Pelvic and Thoracic Injuries in Nearside Impact Crashes: Analysis of Contributory Factors

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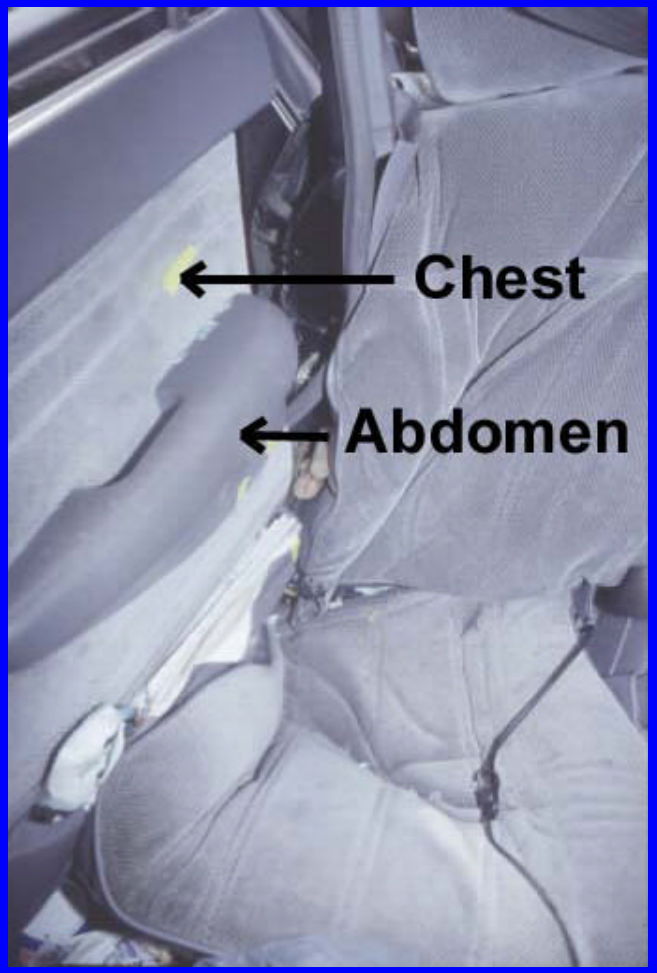
Goal of This Study

To determine whether vehicle design factors relate to thoracic and pelvic injuries from near-side impacts



Background

- Side impacts comprise about 32% of all vehicle crashes with occupants experiencing AIS 3+ injuries.
- Thorax and pelvis are the most likely regions to be injured in near-side impacts (Samaha,'03)
- Thoracic and pelvic injuries are probably the result of a limited stroke punch intrusion of the door, (Lau,'91 Chung '99).
- The predominant injurious contact in thoracic and pelvic injuries is the door (Samaha, '03).

Background – Variables Affecting Injury

- Crash variables
  - masses of both vehicles (Terrel, 18th ESV, ’03)
  - angle of impact
  - speed of bullet vehicle
  - Stiffness of both vehicles
  - Height of contact region on door

- Occupant variables
  - stature of occupant (Samaha 18th ESV, ’03)
  - location of occupant
  - restraint use
  - age of occupant (Austin 18th ESV, ’03)

Vehicle Design Variables

2001 Toyota Sienna, Weight = 2029 kg, Door crush = 29.7 cm
Driver TTI = 69, pelvic g = 94, No side airbag

2002 Toyota Tundra, Weight = 2229 kg, Door crush = 29.8 cm
Driver TTI = 22, pelvic g =27, No side airbag

Background –Vehicle Variables?

- Vehicle weight
- Maximum door intrusion (Chung ’99)
- Location of maximum door intrusion
- Peak door acceleration
- Peak door velocity (Morris, ’01,Viano ‘89)
- Peak relative door to vehicle velocity
- Wheelbase (related to vehicle stiffness?)
- Armrest (panel) stiffness (Rouhana ‘89, Viano ‘91, Deng ‘96, Cavanaugh ‘96, Daniel ’95, Morris ‘01)
- Dummy H-point to door horizontal distance (Morris,’01)
- Deployed thoracic airbag (thoracic injuries)
- Stiff center console (pelvic injuries)

Basic Question

Which vehicle variables relate to dummy accelerations in side impact collisions?

Methods

NCAP side impact data

- Standard moving deformable barrier mass, height, angle, and velocity
- “Occupant” standard DOT SID
- Peak pelvic g and TTI determined as function of vehicle related variables
- Reports on 165 vehicles available at www.dms.dot.gov docket 3835

Methods – Vehicle Door Measurements

Methods – CIREN and NASS

- CIREN
  - Scene inspection
  - Vehicle damage, restraint use, PDOF, DV
  - Occupant interior contact locations
  - Medical records, x-rays, imaging studies of injuries

- NASS
  - NASS-CDS database
  - side impacts, amount of door intrusion
  - highest AIS (MAIS) score of three regions determined

