

**DECELERATION VELOCITY AND ENERGY DISSIPATION
ON IMPACT IN MOTOR VEHICLE CRASHES: KEY FACTORS
IN THE PRODUCTION OF THE PATTERN OF INJURIES AND
PATIENT SURVIVAL AS A FUNCTION OF THE DIRECTION
OF CRASH, WITH SPECIAL REFERENCE TO THORACIC
AORTIC INJURIES.**

**A CRASH INJURY RESEARCH ENGINEERING NETWORK
(CIREN) STUDY**

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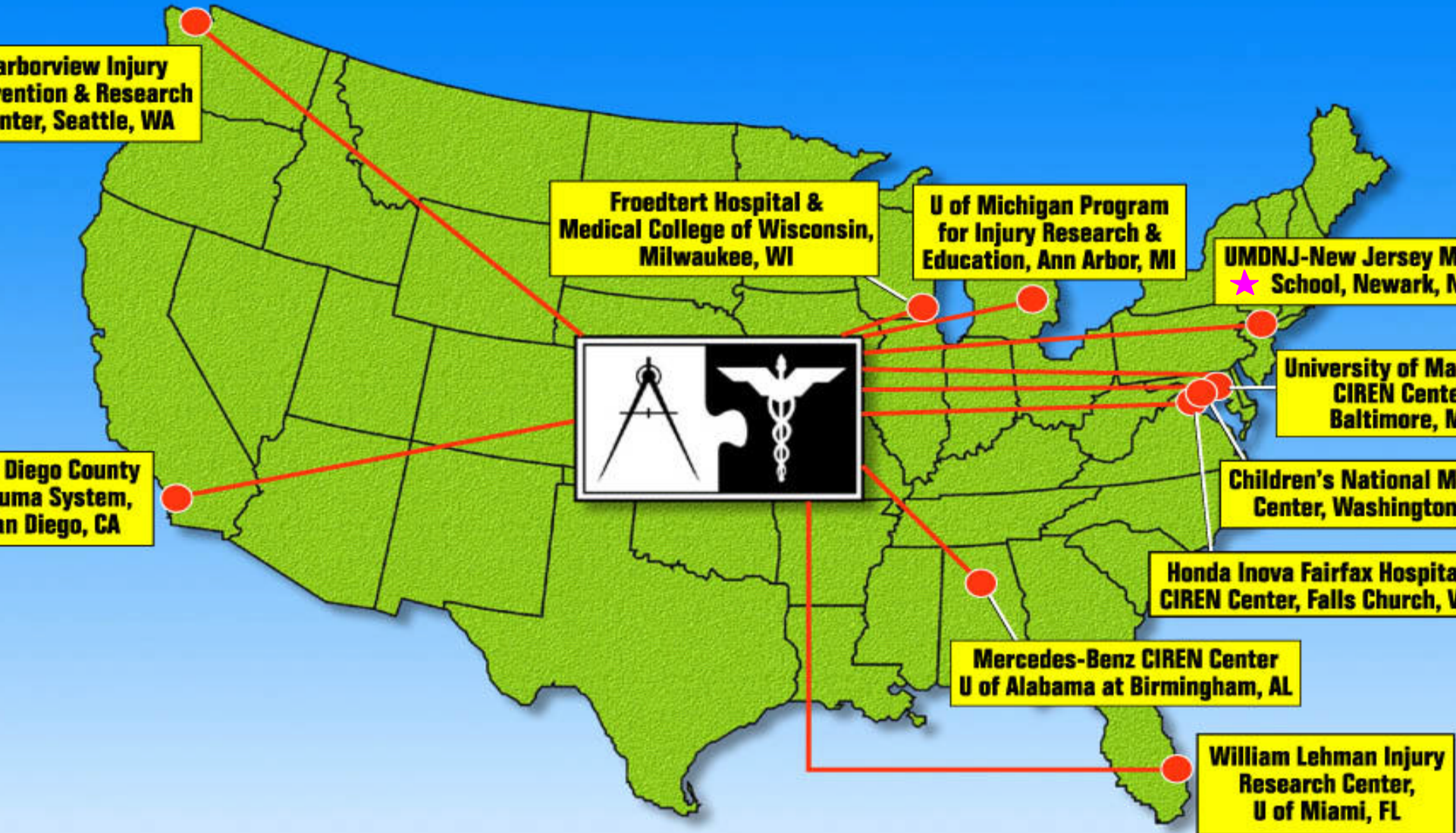
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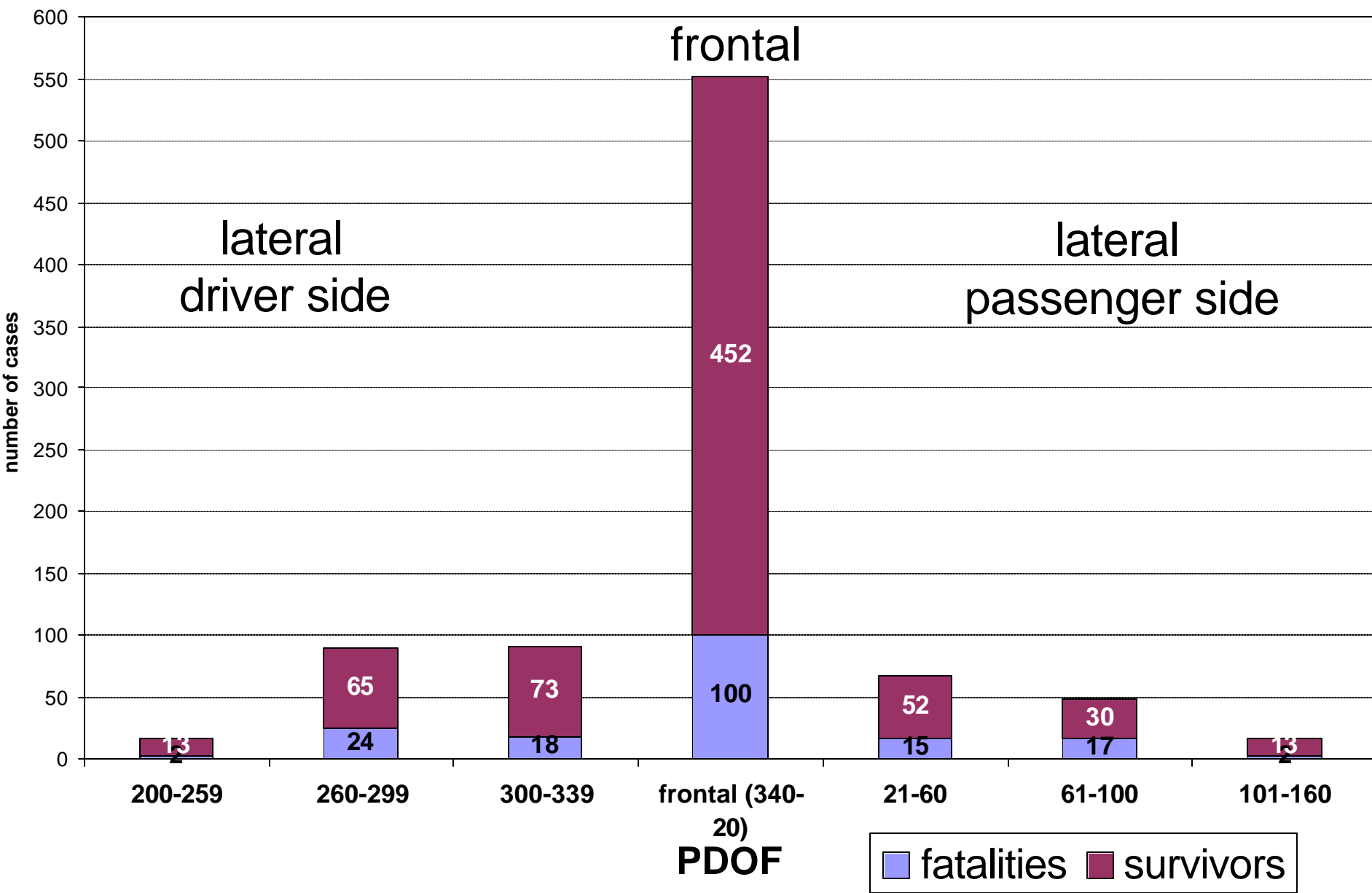
MATERIALS & METHODS I

CIREN DATA FROM 876 ADULT DRIVERS OR FRONT-SEAT OCCUPANTS OF MOTOR VEHICLE CRASHES (MVCs) INVOLVING CARS; OR SPORT UTILITY, VANS, OR LIGHT PICK-UP TRUCKS (SUVT). CRASHES WITH FULL ROLLOVERS, REAR-END COLLISIONS, OR EJECTED PATIENTS EXCLUDED. NO SIDE AIRBAGS IN SERIES. DATA SPAN PERIOD 1996-2002.

552 FRONTAL MVCs (PDOF 340° - 0 - 20°).

334 LATERAL MVCs (PDOF <340°-190° OR >20°-170°).

INCLUDES 46 FRONTAL MVC AORTIC INJURY (AI) AND 34 LATERAL MVC AI CASES.



MATERIALS & METHODS II

PATIENT:

- 1) AGE, SEX, HEIGHT & WEIGHT
- 2) DIRECTION OF CRASH FMVC OR LMVC
- 3) OCCUPANT VEHICLE (V1) VS OTHER VEHICLE (V2) OR NON VEHICLE (FO)
- 4) SEAT-BELT AND AIRBAG DEPLOYMENT
- 5) SURVIVAL OR DEATH STATUS
- 6) PATIENT OR NEXT OF KIN INFORMED CONSENT OR
- 7) MEDICAL EXAMINERS AUTHORITY FOR SCENE FATAL CRASHES
- 8) POLICE, EMS & HOSPITAL RECORDS
- 9) MEDICAL EXAMINER AUTOPSY REPORTS
- 10) PSYCHOSOCIAL EVALUATION IN HOSPITAL & FOLLOW-UP AT 6, 12 & 18 MONTHS

MATERIALS & METHODS III

VEHICLE:

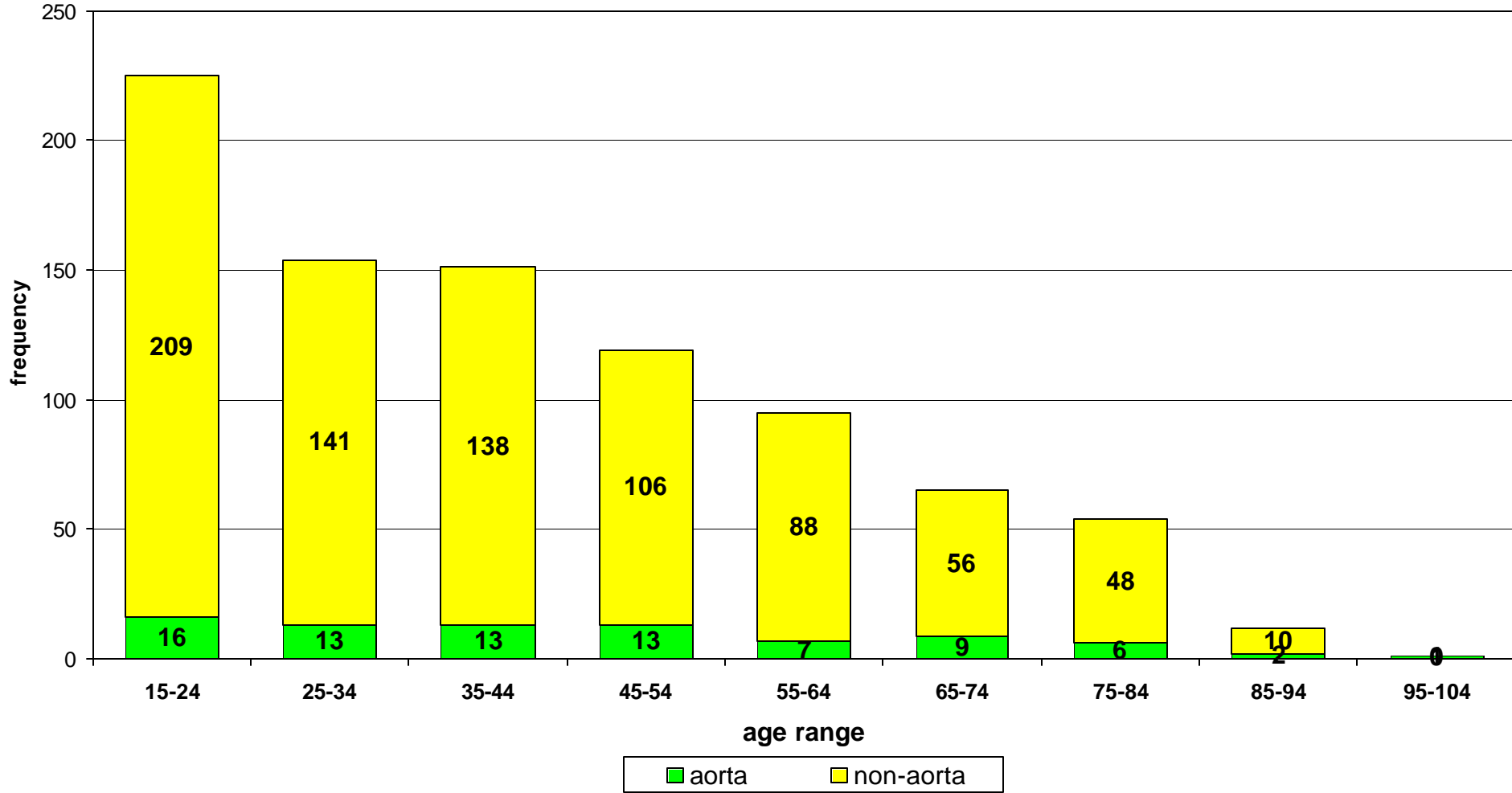
CRASH RECONSTRUCTION DATA FOR MECHANISM OF CRASH WITH SCENE DIAGRAM AND DETERMINATION OF PRIMARY DIRECTION OF FORCE (**PDOF**) ON SUBJECT VEHICLE (**V1**)

DELINEATION OF SITES OF DRIVER AND/OR FRONT-SEAT PATIENT'S INJURY PRODUCING CONTACT WITH PASSENGER COMPARTMENT STRUCTURES

