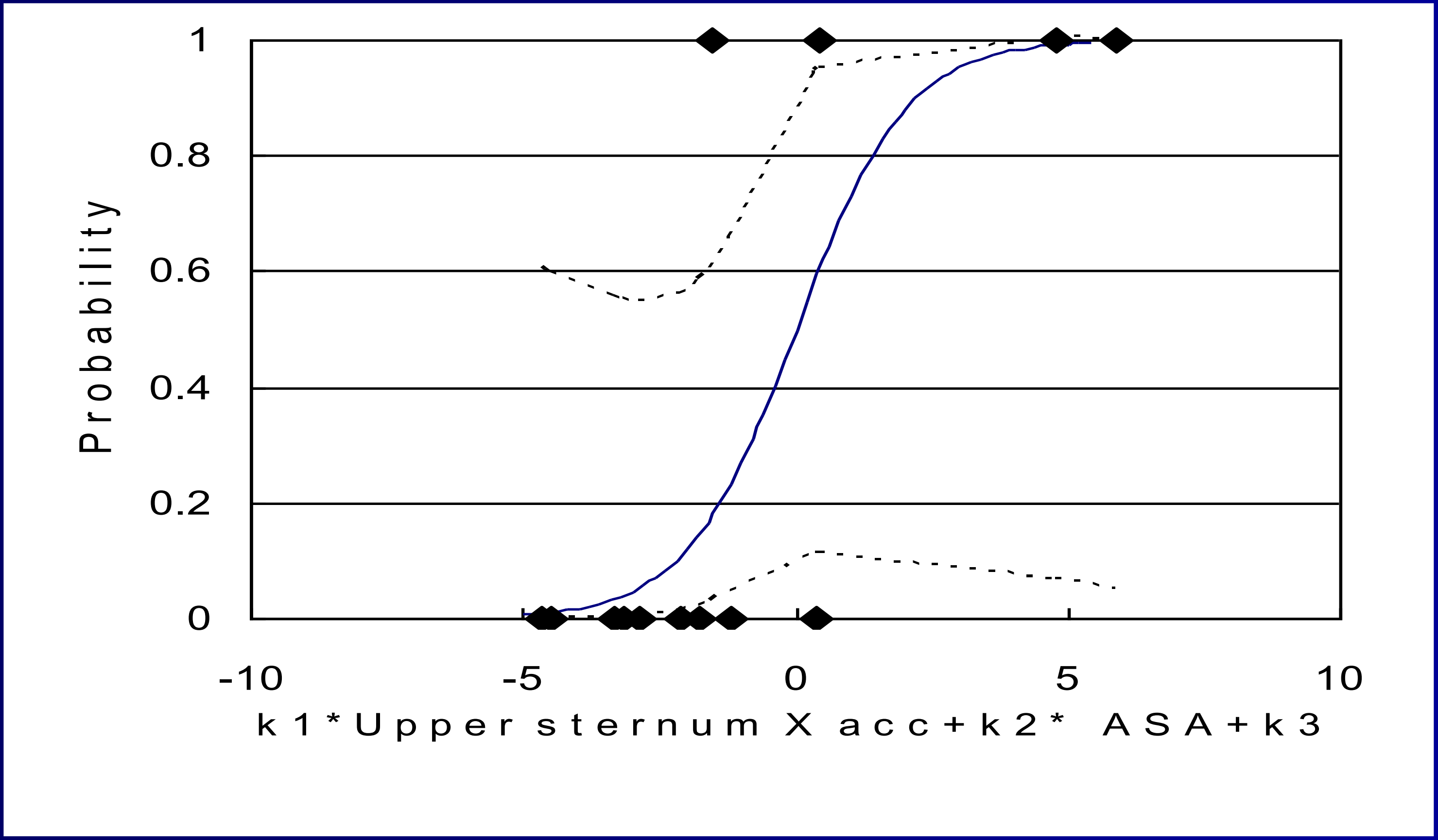
T12z, ASA



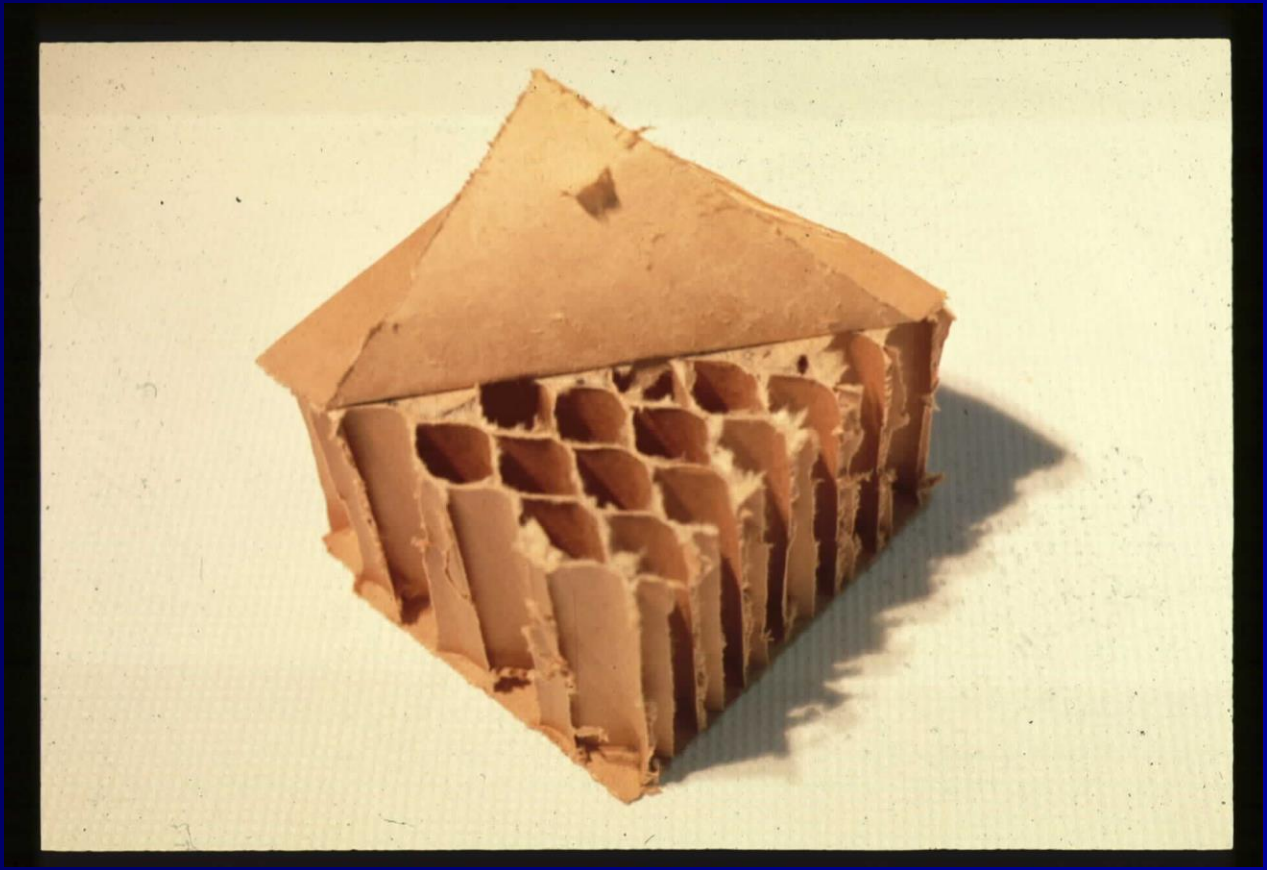
T12z, Cmax



Up Stern X, ASA



THE EFFECT OF PADDING



Soft Padding, 55-70 kPa

Padding and aortic injury

- VCmax averaged 2.8 m/s in the 5 TRA cases.
- VCmax averaged 0.98 m/s in the 5 tests with soft padding (55-70 kPa crush strength). There was no TRA in these tests.

DISCUSSION

Cadaver Pressurization

- Both femoral and carotid arteries were blocked off and arterial pressure was maintained at 100 mm Hg during impact.

Vertical Displacement

- In the current study T12-z itself was not a significant predictor of TRA.
- When T12-z acceleration was combined with ASA, VCmax or Cmax predictive ability was improved.

Vertical Displacement

- Vertical displacement of the heart was cited as being responsible for avulsions of the root of the aorta in helicopter crashes. *Parmley et al. (1958)*
- Inertia of the heart may produce traction on the thoracic aorta along its long axis, putting tensile strain in the region of the isthmus. *Horton et al. (2000)*
- Others *(Tribble and Crosby, 1988), Gotzen et al (1980)*

