# Crash Injury Mechanisms
# What you need to know?

Eileen M. Bulger, MD

Professor of Surgery

Principal Investigator

CIREN- Crash Injury Research & Engineering Network, NHTSA

HARBORVIEW
INJURY PREVENTION
& RESEARCH CENTER

# Road Safety

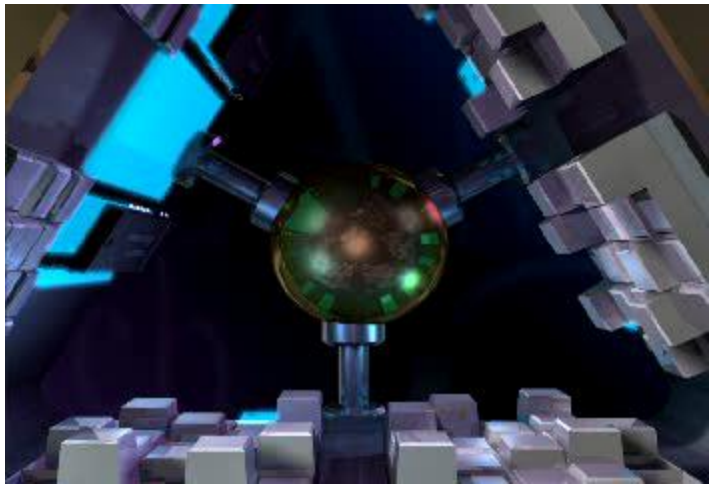
- Roadway and Infrastructure
- Driver Behavior
- Vehicle Design
  - Crashworthiness

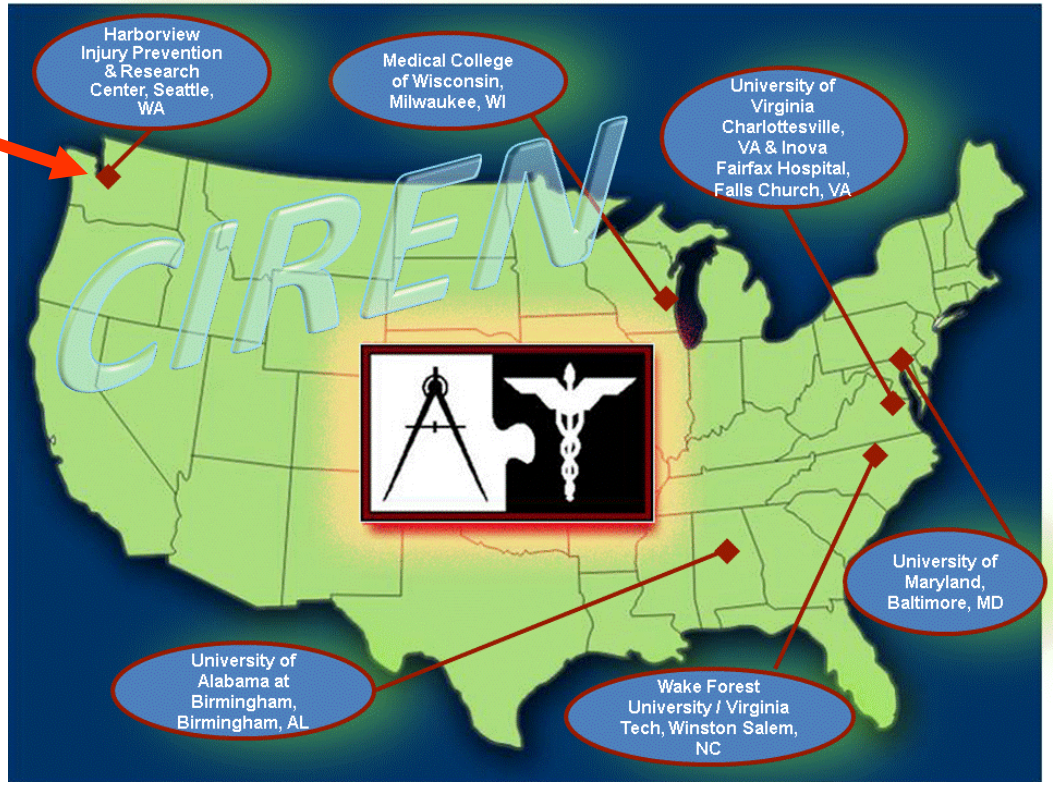
# NHTSA Sponsored Datasets

- National Automotive Sampling System (NASS)
  - Representative sample of all tow away crashes in the US
  - Detailed crash data, limited patient data
- Fatality Analysis Reporting System (FARS)
  - All fatalities from MVC in the US
  - Police report data with autopsy when available
- Crash Injury Research & Engineering Network (CIREN)
  - Selected population from admissions to major trauma centers
  - Detailed crash reconstruction & clinical data

# www.nhtsa.gov/CIREN or find link at HIPRC.org

HARBORVIEW
INJURY PREVENTION
& RESEARCH CENTER





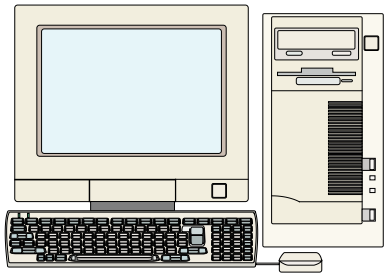

Real world laboratory of motor vehicle crashes created by NHTSA in 1996.

Harborview Injury Prevention and Research Center is one of 6 trauma centers contributing to the CIREN network for NHTSA.

# CIREN Goals

- Determine and document specific injury mechanisms and forces in real world crashes.
- Provide feedback on vehicle safety design for:
  - Auto manufacturers
  - FMVSS / NHTSA
- Provide outreach and training to improve triage and transport of MVC patients

**CIREN Network**
**Detailed Crash/Medical Data**



Crash Biomechanics

Level 1 Trauma Center

SEATTLE CIREN

Epidemiology HIPRC

# RESEARCH FINDINGS

**NHTSA- Safety standard Auto Manufacturers - Safer Vehicles**

**Training of Trauma Care Providers -Better Triage & Transport**

**Outreach**

**Public - seatbelt use**

**Law enforcement**

**Traffic Safety interests**

**REDUCE ECONOMICS COST**

**SAVE LIVES**

# AACN – Advanced Automatic Crash Notification – Utilizes CDC Triage Rules

Crash Notification

?

NHTSA/Calspan Automated Collision Notification System

File View Agencies Locate Incident Help

504

## Crash Information

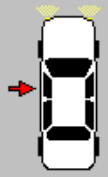
### Time of Crash

Crash Date: 11/19/98
Crash Time: 1:55:00 PM
Elapsed Time: 0 days 00:01:52

### Impact Details:

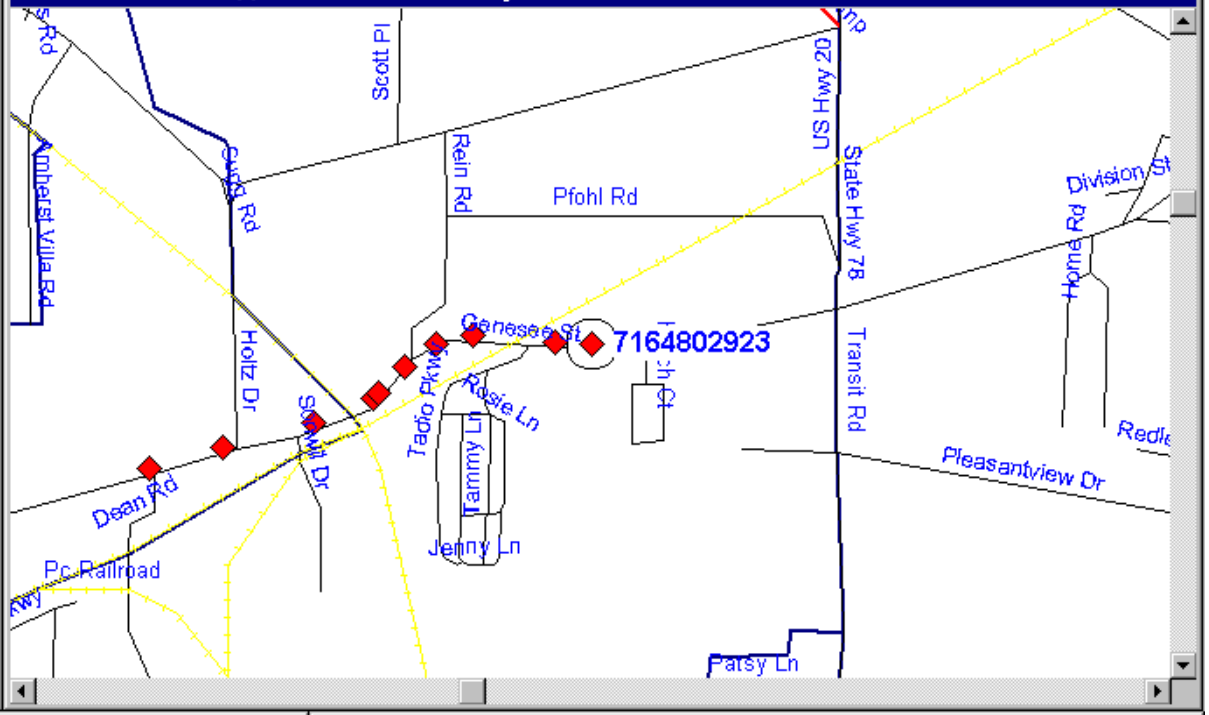
Lat/Long: N 42 56' 12.88"/W 78 42' 19.44"
Position Error: 1.08 m

**Final Resting Position:**
**Left Side**
**Rollover**



**Change in Velocity = 38 mph**

## 504: 4905 Genesee St, , Erie FIRE DISTRICT: Hy-View




## Communications

| | Fax | Voice | Call status | Hold | Prerec |
|---|---|---|---|---|---|
| Vehicle | | | | | |
| Dispatcher | | | | | |
| Cheektowaga Police | | | | | |
| Cheektowaga Fire | | | | | |
| ECMC | | | | | |
| | | | | | |
| | | | | | |

Manual Dial:
Manual Dial:

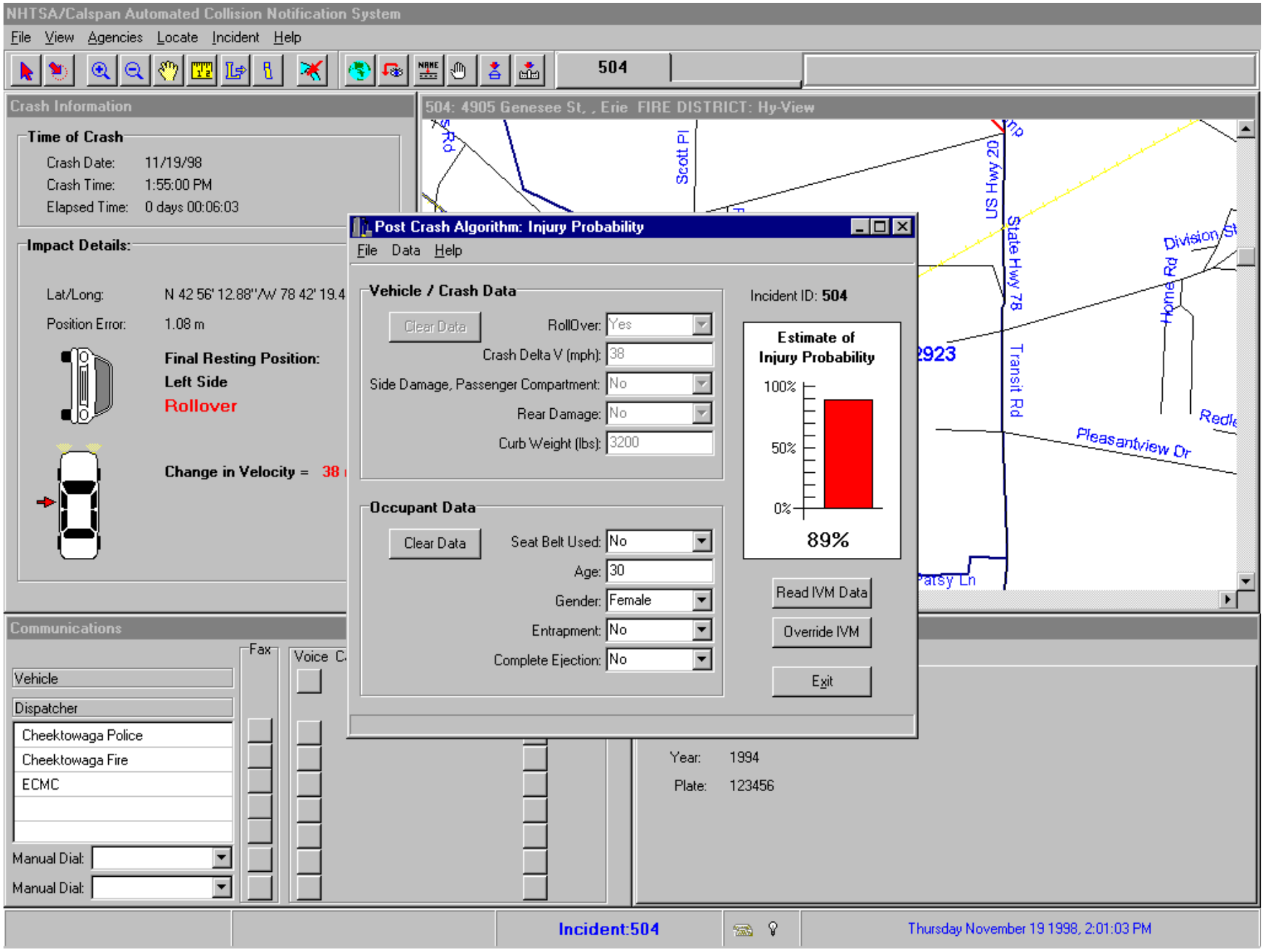
## Vehicle Information - 7164802923

Vehicle | Owner | Likely Occupants

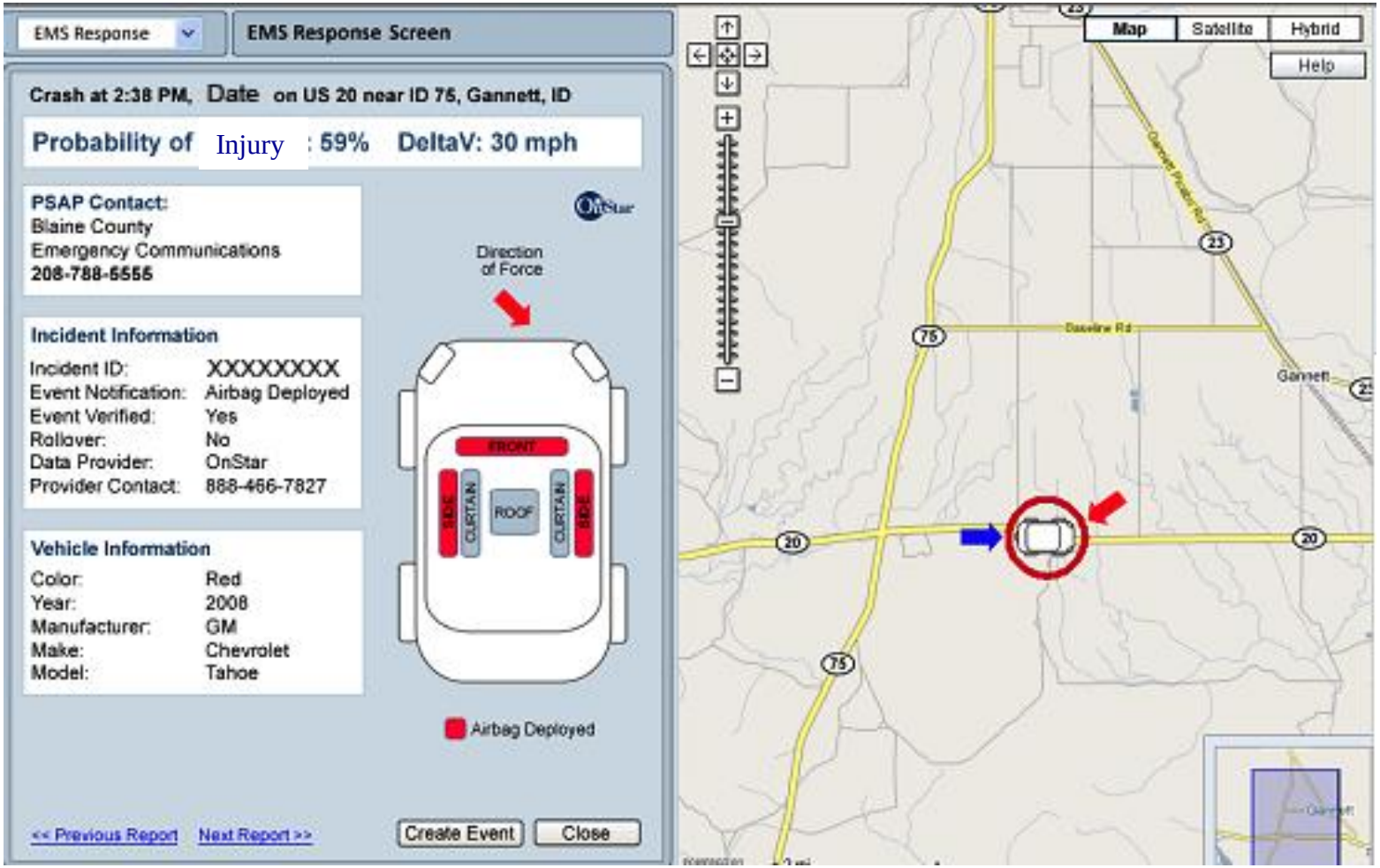
Make: Ford
Model: Taurus
Color: Blue
Year: 1994
Plate: 123456

Incident:504

Thursday November 19 1998, 1:56:52 PM


NHTSA/Calspan Automated Collision Notification System
File View Agencies Locate Incident Help
504
Crash Information
Time of Crash
Crash Date: 11/19/98
Crash Time: 1:55:00 PM
Elapsed Time: 0 days 00:06:03
Impact Details:
Lat/Long: N 42 56' 12.88"/W 78 42' 19.4
Position Error: 1.08 m
Final Resting Position:
Left Side
Rollover
Change in Velocity = 38
504: 4905 Genesee St, , Erie FIRE DISTRICT: Hy-View
Scott Pl
US Hwy 20
State Hwy 78
Transit Rd
Division St
Home Rd
Pleasantview Dr
Patsy Ln
Post Crash Algorithm: Injury Probability
File Data Help
Vehicle / Crash Data
Clear Data
RollOver: Yes
Crash Delta V (mph): 38
Side Damage, Passenger Compartment: No
Rear Damage: No
Curb Weight (lbs): 3200
Occupant Data
Clear Data
Seat Belt Used: No
Age: 30
Gender: Female
Entrapment: No
Complete Ejection: No
Incident ID: 504
Estimate of Injury Probability
100%
50%
0%
89%
Read IVM Data
Override IVM
Exit
Communications
Fax
Voice C
Vehicle
Dispatcher
Cheektowaga Police
Cheektowaga Fire
ECMC
Manual Dial:
Manual Dial:
Year: 1994
Plate: 123456
Incident:504
Thursday November 19 1998, 2:01:03 PM