Results – CIREN Examples

CIREN Side Impact Data and Case Reviews

Lateral Impact Mechanism Reviews

Intrusion = Injury

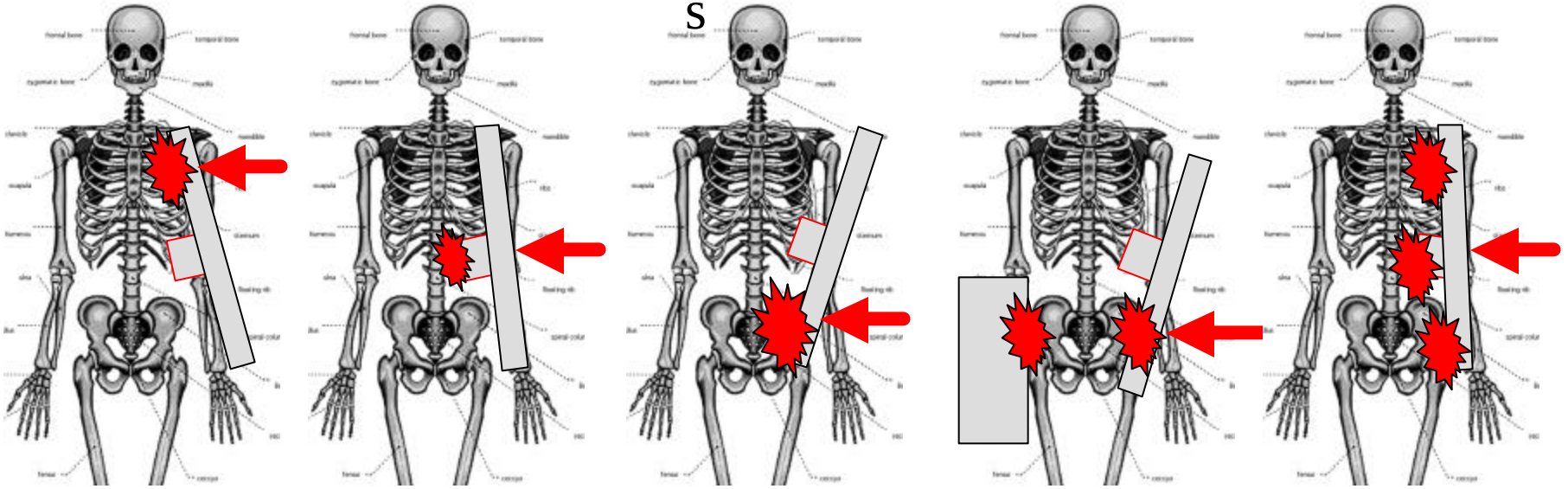
Thorax

Abdominal

Lateral Pelvis

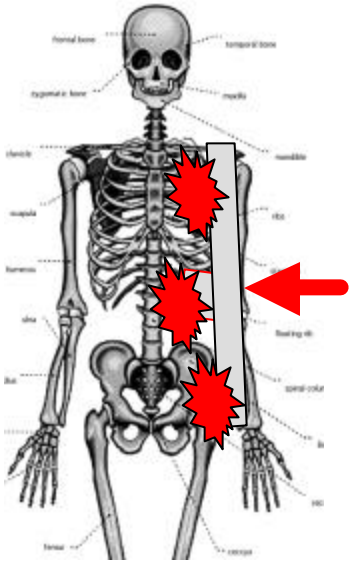
Bilateral Pelvis

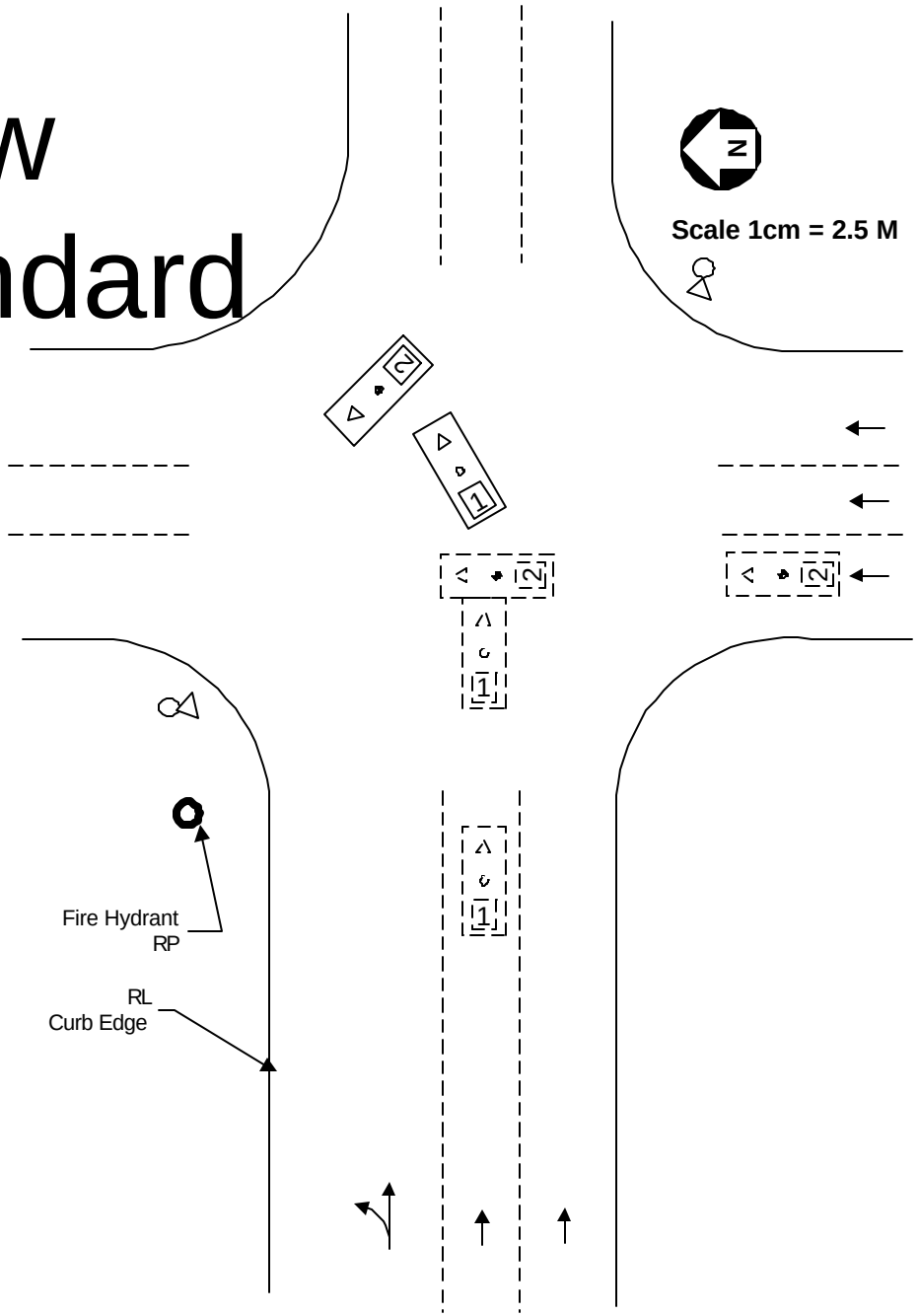
Combination



Case Review
Pre-Standard

Combination





Case Review

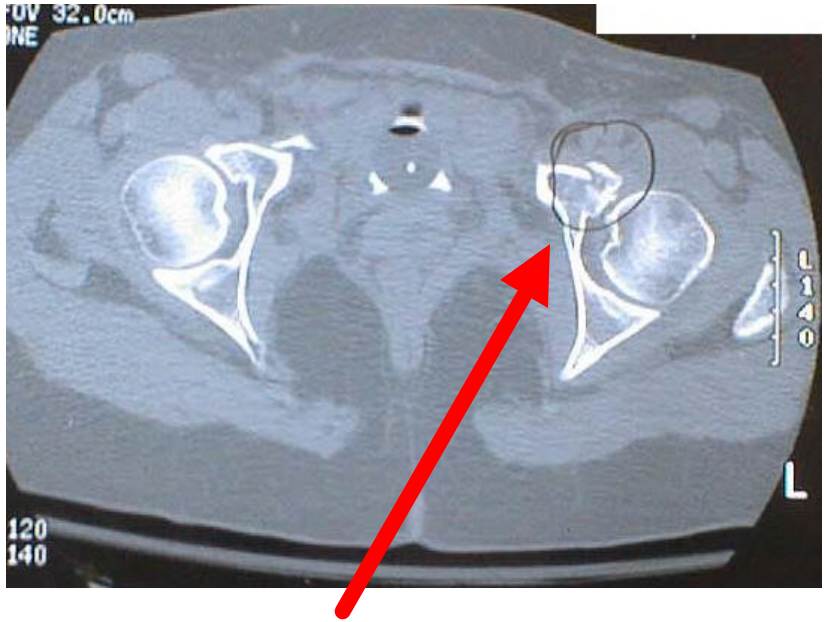
90’s Compact Sedan

90’s Large Sedan

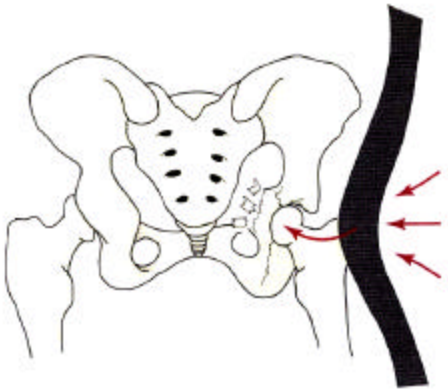
Lateral door intrusion at chest and pelvis

Lower Lateral Door Intrusion

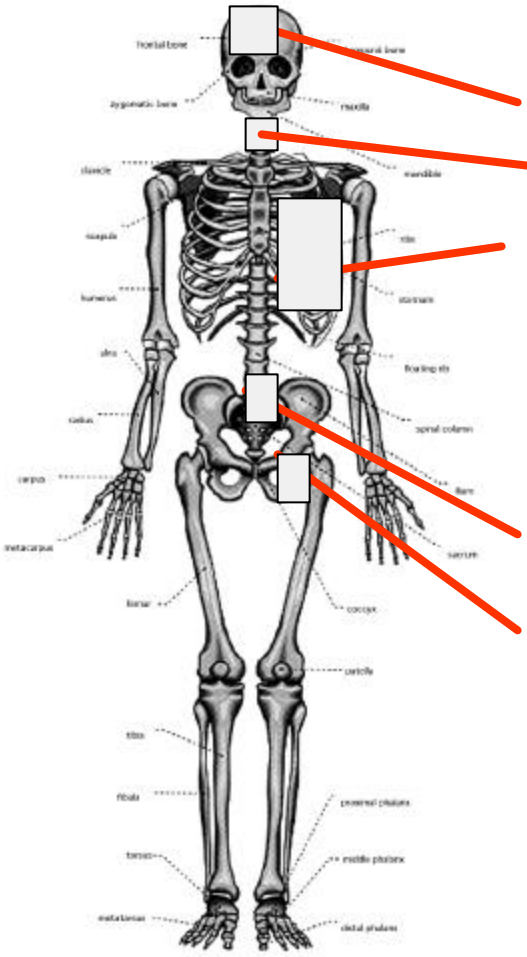
Lower lateral door intrusion



Left acetabular fx



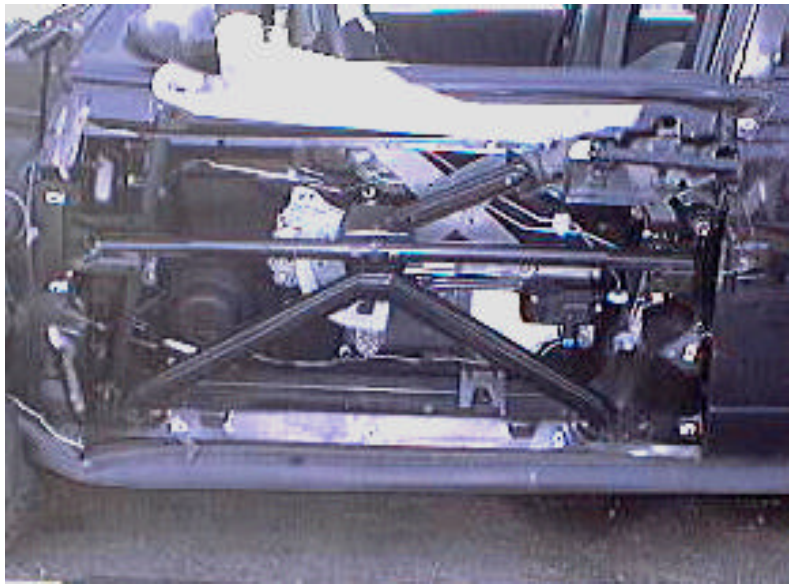
Injuries

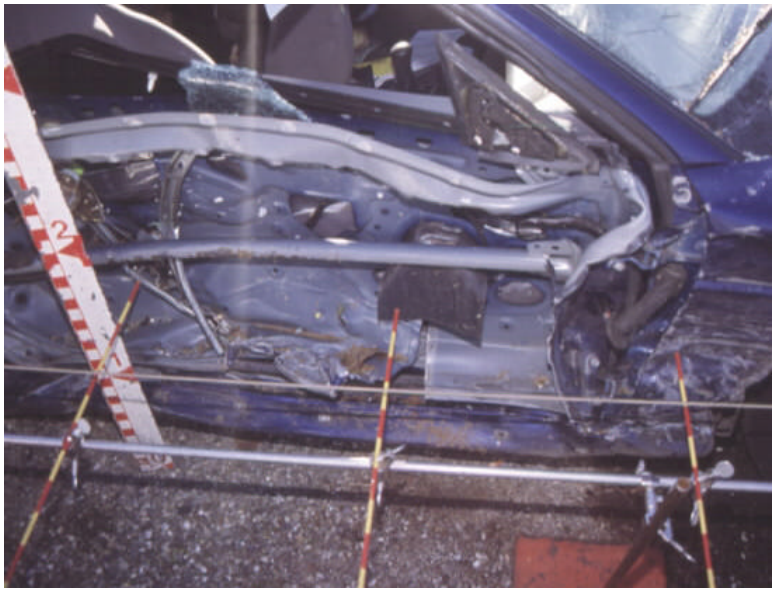


AIS	Region	Injury
2	Head	Concussion
2	Spine	C1 fracture (non-displaced)
4	Chest	L Ribs fractures 3-8 with hemothorax
		Pulmonary contusion
		Ruptured L diaphragm
3	Pelvis	Sacral fx
3	Pelvis	L Acetabular Fx

ISS = 29

Side Impact Standard Improvements





Use of side impact beams in doors

Case Review
Protection From Side Impact Beams

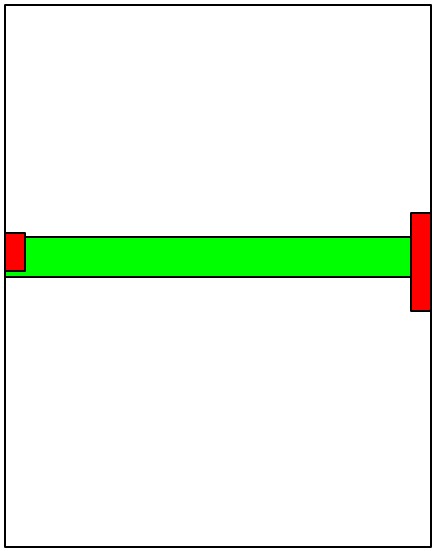
- 1997 Compact 2HB

- Minimal intrusion

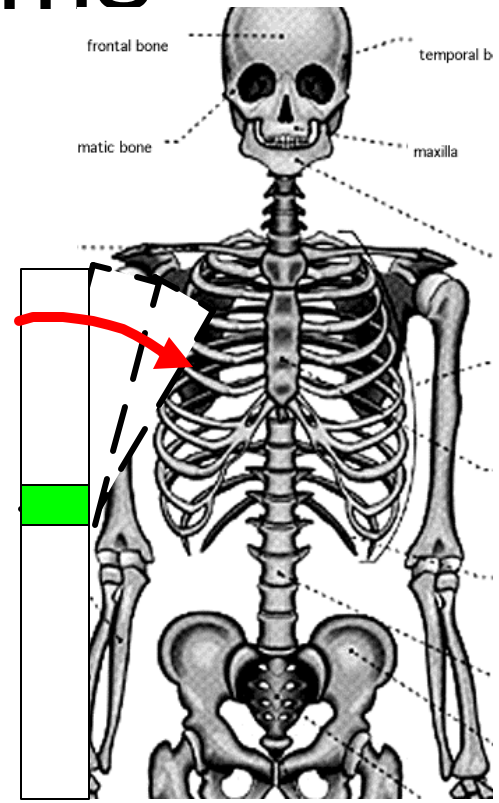
- No injury to front right restrained passenger

Striking vehicle

Side Impacts From Larger Vehicles Impact Above Support Beams



Side View



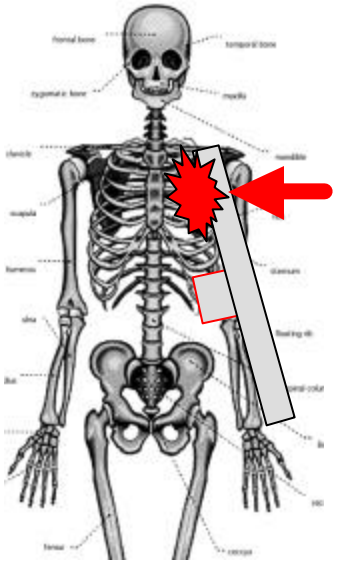
End View

Upper Door Panel Intrusion

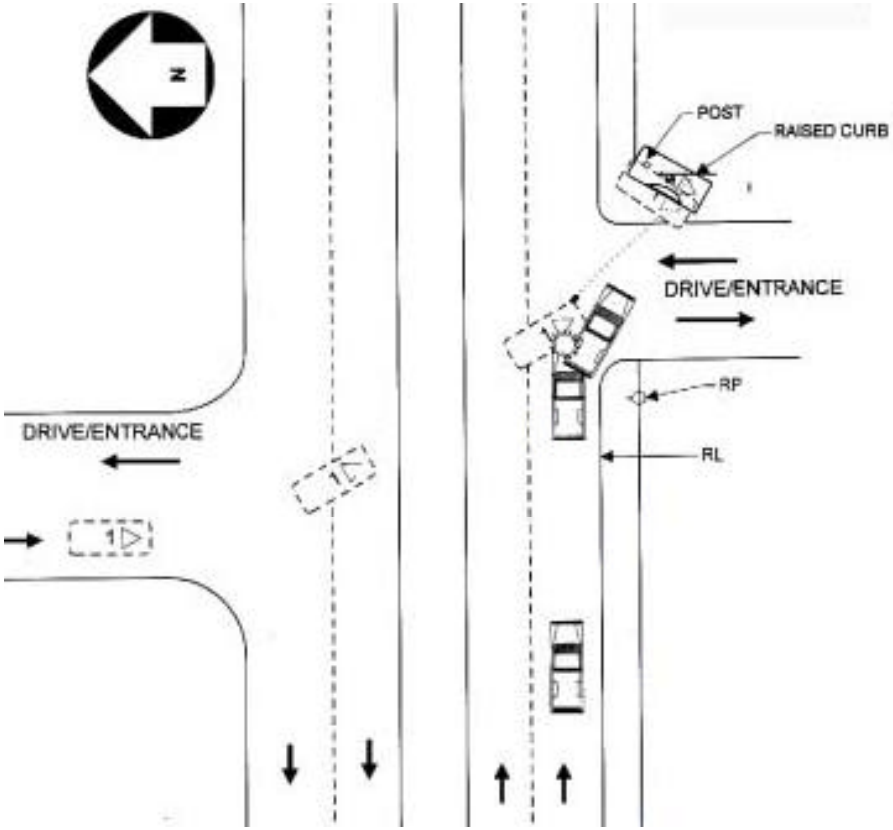
1998 Subaru Impreza vs. SUV

Most light trucks, vans, and SUVs will collapse the upper door panel, and even override the support beam