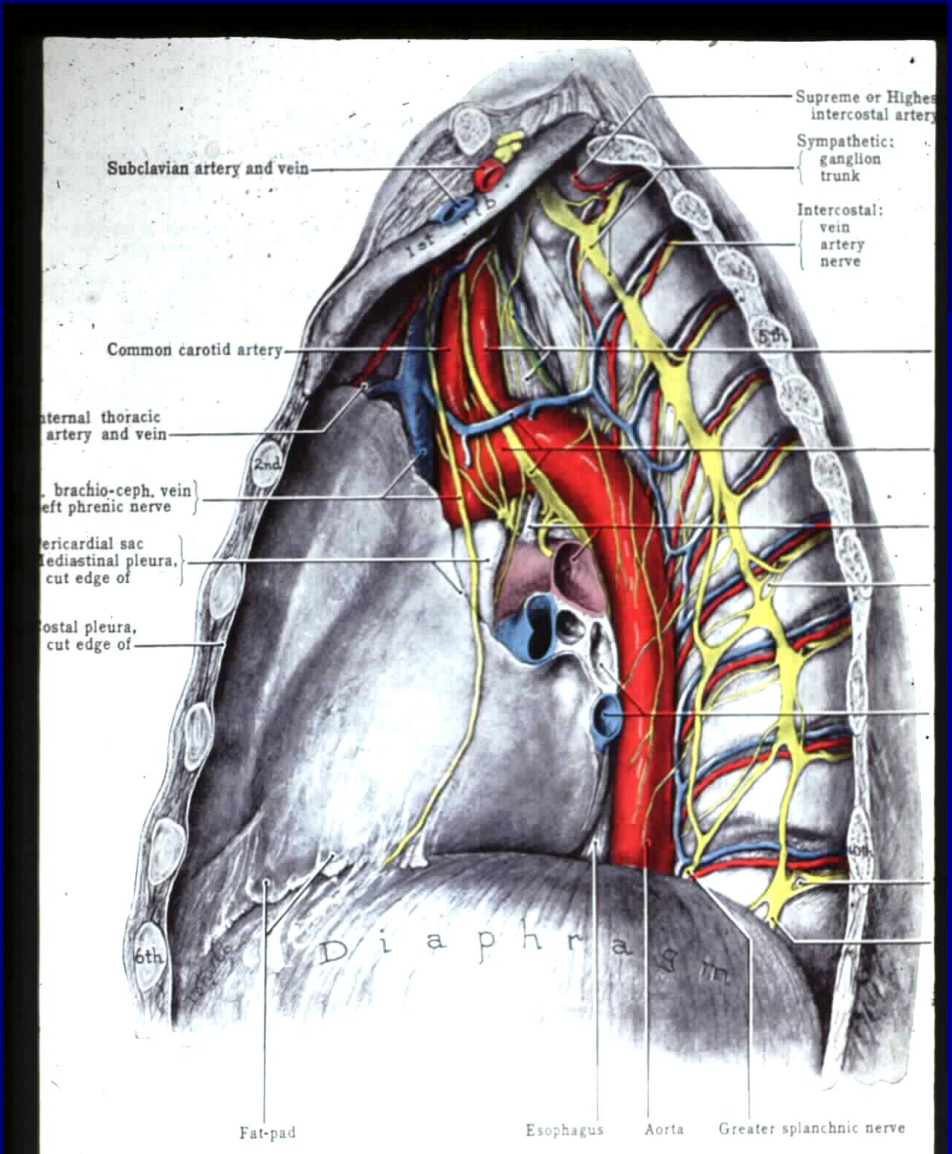
Sternum Displacement

- Improvement in injury prediction with the inclusion of sternum x-acceleration suggests that stretching of the aortic arch in the posterior-to-anterior direction can contribute to TRA.

Indy Car Study (Melvin et al, 1998).

- **143 side impacts**
- **No serious chest injuries occurred.**
- **Peak vehicle acceleration averaged 53.3 g's.**
- **41 cases exceeded 60 g's**
- **7 cases exceeded 100 g's.**
- **These drivers were in six point restraints with tight wide double shoulder straps, uniform support of the body with significant load paths through the shoulder and pelvis and lack of intrusion.**

- **The ability to limit chest wall and spine motion in Indy crashes may be important in preventing movement of the aortic arch relative to it regions of restraint.**



429 Left Side of the Mediastinum

CONCLUSIONS

- Aortic injury occurred in 5 of 17 side impacts. In the five impacts with soft padding no aortic injury occurred.
- ASA, unstruck rib-8 acceleration and VCmax showed correlation with aortic injury.
- The inclusion of subject age modestly improved the predictive ability.

CONCLUSIONS

- **Combining ASA with upper sternum-x acceleration was one of the better predictors TRA.**
- **Combining T12-z (vertical acceleration) with VCmax, Cmax and ASA resulted in the best predictors of TRA.**

ACKNOWLEDGMENTS

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