# Future Direction




CARS MayDay EMS Response Screen Overview, Castle Rock Associates

Seekins, T., Blatt, A., & Flanigan, M. (2011). Characterization of Pathways for Delivery of Crash Telemetry Data to Montana. University of Montana and CUBRC

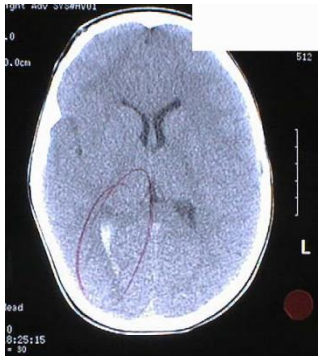
# CIREN Case Studies
# Need for AACN

Case 1

Case 2

# Critical Clues at Crash
# On scene assessment - Step 3

- Given a Damaged Vehicle → Injury



- Given an Injury → Direction of Force or type of crash

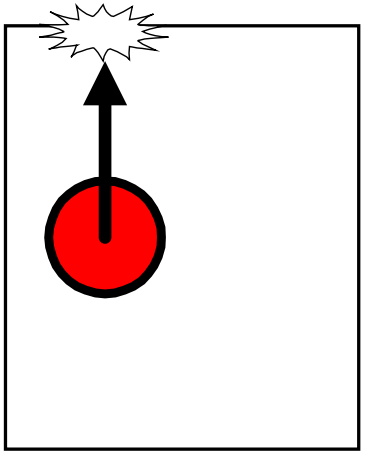
# Critical Clues at Crash

One can determine an injury mechanism based on the following:

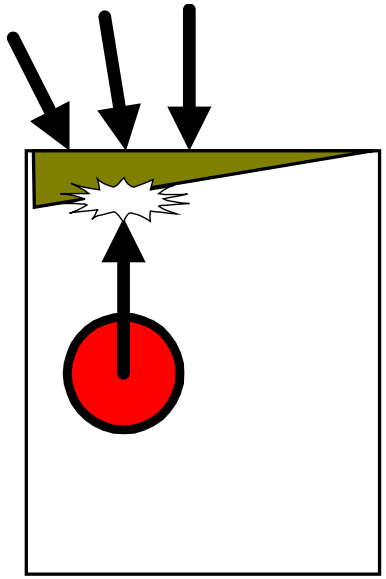
- Restraint status ( most important )
  - witness, first responder, locked open, belt burns
- Seat Location
- Occupant compartment intrusion

  **Intrusion = Injury!!**
- How much Force, based on vehicle damage
- Direction of Force ( most difficult )

FRONTAL



No intrusion
Ride down space

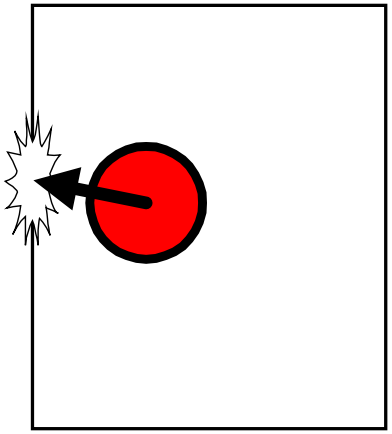


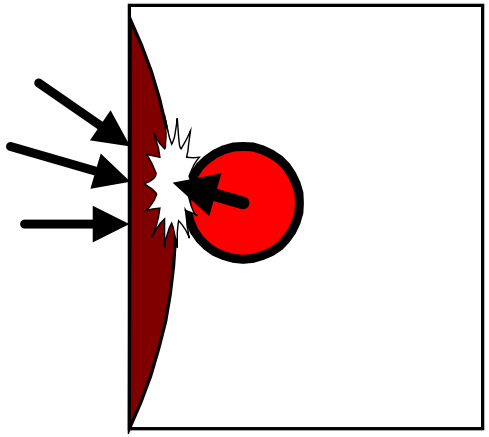
Intrusion and occupant collision

Longitudinal intrusion =

Frontal PDOF

SIDE





Lateral intrusion =

Lateral PDOF

# On-Scene and Vehicle Documentation

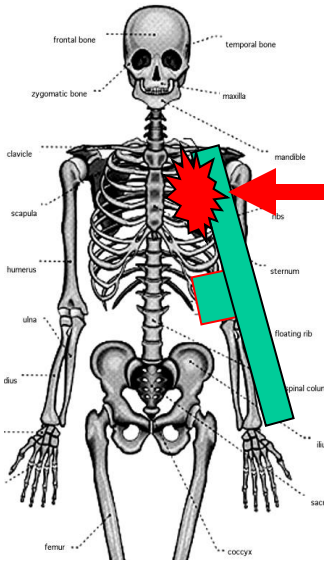
1

# Side Impacts

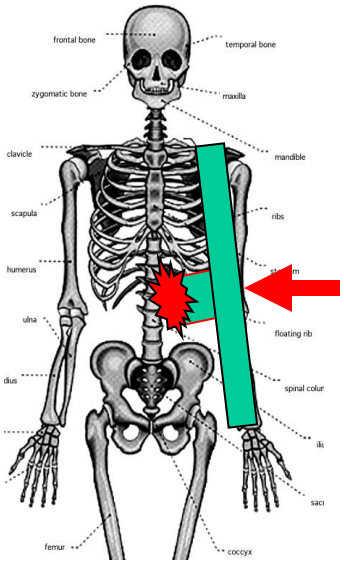
# Lateral Impact Mechanism Reviews

## Intrusion = Injury

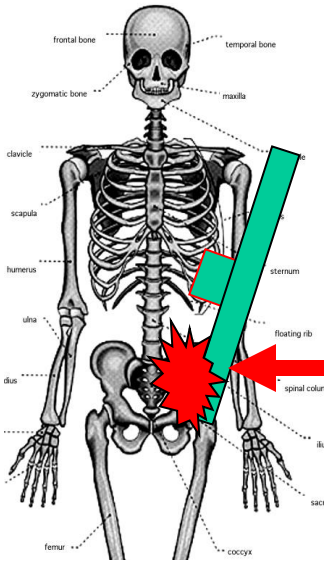
Thorax



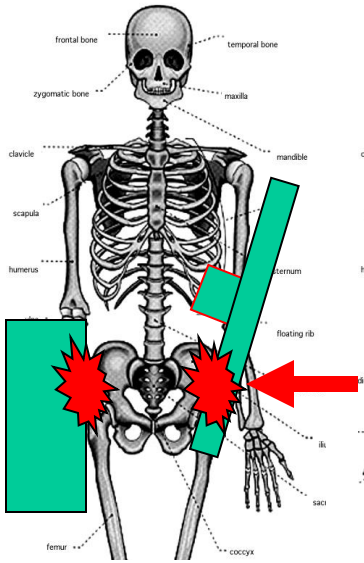

Abdominal



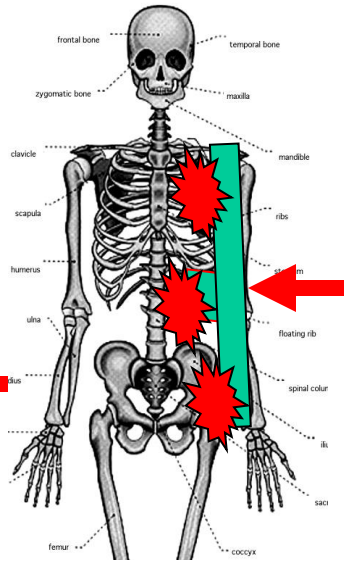

Lateral Pelvis



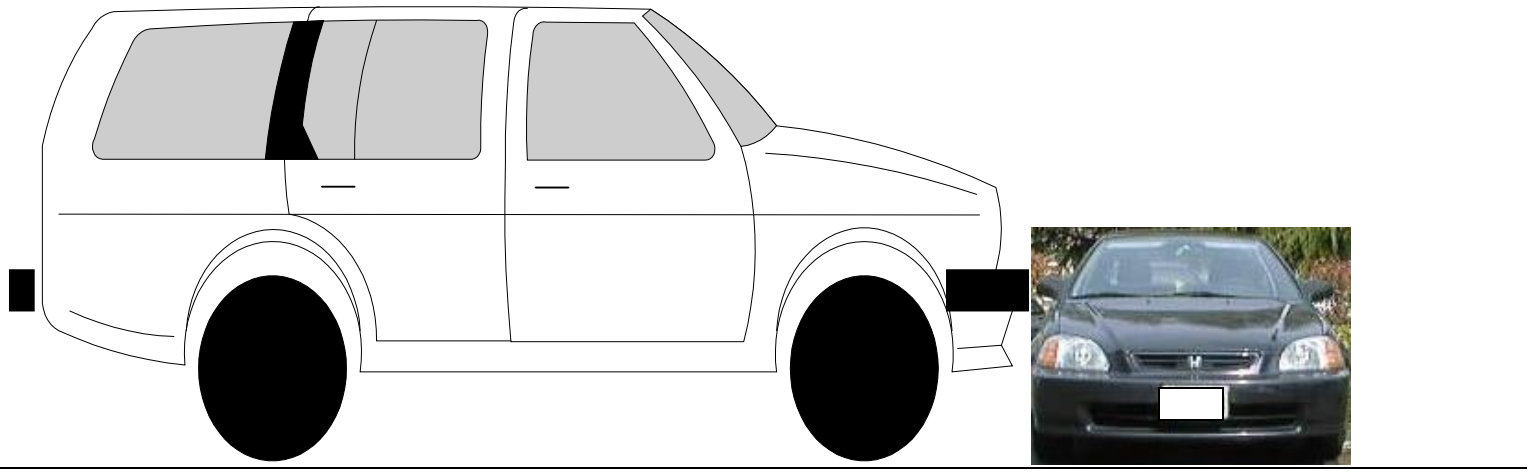

Bilateral Pelvis




Combination



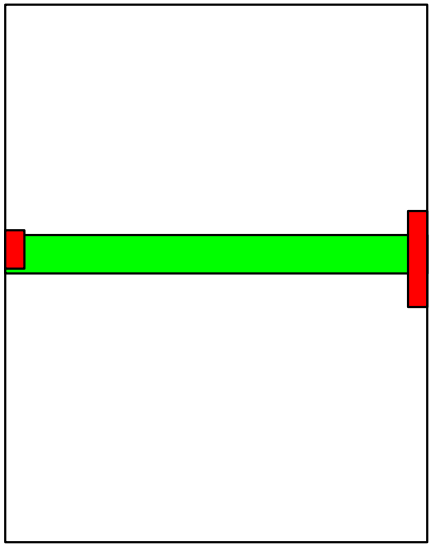
# Larger Vehicle and Side Impacts



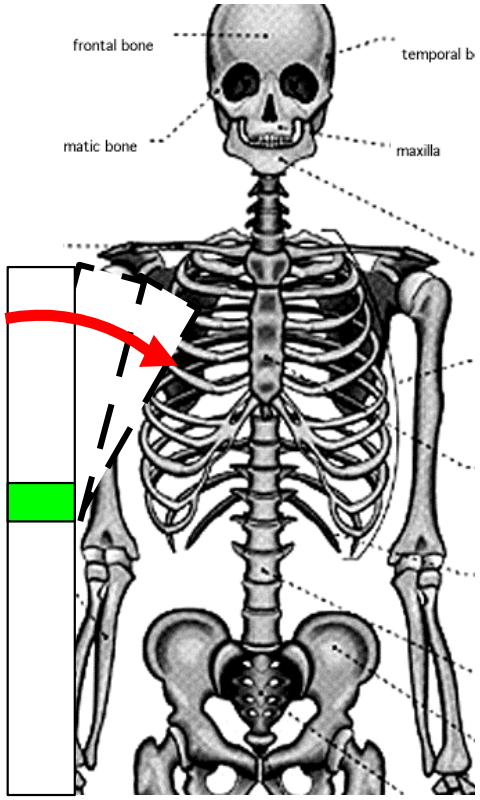
Incompatibility crashes

Some bumper heights are overriding the side impact supports

# Side impacts with larger vehicles with lateral door support beams

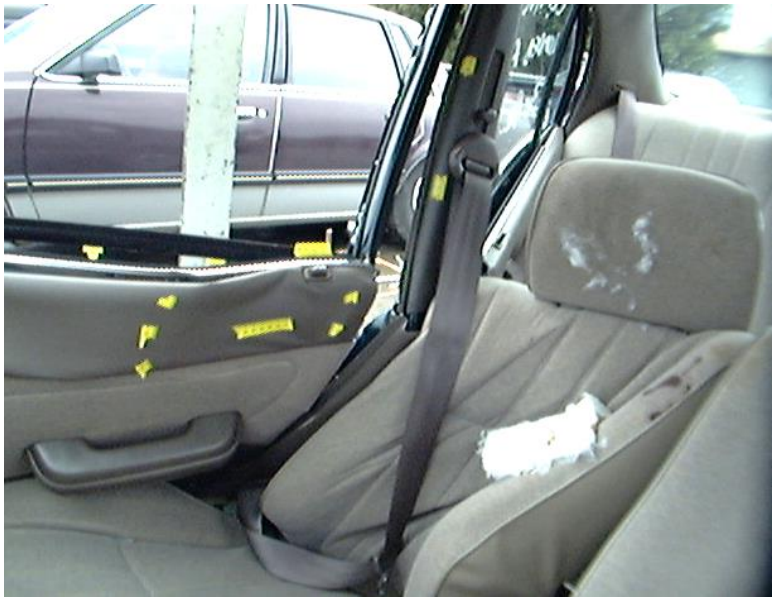


Side View




End View

# Intrusion = Injury



Think Thorax!!

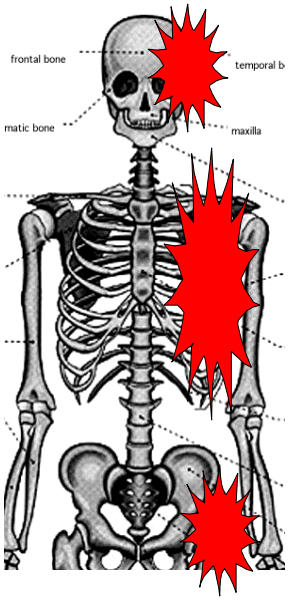
Think Head!!

## Driver's Injuries

Head = AIS 5
(IVH, SAH)

Chest = AIS 4
(L rib fxs 2-11 w/hemo and Aortic tear)

Pelvis = AIS 3 Fx



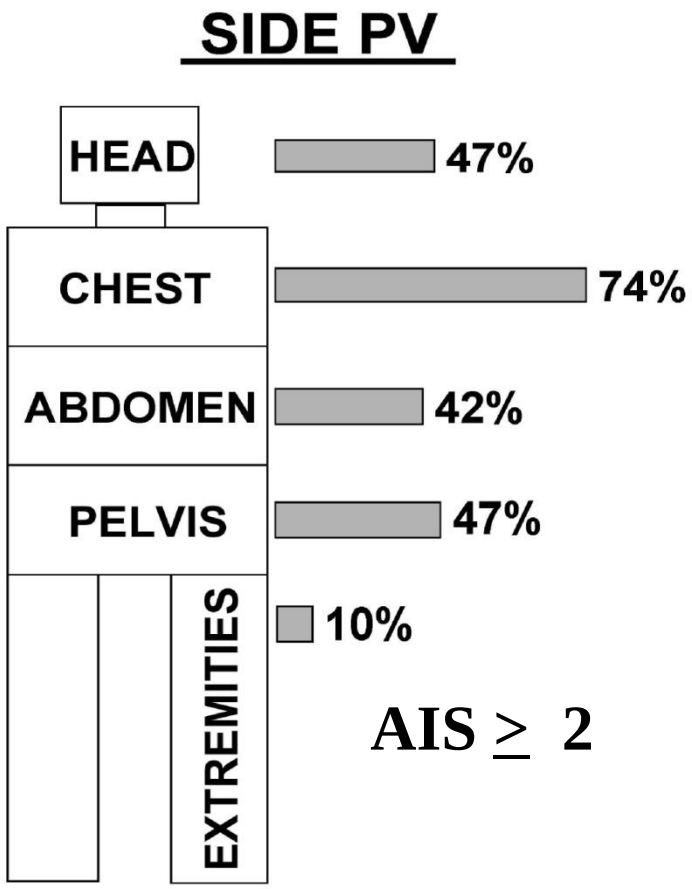
# Interior view

Chest contact

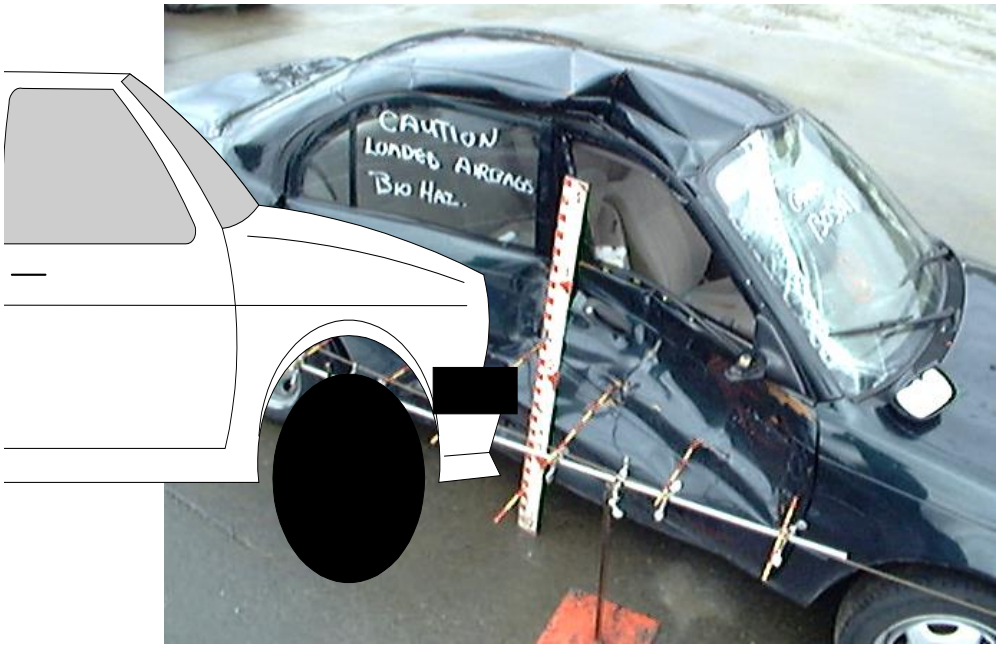
Pelvis contact

Raised center console

Acierno S, Kaufman R, Mock C, Rivara F, Grossman D. Vehicle mismatch: Injury patterns and severity. Accident Analysis and Prevention 39 (2004) 761-772.