Door Intrusion - Thoracic Injuries



Case Review Scene



Look back path of travel

Case Review

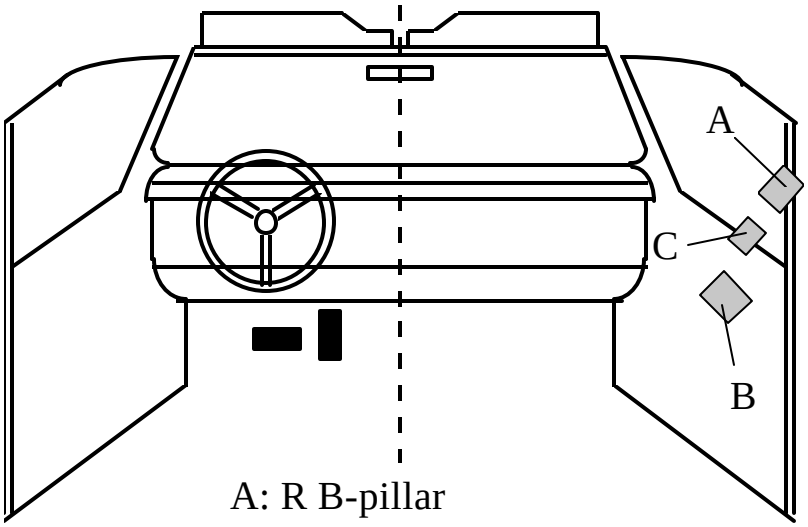
Compact Sedan

- Front Seat Passenger
- 74 yr. , Male
- Lap/Shoulder belt
- Struck by a large pickup
- Lateral Direction of Force

Upper Door Panel Intrusion Case Review

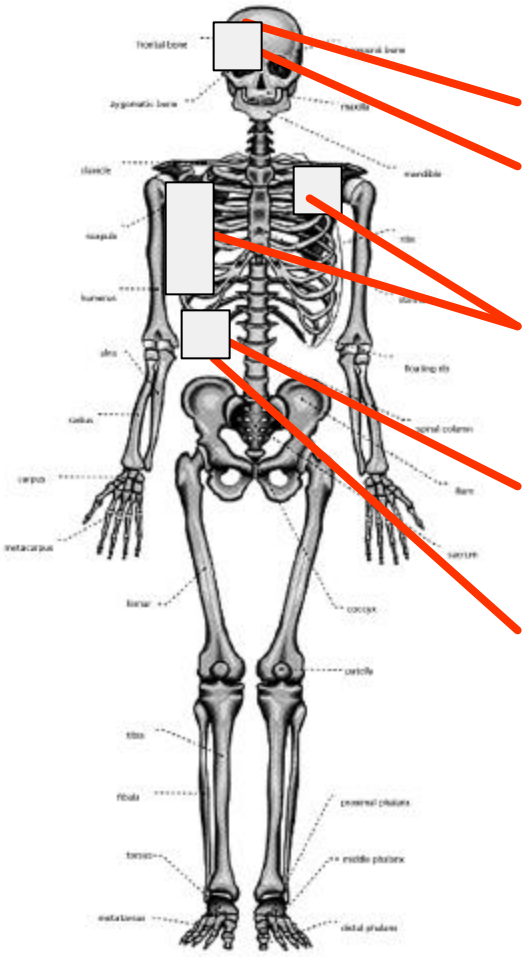
Compact sedan struck by large pickup truck

Upper Door Panel Intrusion Case Review



A: R B-pillar
B: R side interior
C: R window frame

Injuries



AIS	Region	Injury
2	Head	Scalp laceration
3	Head	R subarachnoid bleed/ contusion -parietal/occipital
4	Chest	Rib fxs: L :1-3, R:3-9 with R pneumothorax
2	Abdomen	R perinephric hematoma - small
2	Abdomen	Pancreatic head Lac

ISS = 29

Hospital Course

77 year old restrained male. Confused at scene; intubated.

Day 1: Exploratory laparotomy:
Small hemoperitoneum,
Small R perinephric hematoma

Day 2-25: Prolonged respiratory failure:
Pneumonia
Tracheostomy on day 12
Trach pulled on day 25

Day 26: Transfer to Geriatrics

Day 32: Transfer to Rehab

CIREN Thoracic Injury Summary

Mean Age	44 yrs.	
	Mean Delta V	36.8 kph/22.8
mph	Mean Intrusion	34.1 cm/13.4
inches	Mean AIS	4.2

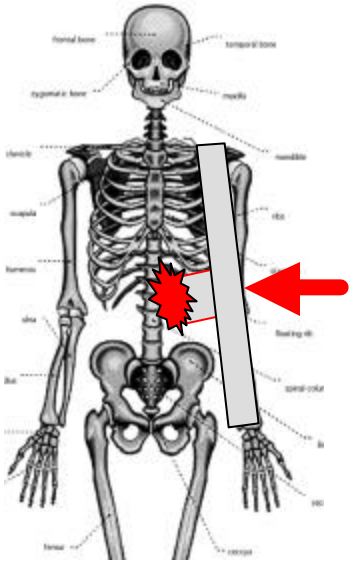
Derived by Thoracic Injury

All thoracic injury patterns associated with the door panel

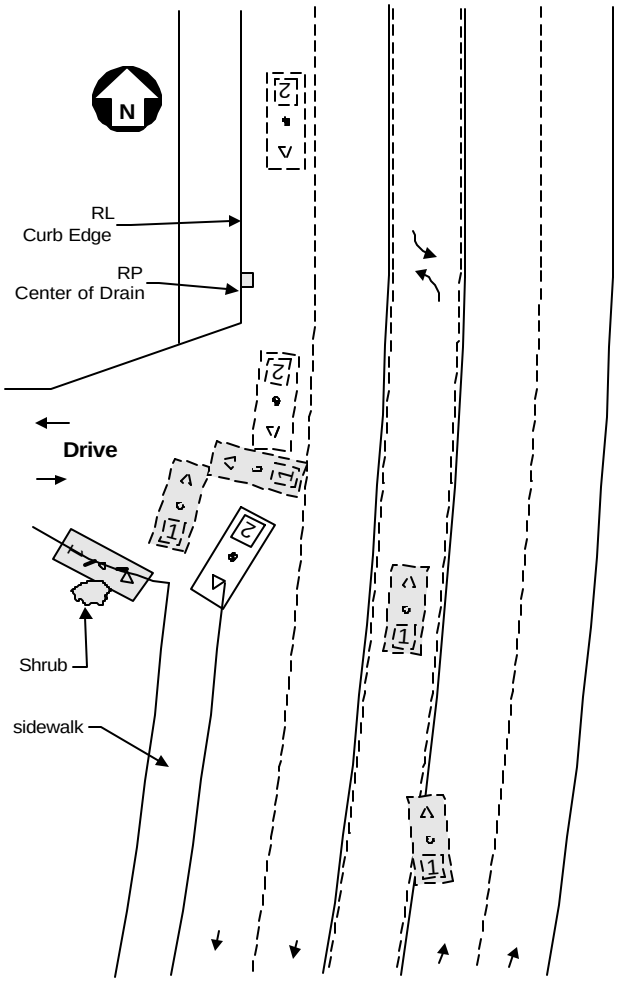
No	age	sex	height (M)	occupant position	restraint	PDOF	delta V (kph)	intrusion (cm)	AIS	thoracic injuries	contact point
T1	62	M	1.85	driver	lap+shldr	270	35.4	45	3	2-3 rib fractures with hemo/pneumothorax	door panel
T2	28	F	1.73	driver	none	280	24.1	16	4	>3 rib fractures with hemo/pneumothorax	door panel
T3	29	F	1.65	driver	none	280	unk	23	4	>3 rib fractures with hemo/pneumothorax	door panel
T4	22	F	1.52	FR pass.	none	70	38.6	44	5	>3 rib fx, both sides with hemo/pneumothorax, lung lac	door panel
T5	87	M	1.75	driver	lap+shldr	280	16.8	44	5	>3 rib fx, both sides with hemo/pneumothorax, lung lac	door panel
T6	17	F	1.65	FR pass.	none	50	46.7	40	5	flail chest with lung contusion	door panel
T7	27	M	1.93	driver	none	350	54.7	37	5	bilateral flail chest	door panel
T8	26	F	1.65	driver	lap+shldr	290	54.7	43	3	2-3 rib fx, hemo/pneumothorax, lung contusion	door panel
T9	62	M	1.78	driver	none	300	46.7	20	4	>3 rib fractures with hemo/pneumothorax	door panel
T10	38	F	1.52	driver	none	300	33.8	40	4	>3 rib fractures with hemo/pneumothorax	door panel
T11	82	F	1.57	driver	lap+shldr	300	16.1	23	4	>3 rib fractures with hemo/pneumothorax	door panel
means	**43.6**	**4M,7F**	1.69				**36.8**	**34.1**	**4.2**		

Side Impact - Abdominal Injuries (Associated With the Armrest)

Abdominal



Abdominal Injury Case Review



90’s Sedan

Delta V = 15 mph

Front Right Pass.