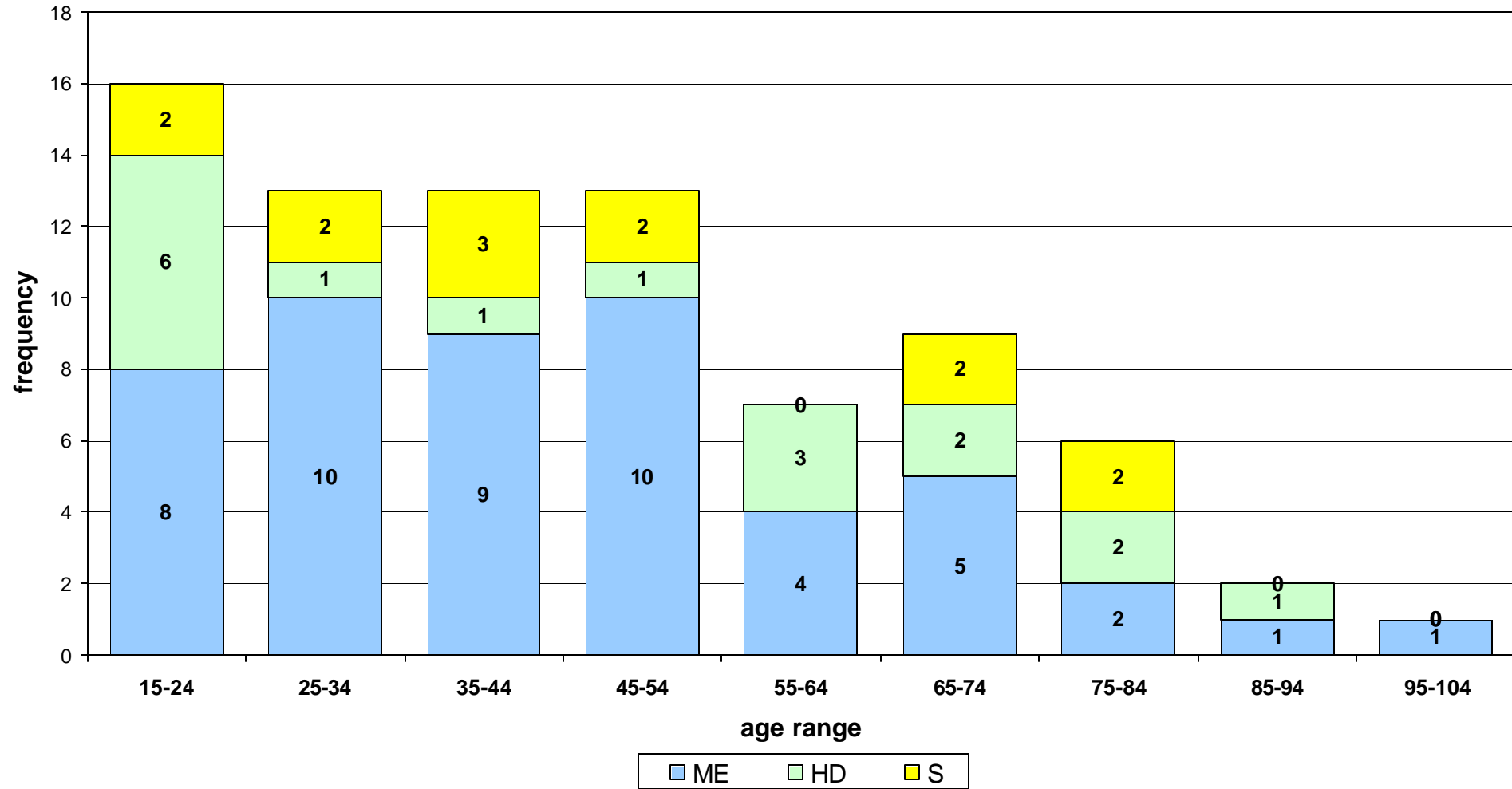
COMPUTATION OF IMPACT DECELERATION VELOCITY (**DELTA V**) ON V1 VEHICLE

COMPUTATION OF IMPACT ENERGY DISSIPATION (**IE**) ON V1 VEHICLE

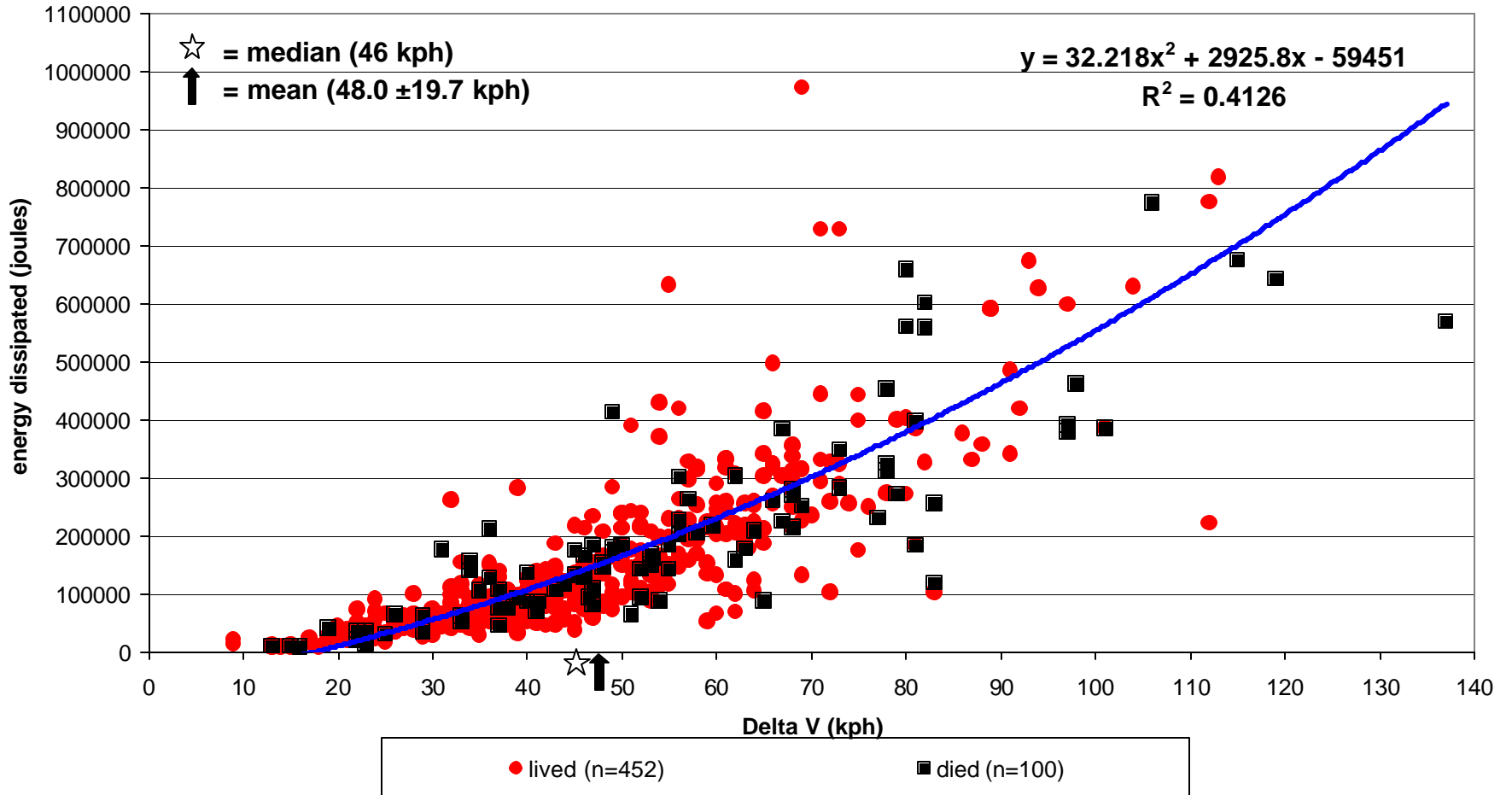
AGE DISTRIBUTION OF ALL CASES



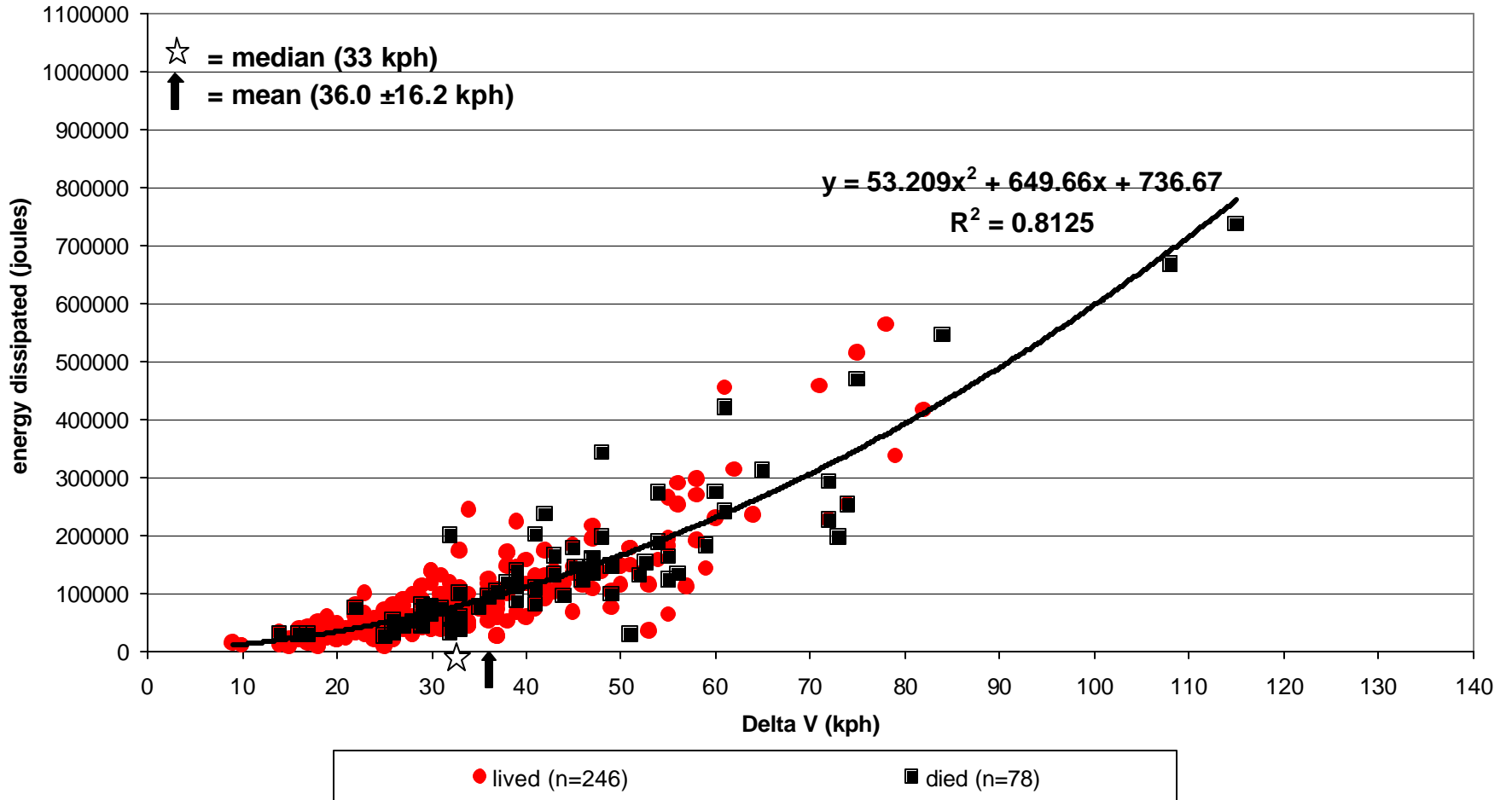
AGE DISTRIBUTION OF ALL AORTA CASES



Frontal cases with complete data from CIREN database by fatality (N=552)



Lateral cases with complete data from CIREN database by fatality (N=324)



SUMMARY & CONCLUSIONS I

COMPUTED CRASH DELTA V_s

1. **Frontal Motor Vehicle Crash :** MEDIAN MEAN & SD SEM
N=552 46 KPH 48 ± 19.7 KPH 0.84 KPH

2. **Lateral Motor Vehicle Crash:** MEDIAN MEAN & SD SEM
N=324 33 KPH 36 ± 16.4 KPH 0.91 KPH

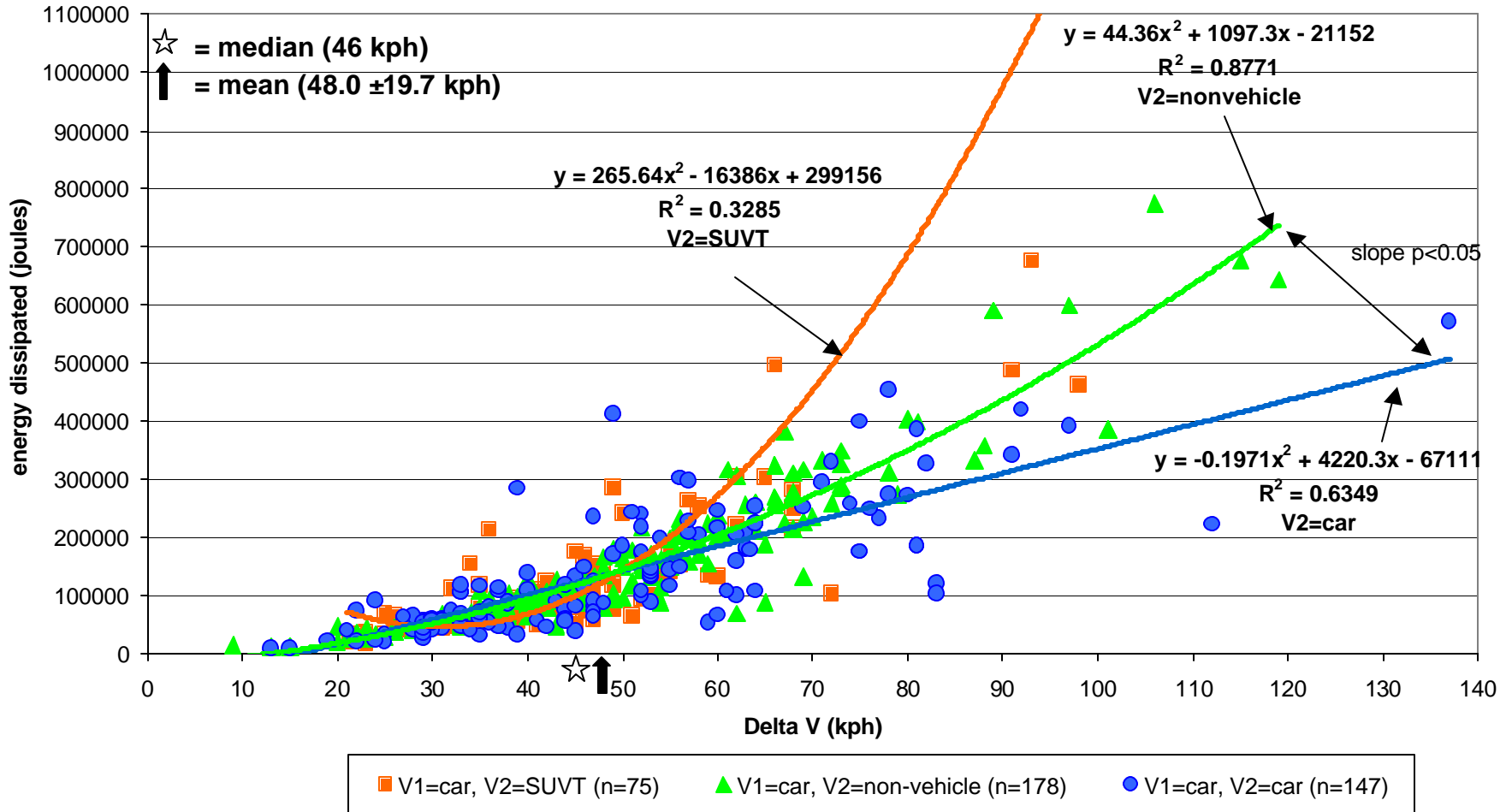
NHTSA Frontal Motor Vehicle Crash Test:
FIXED BARRIER OR OFF-SET AT 48 KPH

NHTSA Lateral Motor Vehicle Crash Test:
MOVING 27° CRABBED BARRIER AT 56 KPH, RELATION TO
ACTUAL DELTA V NOT DEFINED BY MEASUREMENT AT SITE OF
IMPACT ON SUBJECT VEHICLE, BUT APPEARS TO BE 20 -25 MPH
(32 – 40 KPH)

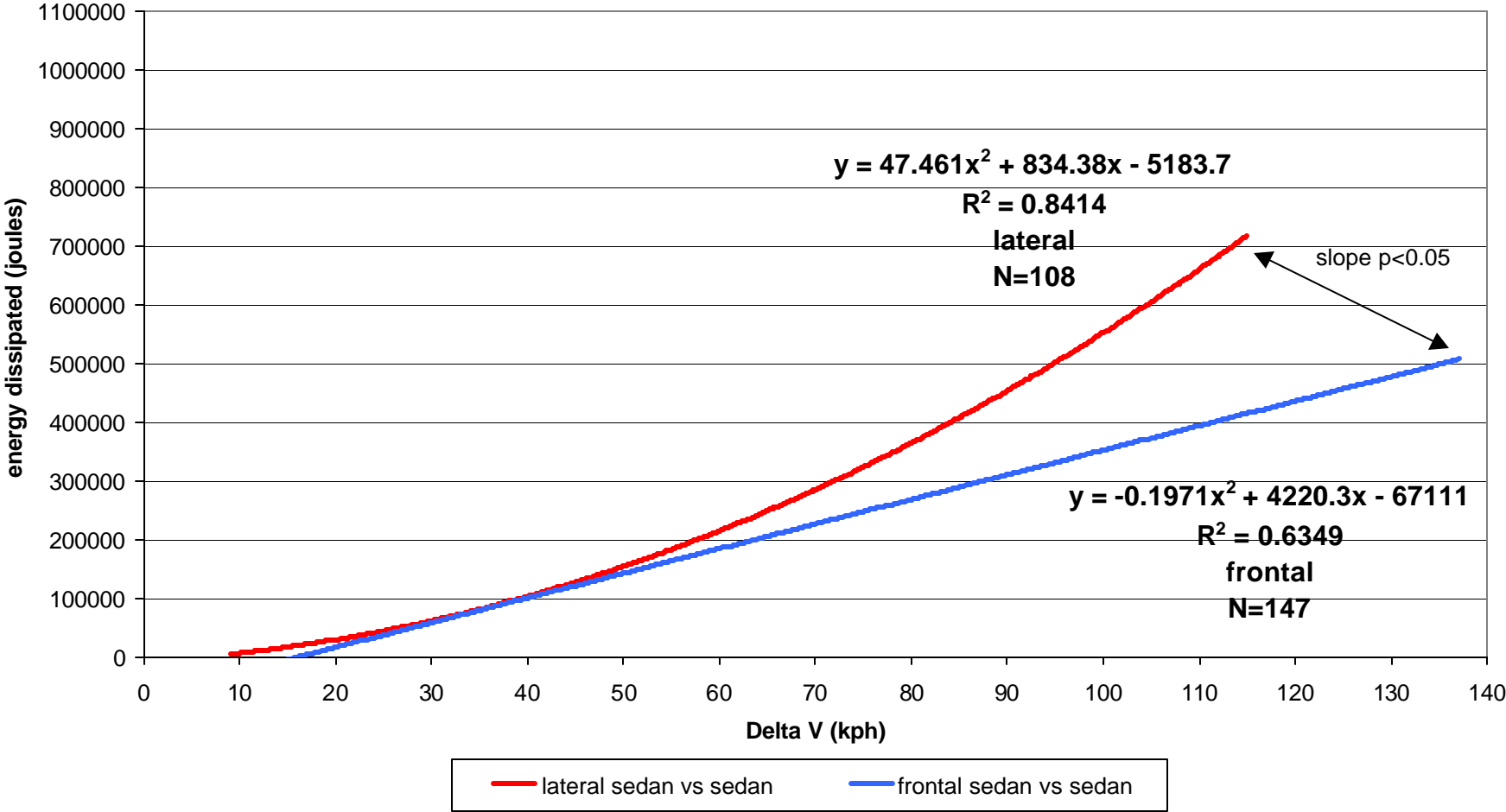
SUMMARY & CONCLUSIONS II

3. TO EXPLAIN SOME OF THE FACTORS INVOLVED IN THESE ISSUES, THE RELATIONSHIP OF THE IMPACT ENERGY (IE) DISSIPATED ON V1 AS A FUNCTION OF THE DECELERATION VELOCITY ON IMPACT (**DELTA V**) WAS EXAMINED IN FMVC VS LMVC.
4. IN BOTH FMVC AND LMVS **THE RELATION BETWEEN IE AND DELTA V WAS SHOWN TO BE EXPONENTIAL**, WITH THE MAJOR INCREASE IN IE FOR A GIVEN DELTA V SEEN TO BEGIN AT DELTA Vs GREATER THAN THE MEAN, **48 KPH FOR FMVC AND 36 KPH FOR LMVC**.