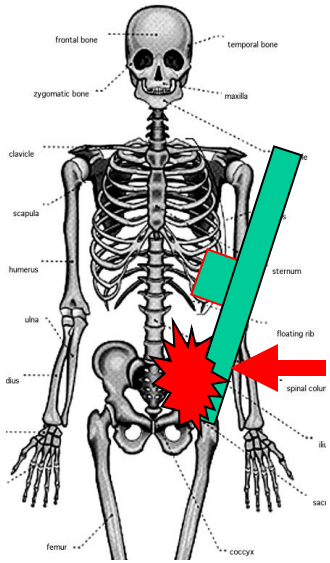



# LTV Front into Side Passenger Vehicle

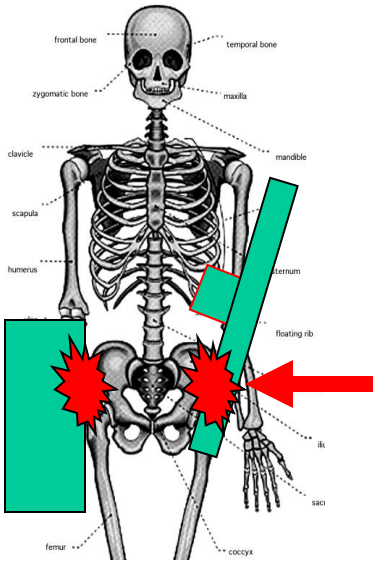


# Side Impacts and Pelvic Injuries

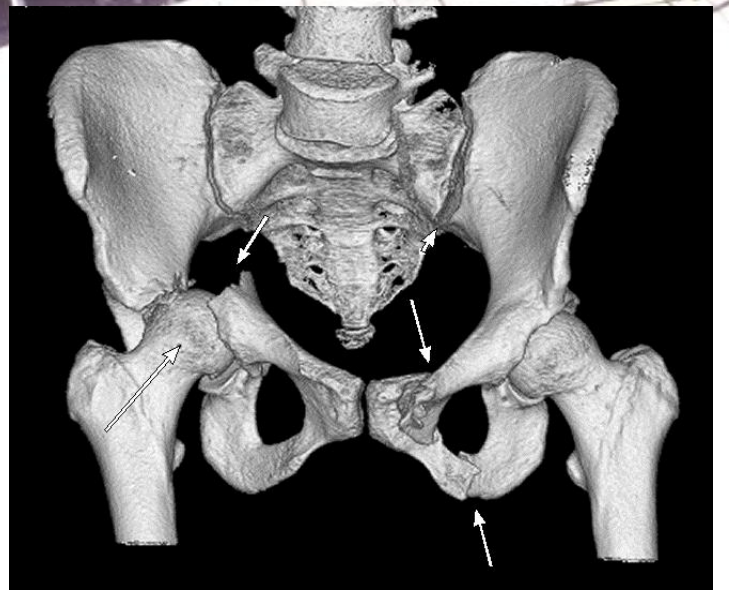
## Lateral Pelvis

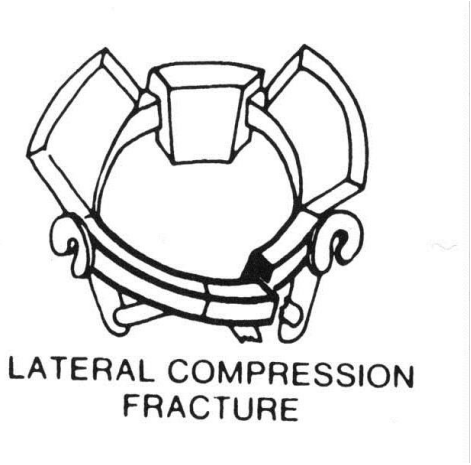



## Bilateral Pelvis



# Lower Lateral Door Intrusion

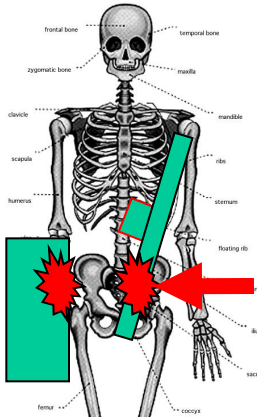


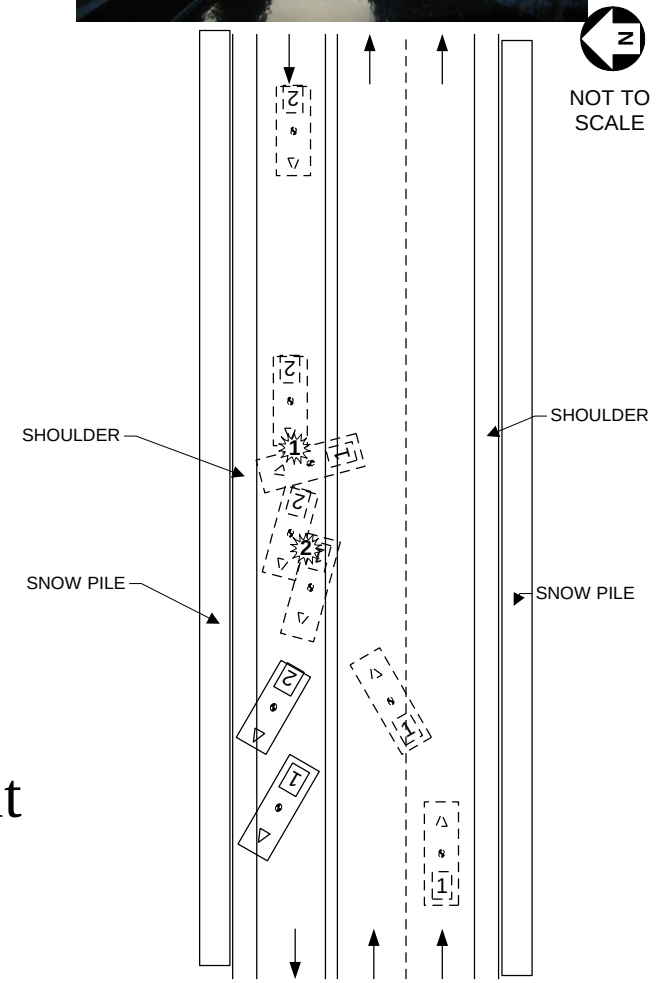


Case Vehicle - 2001 Compact Truck

Struck by a Large Pickup truck

Bilateral Pelvis






Case occupant - 21 year old, female

Front right passenger - Lap/shoulder belt

# Vehicle Inspection

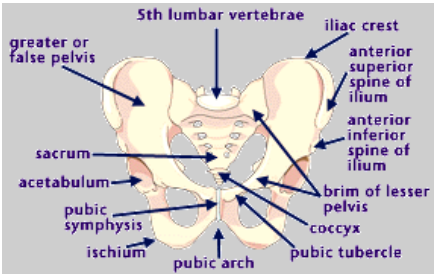
Smash Oldmiss = 30kph/18.6mph

Lateral PDOF

Door panel intrusion = 45 cm/17.7inches

Contact evidence on door/center console

# Pelvic Fractures

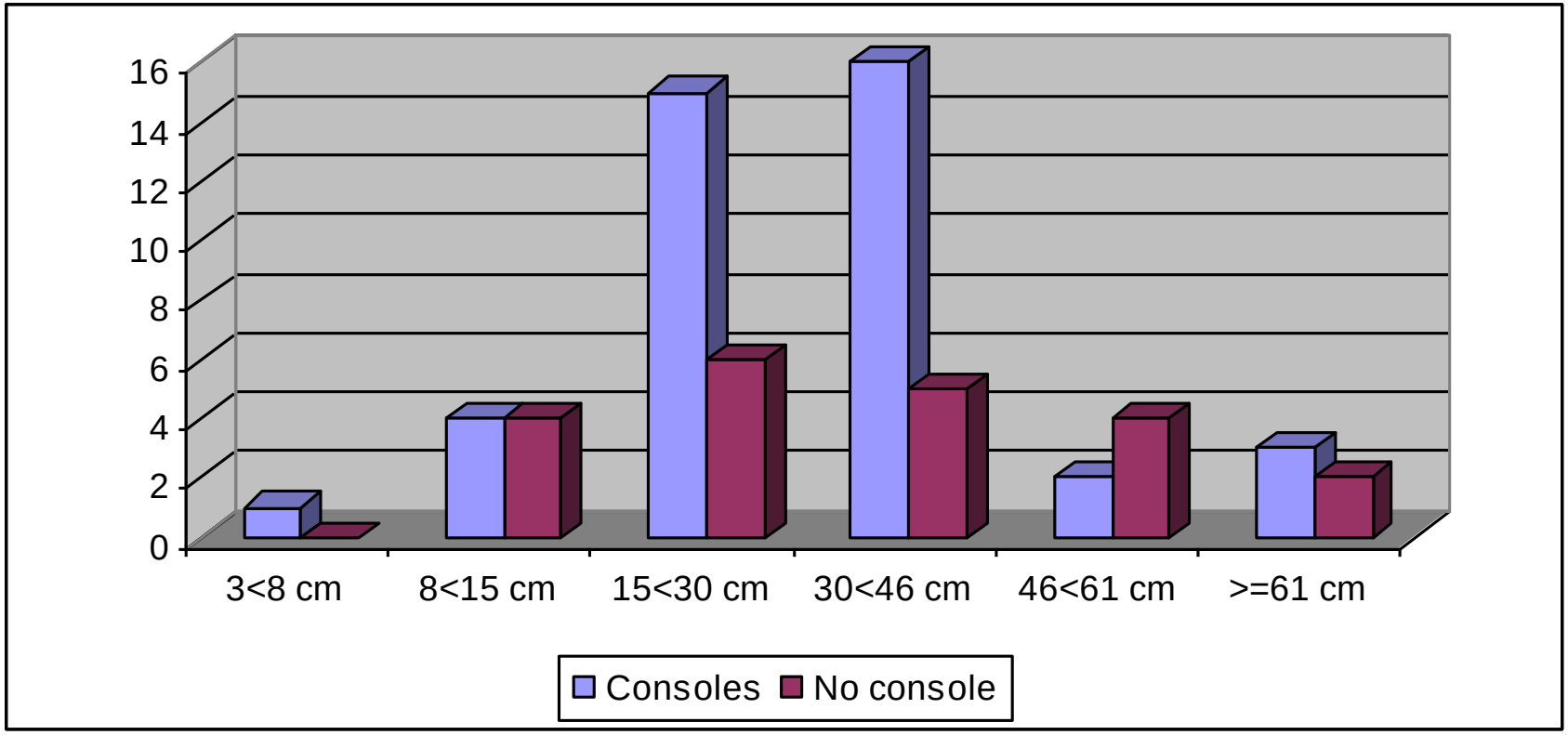


Comminuted fracture of the superior ramus of the right obturator ring which extends into the pubic symphysis. The fracture also extends into the inferior ramus. Comminuted fracture within the superior ramus of the left obturator ring extending into the pubic symphysis

Zone III Sacral Fx/Displaced

Posterior displacement of the left sacral wing

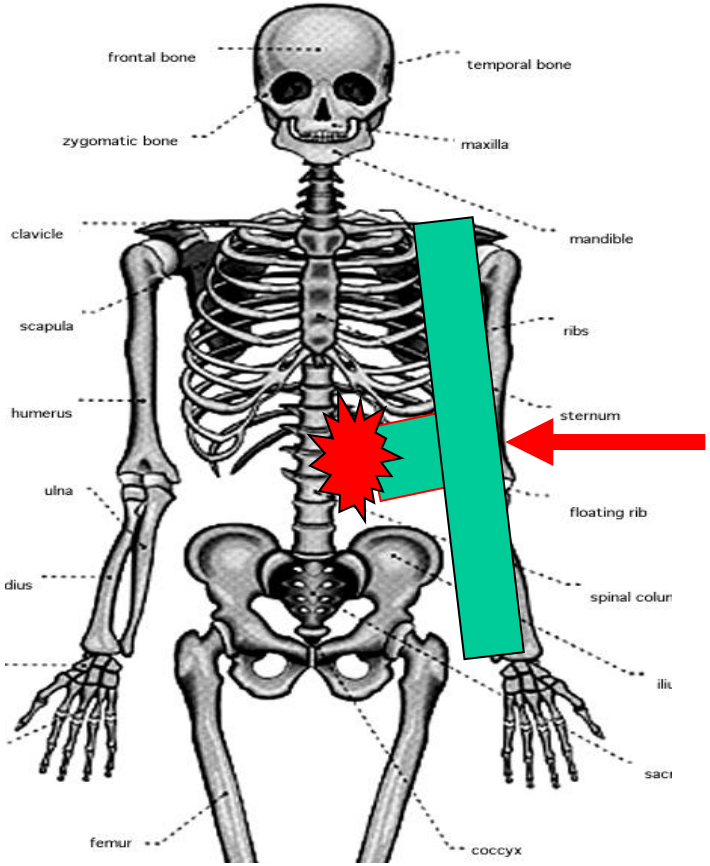
# Moderate and serious pelvic injury in nearside crashes by magnitude of intrusion



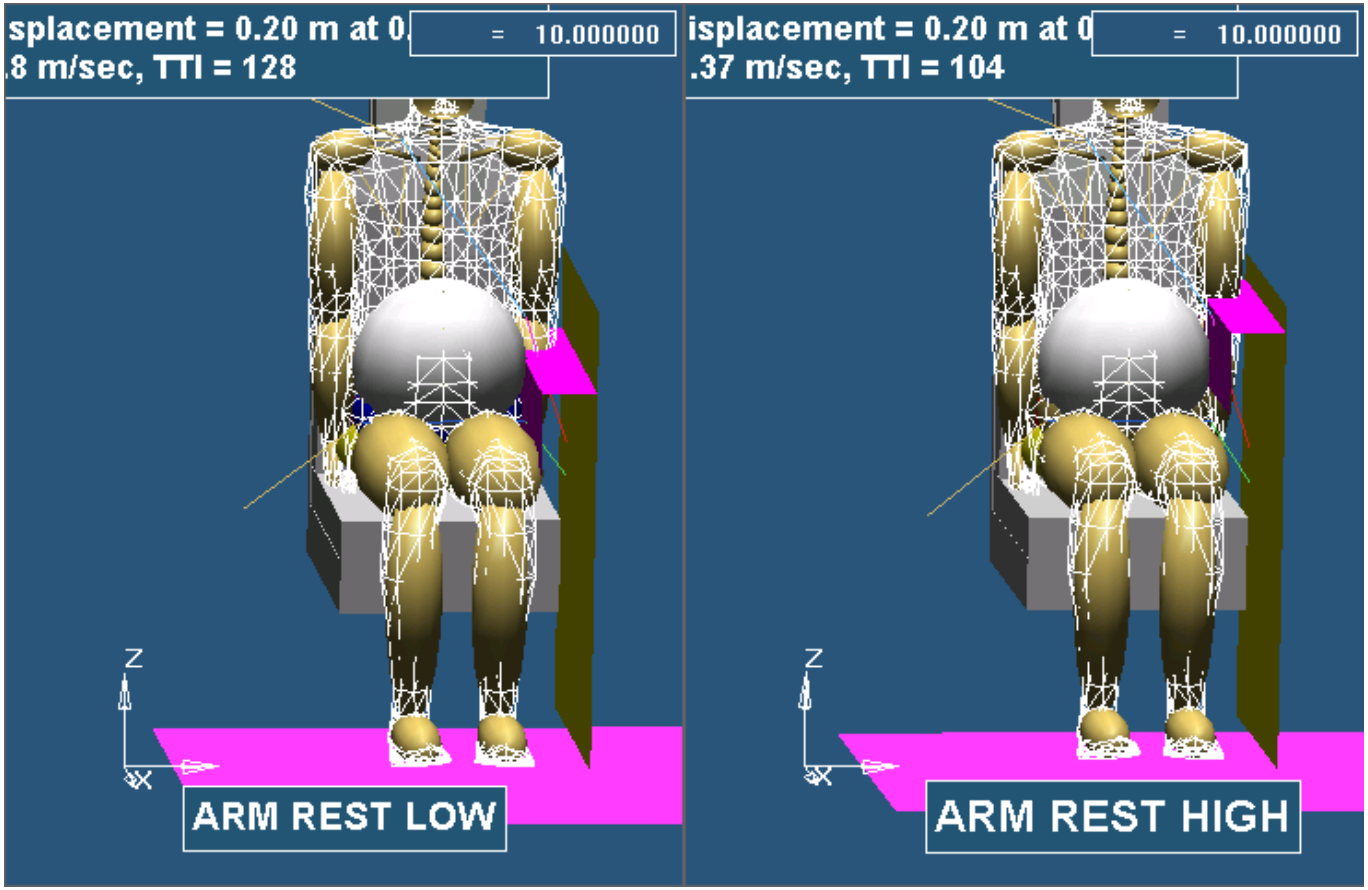

Tencer A., Kaufman R., Mack C., Mock C. Factors affecting pelvic and thoracic forces in near-side impact crashes: a study of US-NCAP, NASS, and CIREN data. Accident Analysis and Prevention - 37 (2005) 287-293.