Lap/Shoulder belt

71 yr. , Female

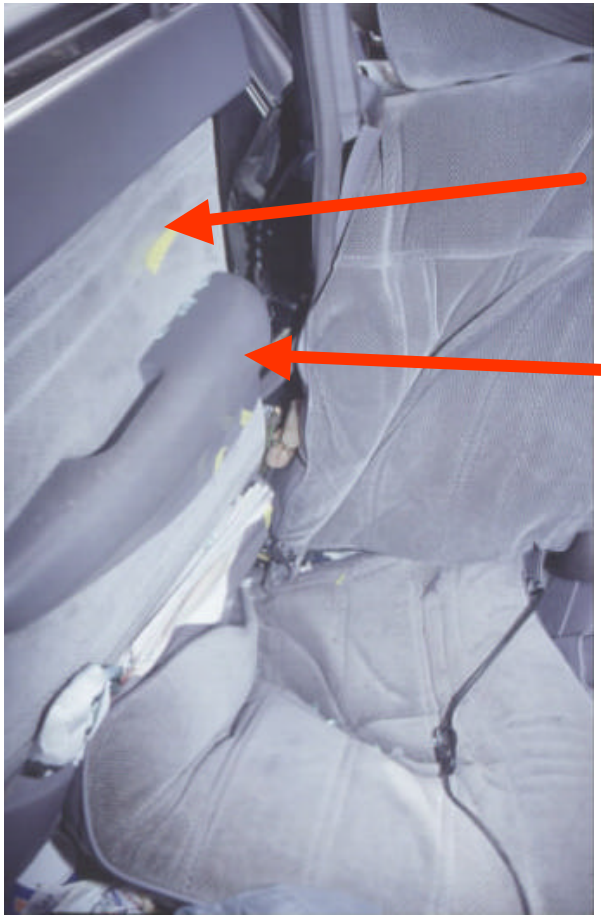
Abdominal Injury Case Review

Injuries associated with armrest:

R kidney laceration

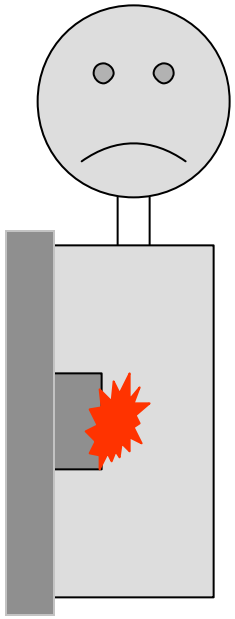
Liver laceration

Other: Splenic laceration, Flail chest , ruptured aorta



Chest

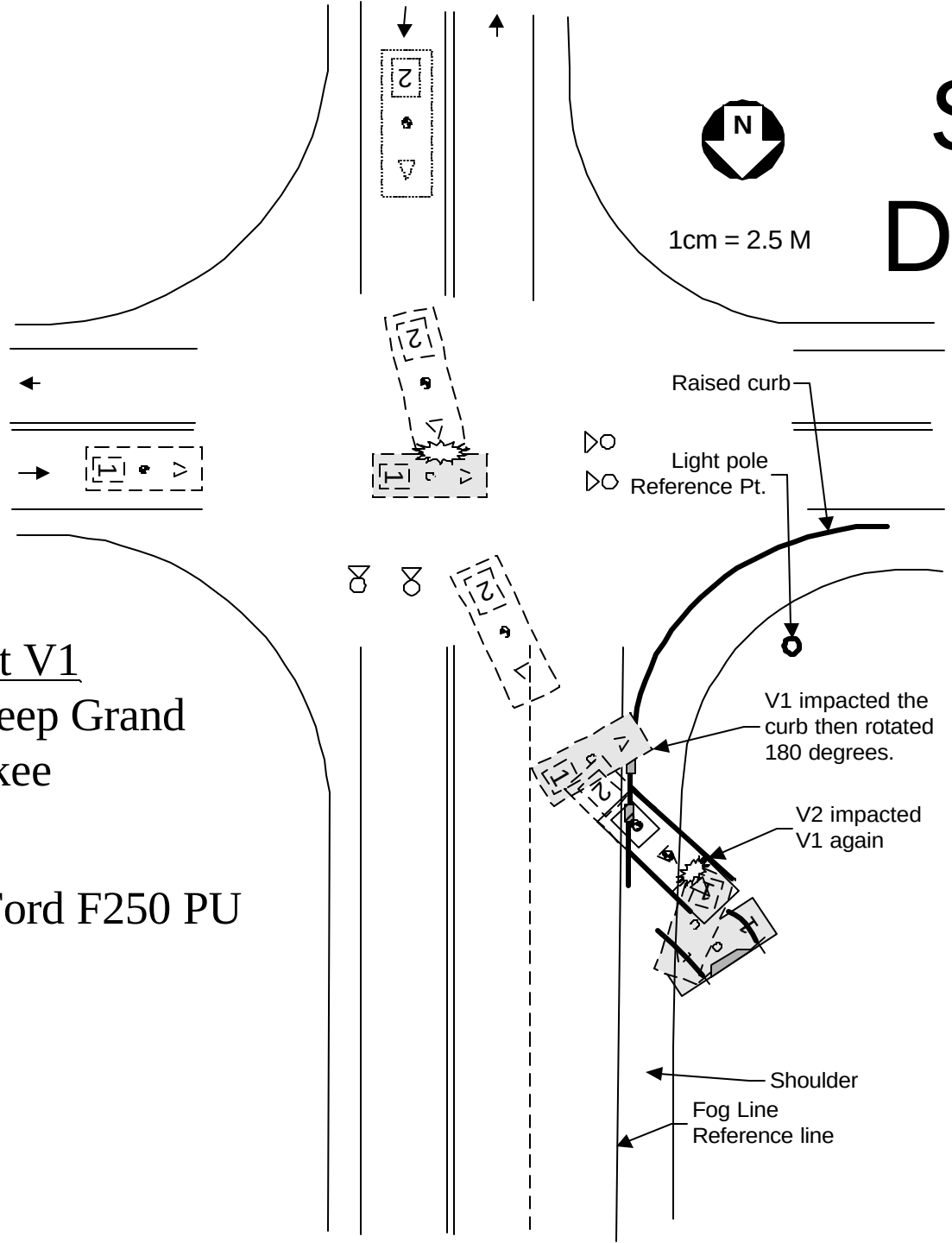
Abdomen



Abdominal Armrest Injury Case Review

1998 Jeep Grand Cherokee

Scene Diagram



Subject V1
1998 Jeep Grand Cherokee

V2
1986 Ford F250 PU

Vehicle Damage

Door Extrication - low profile

Delta V = 15 mph

PDOF = -80

Demographic - Interior Contacts

Driver

Near side SS214
Unrestrained

30 yr., Female

5’8”, 140 lbs.

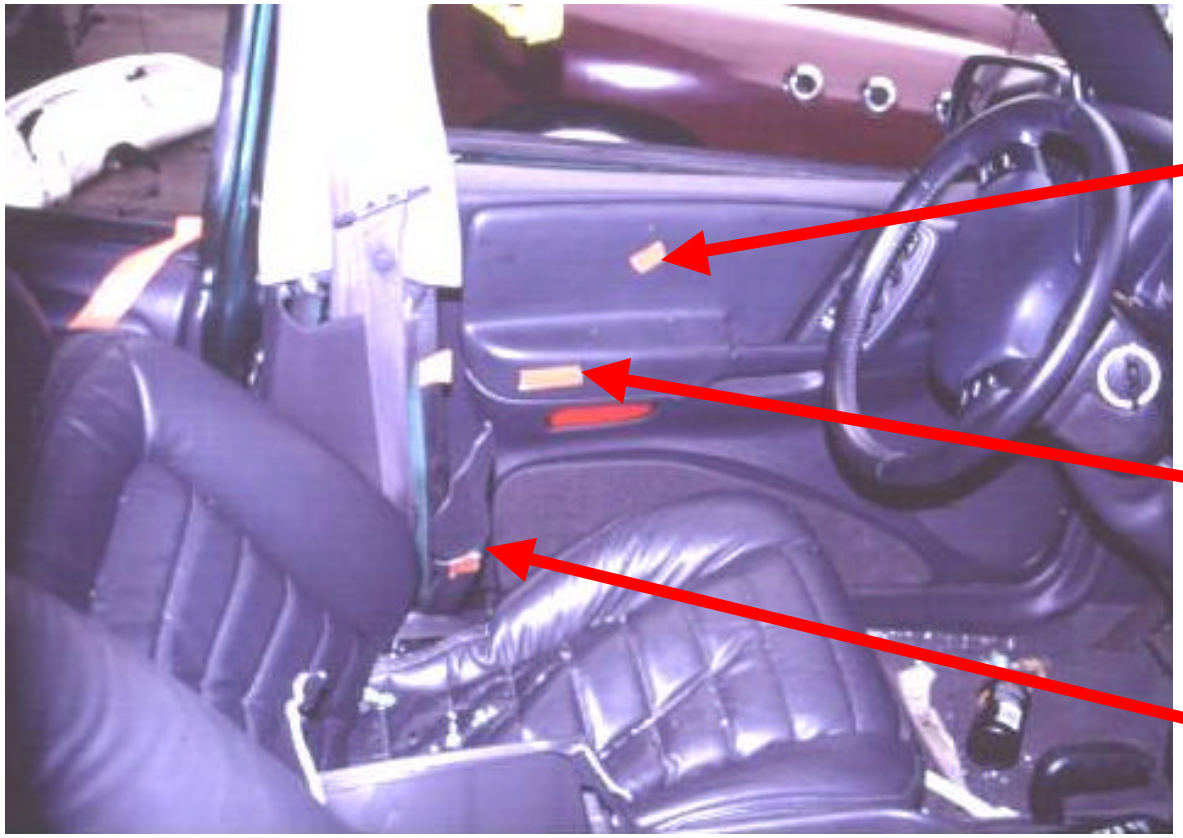
Intrusions

Left B pillar - 22cm - Lat

Driver Door - 16cm - Lat

Roof rail - 12cm - Lat

Occupant Contacts



Treatment - Hospital Course

28 year old Female: Unrestrained in side impact. Alert at scene. Tachypneic (RR 40); tachycardic (125); SBP 100. Intubated in field.

Initial Evaluation: Intubated, BP 145/108
L eye brow laceration

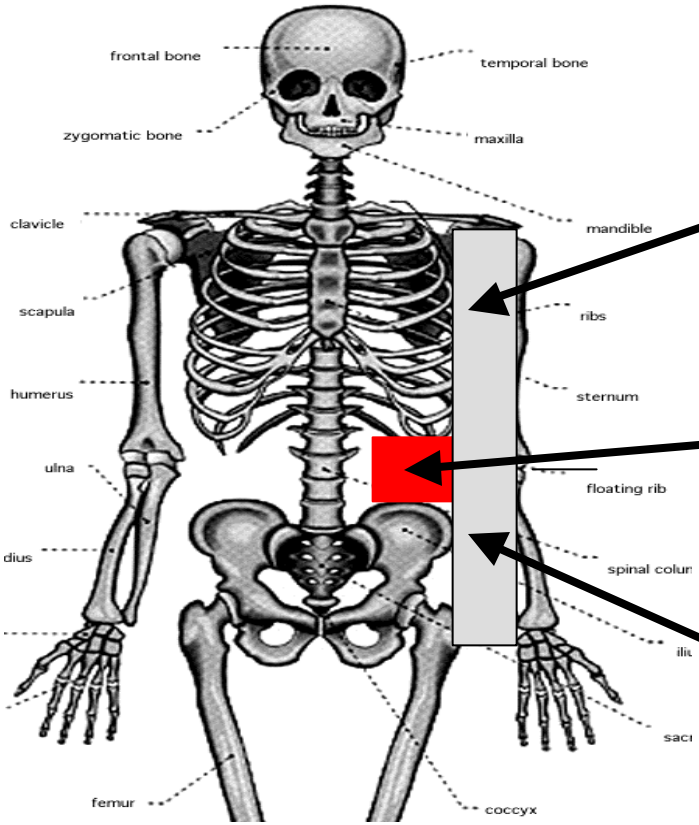
Hospital Course:
Abdominal CT: small liver and spleen lacs
Extubated on day of admission
Nonoperative management of pelvic fx
Day 6: Discharged home (WB as tolerated)

Injuries

Face		AIS
	L eye brow laceration	1
Chest		
	L rib fxs (2-12) w/hemothorax	4
Abdomen		
	L liver laceration	2
	Splenic laceration	2
Lower Extremity		
	L iliac crest fx (comminuted)	3

MAIS = 4
ISS = 29

Injury Contacts Observation Summary



L Ribs 2-12 w/ hemothorax

L sup/inf splenic lacerations

L liver laceration

L iliac wing fracture

L pubic ring fracture

CIREN Abdominal Injury Summary

Mean Age	34 yrs.	
	Mean Delta V	36.7 kph/22.8
mph	Mean Intrusion	30.0 cm/11.8
inches	Mean AIS	3.3

Derived from Abdominal Injuries

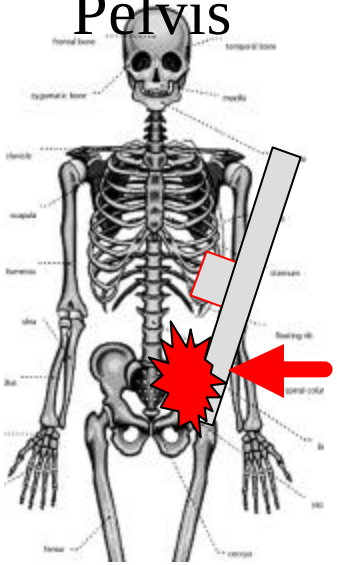
Most of all abdominal injury patterns associated with the armrest