Frontal cases with complete data from CIREN database by type of V2 where V1=car (N=405)



All sedan vs sedan cases with complete data from CIREN database
Frontal vs Lateral regressions

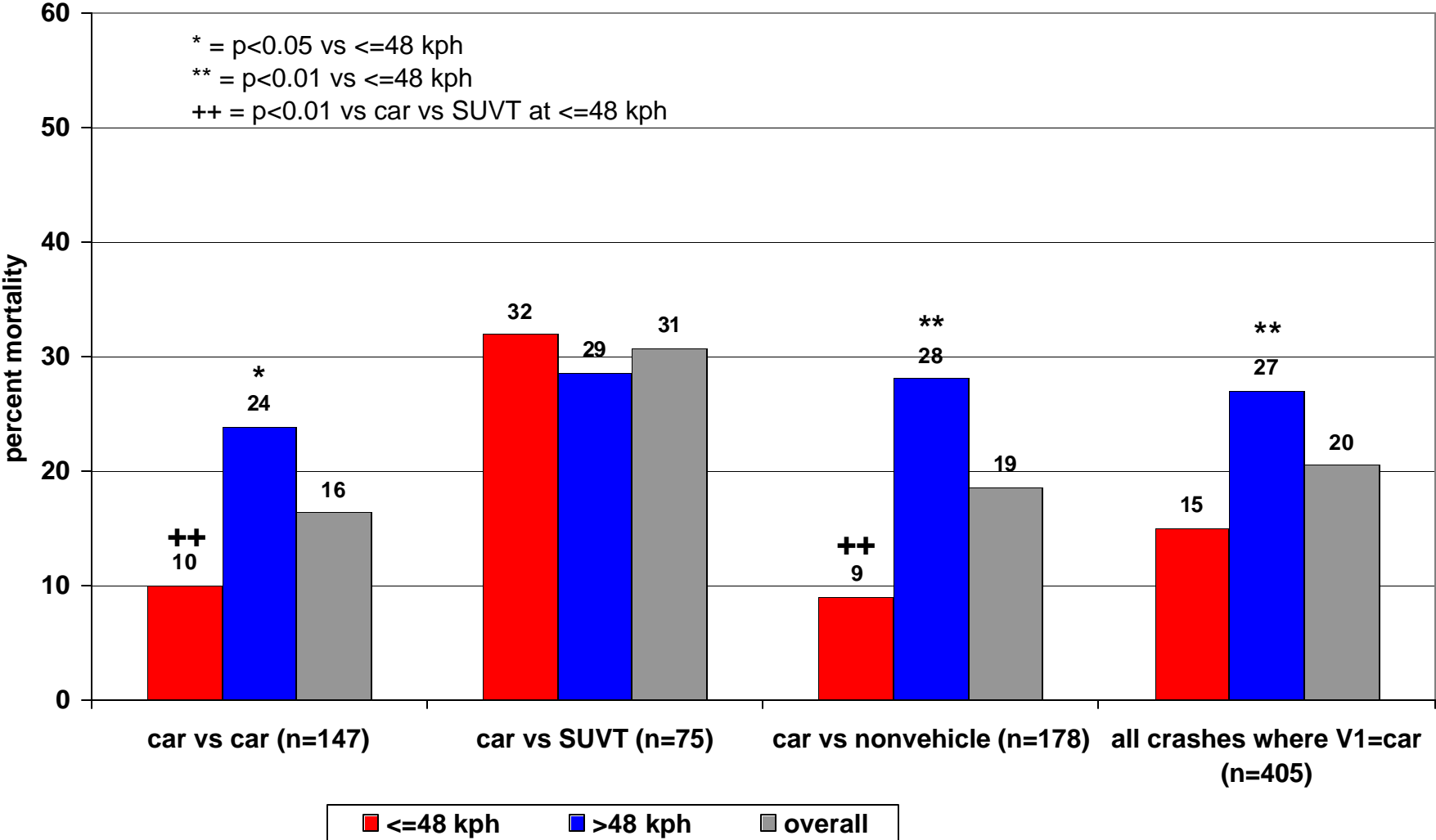


SUMMARY & CONCLUSIONS III

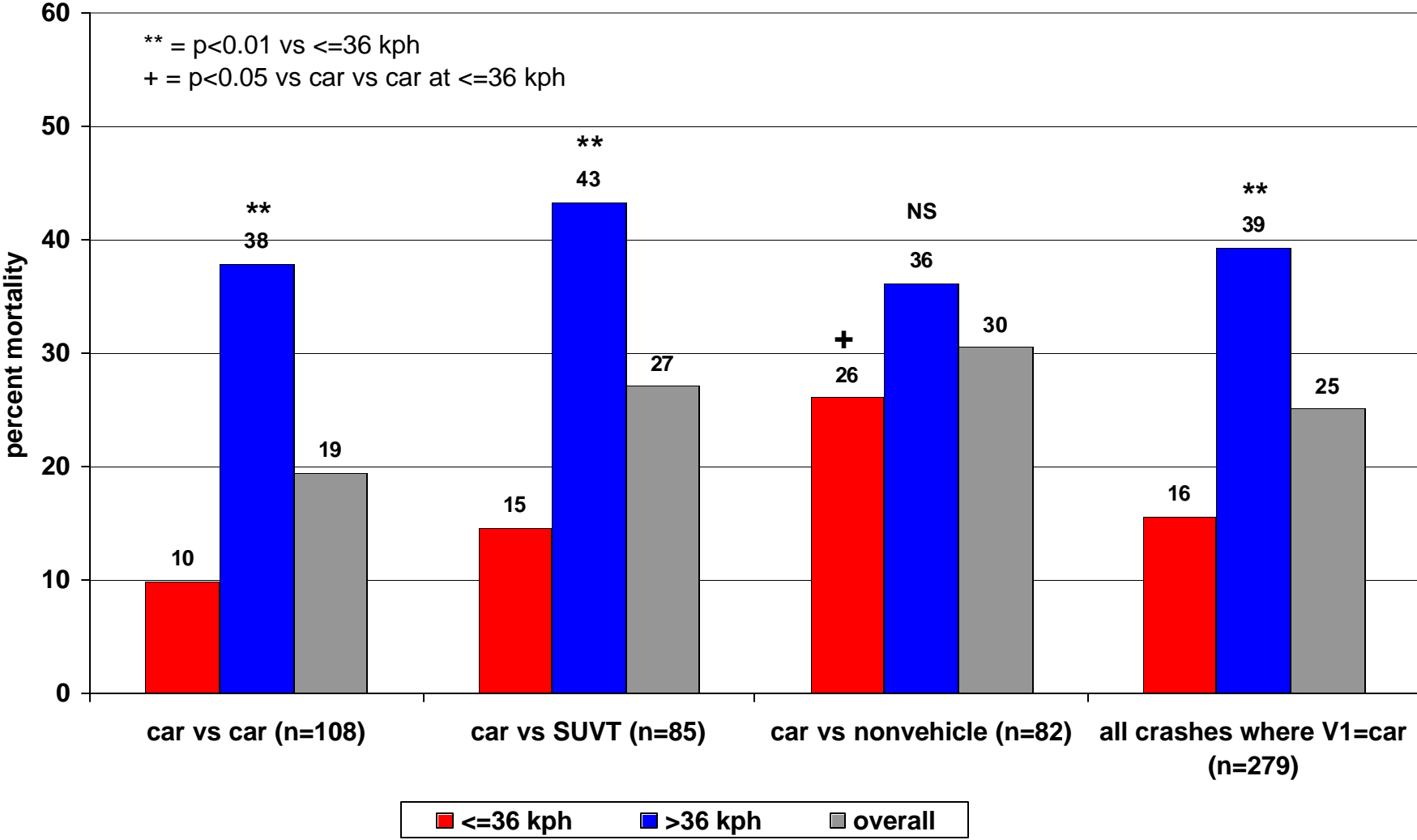
5. MOREOVER, FOR ALL CAR VS CAR MOTOR VEHICLE CRASHES (MVCs), WHEN THE REGRESSIONS FOR IE VS DELTA V ARE COMPARED, THE RATE OF INCREASE IN IE PER UNIT RISE IN DELTA V IS SIGNIFICANTLY GREATER ($P < 0.05$) IN LMVC COMPARED TO FMVC, BECOMING MOST PROMINENT ABOVE DELTA V > 56 KPH (35 MPH).

5. IN FMVC, WHEN THE IE/DELTA V RELATION FOR CARS (V1) STRUCK BY AN SUV/T IS COMPARED TO THAT OF CARS (V1) STRUCK BY ANOTHER CAR, OR CARS STRIKING A FIXED OBJECT IT WAS FOUND THAT THE RISE IN IE FOR CARS IMPACTING A FIXED OBJECT WAS SIGNIFICANTLY GREATER ($P < 0.05$) THAN THAT FOR CARS VS CARS, AND FOR CARS STRUCK BY AN SUV/T WAS ALSO GREATER ($P = 0.052$, NS) COMPARED TO THAT SEEN WHEN A CAR (V1) STRUCK ANOTHER CAR.

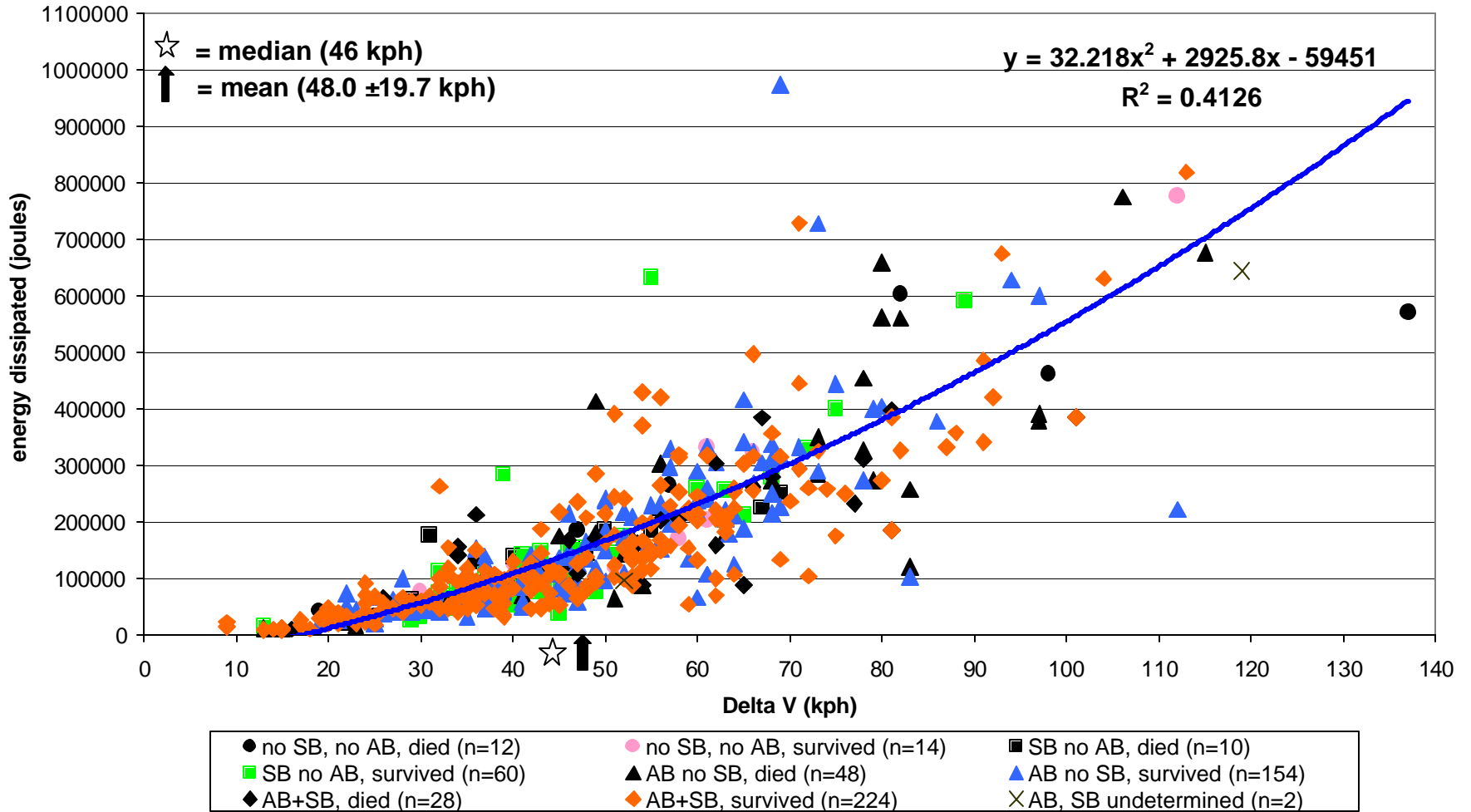
Percent Mortality for Frontal Crashes



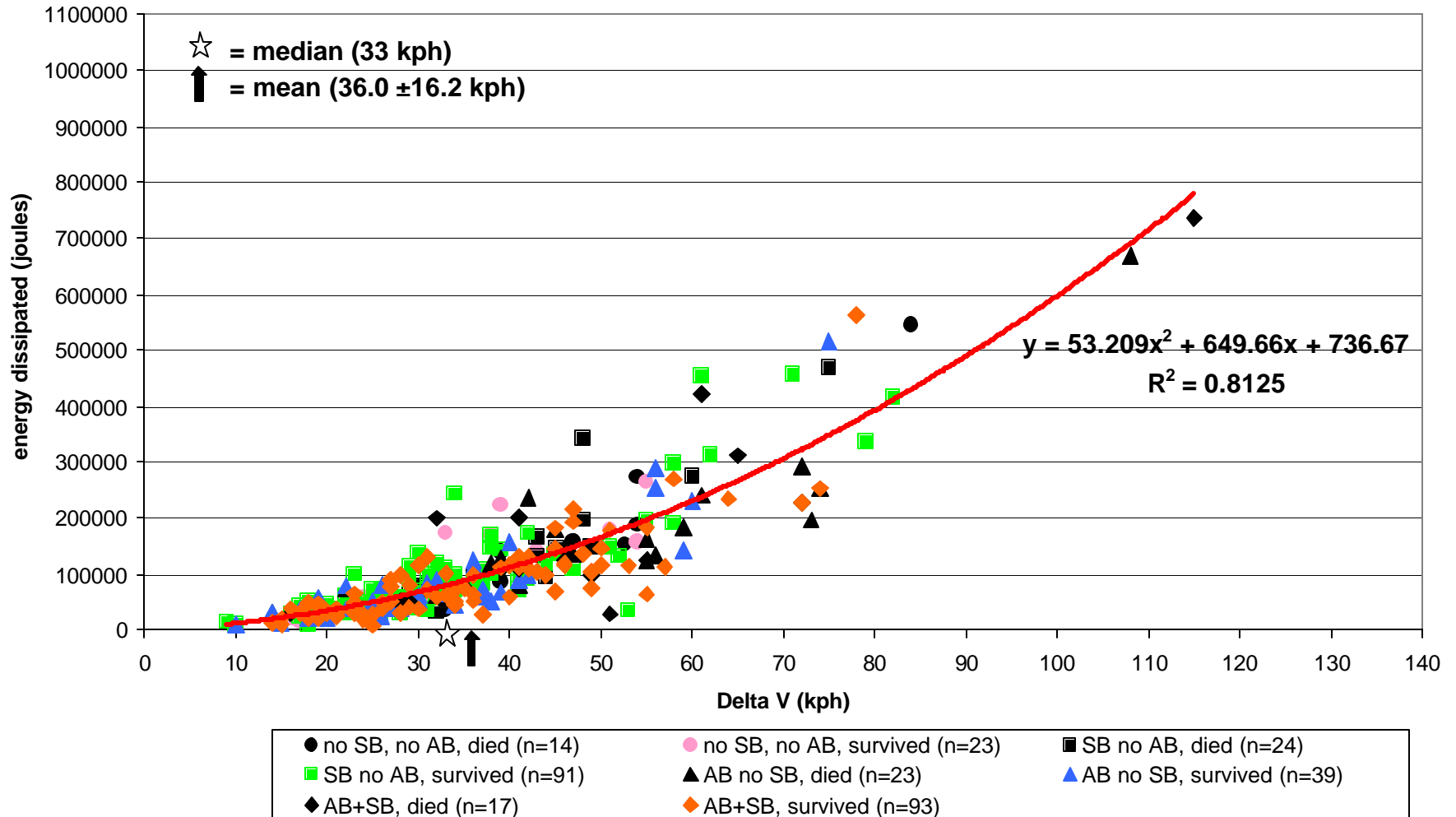
Percent Mortality for Lateral Crashes



Frontal cases with complete data from CIREN database by fatality and restraint use (N=552)