Tencer A., Kaufman R., Conway, C. "Reducing Primary and Secondary Impact Loads on the Pelvis During Side Impact" 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Conference, Paper No. 05-0036-WTencer A.,

# Abdominal


frontal bone
temporal bone
zygomatic bone
maxilla
mandible
clavicle
scapula
ribs
humerus
sternum
ulna
floating rib
dius
spinal colur
ili
sacr
femur
coccyx

# Develop Finite Door Profiles for MADYMO (Mathematical Dynamic Modeling)

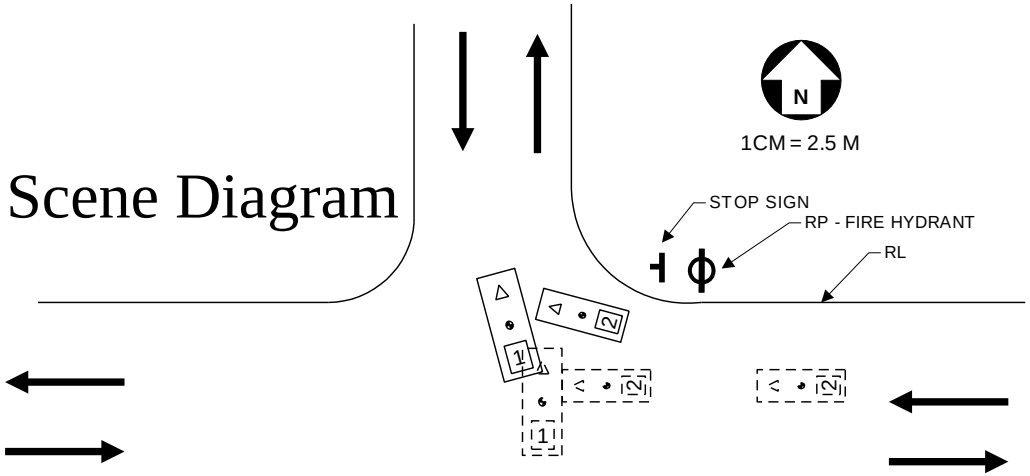



VC = 3.8 m/sec

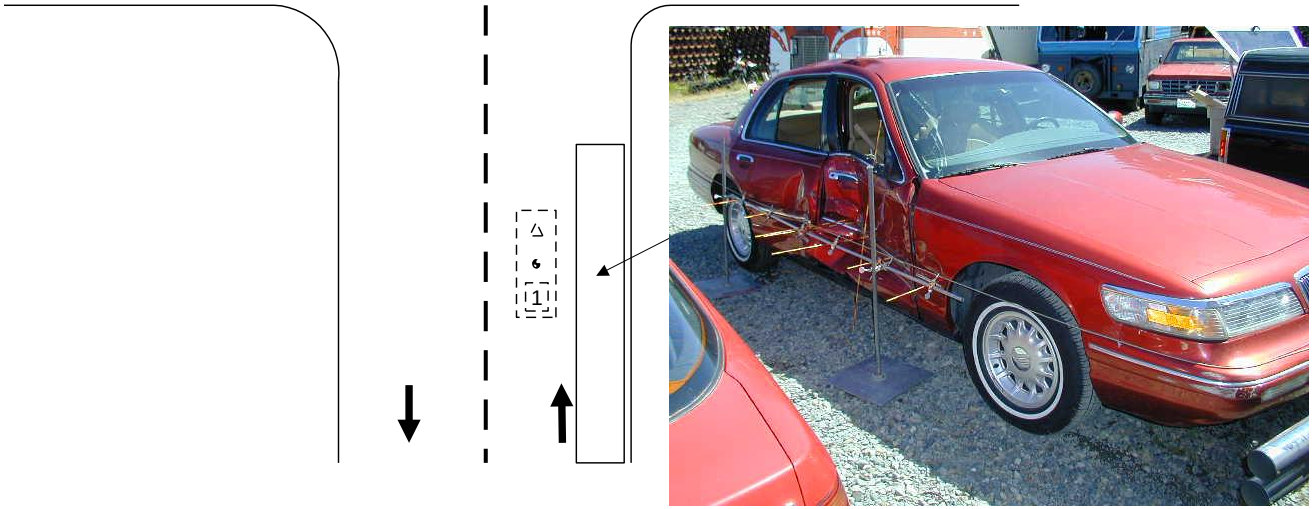
VC = 1.37 m/sec

# CIREN Case Review

Scene Diagram



V2 - 1989 Toyota Pickup




Subject V1
1996
Mercury Grand
Marquis 4-door

(meets the
FMVSS 214)

Case Occupant

Front Right Passenger

91 yr. old
L/S belt

5’ 10”-250lbs.

Max Crush = 29 cm
(11 inches - moderate)

Delta V = 11 mph

## Occupant Contacts

Shape of Door Panel Stiffness and Geometry

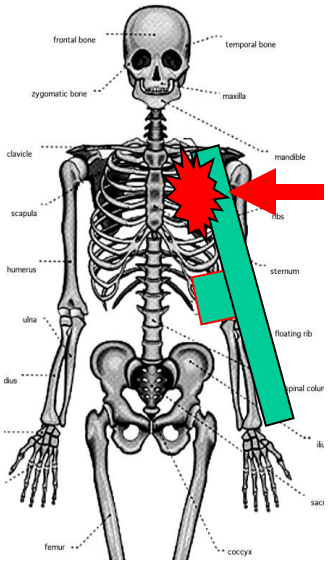
Armrest Protrusion - 8 cm

GRADE IV RENAL INJURY

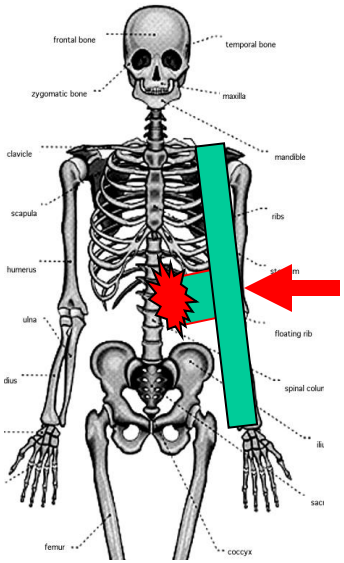
# Lateral Impact Mechanism Reviews

## Intrusion = Injury

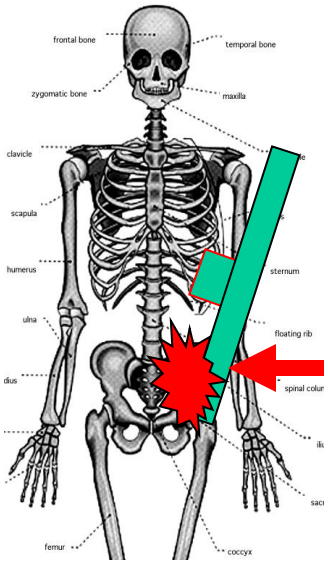
Thorax



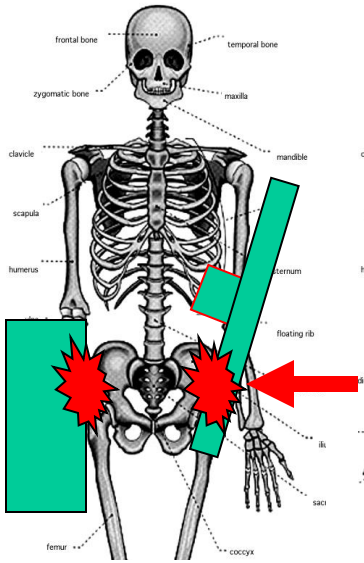

Abdominal



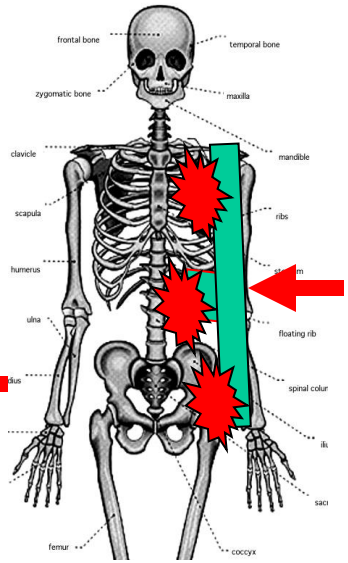

Lateral Pelvis



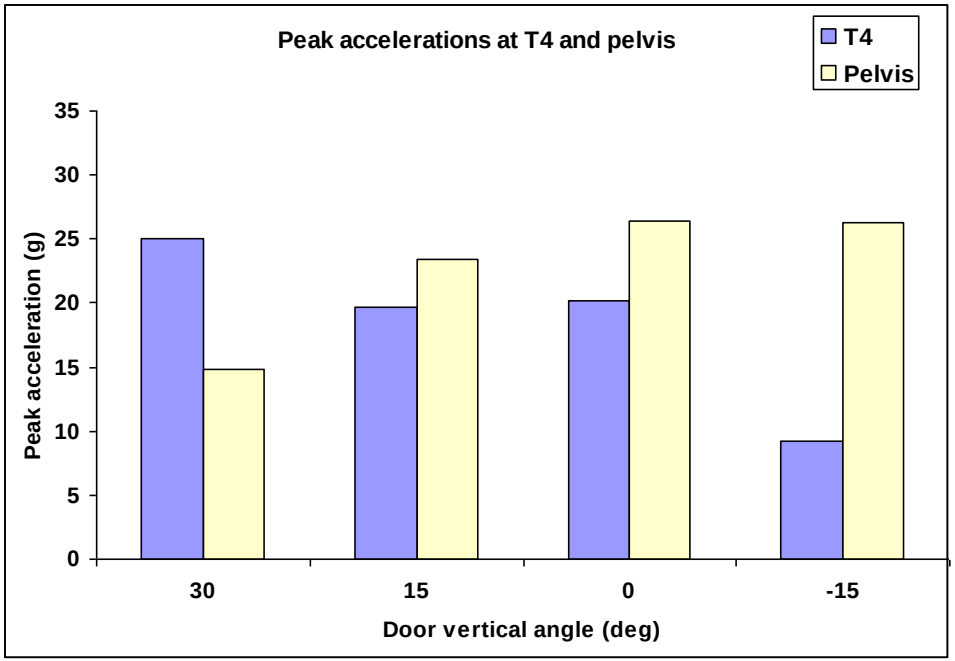

Bilateral Pelvis

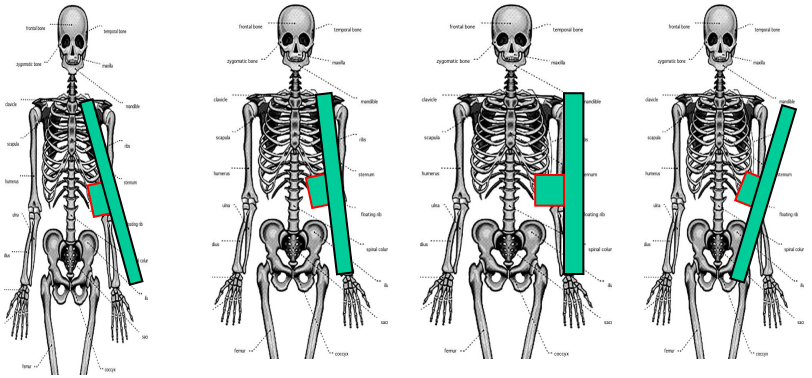



Combination

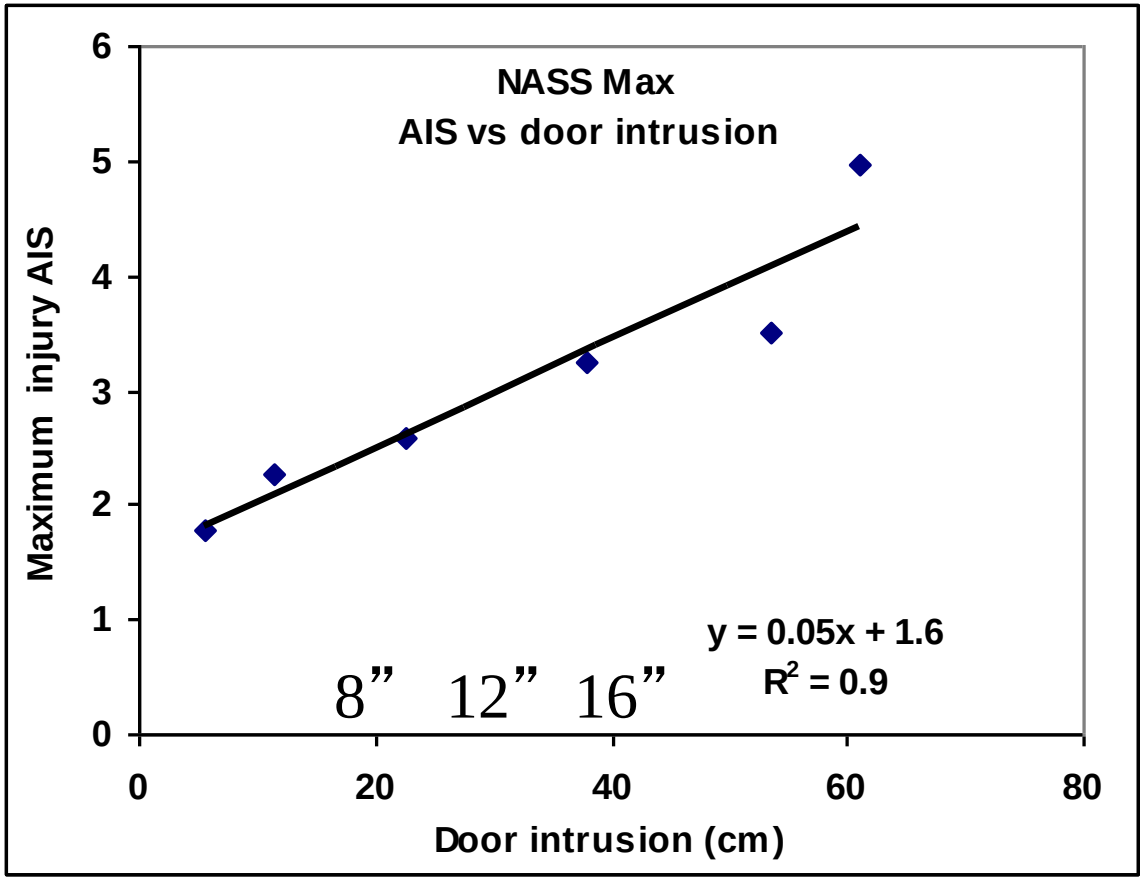


# Door Angle and Peak Acceleration Results (g)



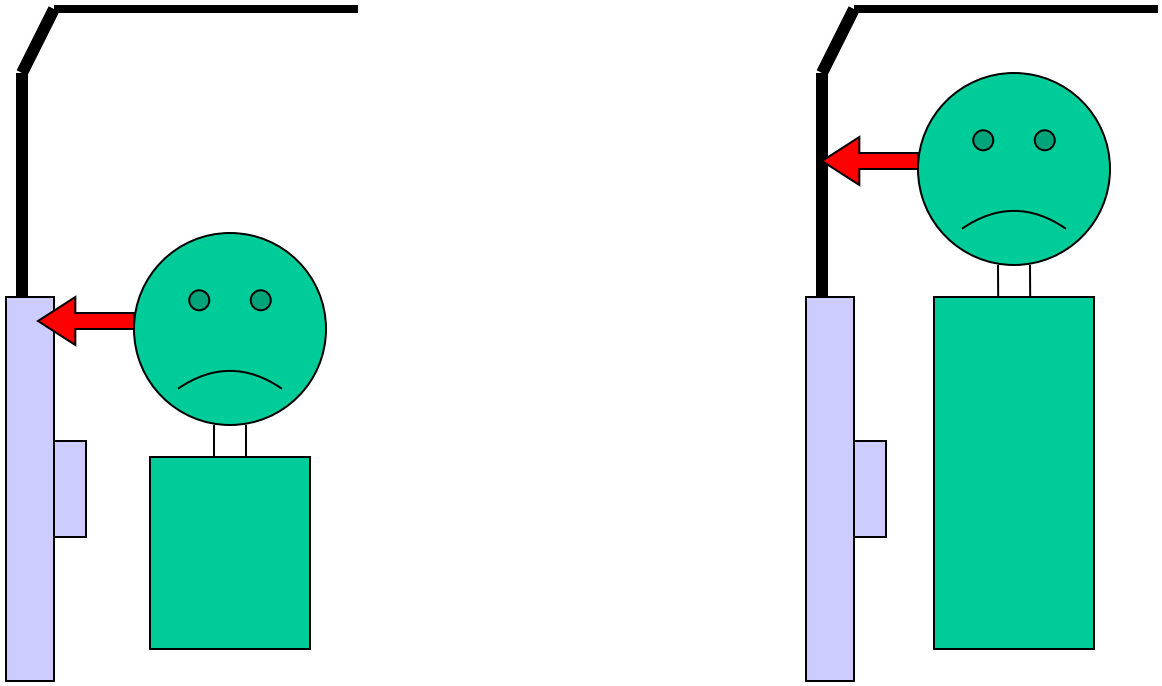
# Results – NASS MAIS v Door intrusion



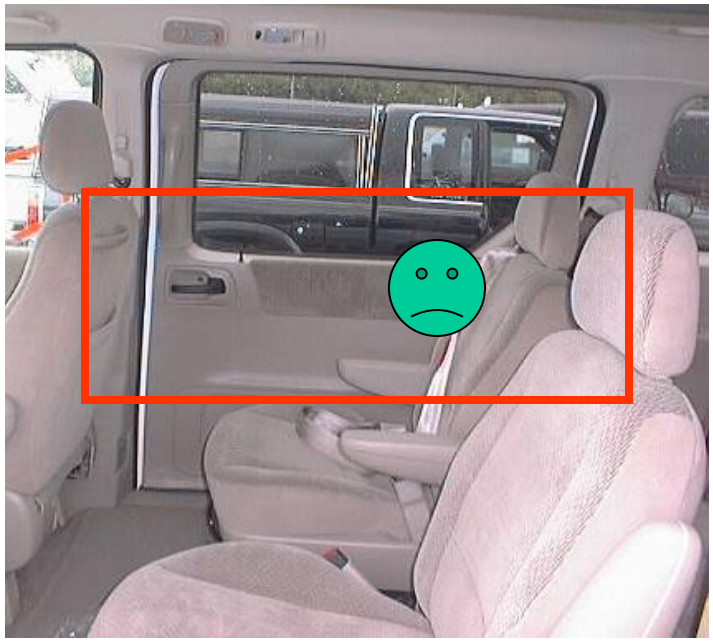

Tencer A., Kaufman R., Mack C., Mock C. Factors affecting pelvic and thoracic forces in near-side impact crashes: a study of US-NCAP, NASS, and CIREN data. Accident Analysis and Prevention - 37 (2005) 287-293.

# Head Injuries

Remember that children are exposed to more surface area for head contact in crashes.