No	age	sex	height (M)	occupant position	restraint	PDOF	delta V (kph)	intrusion cm	AIS	abdominal injuries	contact point
A1	16	M	1.73	driver	lap+shldr	290	32.2	29	3	major spleen contusion	armrest
A2	17	F	1.65	FR pass.	none	50	46.7	40	4	moderate liver and spleen lacerations	armrest/door panel
A3	24	F	1.65	driver	lap+shldr	330	54.7	61	3	spleen and diaphram lac, kidney cont.	armrest/door panel
A4	16	M	1.88	driver	lap+shldr	280	unk	14	4	major spleen laceration	armrest
A5	38	F	1.63	driver	lap+shldr	250	22.5	15	3	moderate spleen laceration	armrest
A6	89	M	1.57	driver	lap+shldr	280	37	29	4	major lac, abdominal arteries, kidney cont	armrest
A7	18	M	1.85	driver	lap+shldr	320	unk	24	3	spleen and liver contusions	armrest
A8	7	M	1.27	Rear L pass	lap+shldr	290	48.3	50	3	moderate spleen laceration	armrest
A9	54	F	1.68	driver	lap+shldr	left lat	unk	26	3	minor kidney cont, retroper, hemomatoma	armrest
A10	28	F		Rear L pass	lap+shldr	270	30.6	19	3	spleen laceration, retroper. Hemomatoma	armrest
A11	48	M	1.83	driver	lap+shldr	290	38.6	43	3	minor liver laceration, diaphram laceration	armrest
A12	47	F	1.70	driver	lap+shldr	270	19.3	10	3	moderate spleen laceration	armrest
means	**34**	**6M,6F**	1.68				**36.7**	**30**	**3.3**		

Side Impacts and Pelvic Injuries

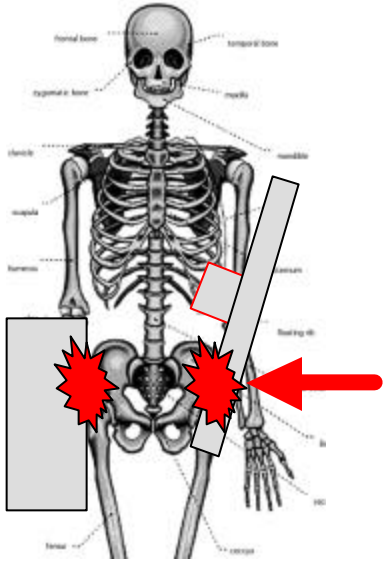
Lateral

Pelvis



Bilateral

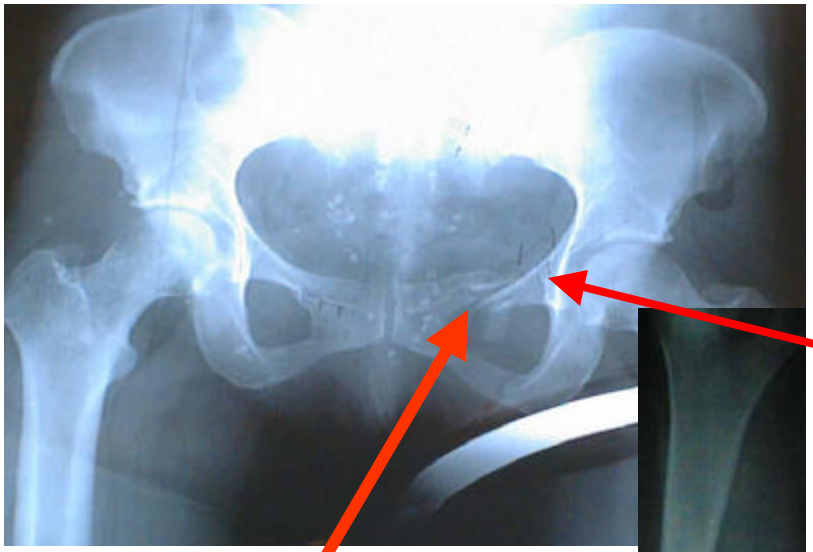
Pelvis

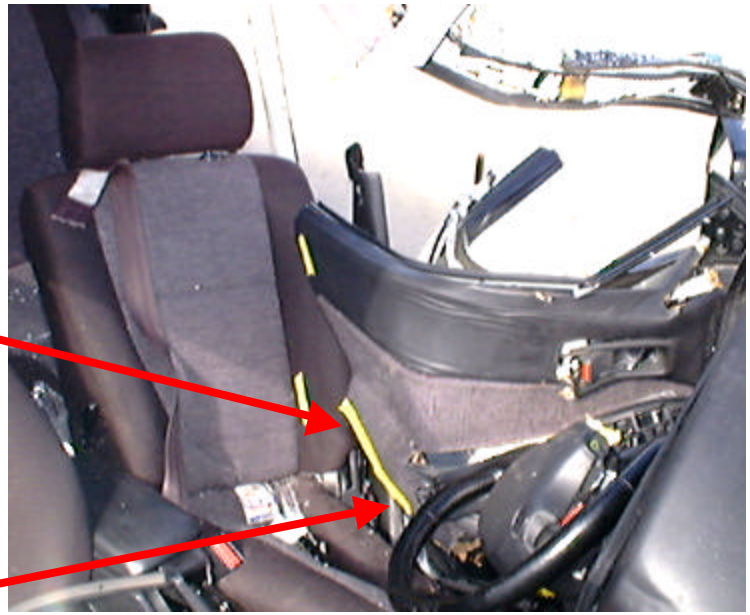


Pelvic Fracture Case Review

Door Panel Intrusion

Pelvic Fractures



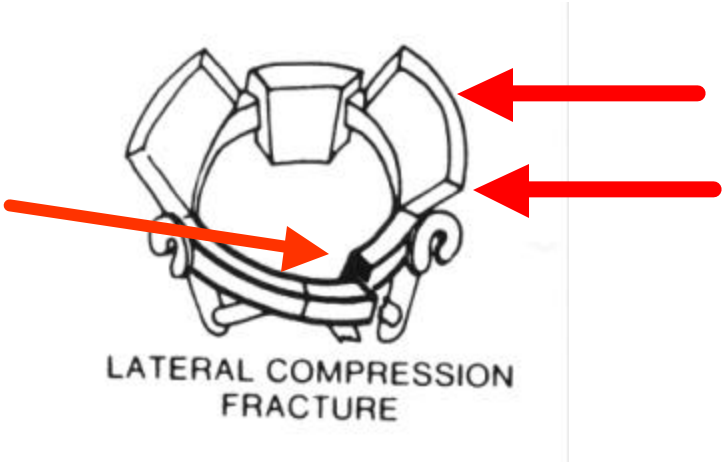


Pelvic fx

Left Femur Fx

Lower Lateral Door Intrusion Associated With Pelvic Fractures

Comminuted pubic rami fracture

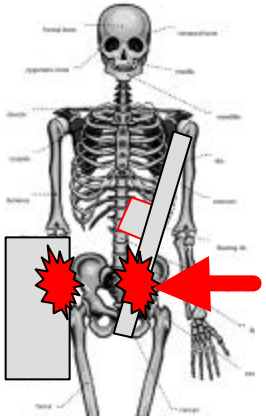


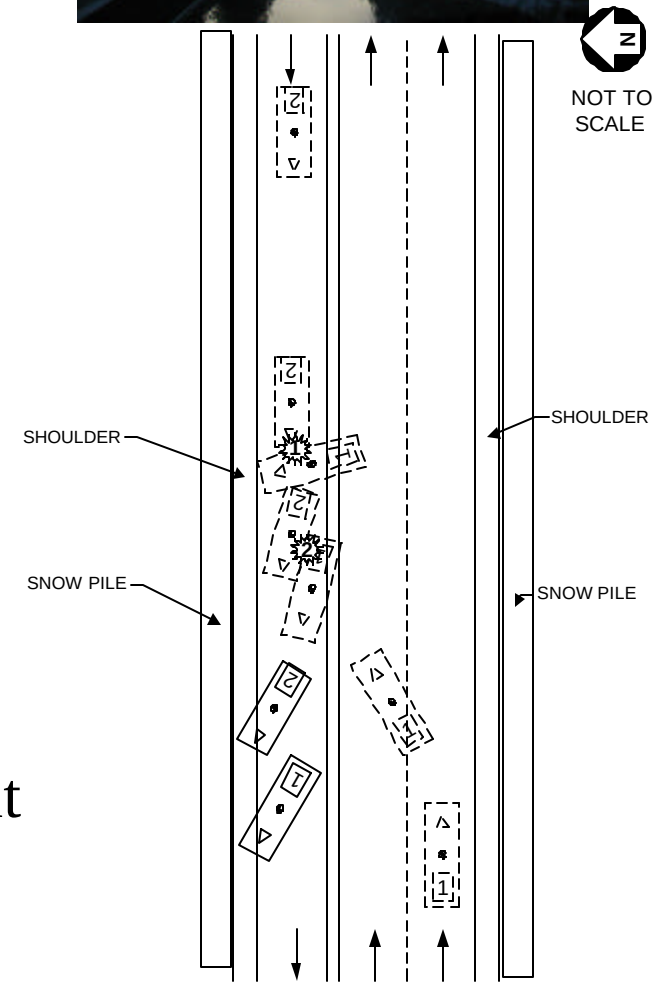
Left side impact with Light Truck - Unrestrained Driver