Lateral cases with complete data from CIREN database by fatality and restraint use (N=324)



MORTALITY BY TYPE OF RESTRAINT: FOR V1 OCCUPANT IN ALL 876 Motor Vehicle Crashes

| <u>552 FMVC</u> | | <u>% M</u> | <u>324 LMVC</u> | | <u>%M</u> |
|-----------------|----------------|-------------------|-----------------|-----------------|-----------|
| | TOTAL | 18.1% | TOTAL | 24.1% | |
| 1° | NONE | 46.2%**++# | NONE | 37.8%**+ | W |
| 2° | SB ONLY | 14.3% | SB ONLY | 20.9% | 2° |
| 3° | AB ONLY | 23.8%** | AB ONLY | 37.1%**+ | W |
| 4° | AB+SB | 11.1% | AB+SB | 15.5% | 1° |

** = p<0.01 vs AB+SB

+ = p<0.05 vs SB only

= p<0.05 vs AB only

++ = p<0.01 vs SB only

SUMMARY & CONCLUSIONS IV

7. FMVC MORTALITY

| | = 48 KPH | > 48 KPH |
|----------------------------|--------------|---------------|
| CAR VS CAR | 10% | 24% * |
| CAR VS FIXED OBJECT | 9% | 28% ** |
| CAR VS SUVT | 32%++ | 29% |

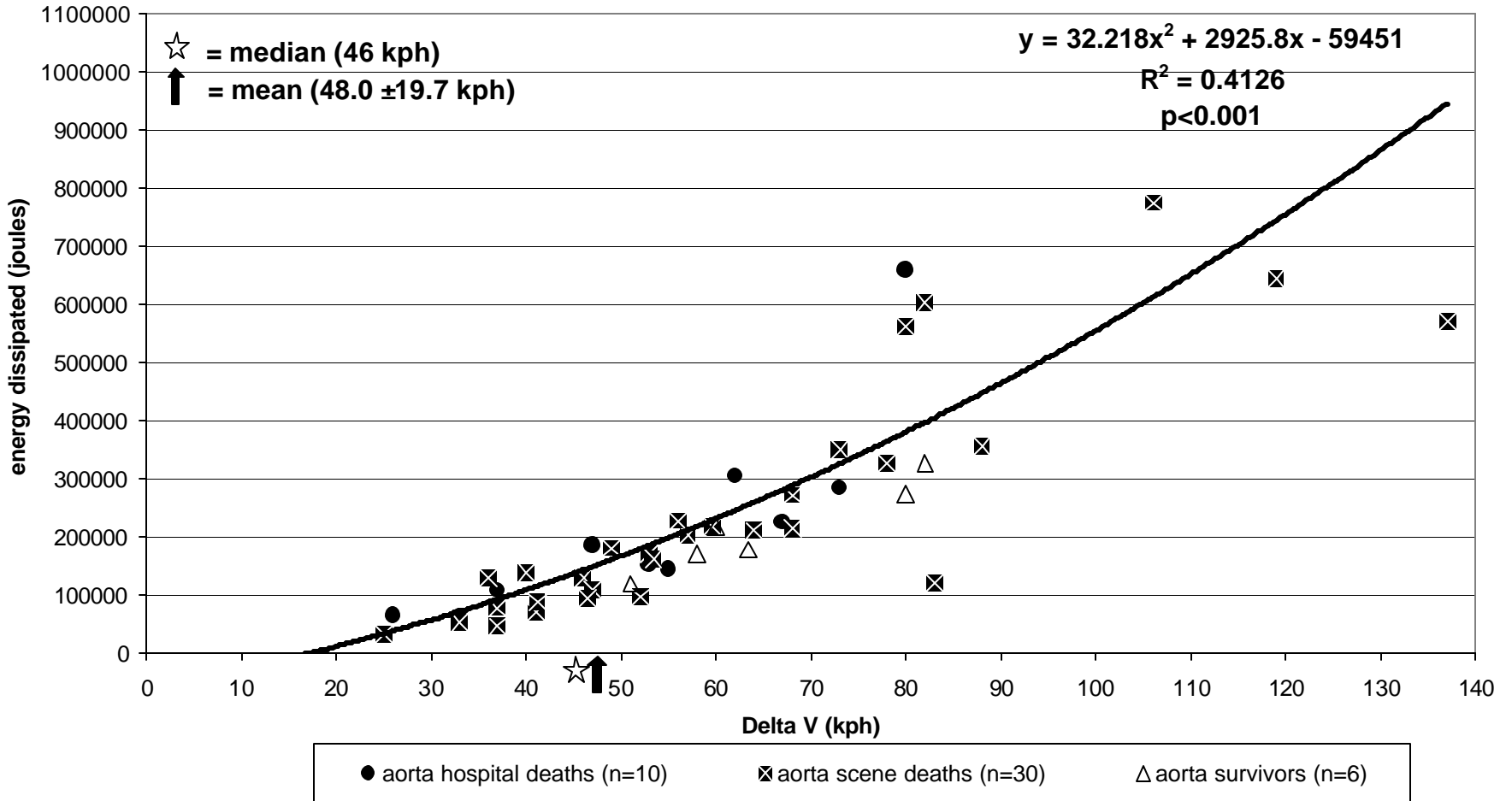
LMVC MORTALITY

| | = 36 KPH | > 36 KPH |
|----------------------------|-------------|--------------|
| CAR VS CAR | 10% | 38%** |
| CAR VS FIXED OBJECT | 26%+ | 36% |
| CAR VS SUVT | 15% | 43%** |

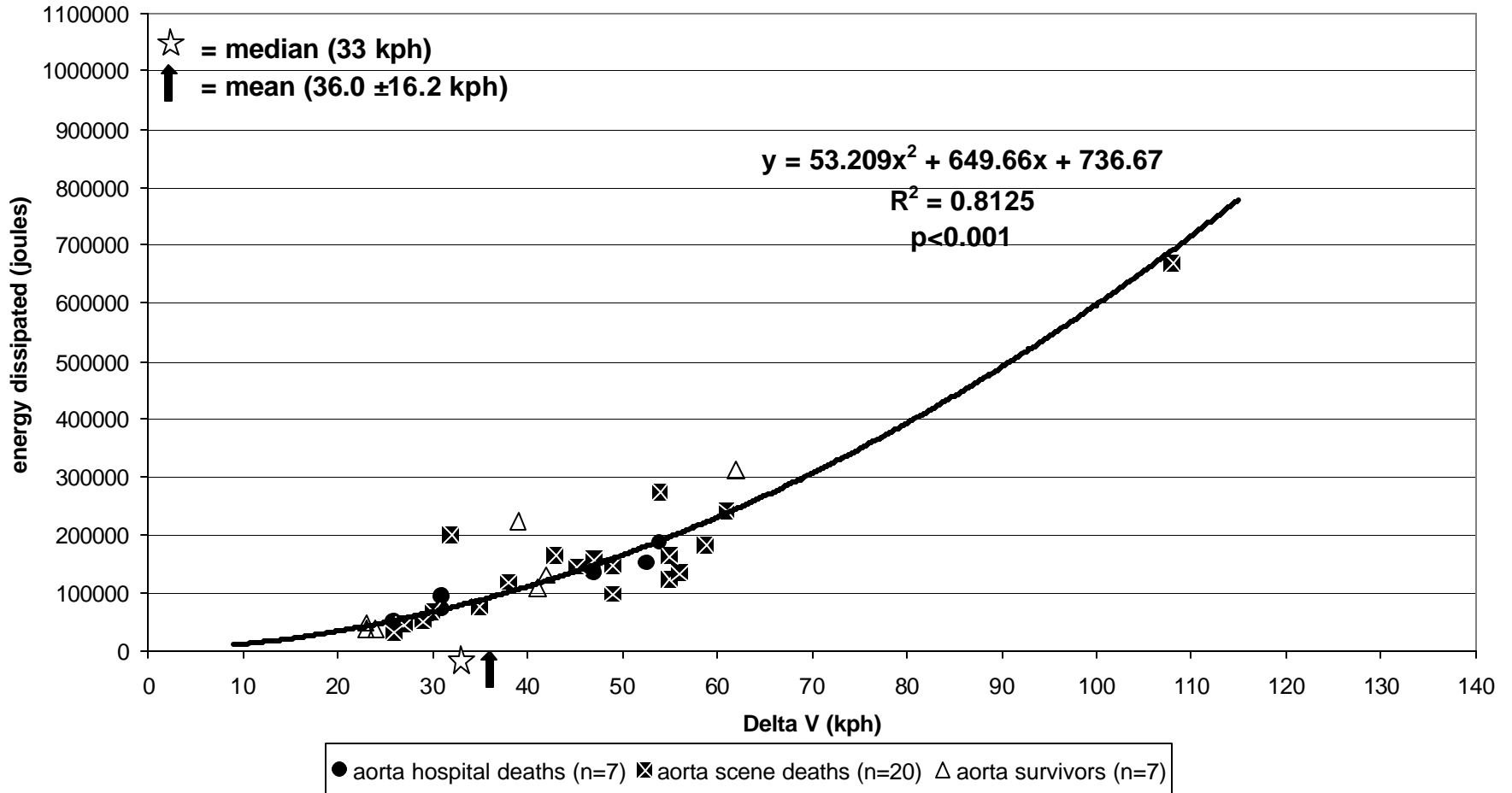
CAR VS OTHER AT = MEAN DELTA V (+ P<0.05, ++ P<0.01)

CAR VS OTHER AT = VS > MEAN DELTA V (* P<0.05, ** P<0.01)

Aorta cases with complete data and outcome indicated (N=46) Frontal only



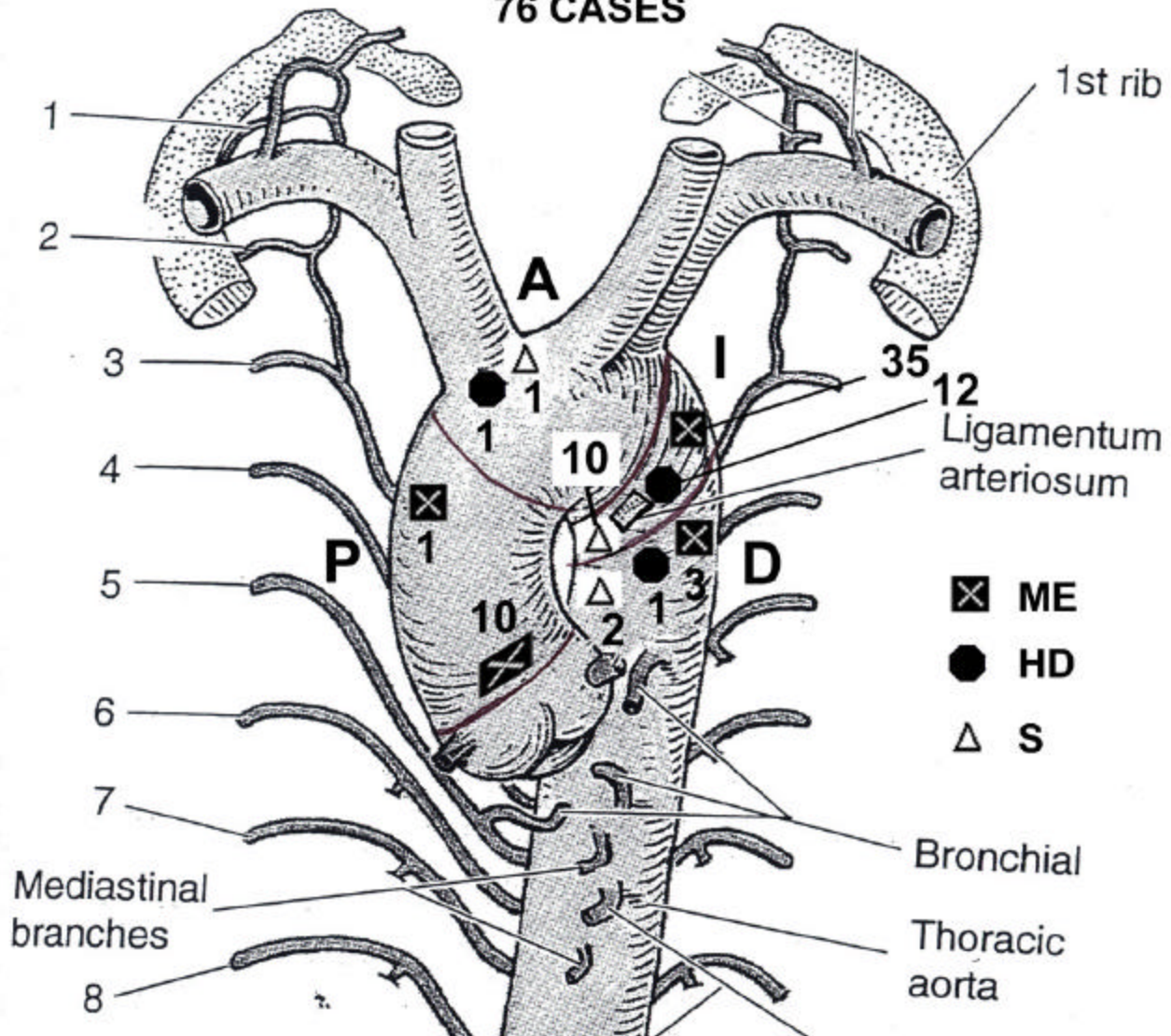
Aorta cases with complete data and outcome indicated (N=34)
Lateral only



SUMMARY & CONCLUSIONS V

8. IN FMVCs **46%** OF THE CRASHES, BUT **58%** OF THE DEATHS OCCURRED AT DELTA V_s ABOVE THE MEAN OF 48 KPH WHICH APPROXIMATES THE 48 KPH OF THE FEDERAL CRASH TEST STANDARD. HOWEVER, **63%** OF THE FMVC AIs AND **60%** OF THE FMVC AI DEATHS OCCURRED ABOVE THE MEAN DELTA V , WITH **IE = 155,524** JOULES RESULTING IN = **77** CM MAXIMUM FRONTAL DEFORMATION.
9. IN LMVCs **40%** OF THE CRASHES, BUT **64%** OF THE DEATHS OCCURRED AT DELTA V_s ABOVE THE MEAN OF 36 KPH. HOWEVER, **64%** OF THE LMVC AIs AND **65%** OF THE LMVC AI DEATHS OCCURRED ABOVE THE MEAN DELTA V , WITH **IE = 92,956** JOULES RESULTING IN = **63** CM MAXIMUM LATERAL DEFORMATION.

PRIMARY AORTIC LESIONS 76 CASES



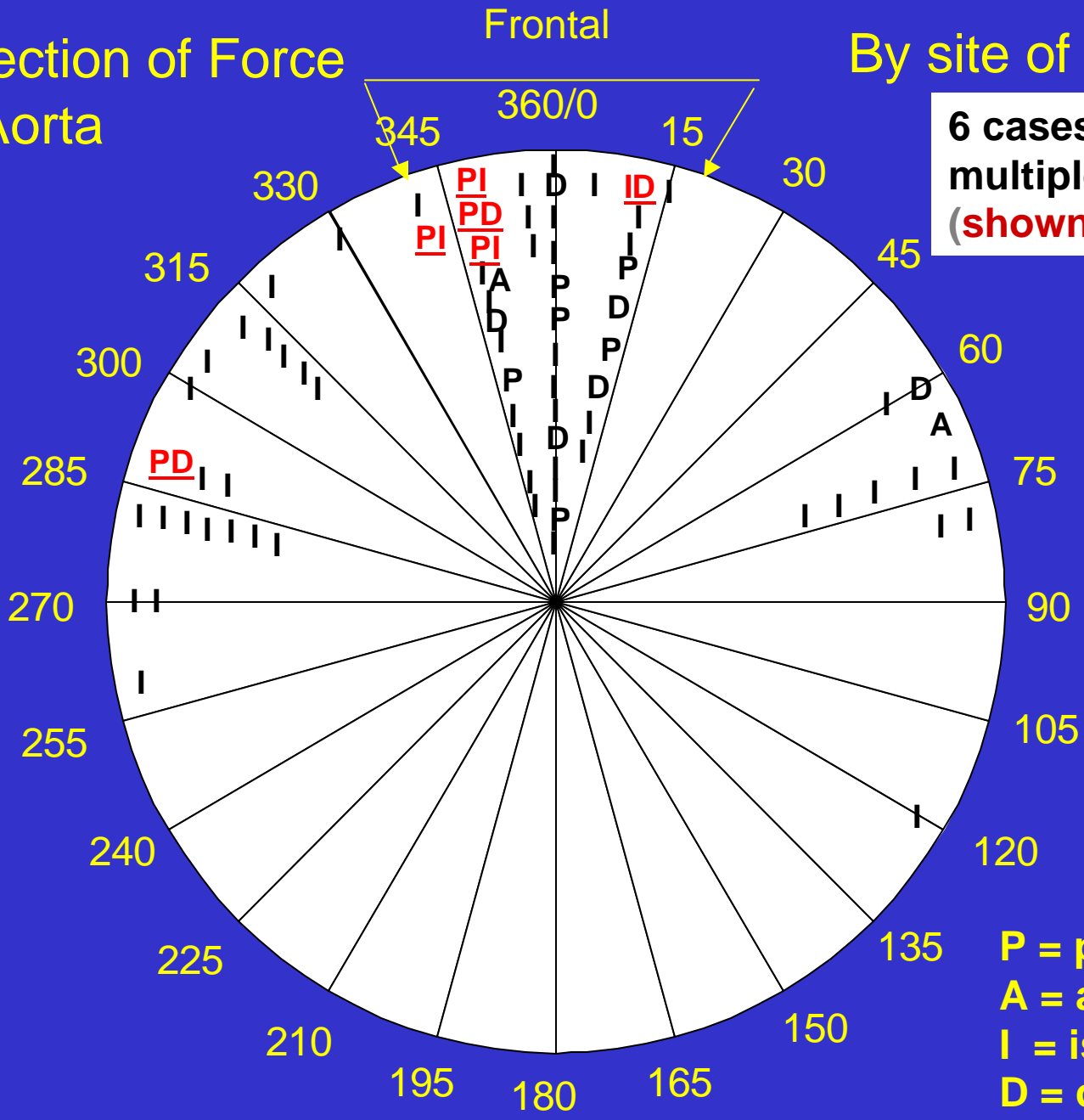
SUMMARY & CONCLUSIONS VI

- 10. OF THE 80 AORTIC INJURIES (AI), 63% WERE DEAD AT THE SCENE (ME), 21% DIED AFTER REACHING THE HOSPITAL (HD) AND 16% SURVIVED (S) TO LEAVE THE HOSPITAL ALIVE.**
- 11. THE ASCENDING AORTA WAS THE PRIMARY SITE OF AI IN 13.2%, THE AORTIC ARCH IN 2.6%, THE AORTIC ISTHMUS IN 75% AND THE DESCENDING THORACIC AORTA IN 7.9% OF THE TOTAL AI CASES.**
- 12. ALL BUT ONE OF THE SURVIVORS HAD THEIR AI AT THE ISTHMUS OR IN THE PROXIMAL DESCENDING AORTA**