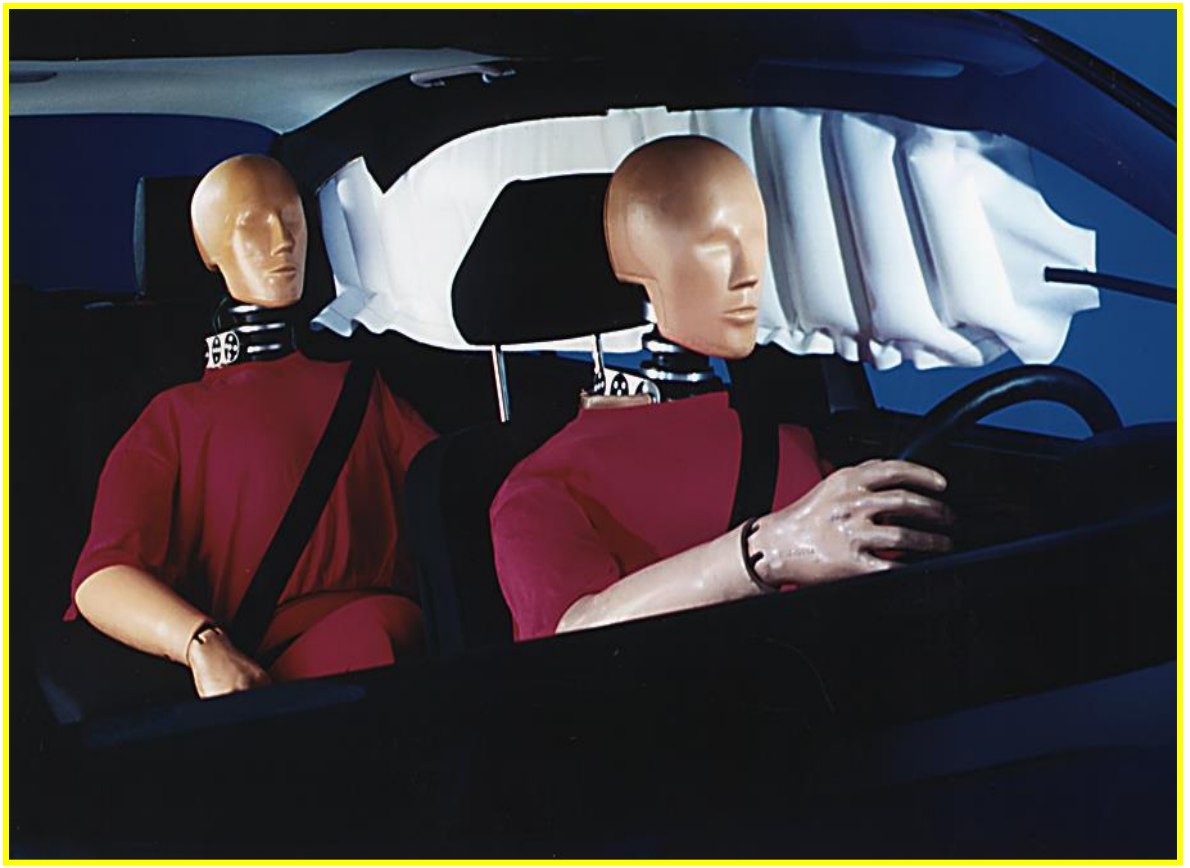
Children that are seated in vehicles expose themselves to more surface area for head contacts



Adults head contacts will occur to the greenhouse structure (roof and roof pillars)

# Inflatable Curtain

- Significant protection of critical Head Injurues

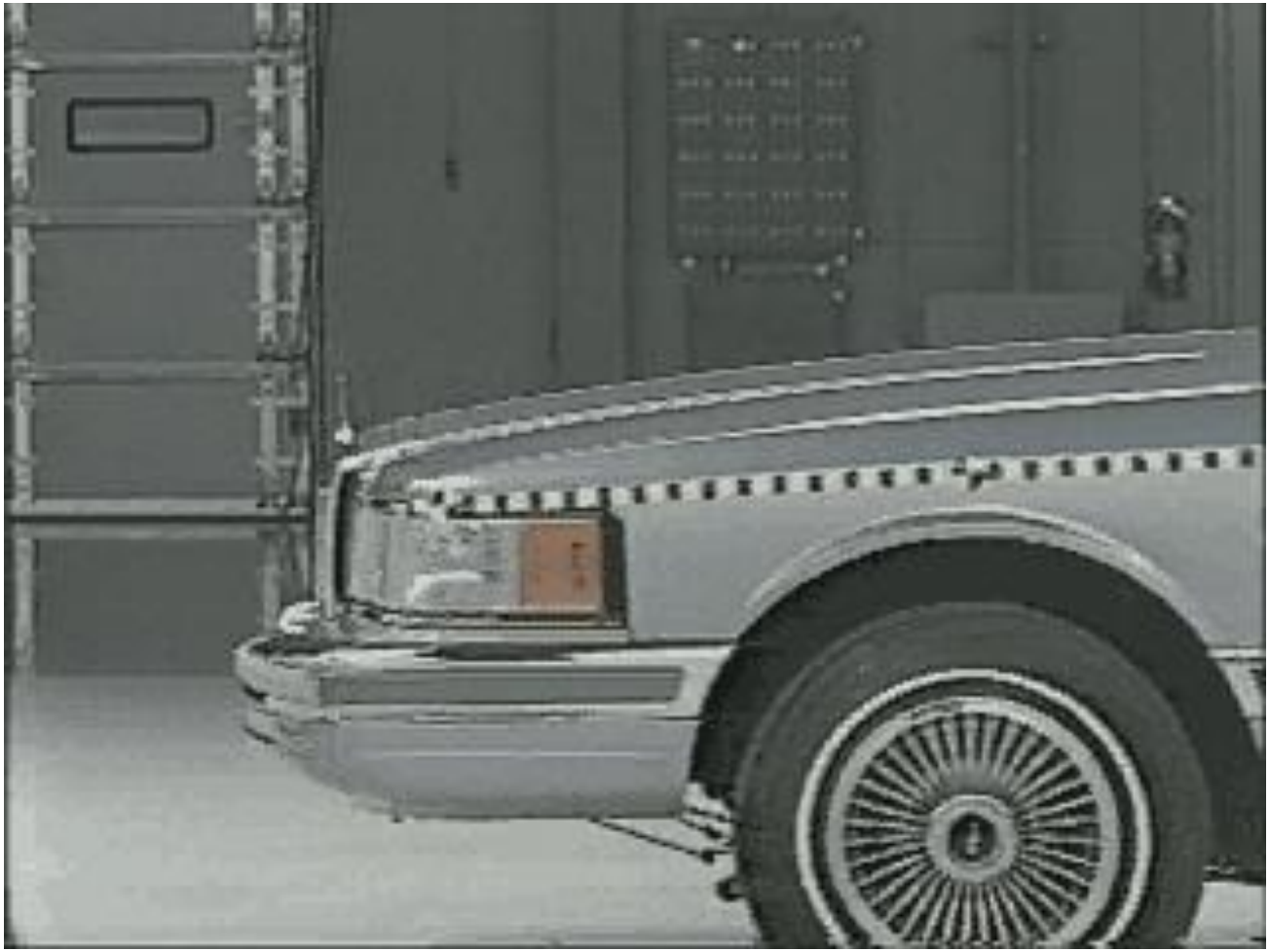


# Door Mounted Side Airbag

Main protection to upper thorax, but extends enough upward for some head protection

# Frontal Crashes

# Crash test video side view showing body moving forward



# Restraints
# Occupant Positioning

Airbags

Restraints - Seat type - Positioning

# Occupant Contact Evidence

Left Knee contact

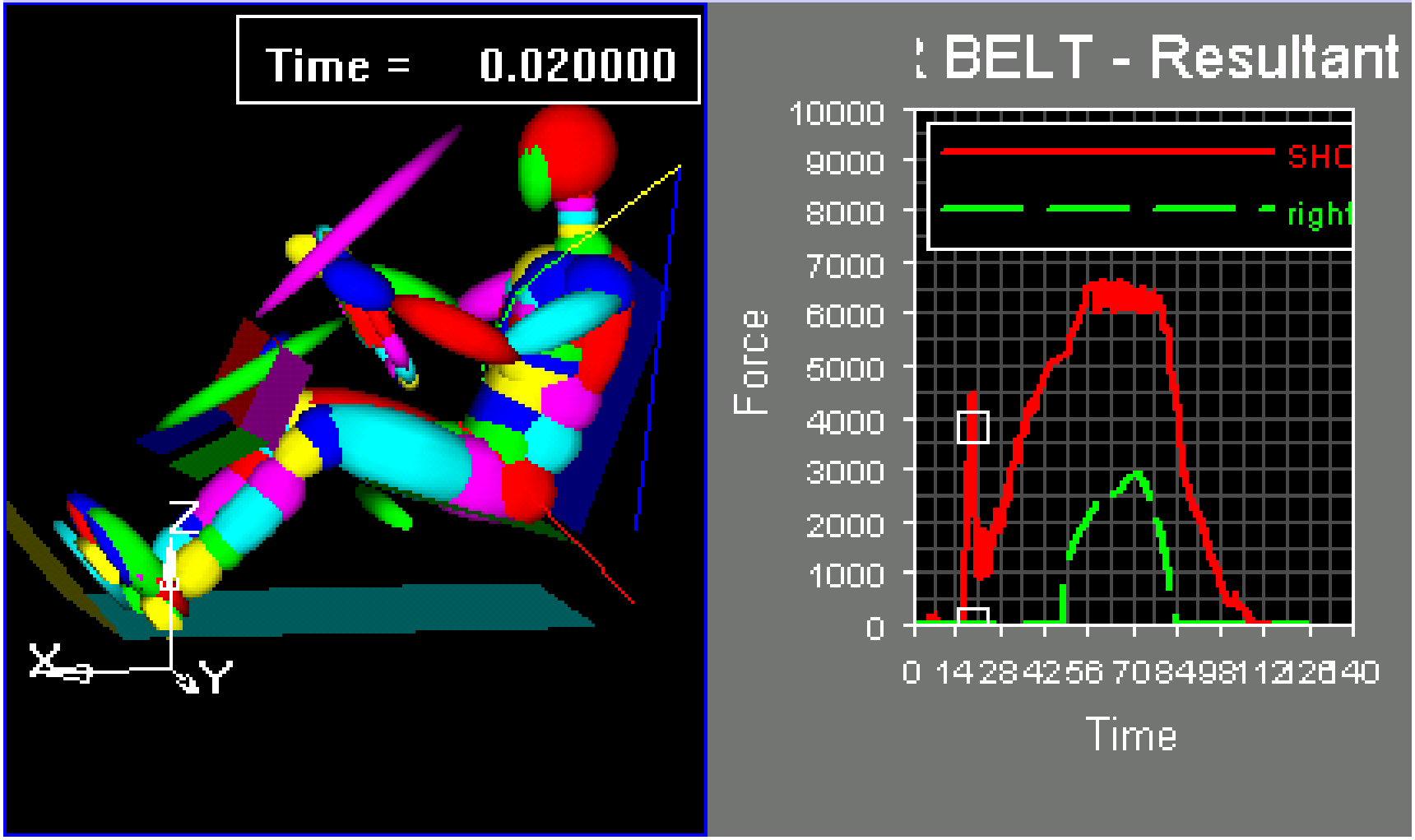
Right Knee Contact

# Occupant Contacts/Evidence

Left Knee contact

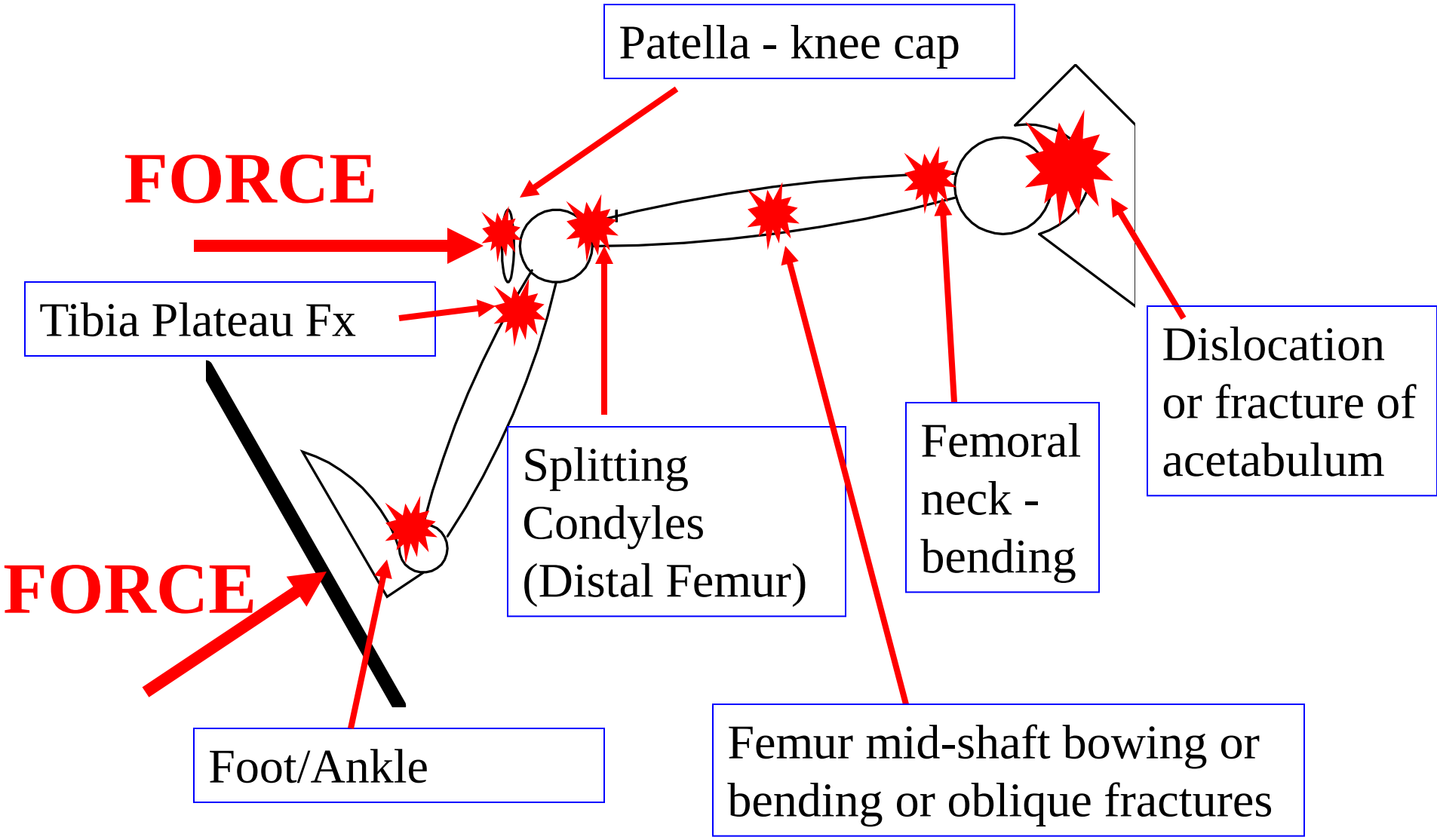
Right mid-shaft femur fx

# Lap/Shoulder Airbag




Right leg brake - contact to steering column

# Axial load and force to lower extremity



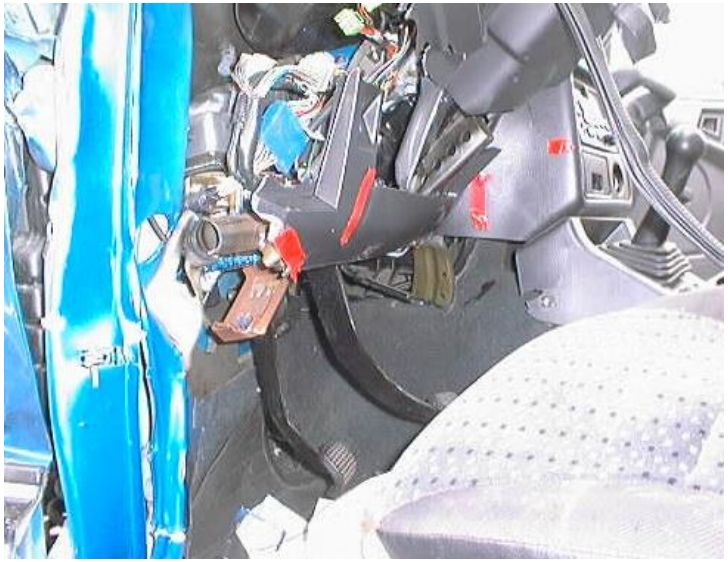
# A-pillar movement
# Sign of Severity

# Crush Depth & A-Pillar movement

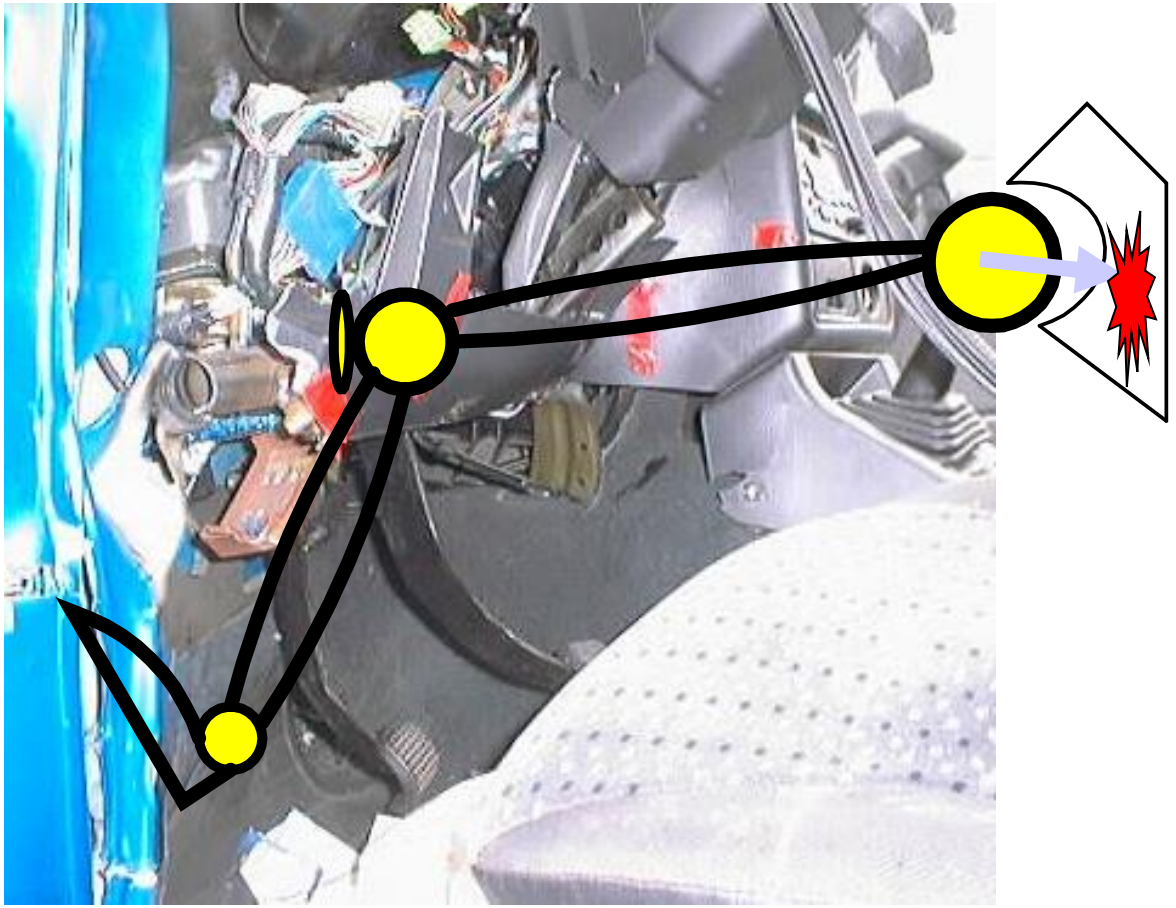
Any severe crush to front is consider significant force

A pillar movement is a definite sign of a more severe frontal force, and intrusion of instrument panel