Case Vehicle - 2001 Toyota Tacoma

Struck by a 1994 Toyota Pickup

Bilateral Pelvis





Case occupant - 21 year old, female

Front right passenger - Lap/shoulder belt

Vehicle Inspection

Smash Missing-ΔV = 30kph/18.6mph

BES = 39kph/24.4mph

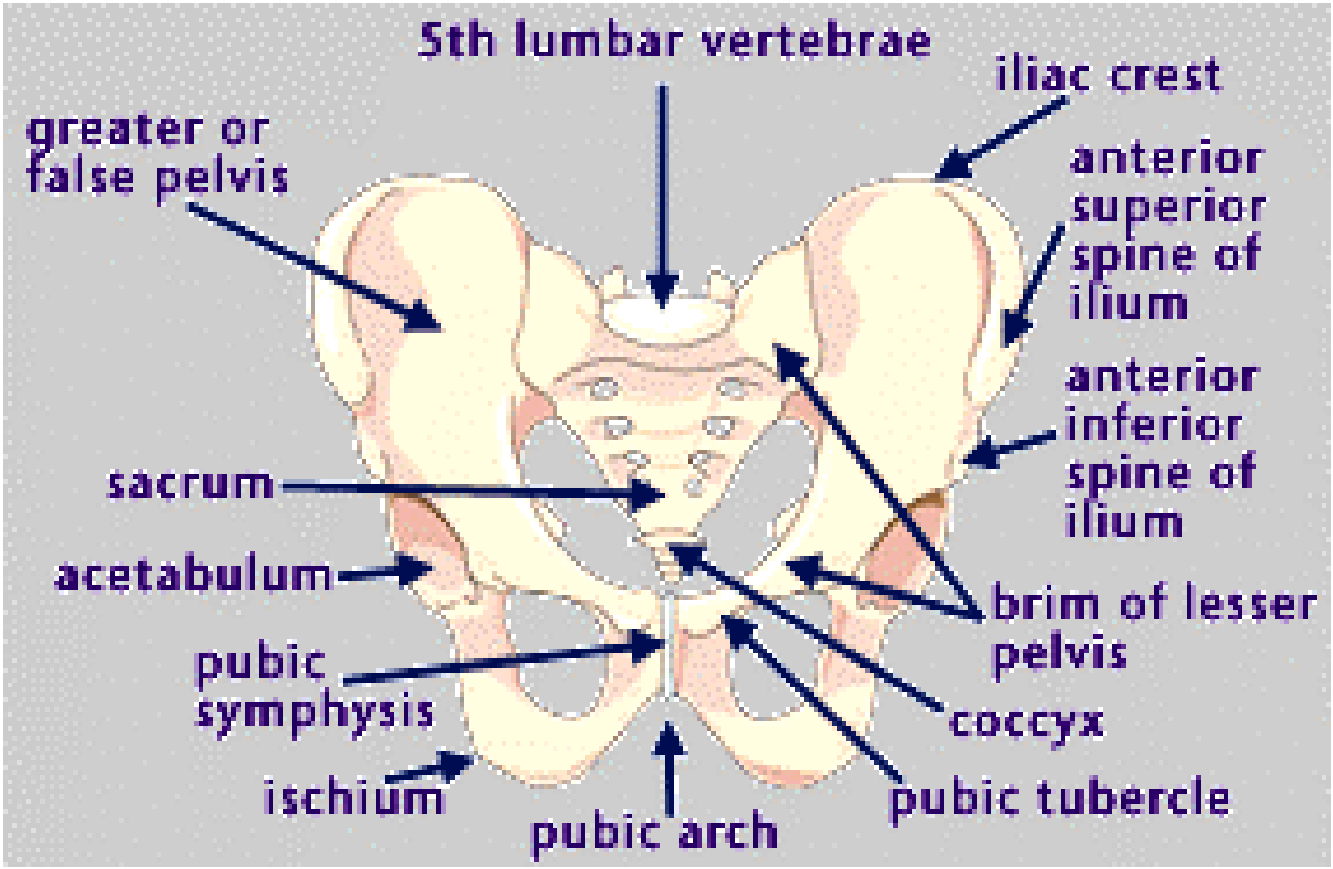
Lateral PDOF

Door panel intrusion = 45 cm/17.7inches

Contact evidence on door/center console

Case Vehicle - 2001 Toyota Tacoma

Pelvis



Comminuted fracture of the superior ramus of the right obturator ring which extends into the pubic symphysis. The fracture also extends into the inferior ramus. Comminuted fracture within the superior ramus of the left obturator ring extending into the pubic symphysis

CIREN Pelvic Injury Summary

Mean Age	30 yrs.
Mean Delta V	36.1 kph/22.5mph
Mean Intrusion	24.9 cm/9.8 inches
Mean AIS	3.1

Various pelvic fracture patterns associated with the door panel injury source

No	age	sex	height (M)	occ. pos.	restraint	PDOF	delta V (kph)	intrusion (cm)	AIS	pelvic injury	Contact point
P1	50	F	1.68	driver	lap+shldr	290	40.2	23	3	Bilateral obturator ring and sacral fx	Door Panel
P2	22	F	1.60	driver	lap+shldr	250	78.8	39	2	L parasymphaseal/pubic ramus fx	Door Panel
P3	41	F	1.68	driver	lap+shldr	260	38.6	25	3	Fx Sacrum/coccyx; Fx L pubis-closed	Door Panel
P4	39	F	1.65	driver	shldr only	320	28.9	10	3	L Fx acetabulum; L Fx of pubis w/SI widening	Door Panel
P5	32	F	1.55	driver	lap+shldr	280	38.6	24	3	L pubic root fx/SI widening; Zone I Sacral Fx	Door Panel
P6	19	F	1.75	driver	lap+shldr	280	27.4	26	3	L zone III sacral fx (buckle); L superior/inferior rami fxs	Door Panel
P7	36	F	1.57	driver	lap+shldr	280	41.8	20	4	R SR/IR buckle fx; R zone II sacral fx; R acetabular buckle vs pubic root with arterial bleeding	Door Panel
P8	18	F	1.63	driver	shldr only	280	22.5	13	3	L displ. Acetabular fx; L iliac wing fx; L inf. Pubic ramus	Door Panel
P9	30	F	1.73	driver	none	280	24.1	16	3	L iliac wing fx / pubic ring fx inf.	Door Panel
P10	31	M	1.70	driver	lap+shldr	270	28.9	36	2	Both zone I sacral alar fxs; R pubic rami fxs; L sup/inf pubic rami and pubic root fx; L ant. wall and	Door Panel
P11	23	F	1.73	driver	lap+shldr	290	46.7	34	5	Pelvic fx w/large ruptured retropenitoneal hematoma	Door Panel
P12	22	F	1.78	driver	lap+shldr	300	35.4	27	3	L pelvic fx extending to sup/inf pubic rami, L acetabelum, L iliac wing, w/SI, symphysis pubis disp.	Door Panel
P13	35	F	1.60	driver	lap+shldr	330	25.7	9	3	Bilateral pubic root fx, superior; L zone 5 sacral alar fx	Door Panel
P14	23	M	1.88	driver	lap+shldr	290	33.8	24	3	L zone II sacral fx; L inf/sup pubic rami fx	Door Panel
P15	24	M	1.83	driver	lap+shldr	240	30.6	47	3	L zone I sacral fx; L inf. Pubic root fx; L parasymphyseal fx; L inf. Pubic rami fx	Door Panel
means	**30**	**3M,12F**	**1.69**				**36.1**	**24.9**	**3.1**		

San Diego CIREN Project

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Research Question

Are vehicles with raised center consoles associated with pelvic injury in nearside crashes?

Selection Criteria

- NASS CDS and CIREN databases used
- Identify vehicles with raised center consoles
  - Assumed no change over +/- 2 model years
  - Assumed console standard equipment
  - Only 1998-2004 model years included

Selection Criteria

- Only nearside impact crashes
- Only drivers or front right seat passengers included
- Only pelvic and hip injuries included

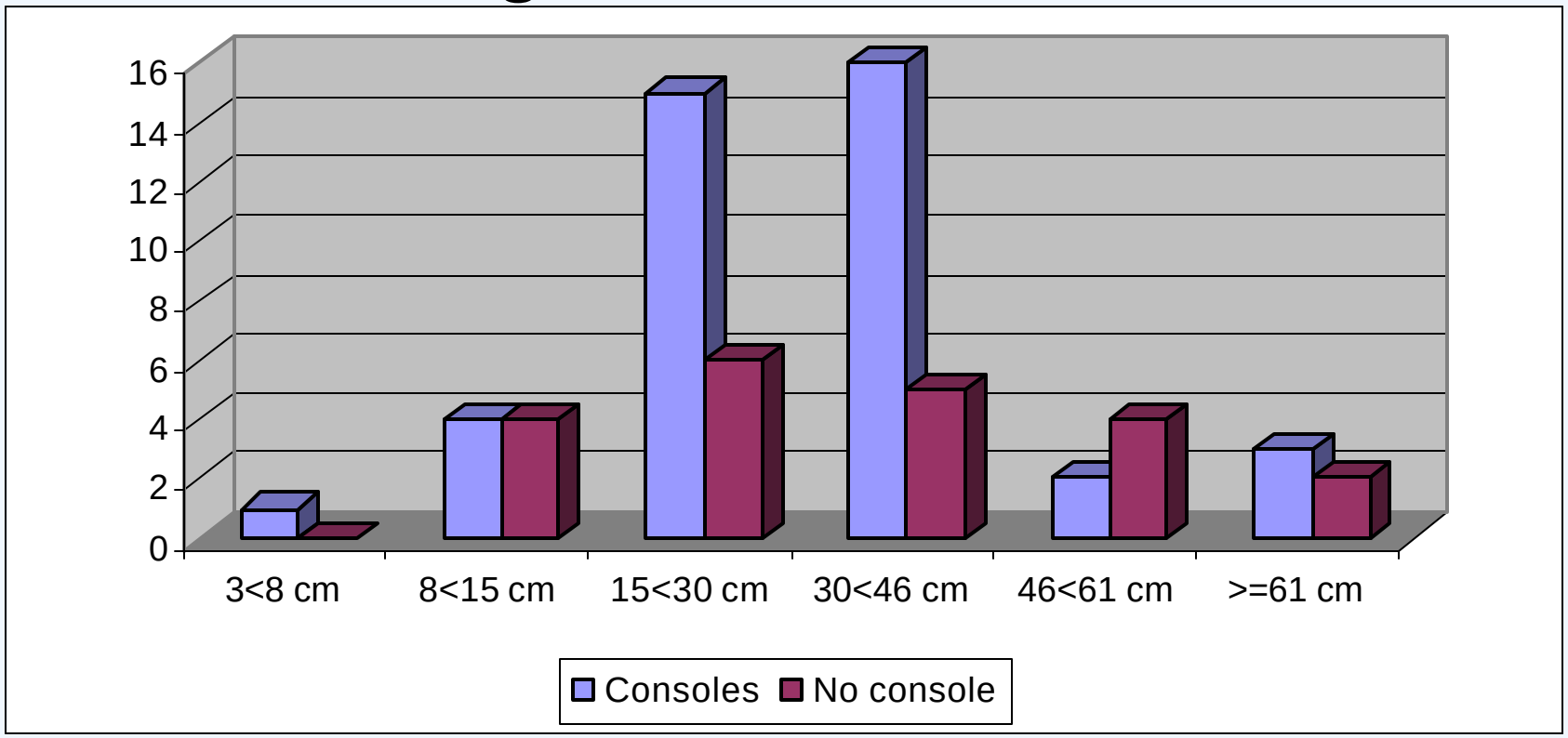
Methods

- Missing data excluded from analyses
- Injury assessed by Abbreviated Injury Scale (AIS)
- Total Delta V used to assess speed at impact
  - BES used when Total Delta V was missing

Profile : Occupants with moderate (AIS 2) and serious (AIS 3) pelvic injury in nearside crashes

	Console (41 occupants)	**No console (21 occupants)**
Mean age and range	40 years (15-89 years)	43 years (15-80 years)
Gender	33 (80%) women	11 (52%) women
Single pelvic injury	16 (39%)	8 (38%)
Driver	29 (71%)	13 (62%)
Seatbelt Use	36 (88%)	19 (90%)
Total Delta V (kmph)	Mean 36 Median 33	Mean 35 Median 31

Moderate (AIS 2) and serious (AIS 3) pelvic injury in nearside crashes by magnitude of intrusion



Limitations

- Results may not be representative
- Small sample size
- Possible misclassification bias of console status
- NASS intrusion is measured at the maximum point of intrusion on the door panel
  - May not be at the occupant's seat location

Conclusion

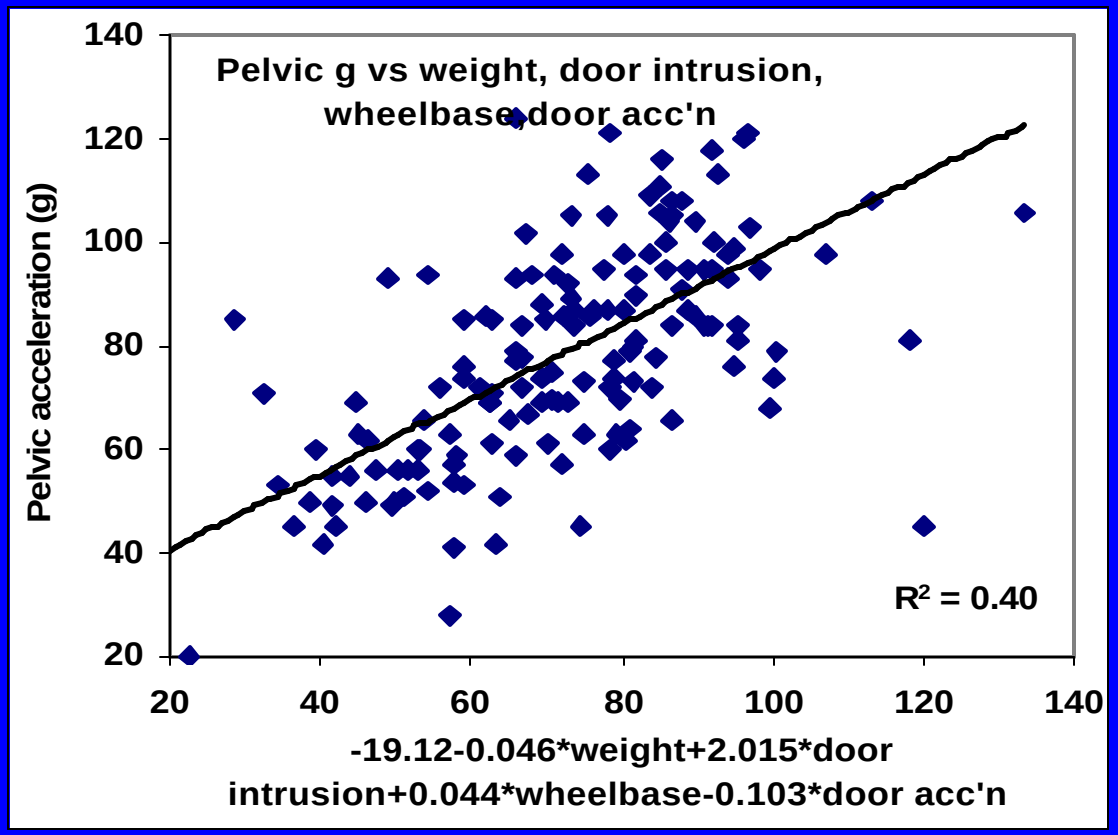
This exploratory study found it may be important to continue researching the role of consoles and pelvic injury in nearside crashes.