Principal Direction of Force (PDOF) for Aorta Injury Cases

By site of aortic lesio

6 cases had lesions multiple locations (shown in red)

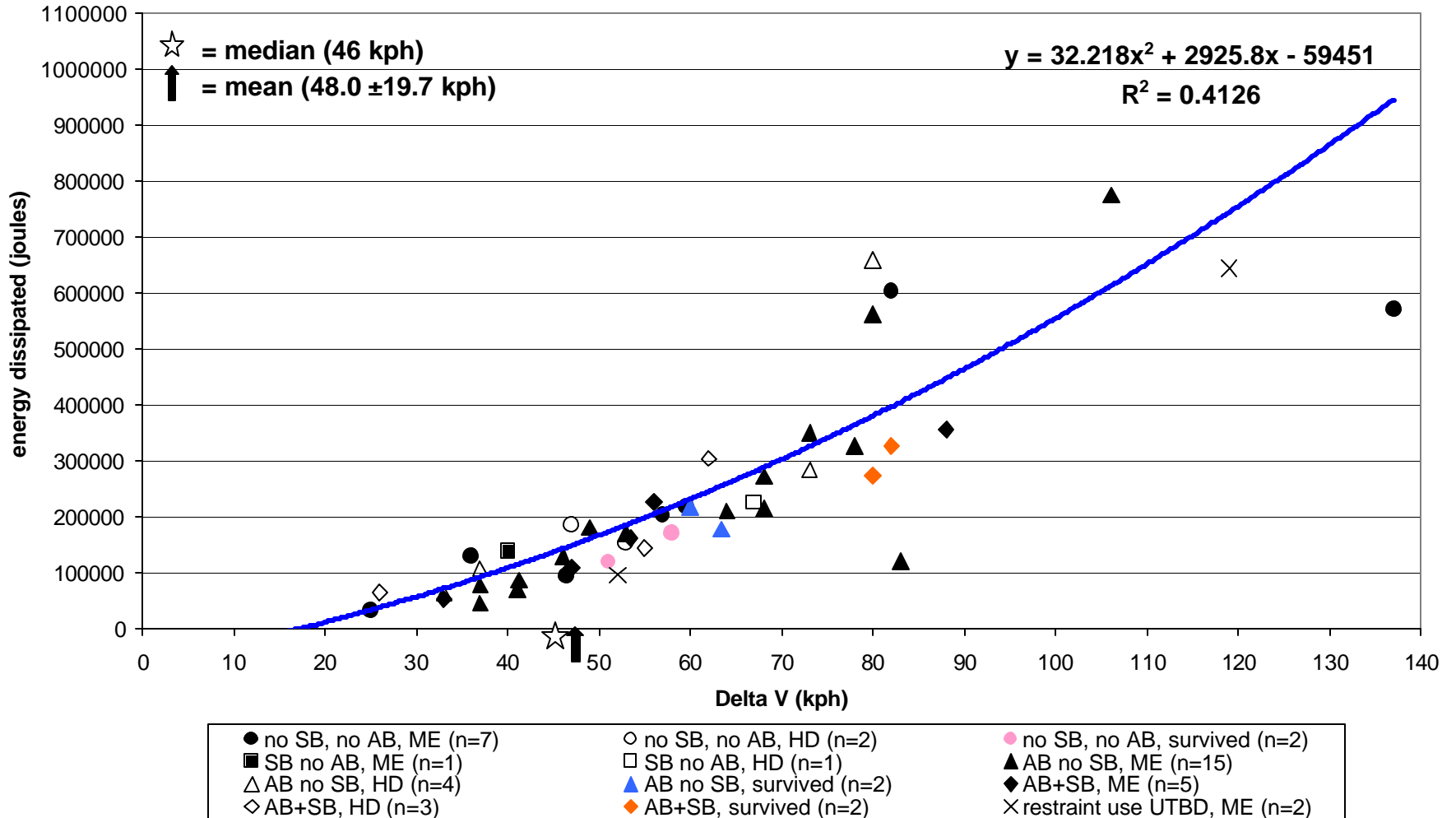


P = proximal
 A = arch
 I = isthmus
 D = desc. thor.

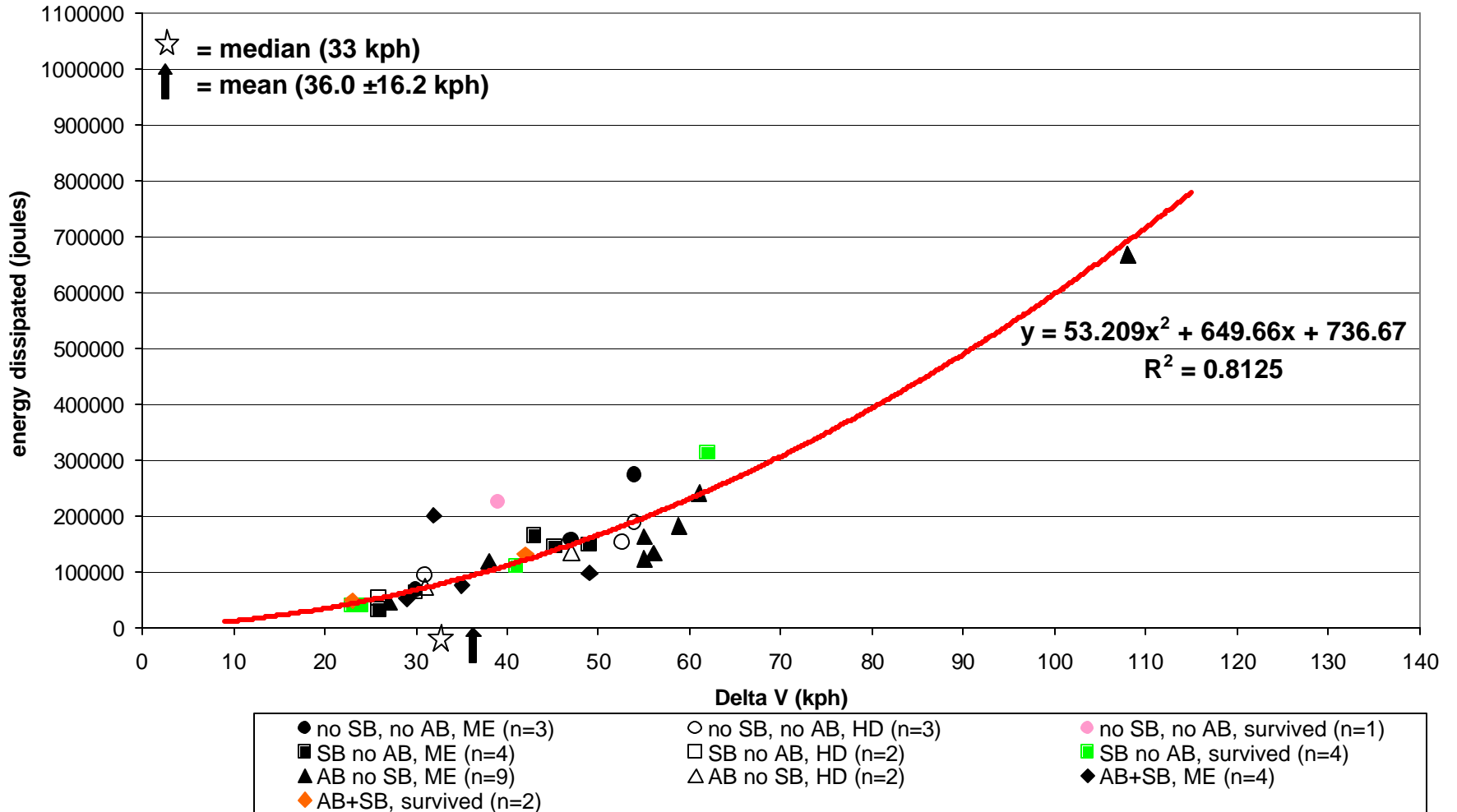
SUMMARY & CONCLUSIONS VII

13. IN 76 OF THE 80 AORTIC INJURY CASES, THE SITE OF THE LESION AND THE PRINCIPAL DIRECTION OF FORCE (PDOF) COULD BE IDENTIFIED.
14. AS DEFINED BY PDOF (340° - 0° - 20°) ALL BUT ONE OF THE 11 PROXIMAL AORTIC INJURIES OCCURRED IN FRONTAL MOTOR VEHICLE CRASHES (FMVC)s, 1 PRIMARY AORTIC ARCH, 27 PRIMARY AND 6 SECONDARY ISTHMUS TEARS AND 5 PRIMARY AND 1 SECONDARY TEAR OF THE DESCENDING AORTA ALSO RESULTED FROM FMVCs.
15. IN LMVC AIs, THERE WERE 30 PRIMARY ISTHMUS, 1 PRIMARY DESCENDING AORTA, 1 PROXIMAL AORTA TEAR & 1 AORTIC ARCH LACERATION.

Aorta cases (frontal) with complete data from CIREN database by fatality and restraint use (N=46)



Aorta cases (lateral) with complete data from CIREN database by fatality and restraint use (N=34)



SUMMARY & CONCLUSIONS VIII

16. VALUE OF RESTRAINTS IN AORTIC INJURY (AI):

FMVC AIs: 46 CASES

16 REACHED HOSPITAL ALIVE (35%)

6 SURVIVED HOSPITAL (13%)

ALL SURVIVORS RESTRAINED, 2/3rds BY AB OR AB+SB.

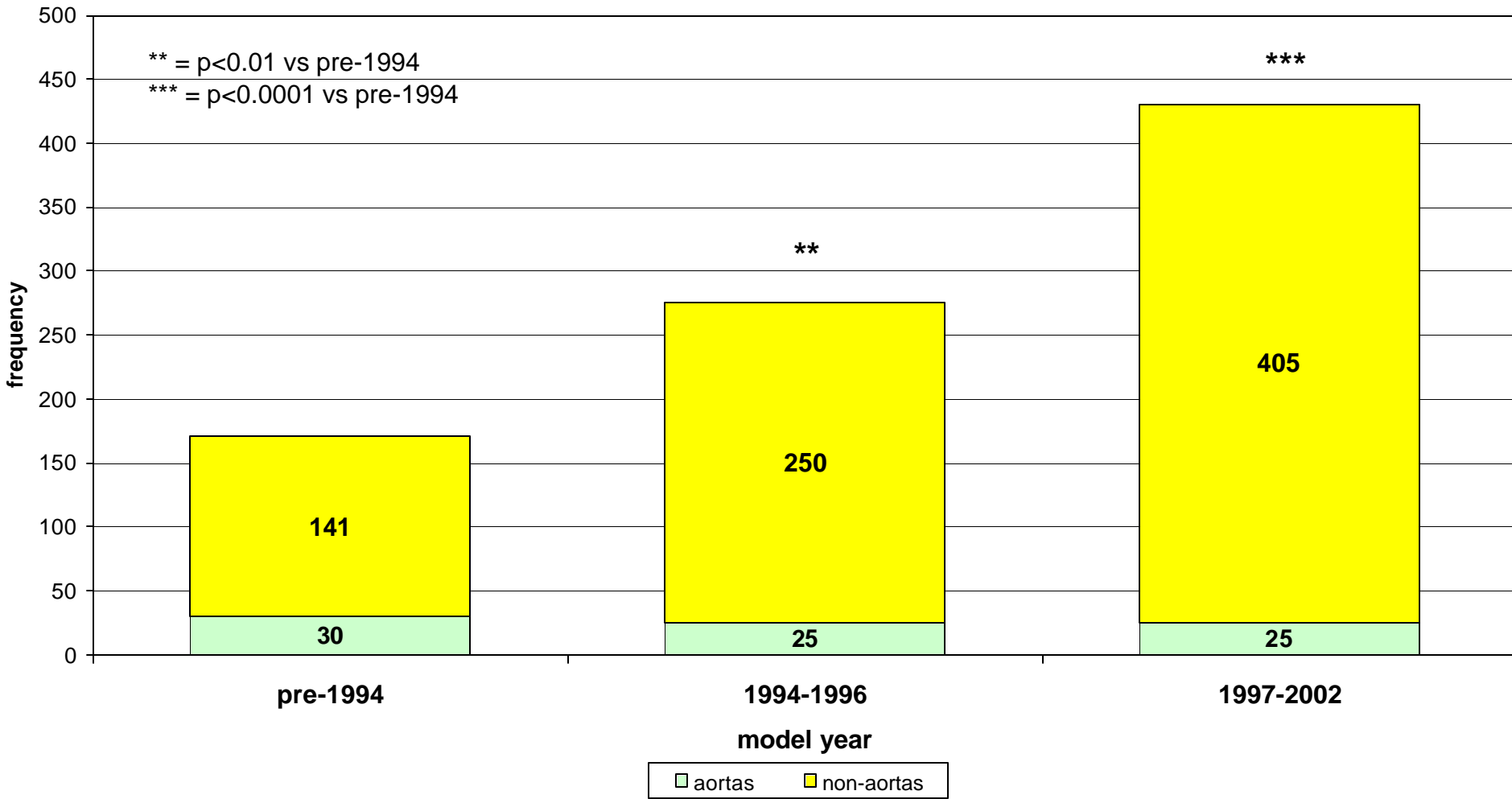
LMVC AIs: 34 CASES (50% HAD SUFFICIENT ARRESTED FORWARD DELTA V COMPONENT TO CAUSE AIRBAG (AB) DEPLOYMENT)

14 REACHED HOSPITAL ALIVE (41%)

7 SURVIVED HOSPITAL (21%)

6 OF THE 7 SURVIVORS HAD SB OR SB+AB.

MODEL YEAR DISTRIBUTION OF ALL COMPLETE CASES (N=876)



SUMMARY & CONCLUSIONS IX

7. EXAMINING INCIDENCE OF AI BY MODEL YEAR OF STRUCTURE OF VEHICLE:

PRE 1994 (SB, BUT AB NOT REQUIRED)

AI INCIDENCE 17.5%

1994-1996 (SB AND AB MANDATORY)

AI INCIDENCE 9.1% *

1997-2003 (SB, AB & SIDE-STANDARDS)