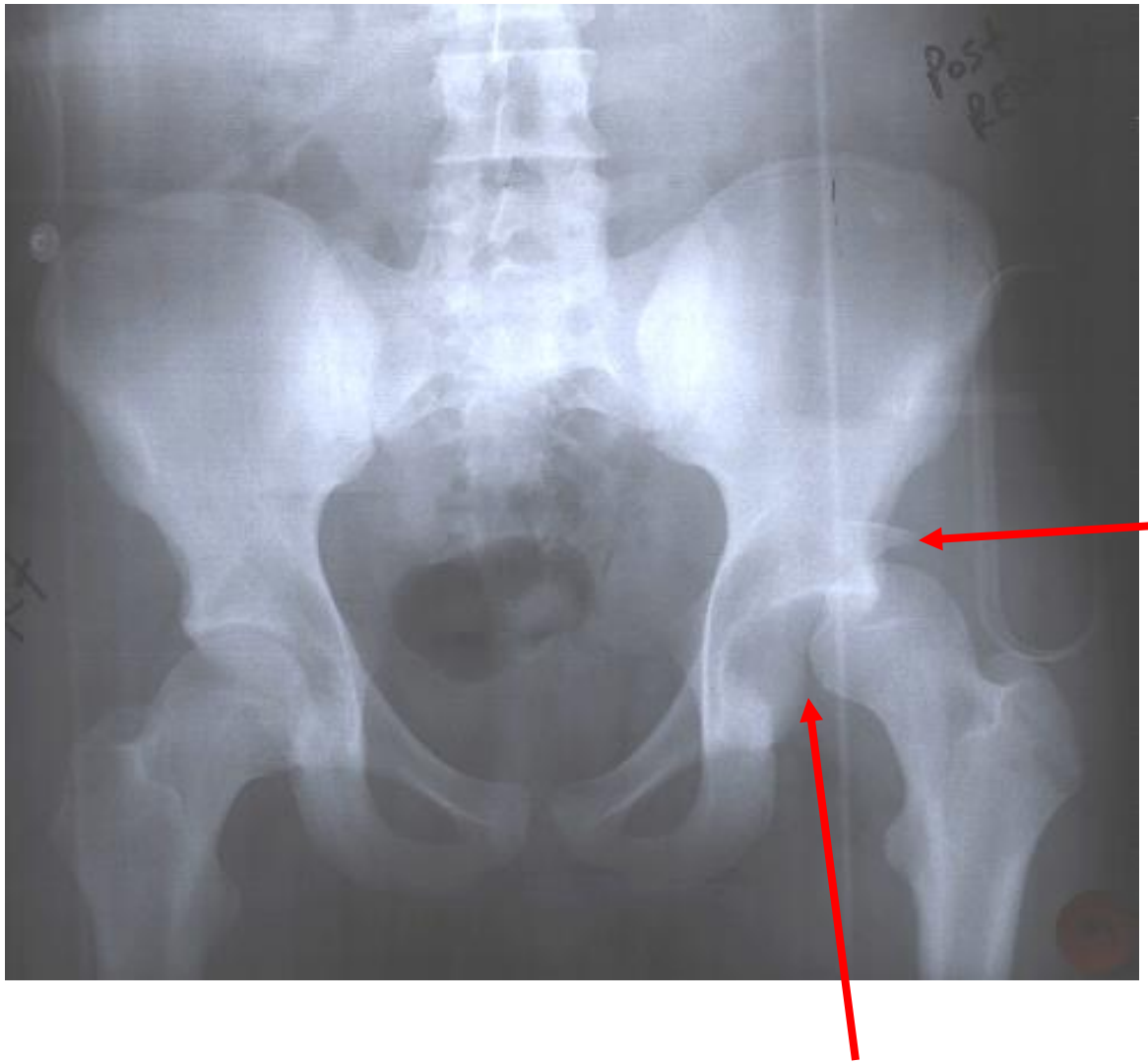
17 year male driver, restrained



# Acetabular Fracture/Dislocation



# Acetabular Fracture/Dislocation



Acetabular fracture with dislocation

# SUV/Truck Frontal Impacts

## Intrusion to Toe/Floor Pans

‘99 Chevrolet Suburban

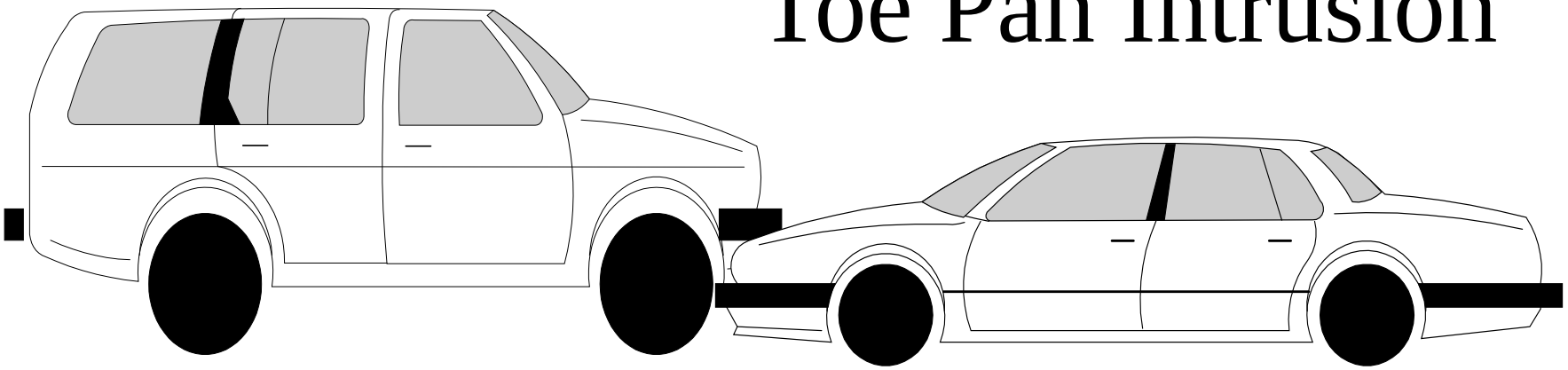
Delta V = 22 mph

‘95 Toyota Avalon

Delta V = 52 mph

FATALITY

# Offset Frontal Case Review
# Toe Pan Intrusion



2000 Lincoln Navigator

1997 Ford Escort

Driver fatally injured

<u>Subject Driver</u>

50 yr. old female 4’ 11”, 105 lbs.

Manual Lap/shoulder belt

Deployed Frontal and Side airbags

Delta V = 20 mph

Impact to front left tire

55 cm (21”) longitudinal intrusion of toe pan

Driver's right shoe pinched by intrusion

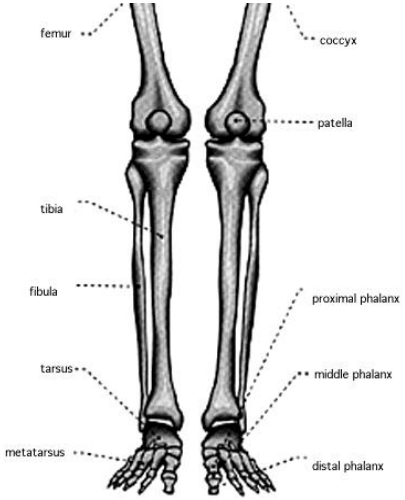
# Injury summary

**Right Foot**

- Distal tibia Fx, comm.

- Distal fibula fx

- 1-5 metatarsals fx




**Left Foot**

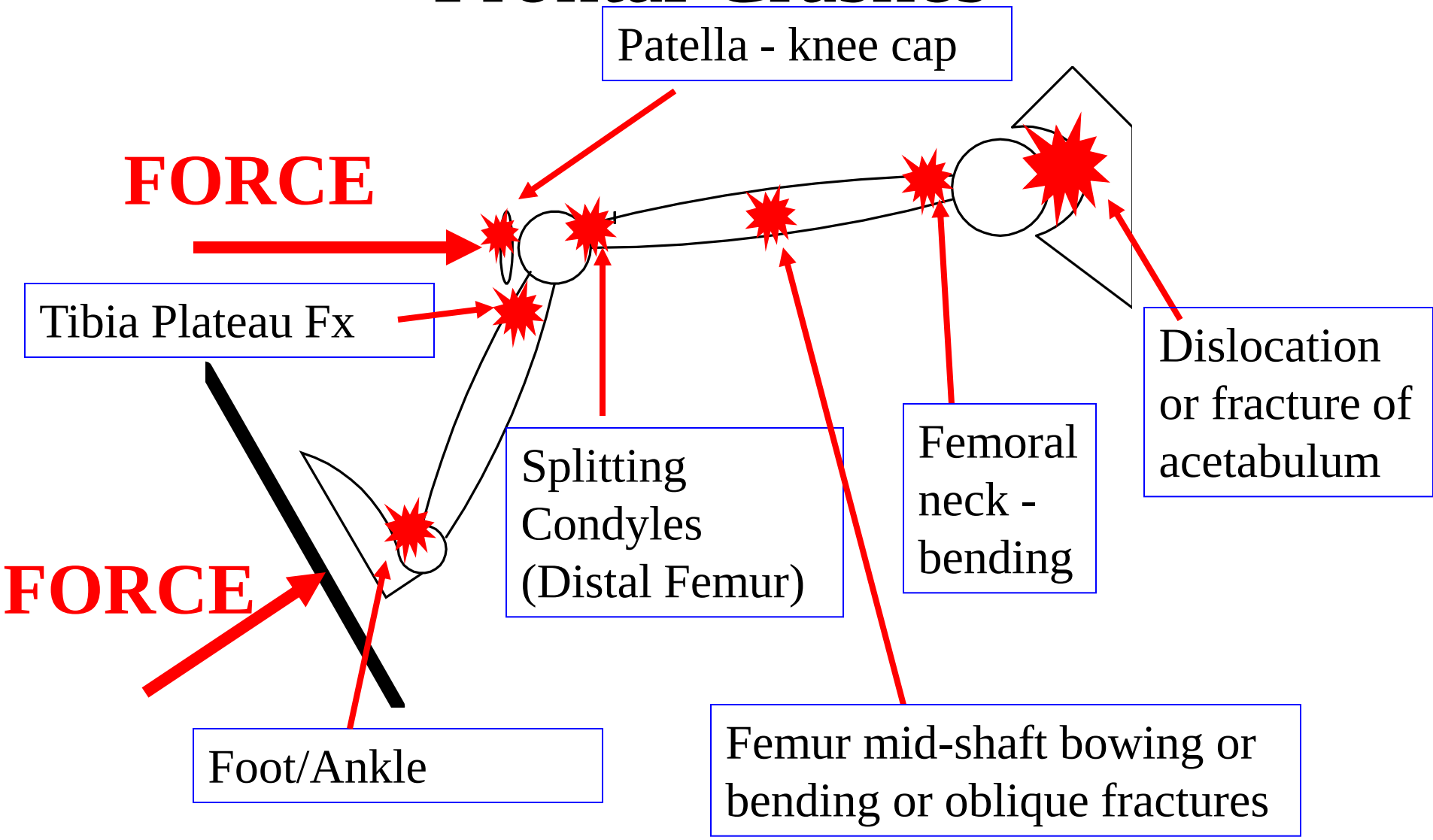
- Cuboid fx

- Cuneiform fx (medial)

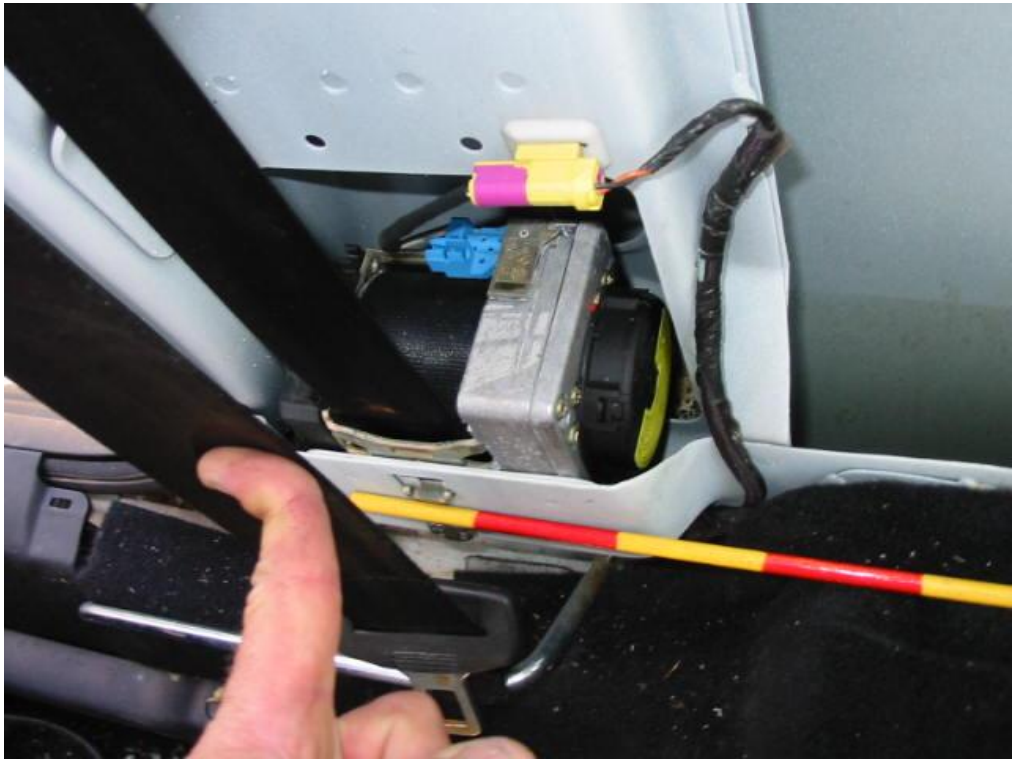
- 1,2,3,5 metatarsal fx

- L great toe proximal phalynx fx

# Force loads to lower extremity in Frontal Crashes



# Safety Belt Retractor Pretensioner
# Determine belt use on scene

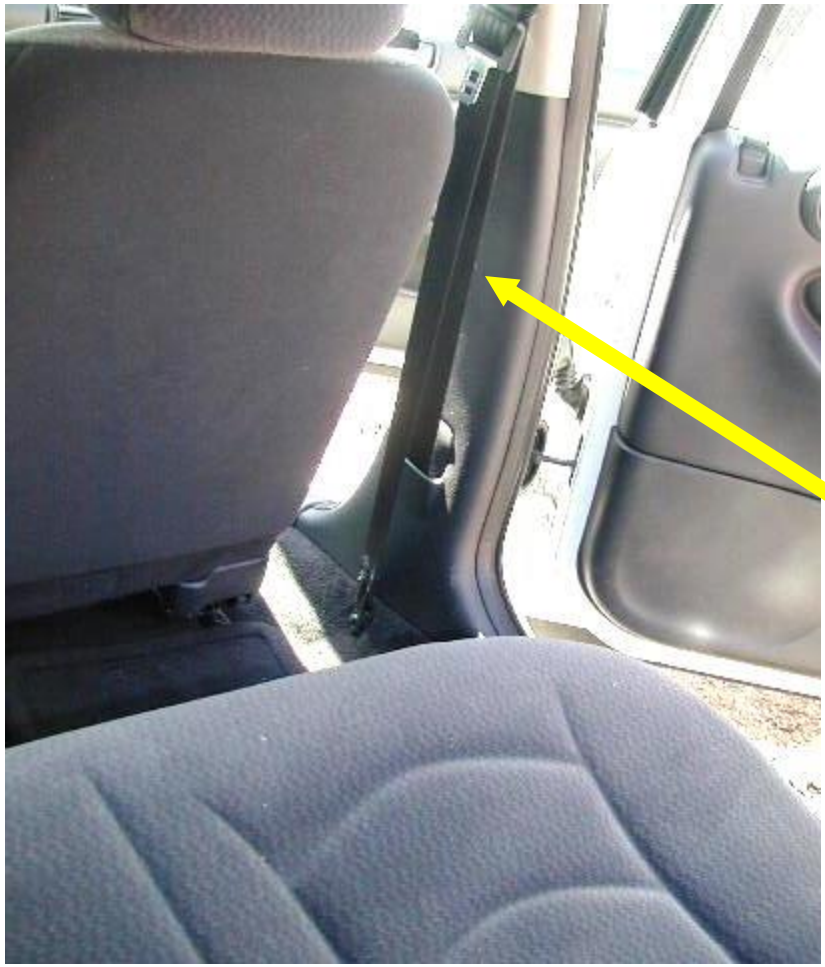


# Pretensioners fired, belt won't retract

Belt webbing load marks

Belts remains out and won't retract and freezes in place

# Pretensioners fire, if not in use



Locks in place like a guitar string.

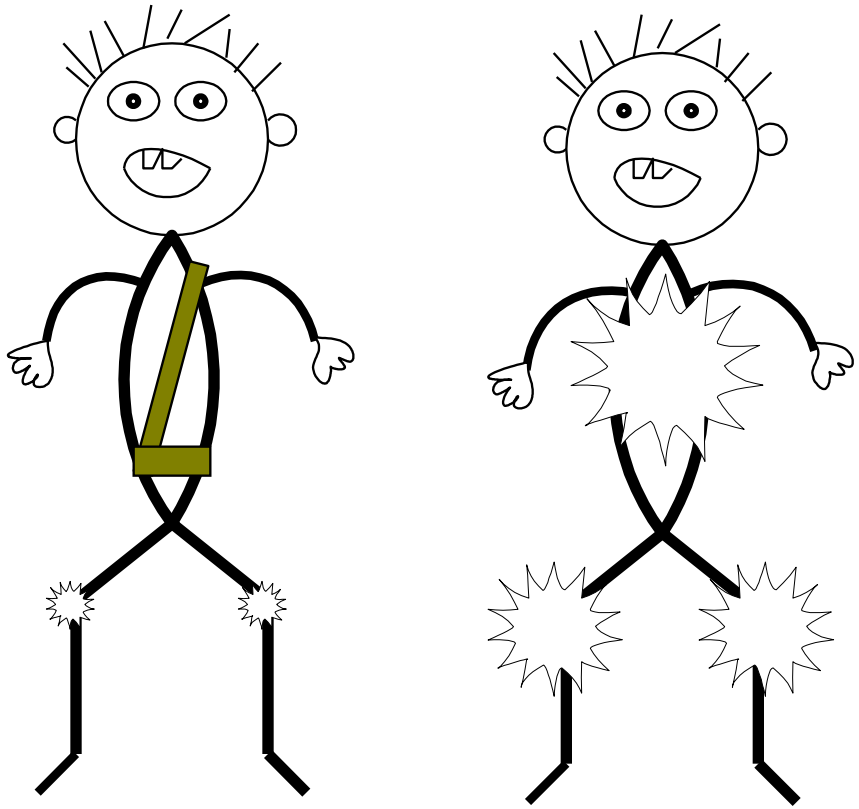
Indication of not in use.

# Seatbelt Success Story

Discharged home on day three.