Results – CIREN Summary

- Thoracic injuries, AIS of 4.2, door panel main injury source, intrusion 34cm, ΔV of 25 mph. Injuries multiple rib fractures with hemothorax, or pneumothorax, with lung contusions and lacerations.
- Abdominal injuries, AIS of 3.3 armrest main injury source, intrusion 30cm, ΔV 23 mph. Injuries, 9 spleen lacerations or contusions, 3 liver lacerations or contusions, 3 kidney contusions, 2 diaphragm lacerations, and 2 retroperitoneal hemorrhage.
- Pelvic injuries, AIS of 3, door panel main injury source, intrusion 25cm, ΔV 22 mph. Injuries included pelvic fx with 11 involving the sacrum.

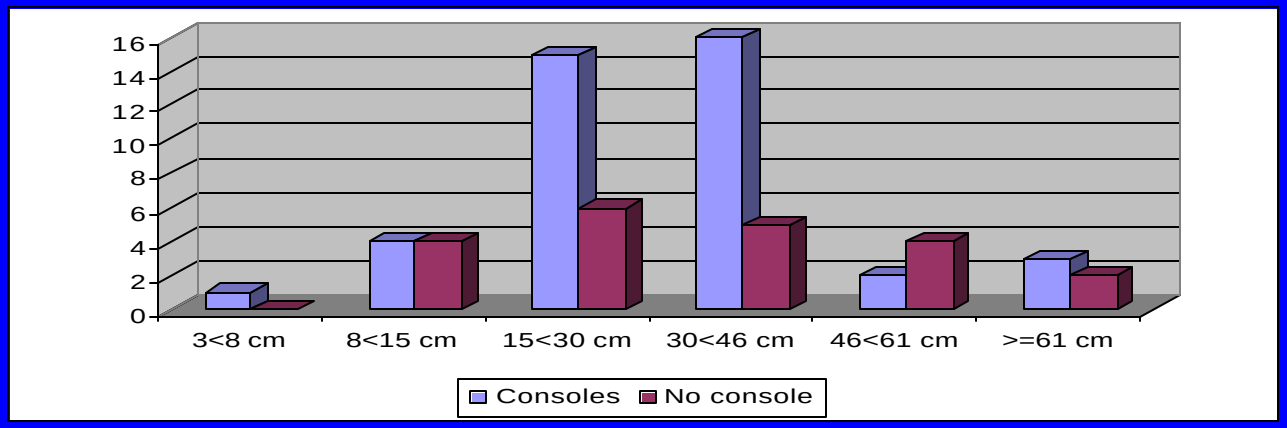
Results - Vehicle Variables and Pelvic g

variable	Pelvic accel
overall r squared	0.580
overall p value	0.002
vehicle weight	**0.003**
max door intrusion	**0.003**
max intrusion height	0.250
max intrusion level	0.297
max door velocity	0.221
door velocity diff	0.271
door acceleration	0.171
wheelbase	**0.045**
panel deflection	0.522
dummy H point	0.503



- Vehicle weight, door intrusion, wheelbase correlate to pelvic g
- All variables explain about 58% of pelvic g variation

CIREN Example and Console Data
Pelvic Acceleration and Console Trapping



Results - Peak Pelvic g v Center Console

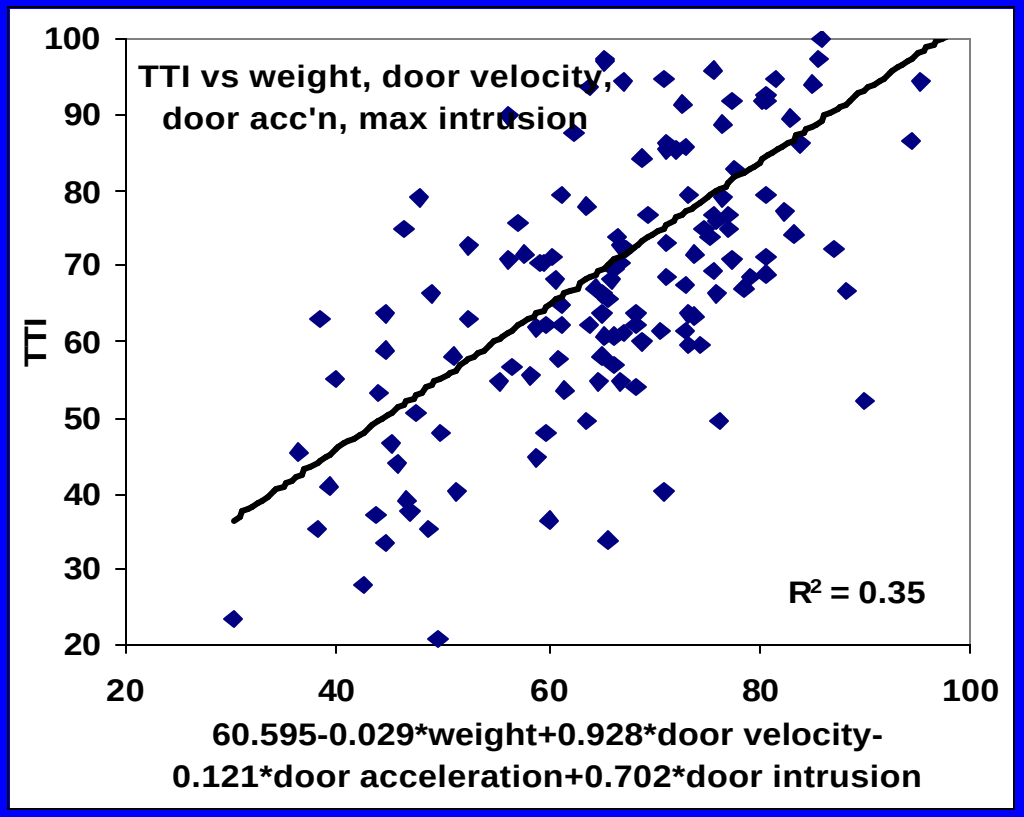
without center consoles, 69.4g
sd = 19.7g, n = 41

with center consoles, 77.3g
sd = 21.8g, n = 96

(p = 0.05)

Results - Vehicle Variables and NCAP Thoracic Trauma Index (TTI)

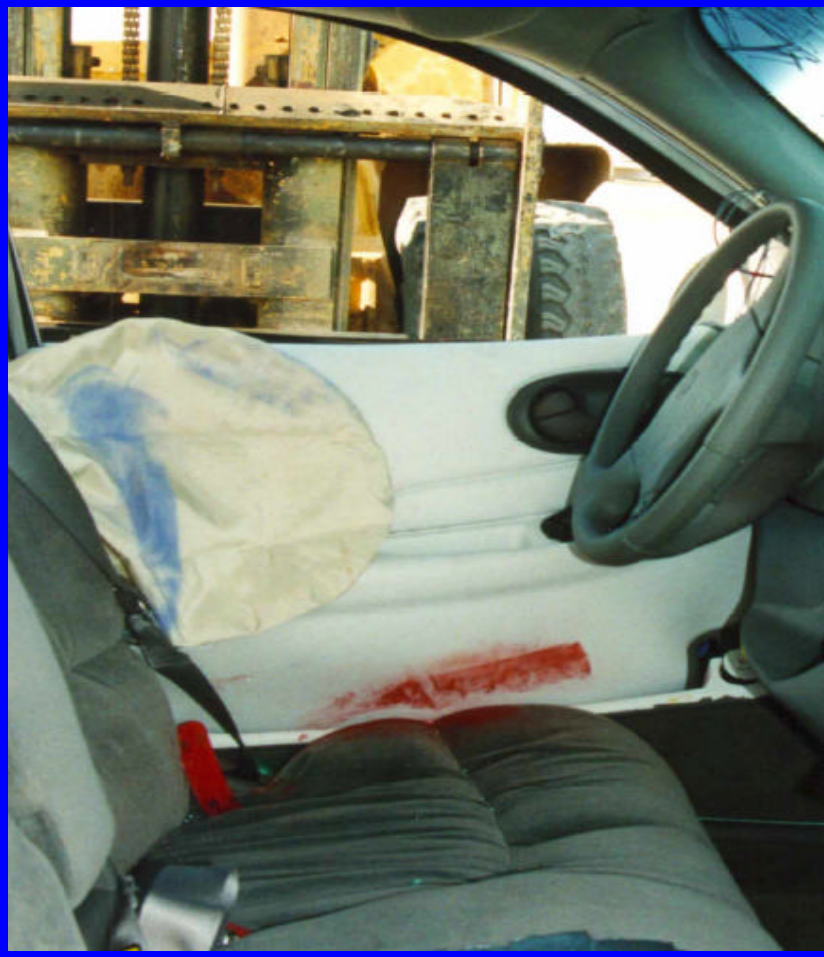
variable	TTI
overall r squared	0.410
overall p value	0.030
vehicle weight	**0.064**
max door intrusion	0.191
max intrusion height	0.976
max intrusion level	0.779
max door velocity	**0.049**
door velocity diff	0.756
door acceleration	0.128
wheelbase	0.926
panel deflection	0.866
dummy H point	0.550



- Vehicle weight and max door velocity correlate to TTI
- All variables explain about 41% of TTI variation