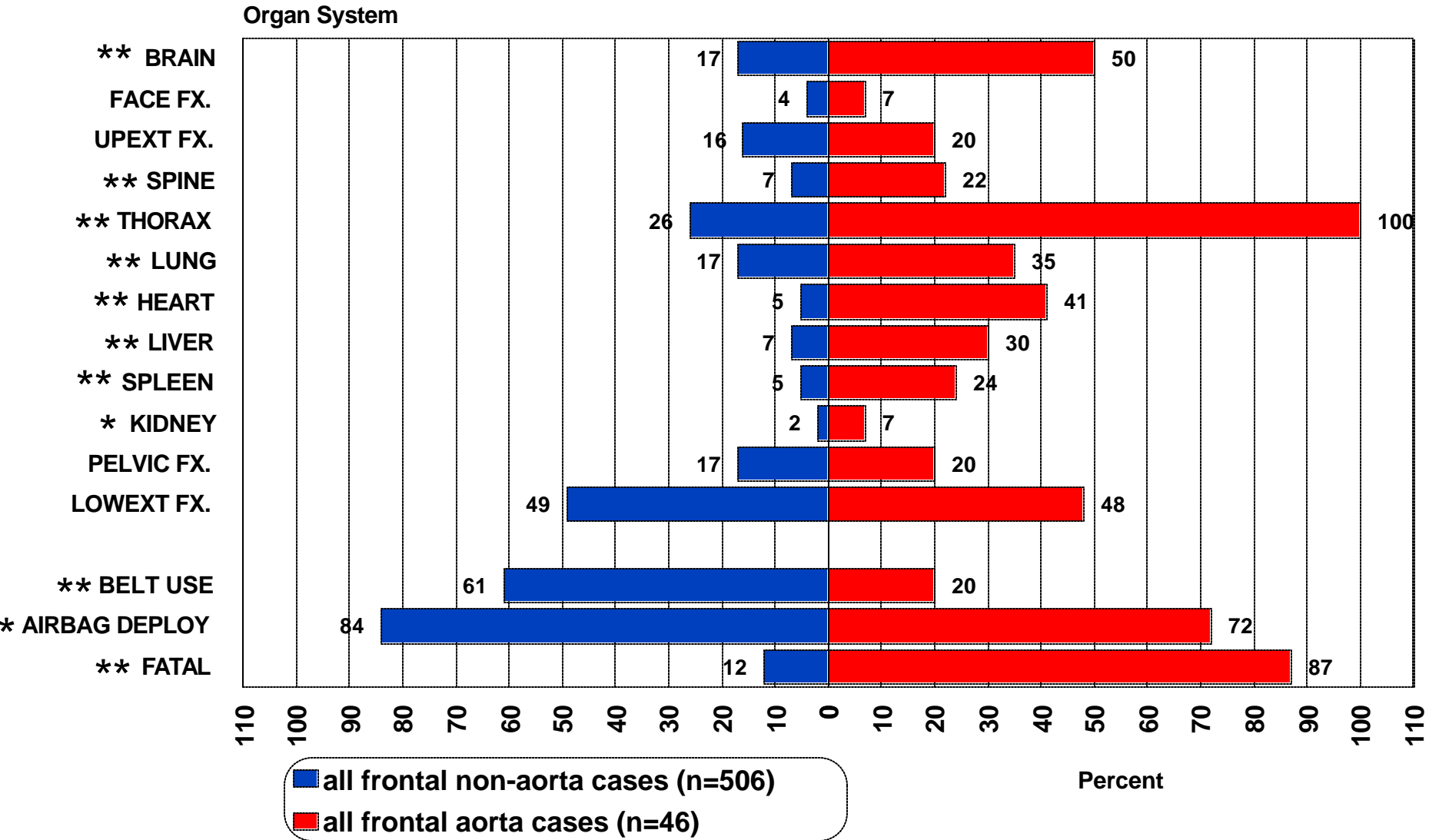
AI INCIDENCE 5.8% **

8. THE DATA SUGGEST THAT THE INTRODUCTION OF SAFETY STANDARD REGULATIONS IN SUCCESSIVE MODEL YEAR VEHICLES HAVE PROGRESSIVELY REDUCED THE INCIDENCE OF AORTIC INJURIES IN DRIVERS AND FRONT-SEAT PASSENGERS OF THESE VEHICLES

***P < 0.05 VS PRE 1994**

*** P < 0.01 VS PRE 1994**

Frontal Non-Aorta vs Aorta Injury Cases

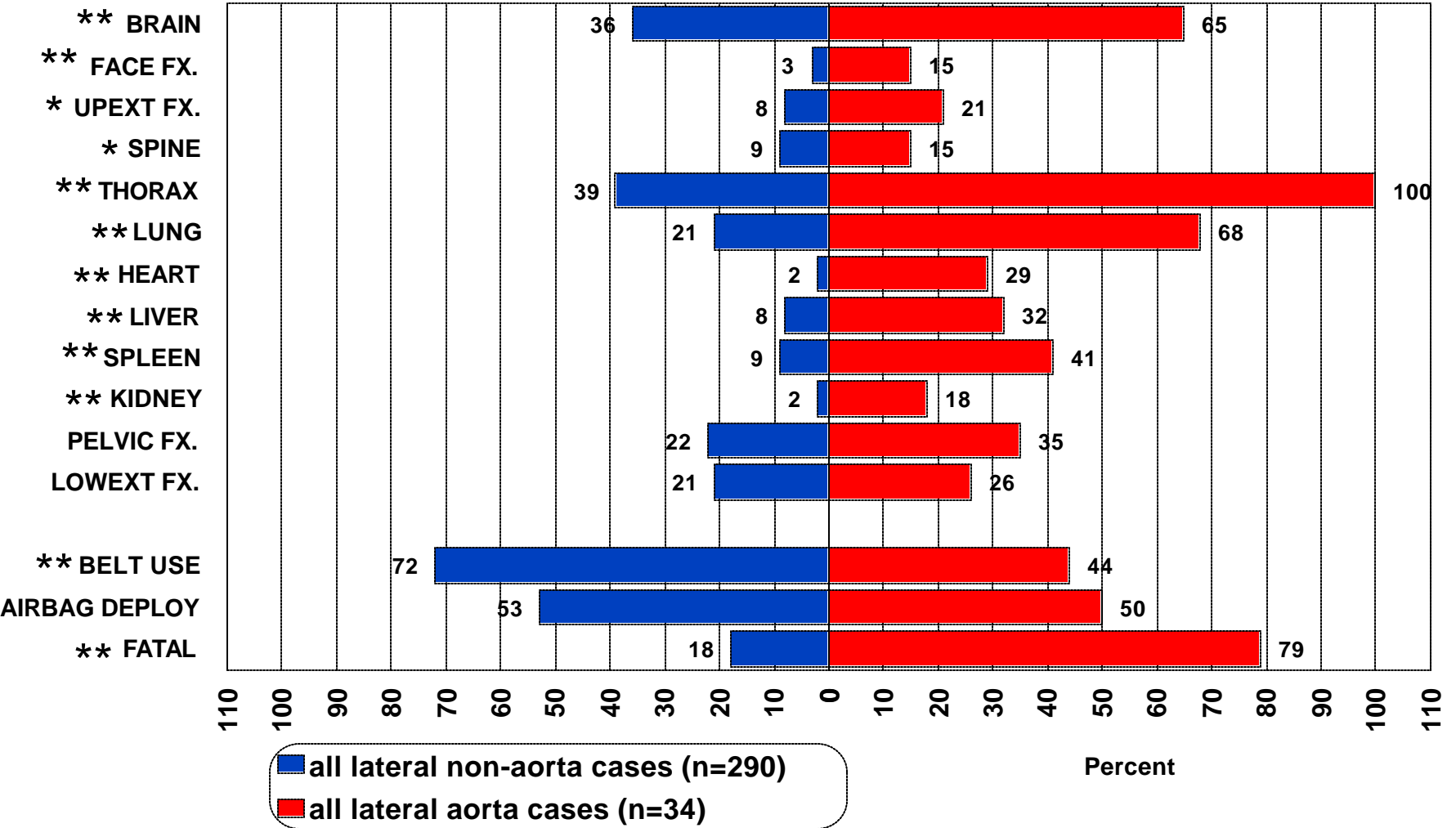


* = p<0.05

** = p<0.01

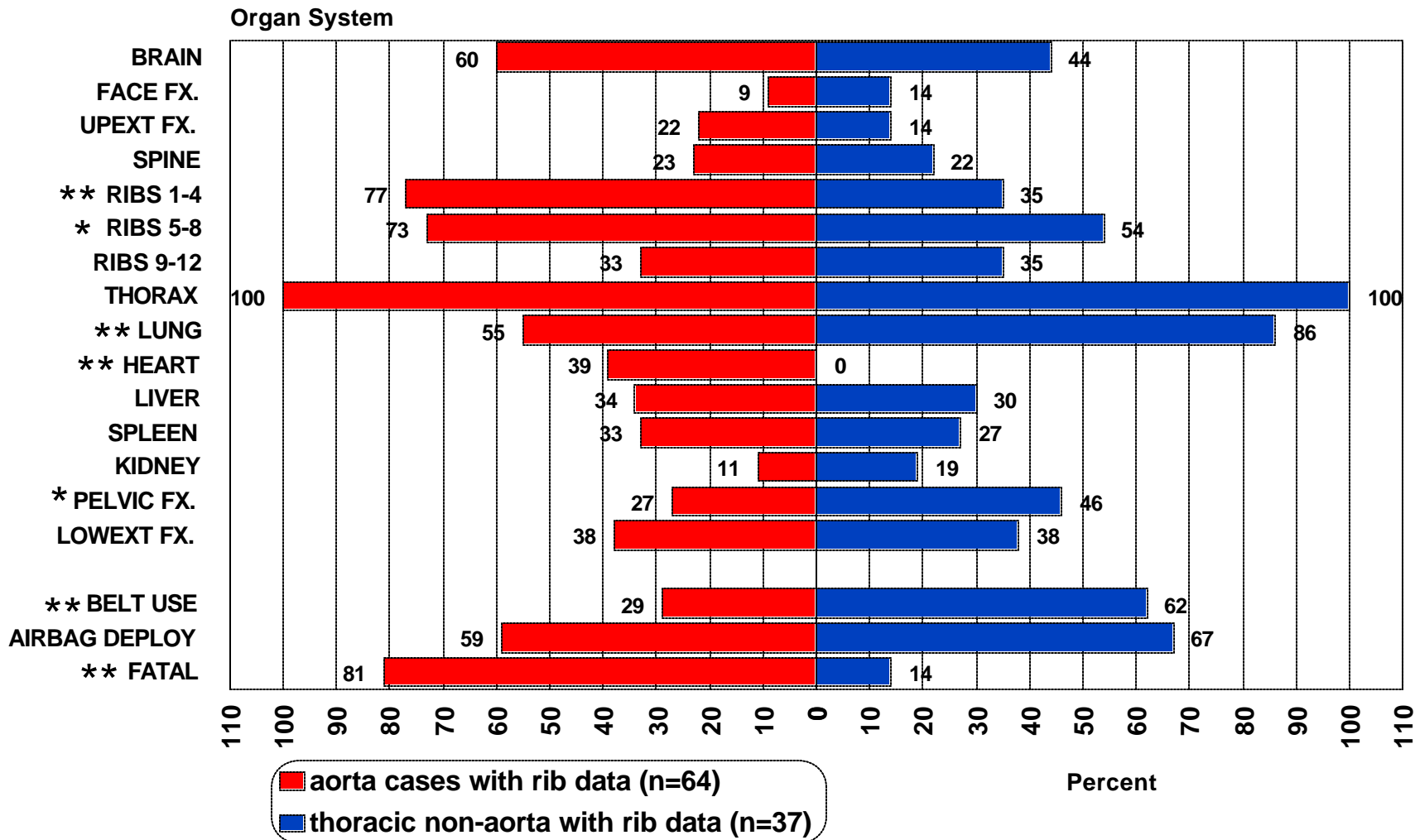
Lateral Non-Aorta vs Aorta Injury Cases

Organ System



* = p<0.05
 ** = p<0.01

Aorta Injury vs Thoracic Non-Aorta Cases



* = p<0.05
 ** = p<0.01

SUMMARY & CONCLUSIONS XI

9. **HOWEVER, WHEN AORTIC INJURY PATIENTS WERE COMPARED TO PATIENTS WHO SUSTAINED SEVERE GRADE II OR GREATER THORACIC INJURIES WITHOUT AORTIC DISRUPTIONS, IT WAS FOUND THAT THE AORTIC INJURY PATIENTS HAD A SIGNIFICANTLY GREATER INCIDENCE OF FRACTURES OF RIBS 1-4 & 5-8. THEY ALSO HAD SIGNIFICANTLY MORE CARDIAC INJURIES AND PELVIC FRACTURES, BUT A MUCH LOWER INCIDENCE OF SEAT-BELT USE AND A HIGHER FATALITY RATE. IN CONTRAST, THE NON-AORTIC THORACIC INJURY PATIENTS HAD A SIGNIFICANTLY GREATER INCIDENCE OF LUNG INJURY.**

SUMMARY & CONCLUSIONS XII

D. THE SIGNIFICANT INCREASE IN FRACTURES OF RIBS 1-4 CONTINUED TO BE SEEN EVEN WHEN THE AORTIC INJURY SURVIVORS WERE COMPARED TO THE NON-AORTIC INJURY THORACIC TRAUMA SURVIVORS, WHO IN CONTRAST CONTINUED TO MANIFEST A SIGNIFICANTLY HIGHER INCIDENCE OF LUNG INJURY THAN THE AORTIC INJURY PATIENTS. HOWEVER, THE AI SURVIVORS HAD A SIGNIFICANTLY LOWER AIRBAG DEPLOYMENT THAN THE NON-AORTIC THORACIC INJURY SURVIVORS.

1.



HUMAN
Y DAMAGE

2.



HUMAN
Y DAMAGE

3.

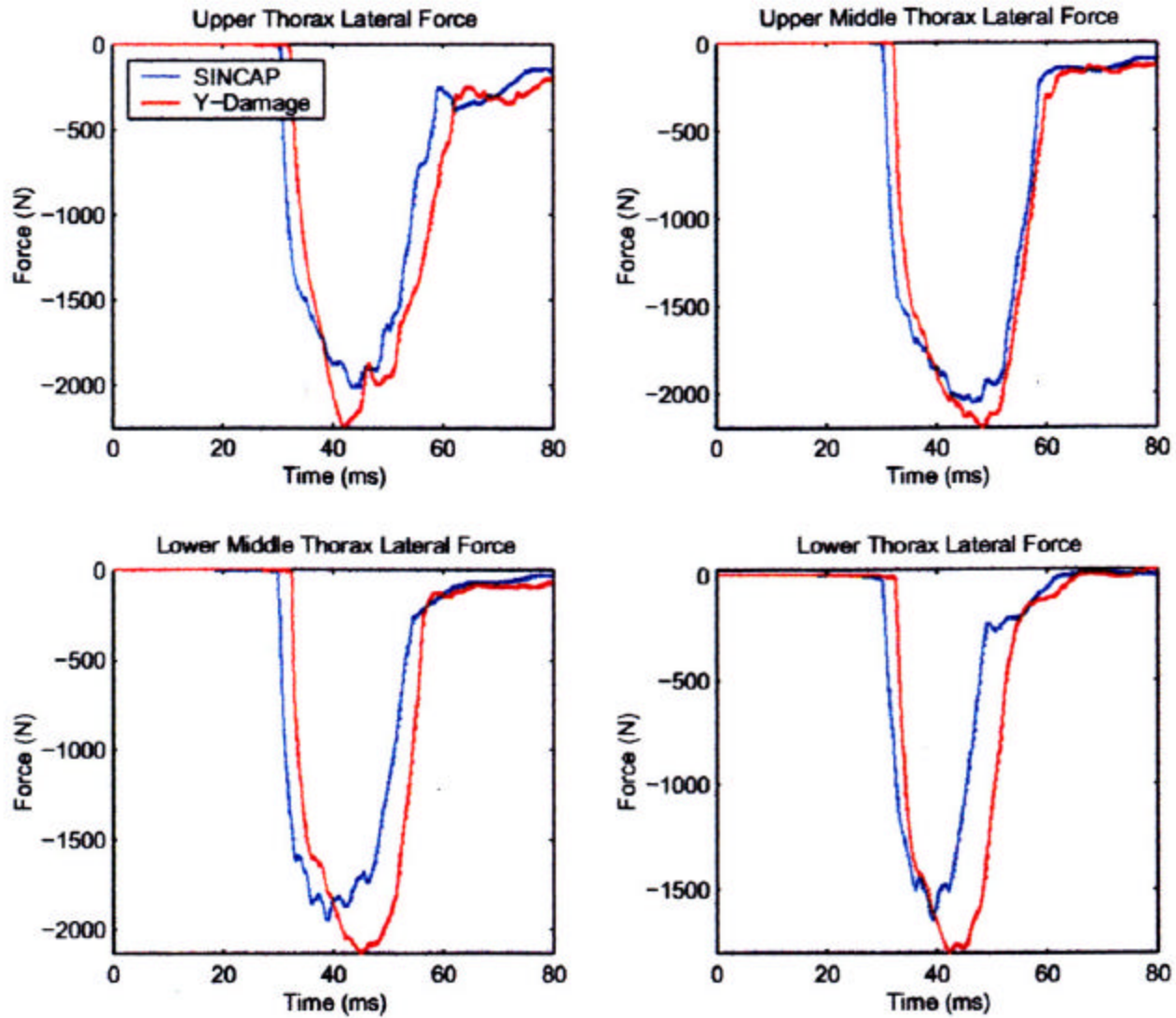


HUMAN
Y DAMAGE

4.