-minor abdominal injury

# Occupant energy distribution

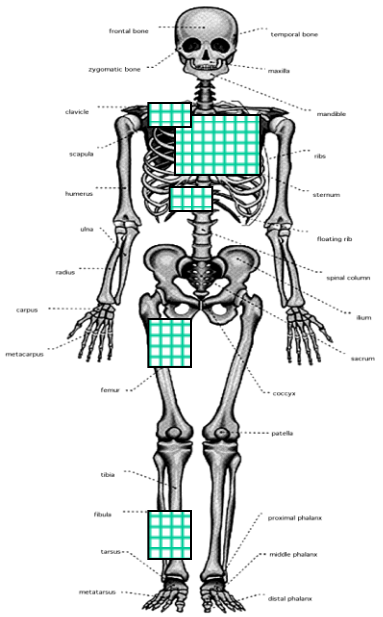


Restrained vs. Unrestrained

NISSAN

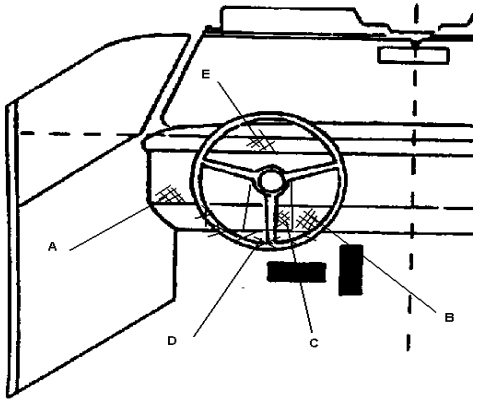
# Female: age 45 5’ 4”, 108 lb

| AIS | Region | Injury |
|---|---|---|
| 5 | Thorax | Ant/Sup Near complete transection of root of aorta (w/in 1cm valve ring) |
| 5 | | R atrium lac - 1 cm long into chamber(near attachment to IVC) |
| 3 | | R 2 cm pericardial lac w/ hemorrhage (1700 cc R hemtx due to cardiac aortic lacs) |
| 3 | | R Ant. rib Fxs #3-6 / R hemothorax / L rib Fx #1, post w/ LUL, LLL lung contusions |
| 1 | | R inf chest 1/2" abrasion |
| 3 | Lower Ext. | R midshaft femur Fx |
| 3 | | R distal tibia Fx, open |
| 3 | | R distal fibula Fx, open |
| 1 | | R ant thigh contusion 1" |
| 1 | | R medial foot lacerations 2" |
| 2 | Abdomen | R inf liver lac (3 cm of capsule) w/ minimal associated hemorrhage |
| 1 | | L upper abd 1/4" abrasion |
| 1 | Upper Ext. | L proximal hand lac 1/2" (ant) |
| 1 | | L 3rd, 4th metacarpal contusions 1/2" |
| 1 | | R 2nd finger (ant) 1/4" contusion |




**ISS = 38**

| Contact | Area | Component | Occ # | Body Region | Evidence | Confidence |
|---|---|---|---|---|---|---|
| A | Front | Knee bolster | 1 | Knee - Left | Scuffed | CERTAIN |
| B | Front | Knee bolster | 1 | Knee - Right | Scuffed | CERTAIN |
| C | Front | Steering column,transmission sele | 1 | Abdomen | Transfer (Specify) | PROBABLE |
| D | Front | Steering wheel rim | 1 | Chest | Deformed | PROBABLE |
| E | Front | Left instrument panel and below | 1 | Lower Arm - Unknowr | Scuffed | POSSIBLE |



What is the risk of injury and death in crash to an occupant with other unrestrained occupants?

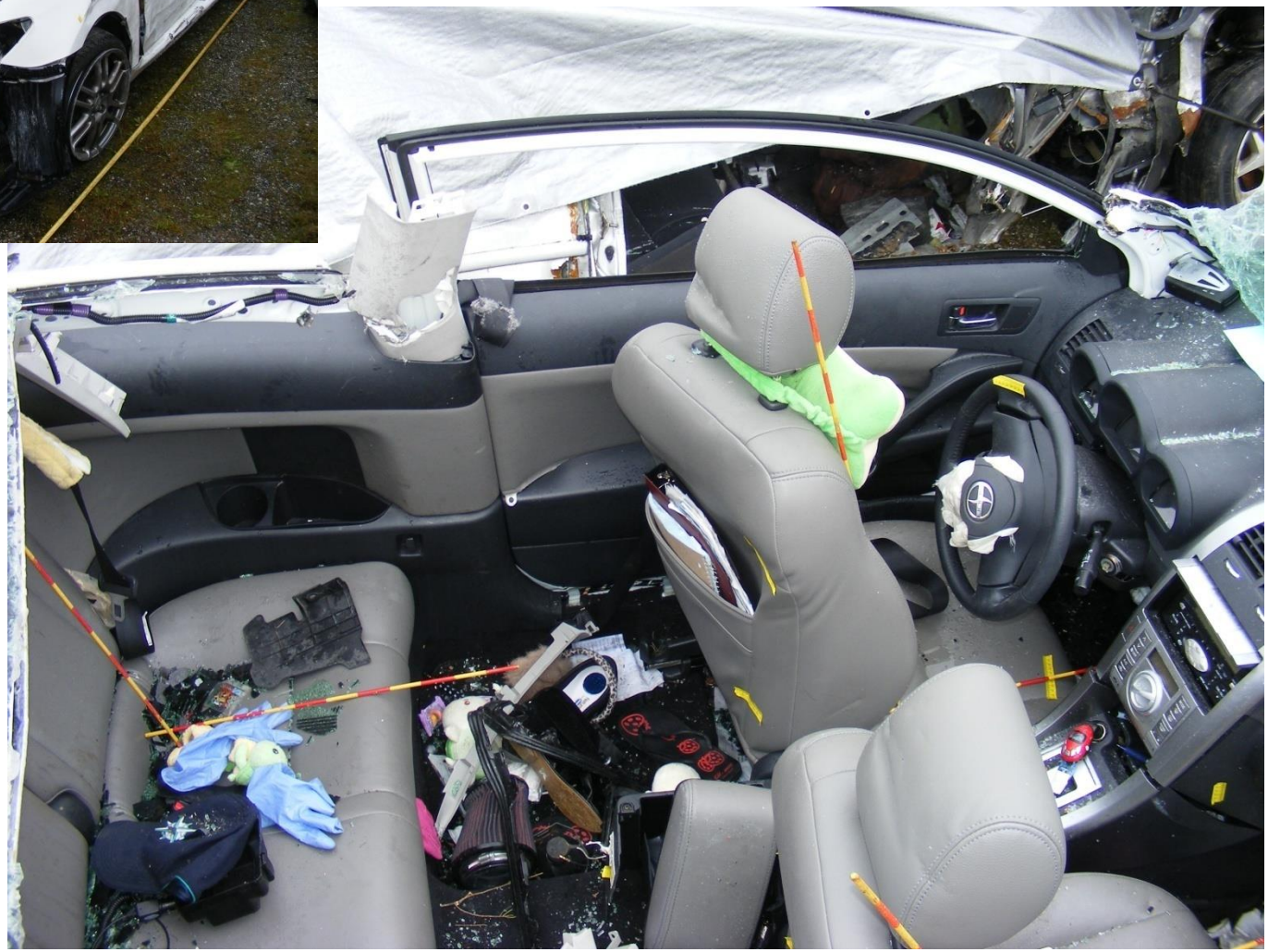
# Seattle CIREN Research Publication (FARS data)

Rivara F, Cummings P. Car occupant death according to the restraint use of other occupants: a matched cohort study. JAMA. Jan 21;291(3):343-9, 2004

- Restrained occupants can have an increased risk of death by 22-25% with an unrestrained person in the vehicle behind or next to them.

- 1 out of 6 deaths may have been prevented if the other occupants were restrained

- To reduce the risk of death, all occupants must be restrained in the vehicle



# Seatback Intrusion & Cargo Related Injuries

Describing a Problem: Rear Seatback Failure and Unsecured Cargo
Samuel P. Mandell, MD b*, Robert Kaufman, BS a, Christopher D. Mack, MS a, Eileen M. Bulger, MD – *Prehospital and Disaster Medicine.*

# Case 1
# Seatback Intrusion Fatality

6 year old male – Lap belt with shoulder belt behind back

Fatality: Critical head, spine and abdominal injuries

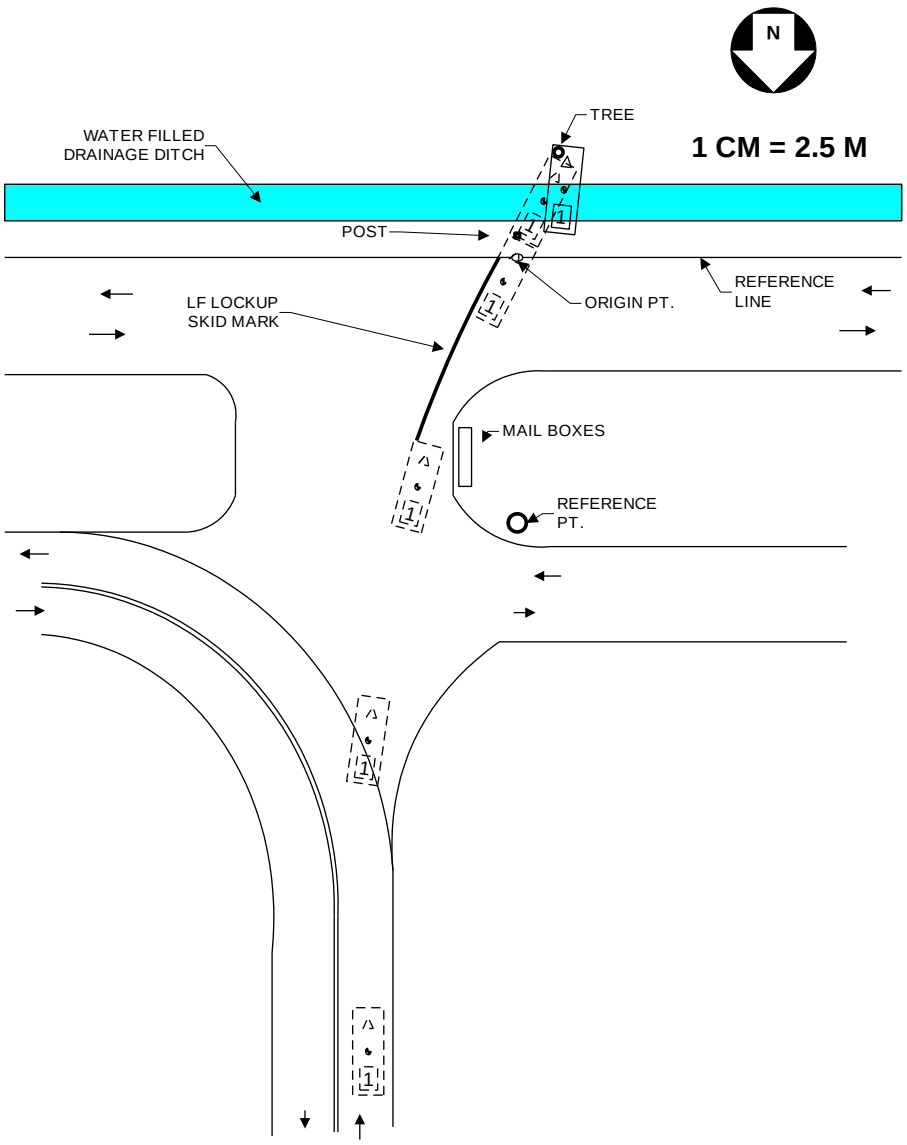
# Case 2

4 yr./Male - 35lbs.

Lap belted - Back middle

1997 Oldsmobile Achieva

Delta V = 28 mph

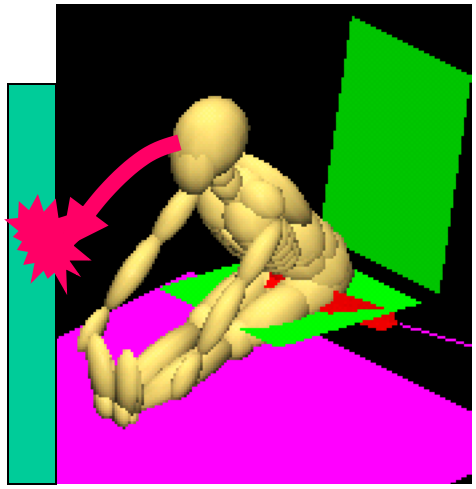


# Interior contacts

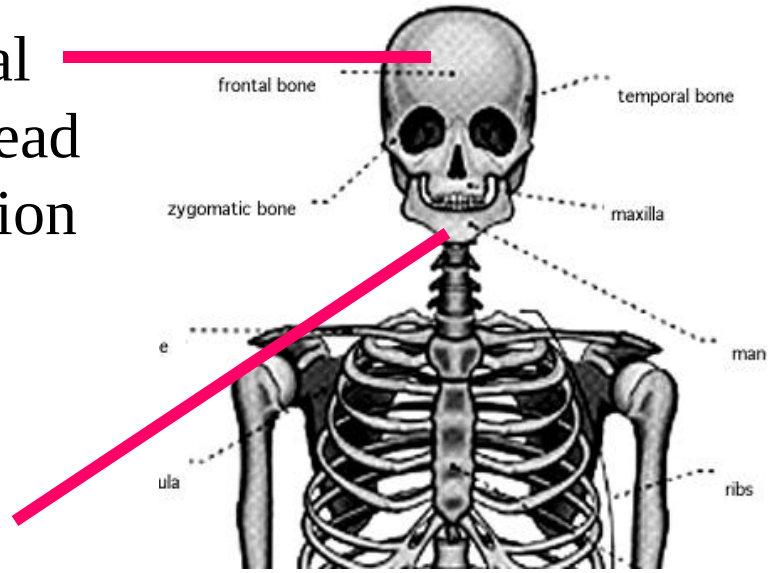
Lap belt only in use

Seatback intrusion due to cargo in trunk

# Injuries



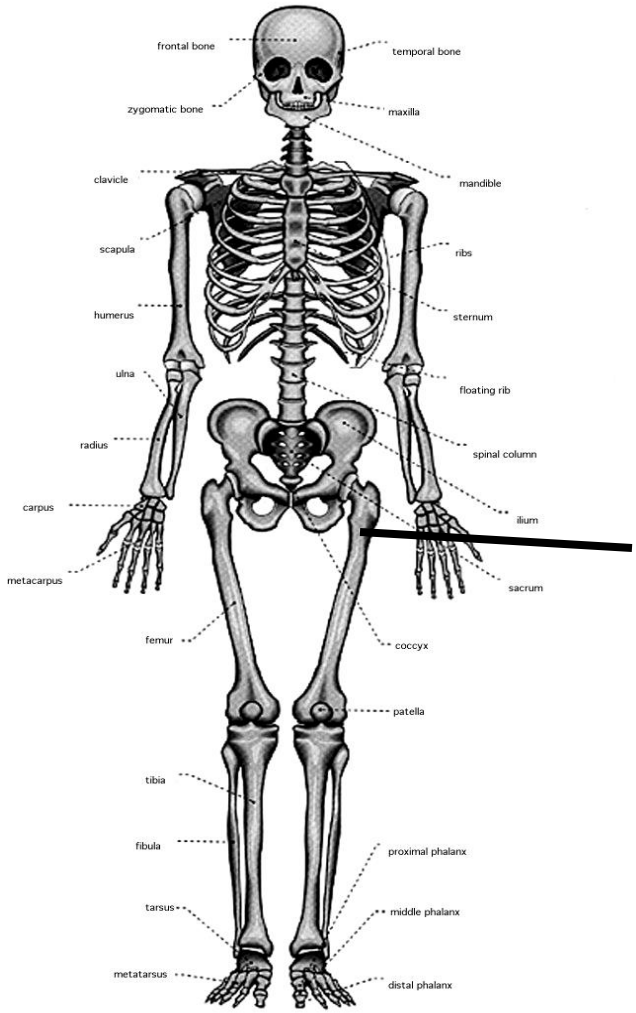
Central
Forehead
Abrasion



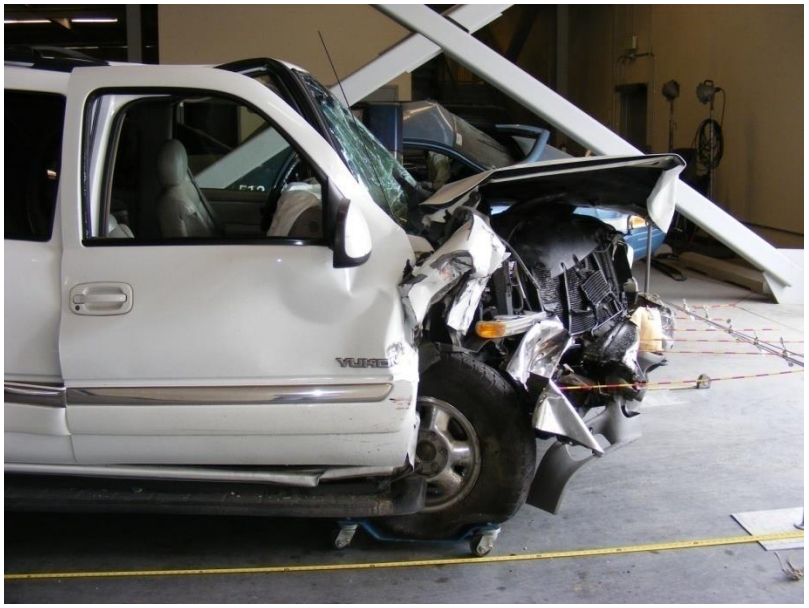
C1-C2 rotary subluxation with incomplete quadriplegia C2 cord contusion