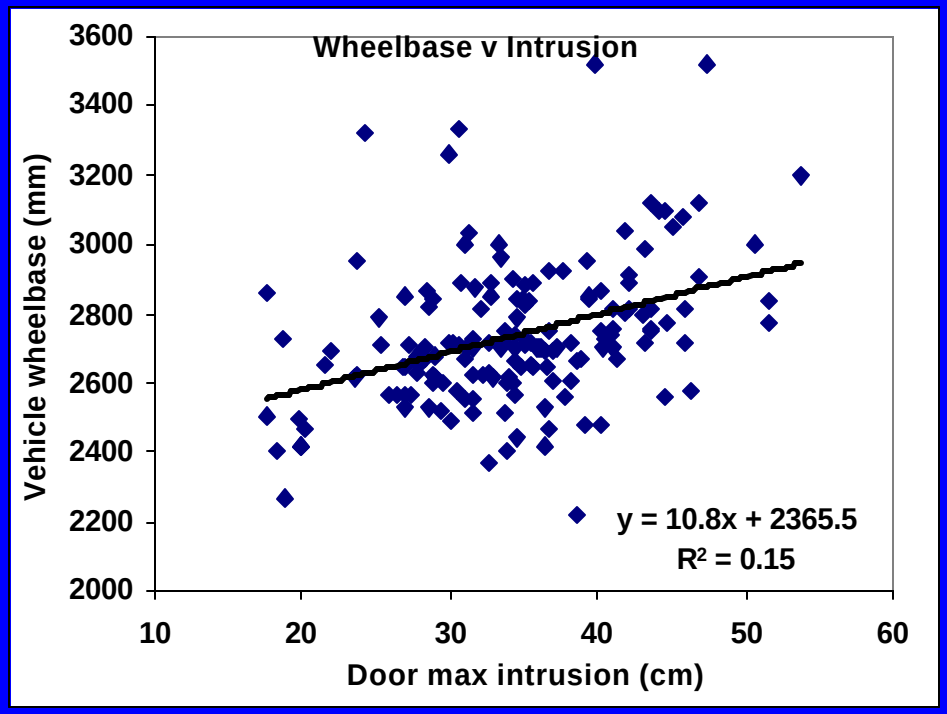
Results – NCAP TTI and Thoracic Airbags

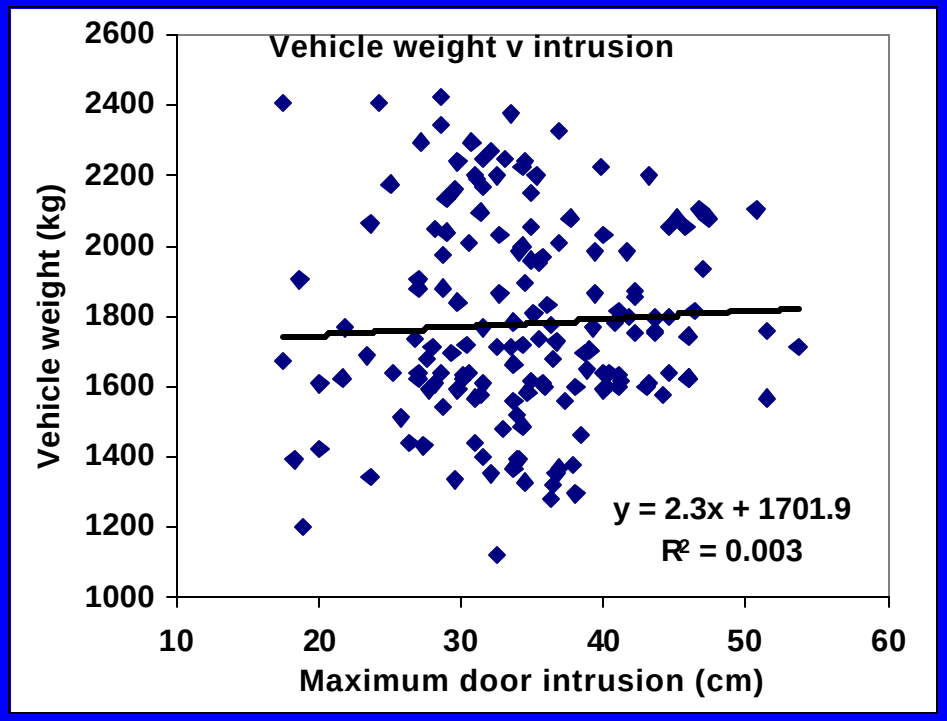
without thoracic airbag, 63.7g
sd = 20.7g, n = 108



with thoracic airbag, 55.6g
sd = 13.7g, n = 54
(p = 0.003)

Results - Is Door Intrusion Related to Vehicle Weight or Wheelbase?

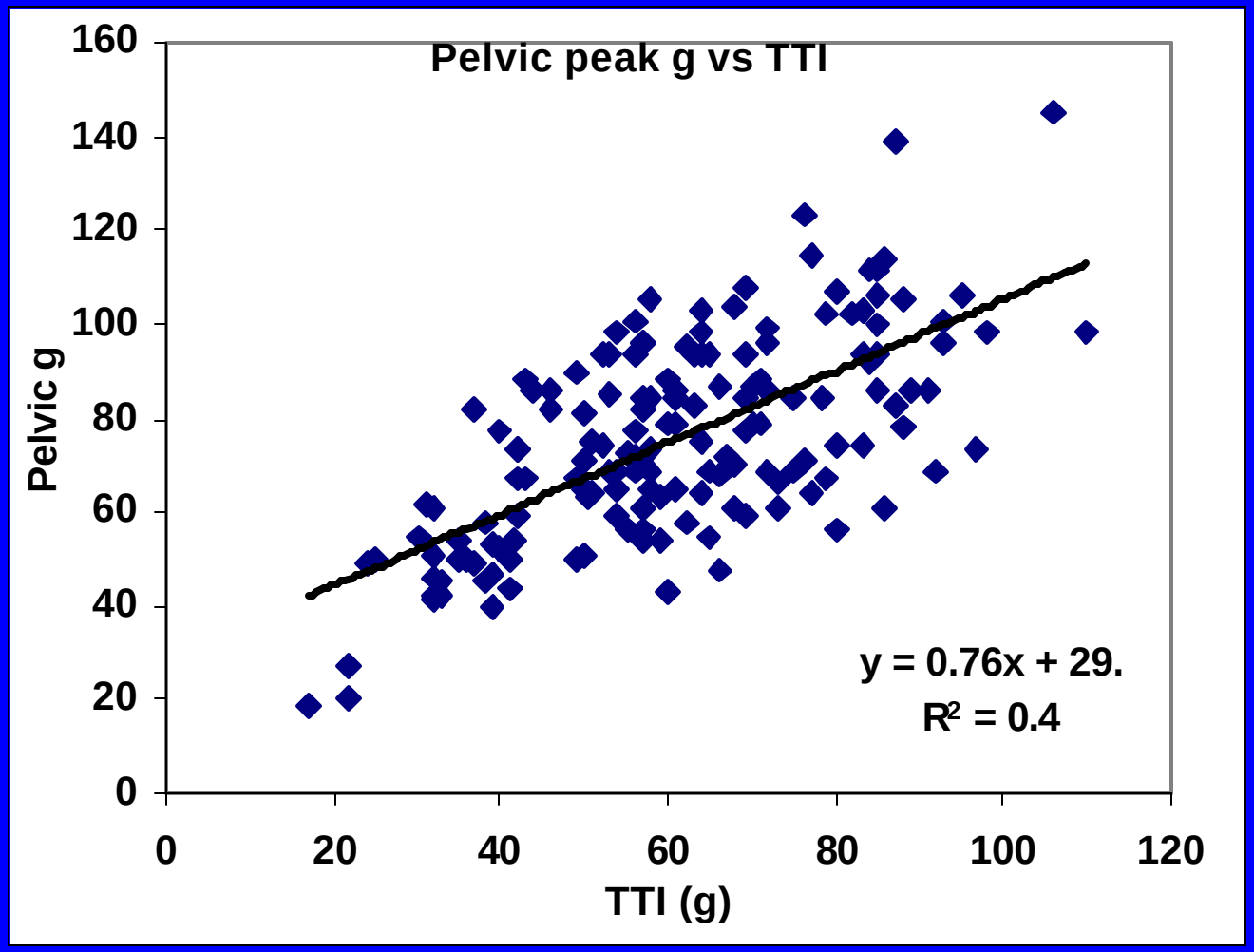




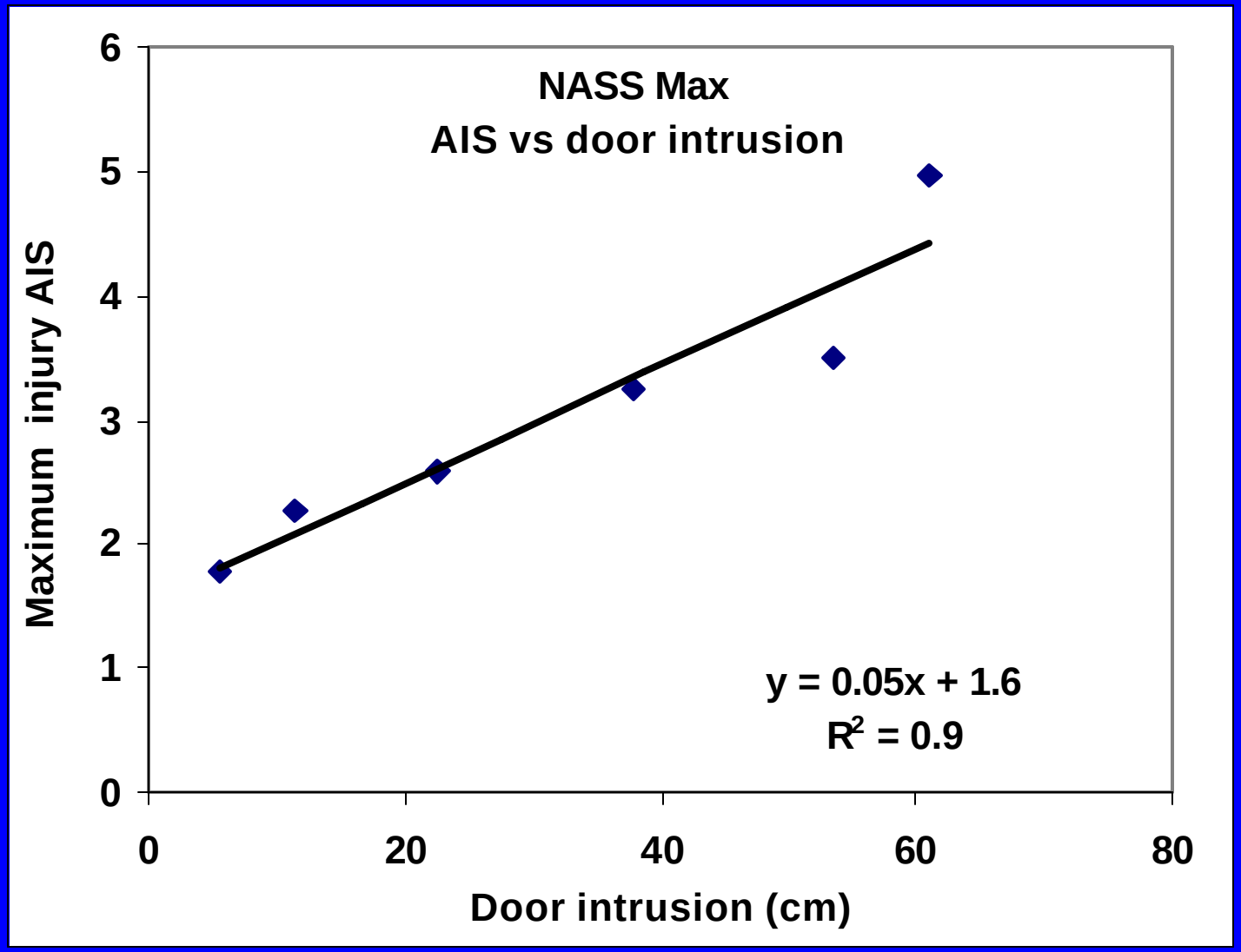
Door intrusion, weak correlation to wheelbase ($r^2 = 0.15$)

Door intrusion, none to vehicle weight ($r^2 = 0.003$, NS)

Results – Does Peak Pelvic g Correlate to Peak TTI?



Results – NASS MAIS v Door Intrusion



Discussion - Limitations

- NCAP tests, moving barrier simulates smaller vehicle
- NCAP doesn’t consider door beam over-ride from high SUV and truck bumpers
- More biofidelic dummies than DOT-SID available
- TTI may not correlate well with actual injuries
- Effects of occupant stature and age not considered
- NASS, plot of data only of those in group who were injured (ie AIS 1+)

Summary of Findings

- For a given vehicle weight, door intrusion, wheelbase correlate to pelvic g, and door velocity to TTI
- Vehicle variables studied only account for 41% of TTI, 58% of pelvic g variation
- A center console increases peak pelvic g
- A thoracic airbag lowers peak TTI
- Real-world crash studies also show correlation of door intrusion and thoracic and pelvic injury
- Door intrusion is not directly related to vehicle weight but increases with greater wheelbase

Future Work

There is still considerable debate over appropriate chest injury criteria, Favg * Cmax, Cmax, stored energy (Cheung ’99)

Using highly detailed CIREN crash data and data from equivalent NCAP tests, to model actual crashes and compare real life injuries to crash dummy measurements in the same crash