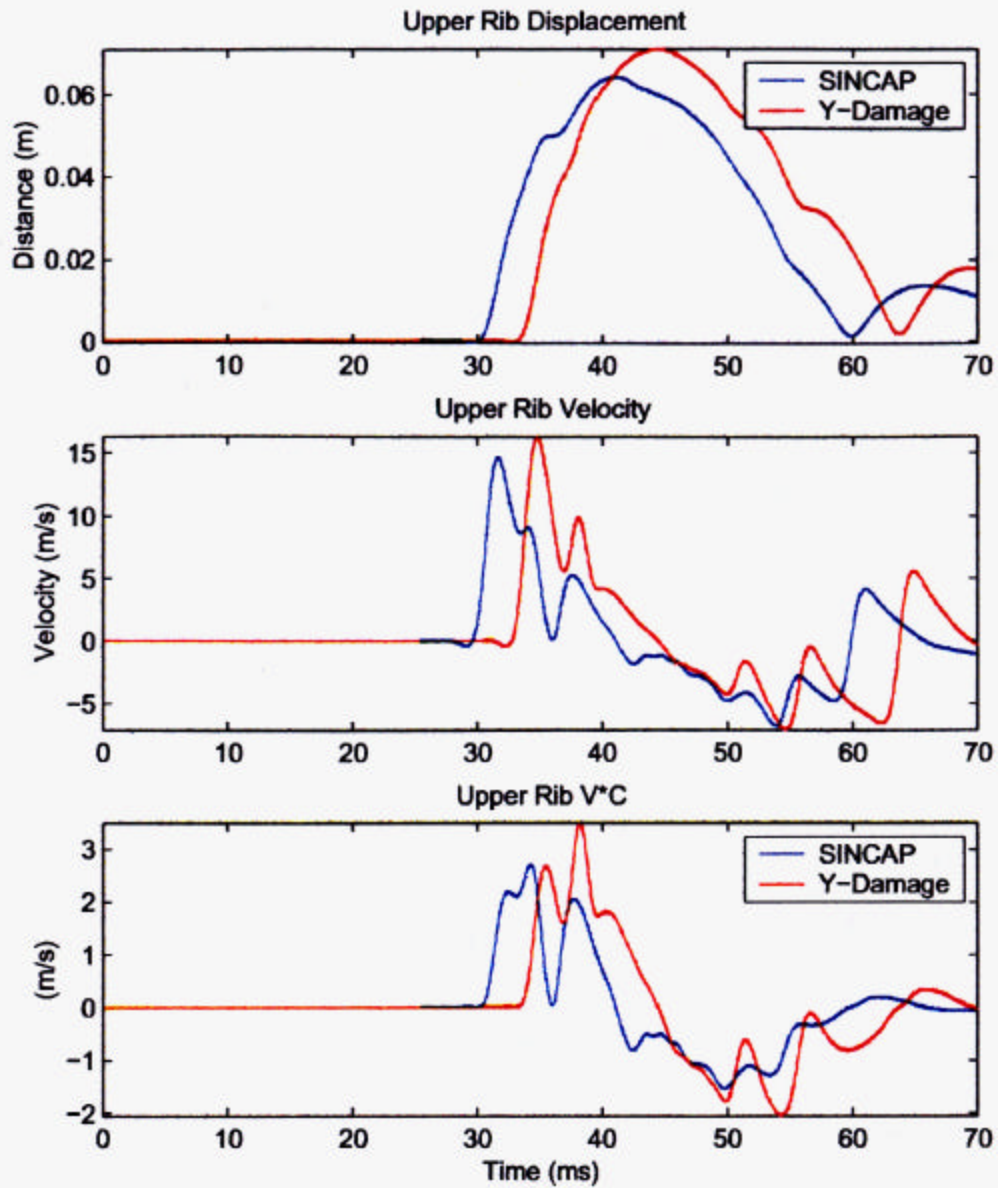
HUMAN
Y DAMAGE



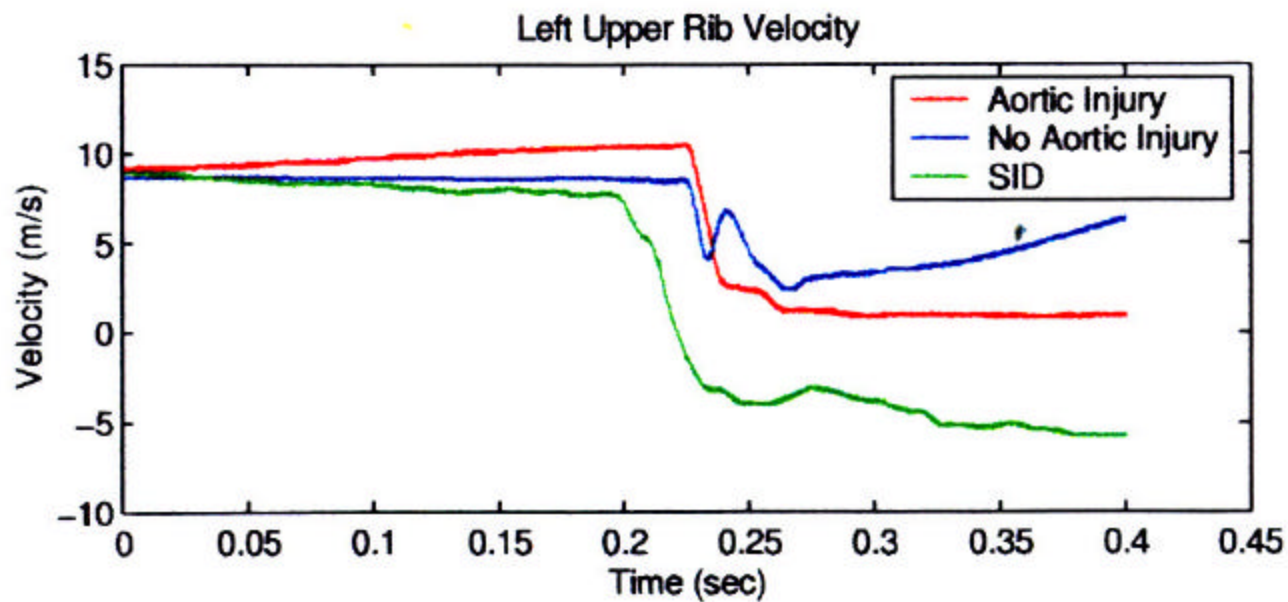
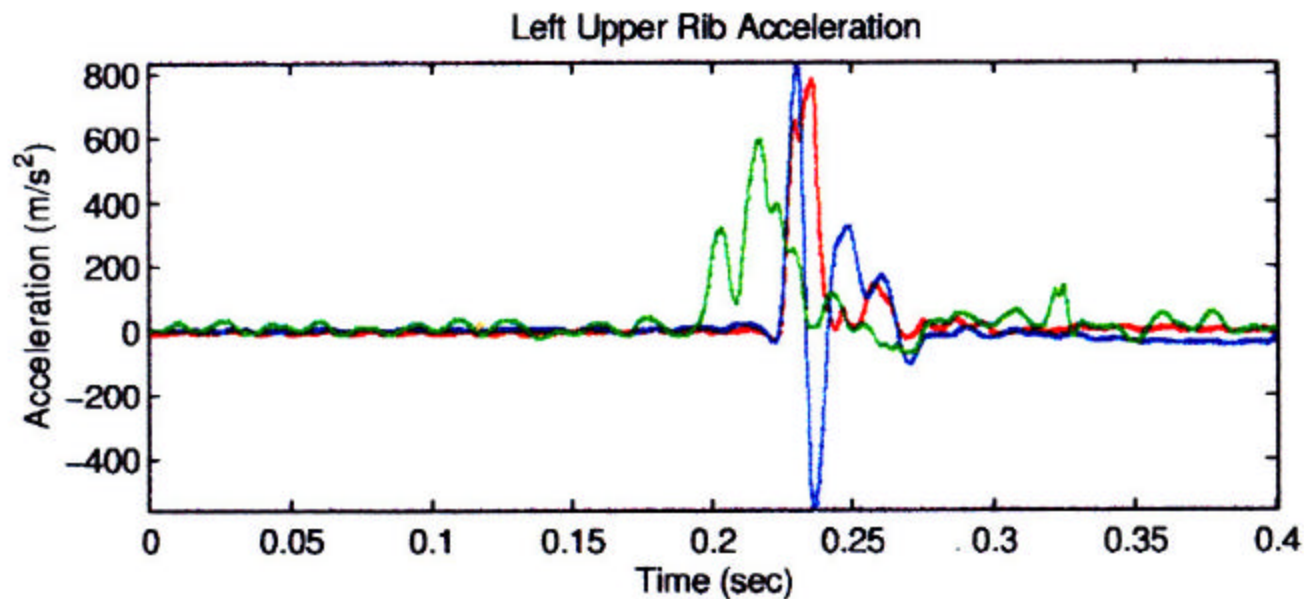
Human Model Lateral force at four levels along the thorax

CRUSH MEASUREMENTS ON SIDE IMPACT





EuroSID 2 upper rib displacement, velocity and V*C



Cadaver Sled Tests vs SID Model

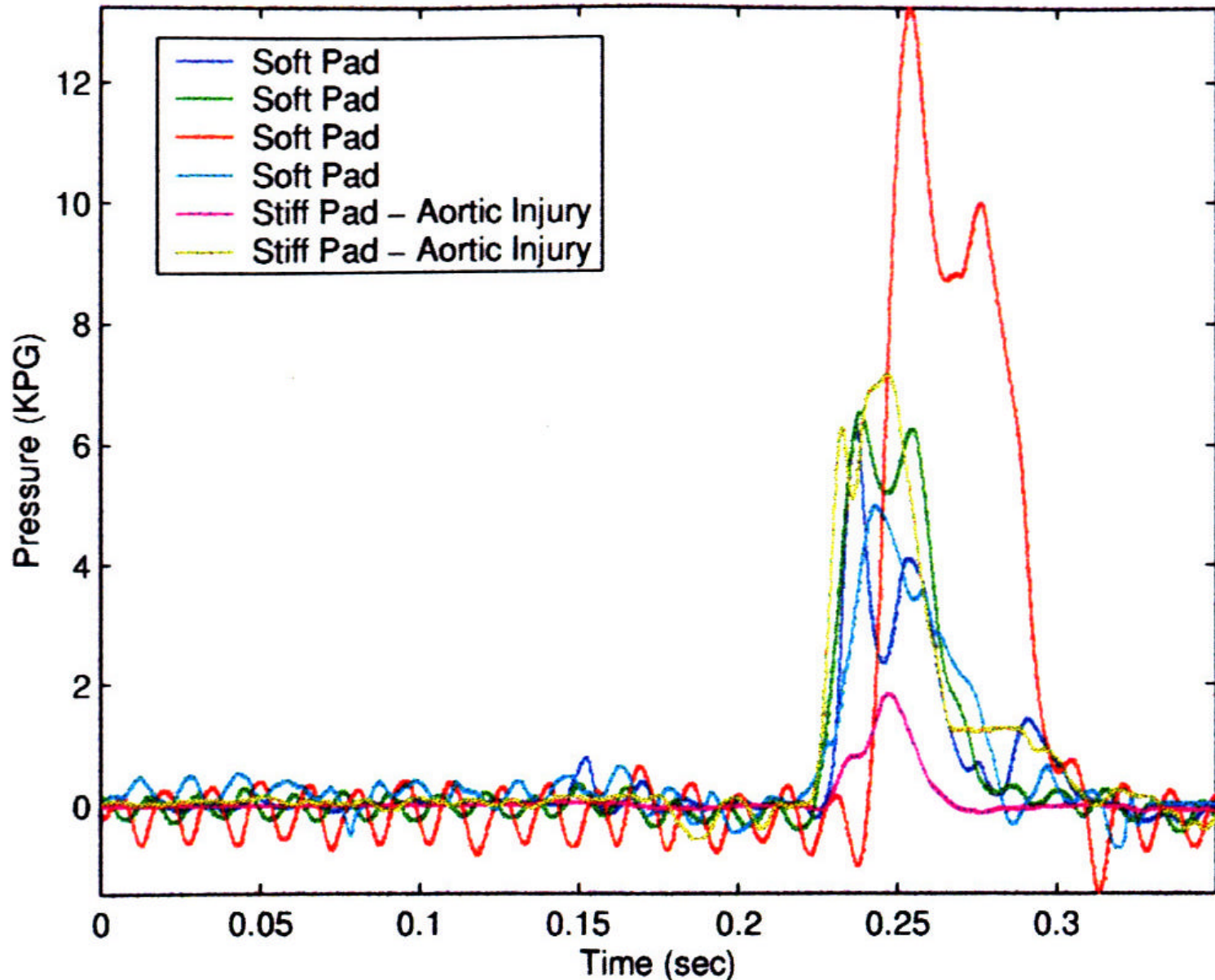
THE ARCHIMEDES LEVER HYPOTHESIS REGARDING THE MECHANISM OF AORTIC INJURY: “GIVE ME A LEVER LONG ENOUGH, A FULCRUM AND A PLACE TO STAND, AND I WILL MOVE THE WORLD”.

. ANATOMIC: AS THE THORACIC AORTA ARISES FROM THE HEART, IT IS SUSPENDED FROM THE GREAT VESSELS, INNOMINATE, LEFT CAROTID AND LEFT SUBCLAVIAN ARTERIES, THE LATTER BEING MOST FIXED AS IT EXITS THE THORAX OVER THE FIRST RIB. THE DESCENDING AORTA IS FIXED TO THE SPINE AND RIBS BEGINNING AT THE ORIGINS OF THE 3rd INTERCOSTAL ARTERIES. THE ISTHMUS LYING BETWEEN THE SUBCLAVIAN AND THE ORIFACES OF THE 3rd INTERCOSTALS IS UNTETHERED EXCEPT FOR A POTENTIAL TEAR-TAB AT THE LIGAMENTUM ARTERIOSUM.

FUNCTIONAL: THE ASCENDING AORTA AND THE ARCH AS FAR AS THE LEFT SUBCLAVIAN ARTERY, IF MADE RIGID, CAN FUNCTION AS A LONG LEVER ARM WITH THE SUBCLAVIAN TAKE-OFF AS THE FULCRUM TO EXERT A LARGE TORSIONAL FORCE ON THE RELATIVELY SHORT ARM OF THE UNTETHERED ISTHMUS WHICH IS ATTACHED AT ITS LOWER END TO THE FIXED PROXIMAL DESCENDING AORTA

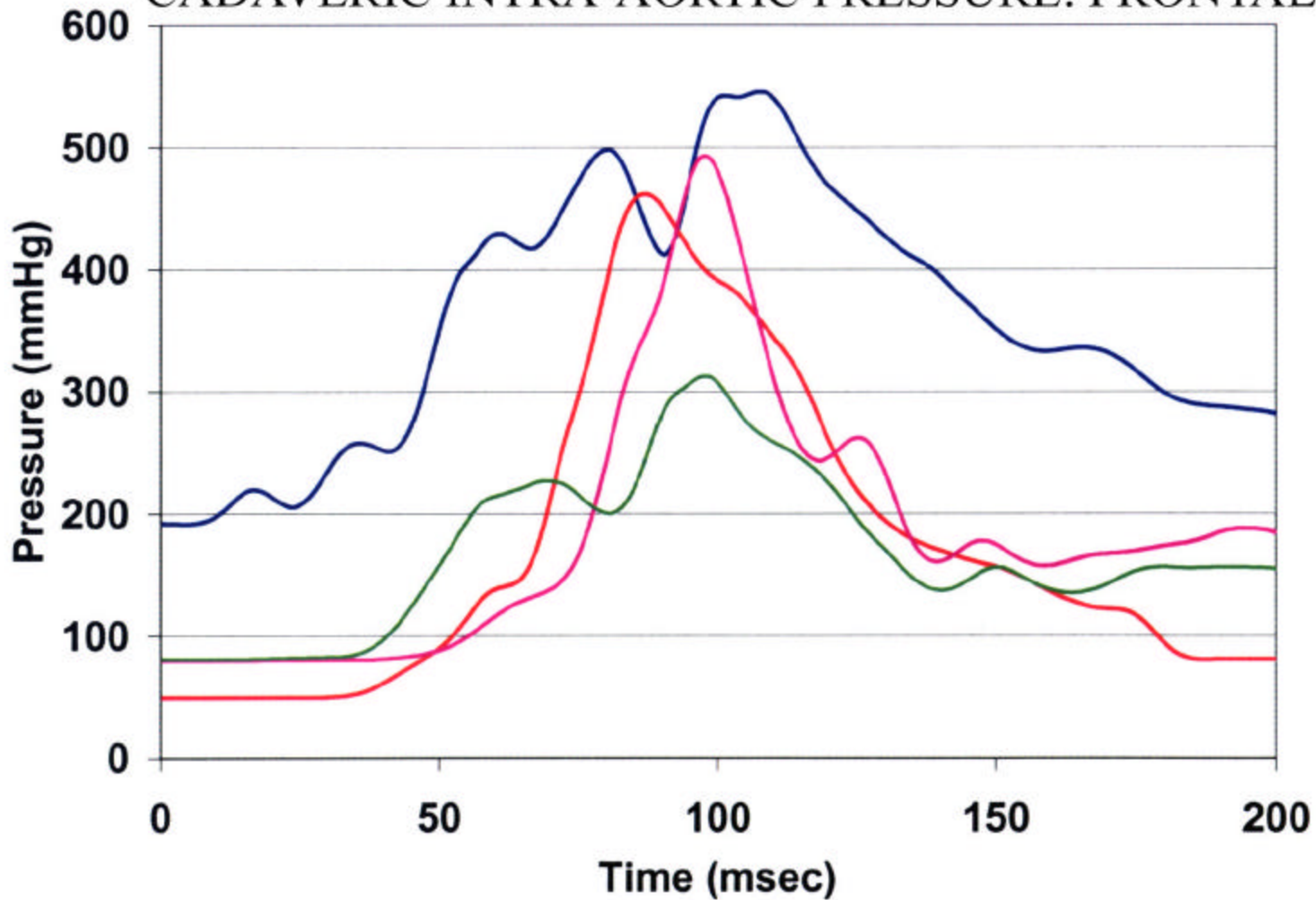
MECHANISTIC I: WITHIN 10-20 MSEC OF A CRASH MEDIATED IMPACT FORCE WHICH IS NARROWLY FOCUSED ACROSS THE REGION OF THE 2nd TO 5th RIBS (WHICH DELINEATES THE LOCUS OF THE AORTIC ARCH – ISTHMUS SYSTEM), THE INTRA-AORTIC PRESSURE RISES TO LEVELS WHICH MAY APPROXIMATE OR EXCEED 500 MM HG. THIS INTRA-AORTIC PRESSURE SELDOM RUPTURES THE AORTA IN ITSELF, BUT RATHER FUNCTIONS TO CAUSE THE ENTIRE ASCENDING AORTA – AORTIC ARCH SYSTEM TO FUNCTION AS A SINGLE TURGID, RIGID LEVER WHOSE FULCRUM IS THE SUBCLAVIAN ARTERY.

CADAVERIC INTRA-AORTIC PRESSURE: LATERAL CRASH



WSU: Aortic Pressure in Cadaver Sled Tests

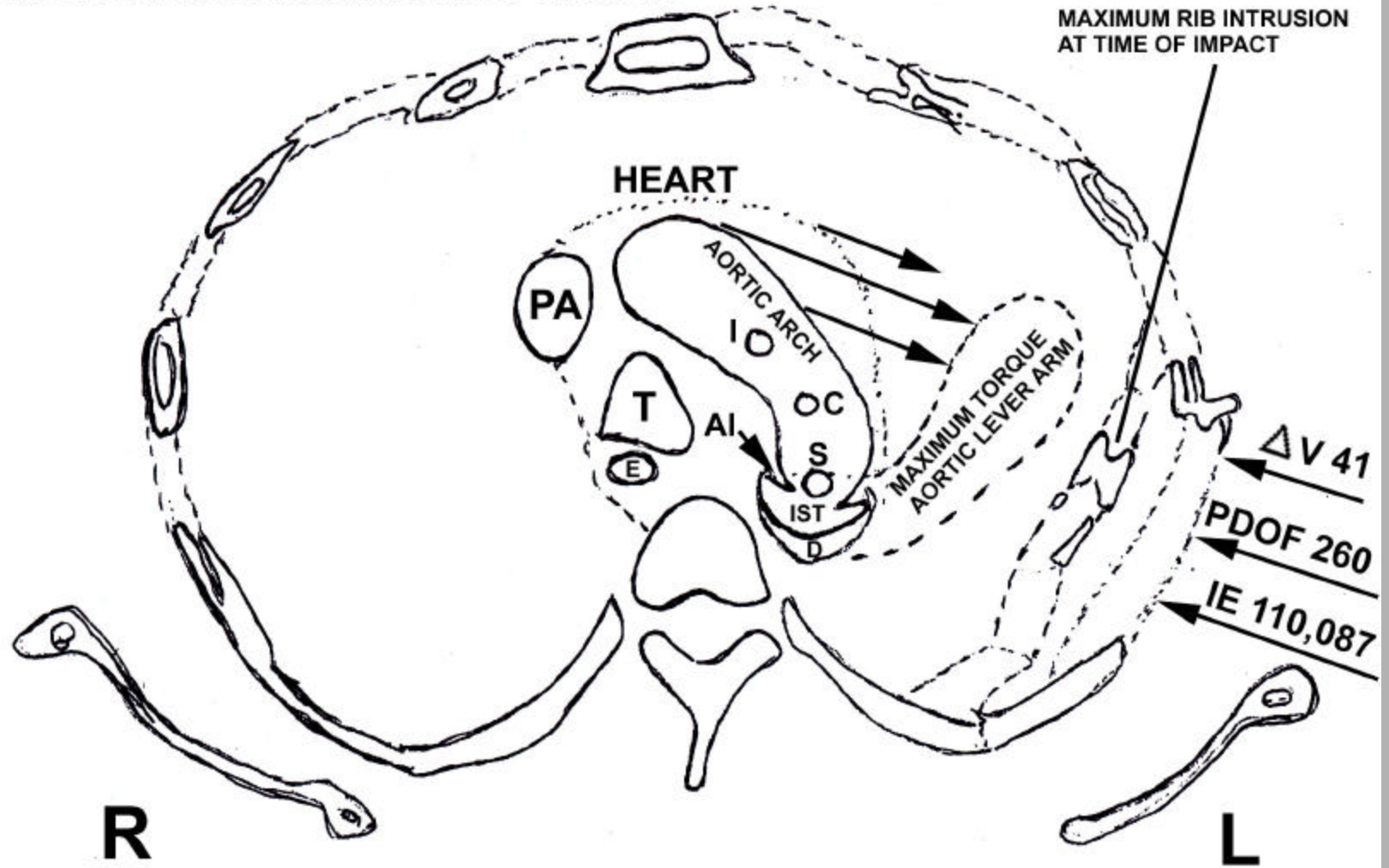
CADAVERIC INTRA-AORTIC PRESSURE: FRONTAL CRASH

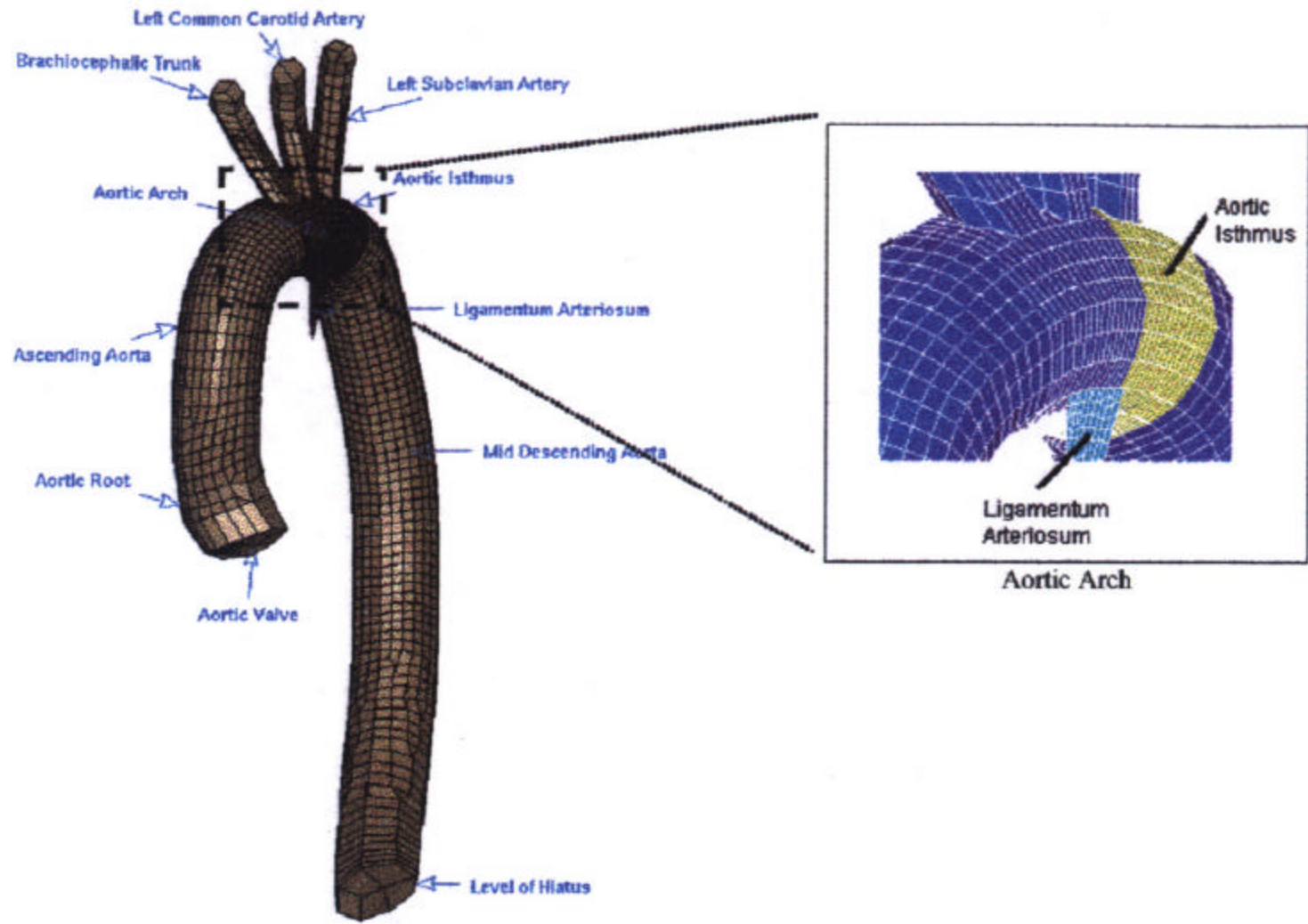


UVA: Internal aortic pressure time histories from frontal sled tests.

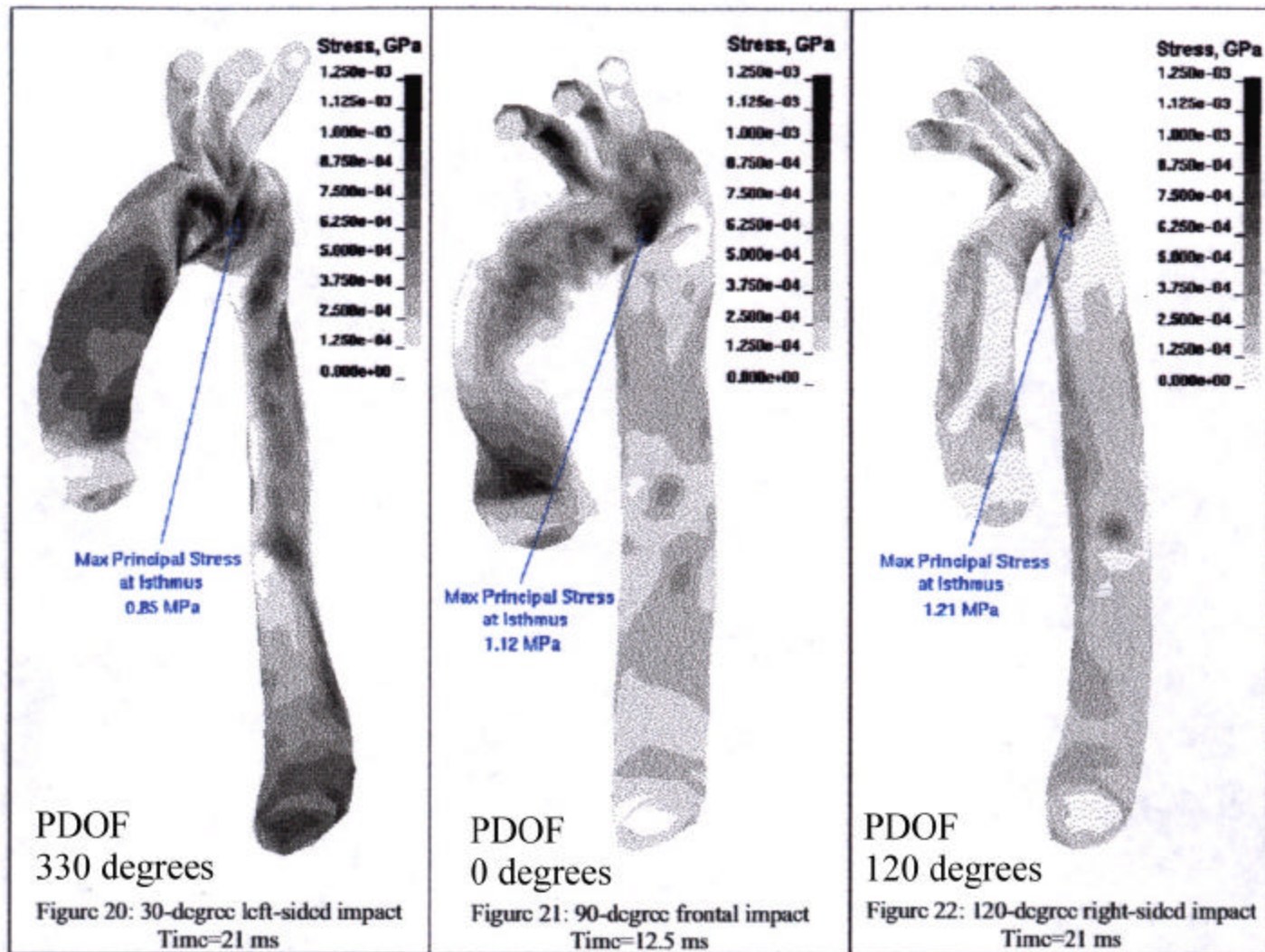
MECHANISTIC II: AT THE SAME TIME, THE ENTIRE SYSTEM OF HEART, ASCENDING AORTA AND AORTIC ARCH MOVES TOWARD THE IMPACTING FORCE, THUS CAUSING THE AORTIC LEVER ARM TO PRODUCE A FORCEFUL TORSIONAL ROTATION OF THE ISTHMUS ON THE PROXIMAL DESCENDING AORTA, WITH ITS TEAR POINT IN THE REGION OF THE LIGAMENTUM ARTERIOSUM, WHICH IS FIXED TO THE LEFT PULMONARY ARTERY. THIS TORSIONAL FORCE, WHICH IS MAGNIFIED BY THE DIFFERENCE IN LENGTH BETWEEN THE AORTIC ARCH SYSTEM AND THE ISTHMUS, PRODUCES A SUFFICIENT AMPLIFICATION OF THE IMPACT ENERGY TRANSMITTED TO THE PATIENT'S THORAX AT THE MOMENT OF IMPACT DECELERATION VELOCITY TO TEAR THE AORTA AT THE ISTHMUS OR PROXIMAL DESCENDING AORTA.

MECHANISM FOR AORTIC INJURY





WSU model of the thoracic aorta



WSU Maximum principal stresses at the isthmus of the aorta for three impact angles

RECOMMENDATIONS I

LIGHTY LESS THAN HALF OF ALL FMVC SERIOUS INJURIES REQUIRING HOSPITALIZATION AND **58%** OF ALL FMVC DEATHS AND **65%** OF THE FMVC AORTIC INJURIES OCCURRED IN CRASHES WHERE THE DELTA V WAS GREATER THAN THE **48 KPH** AT WHICH THE FEDERAL CRASH SAFETY STANDARD TESTS ARE CONDUCTED, AND THE IMPACT ENERGY EXCEEDED **155,524 JOULES**.

N LMVCs **64%** OF THE DEATHS AND **64%** OF THE AORTIC INJURIES OCCURRED IN CRASHES WHERE THE DELTA V WAS GREATER THAN **36 KPH**, AND THE IMPACT ENERGY EXCEEDED **92,956 JOULES**.

RECOMMENDATIONS II

TO REDUCE SERIOUS INJURES AND RELATED FMVC DEATHS, CRASH SAFETY TESTING SHOULD BE CARRIED OUT AT A DELTA V EQUAL TO THE MEAN PLUS ONE STANDARD DEVIATION OF THE ACTUAL DELTA V FOUND IN THE CIREN MULTICENTER STUDY. THIS LEVEL OF DELTA V WOULD BE 48 ± 19.7 KPH = 67.7 KPH (OR 42 MPH) WITH A CORRESPONDING IMPACT ENERGY OF 286,775 JOULES.

IN LMVCs THIS DELTA V WOULD BE 36 ± 16.4 KPH = 52.4 KPH (OR 33 MPH), WITH A CORRESPONDING IMPACT ENERGY OF 179,299 JOULES, AS ACTUALLY MEASURED AT IMPACT.

THESE LEVELS OF CRASH DYNAMICS SHOULD ENCOMPASS 84% OF ALL SERIOUS MVC INJURIES ADMITTED TO LEVEL I TRAUMA CENTERS.

RECOMMENDATIONS III

IT WOULD APPEAR THAT IN FMVCs THE COMBINATION OF SEAT BELT RESTRAINT USAGE PLUS AIRBAG DEPLOYMENT HAS THE BEST PROTECTIVE EFFECT IN THE REDUCTION OF MORTALITY AND SEVERE BRAIN AND THORACIC INJURIES EVEN AT HIGH DELTA V_s AND LARGE VEHICLE IMPACT ENERGY (IE) DISSIPATIONS. THIS SUGGESTS THAT THE OCCUPANT NEEDS TO BE HELD IN A POSITION WHICH ENSURES THAT THE AIRBAG CAN MOST EFFECTIVELY BUFFER THE CRASH IMPACT ENERGY DISSIPATED INTO THE VEHICLE

RECOMMENDATIONS IV

**T ALSO IMPLIES THAT IN LATERAL MOTOR VEHICLE CRASHES
A SIMILAR COMBINATION OF EFFECTIVE SEAT-BELT
IMMOBILIZATION TOGETHER WITH SIDE-AIRBAG
DEPLOYMENTS FOCUSED AT BUFFERING THE HIGH IE
TRANSMITTED TO THE HEAD, UPPER THORAX (INCLUDING
RIBS 1-4), AND PELVIS WILL PRODUCE A PROTECTIVE EFFECT
ON OVERALL MVC MORTALITY AND MORE SPECIFICALLY, ON
AORTIC INJURY PRODUCTION.**