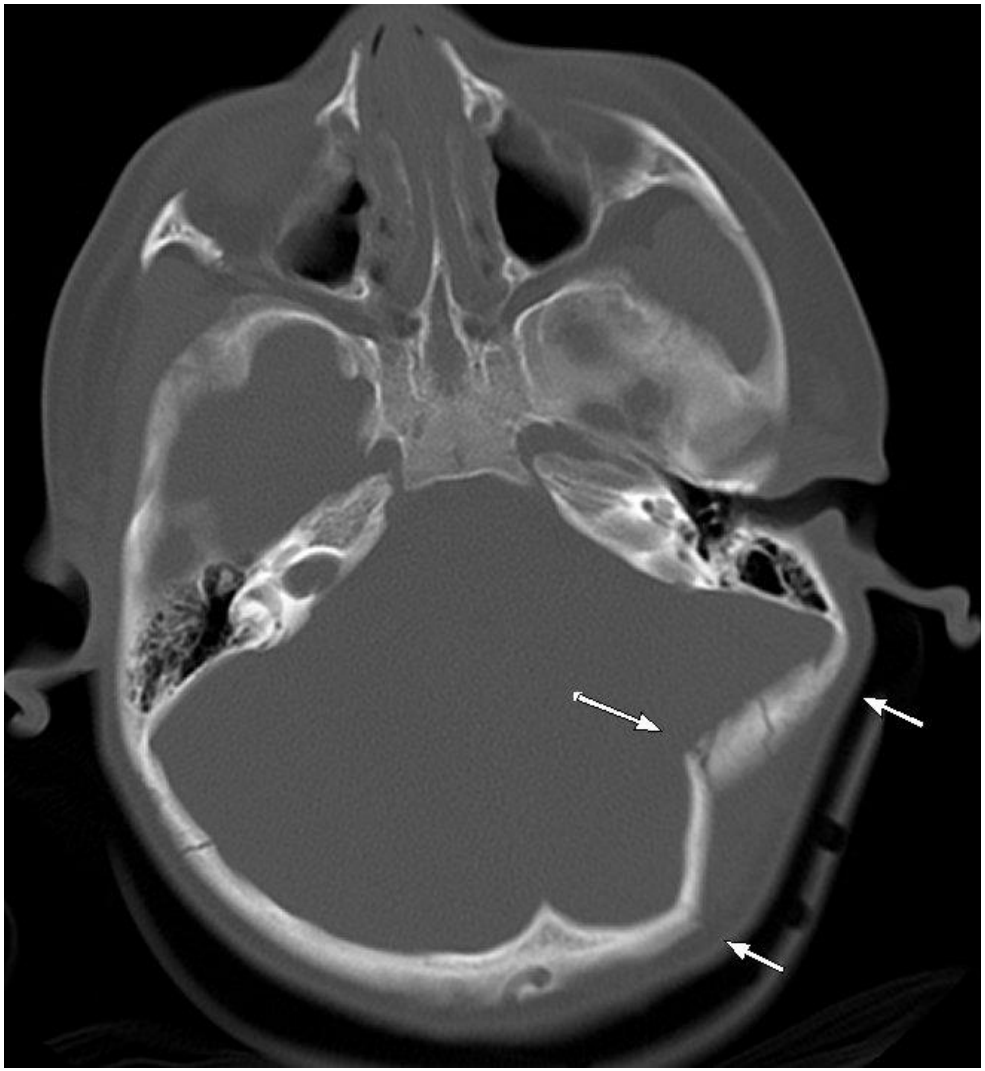
C0-C1 subluxation

# Injuries

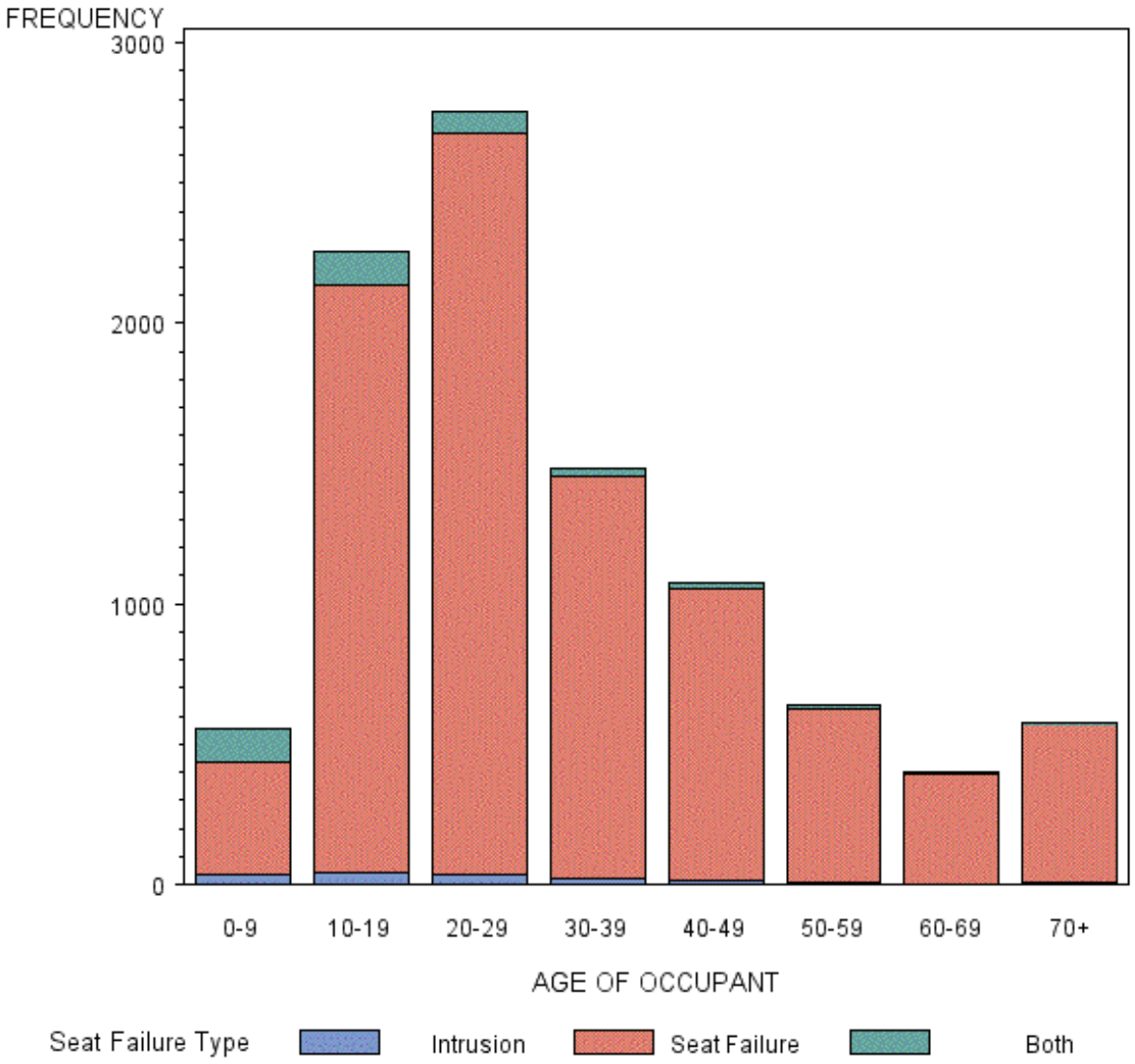



L Femur Fx midshaft displaced





# Seat Failures and Intrusions by Age



# The Effects of Seatback Reclined Positions of Occupants in Motor Vehicles Collisions

Seattle CIREN Team (Bulger, Dissanaike, Kaufman, Mack)

University of Washington

Harborview Injury Prevention and Research Center

HARBORVIEW
INJURY PREVENTION
& RESEARCH CENTER

Dissanaike S, Kaufman R, Mack CD, Mock C, Bulger E. The effect of reclined seats on mortality in motor vehicle collisions. *The Journal of Trauma, Injury, Infection and Critical Care*. 2008 Mar; 64(3):614-9.

# Mortality risk – regression analysis

- Difference in mortality persist when adjusted for age, sex, seatbelt use and type of vehicle

| Mortality Risk | Odds Ratio | 95% CI |
|---|---|---|
| Partial Reclined | 1.14 | 1.02 – 1.22 |
| Fully Reclined | 1.77 | 1.13 – 2.78 |

# Seatback Recline
# CIREN Case Review 1 – Vehicle

2003 Chevrolet Cavalier

PDOF – 12 o’clock

Delta V = 44kmph/ 27 mph (smash missing run)

# Seatback Recline
# CIREN Case Review 1 – Vehicle

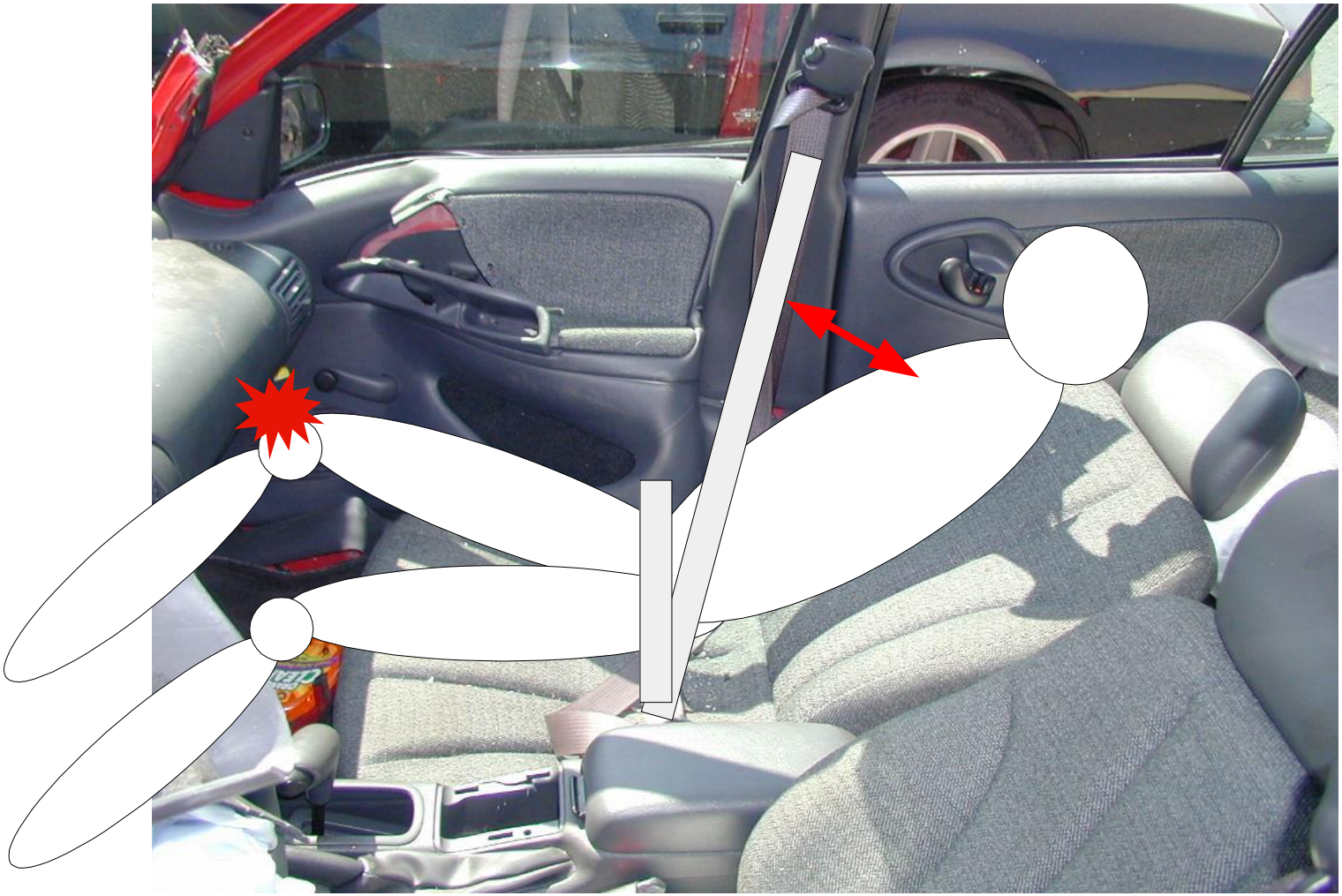
27 yr. – Female

Lap/shoulder & Air bag

Fully reclined seatback position and sleeping

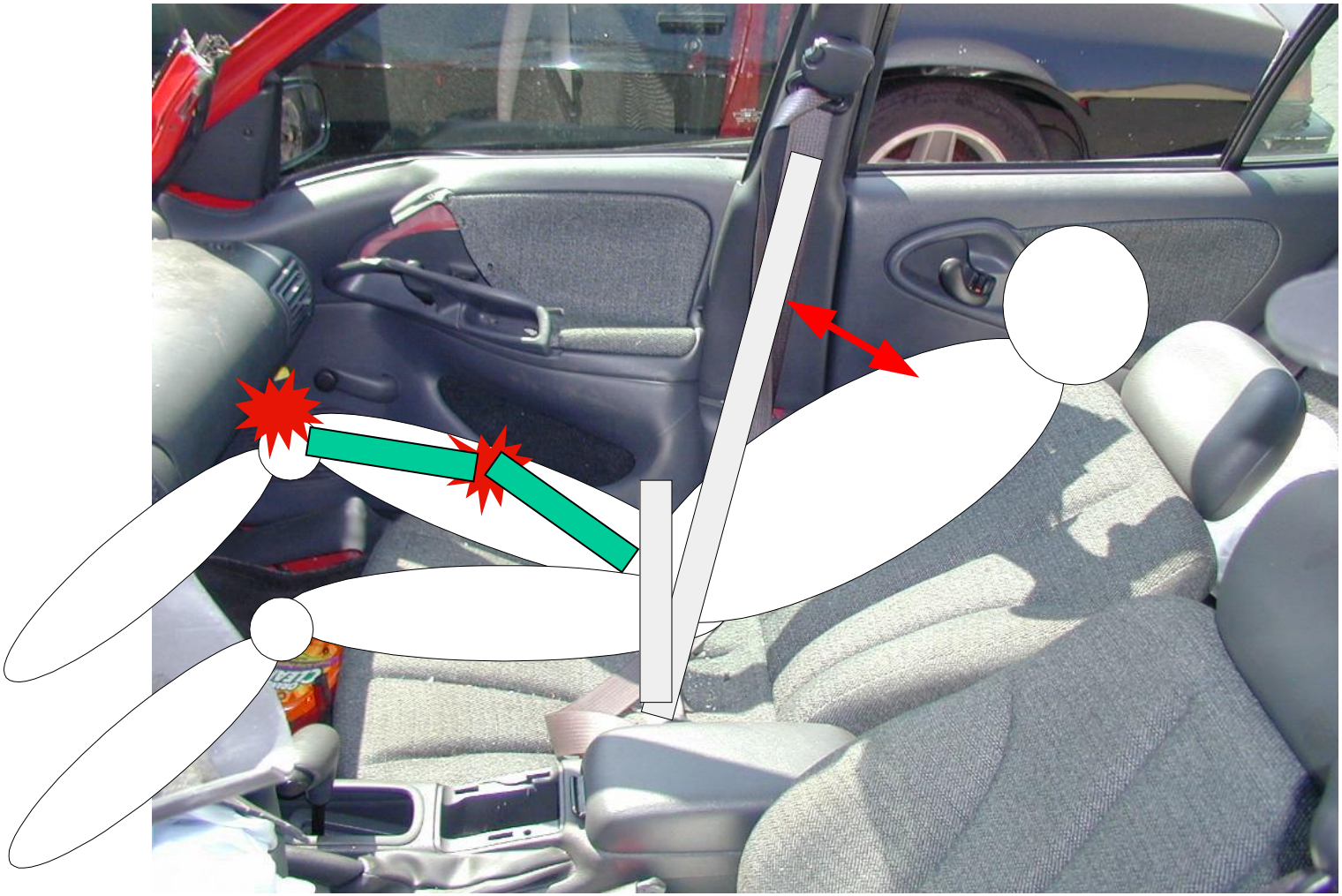
# Seatback Recline

## Case Review 1 – Occupant Kinematics



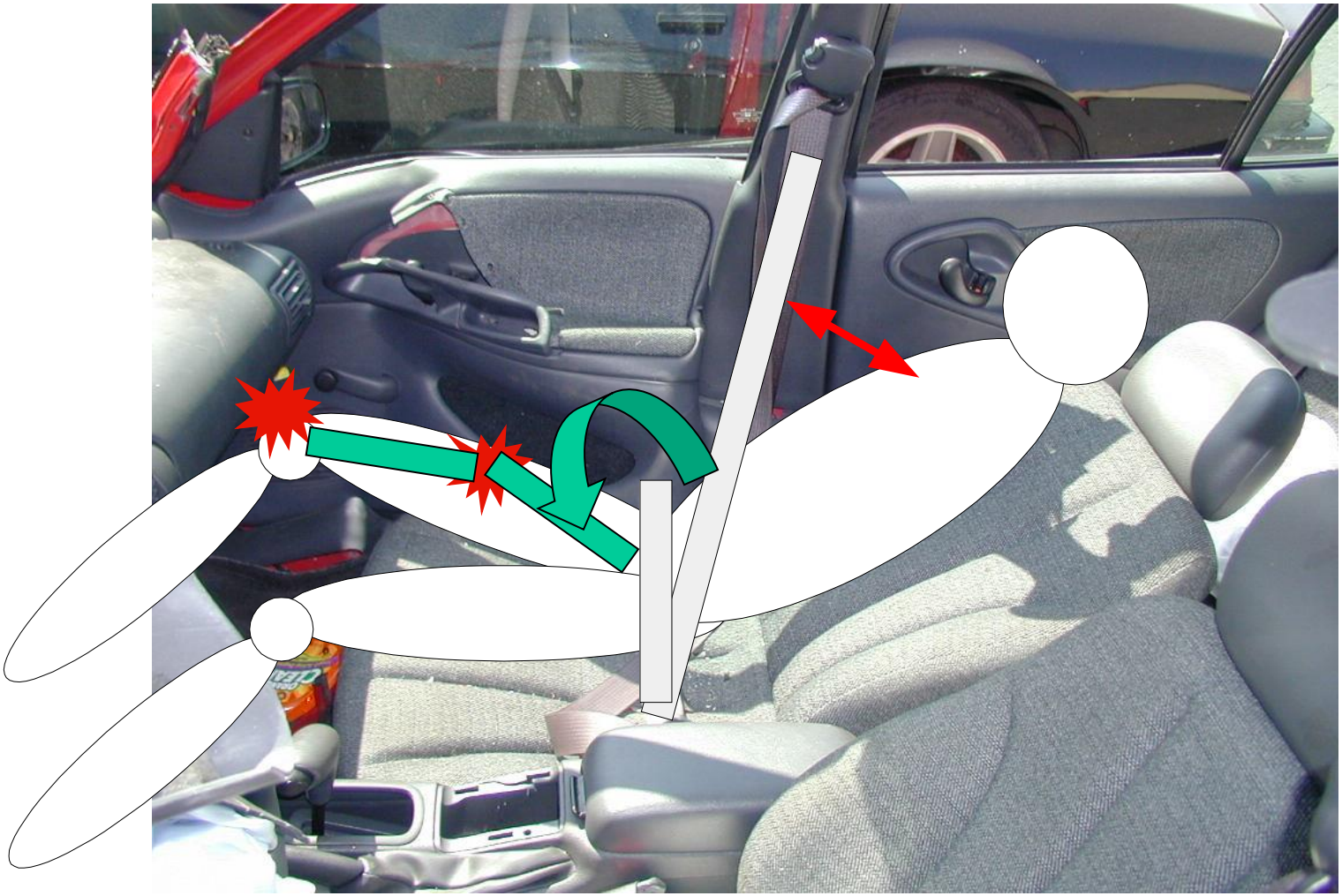
# Seatback Recline

## Case Review 1 – Occupant Kinematics



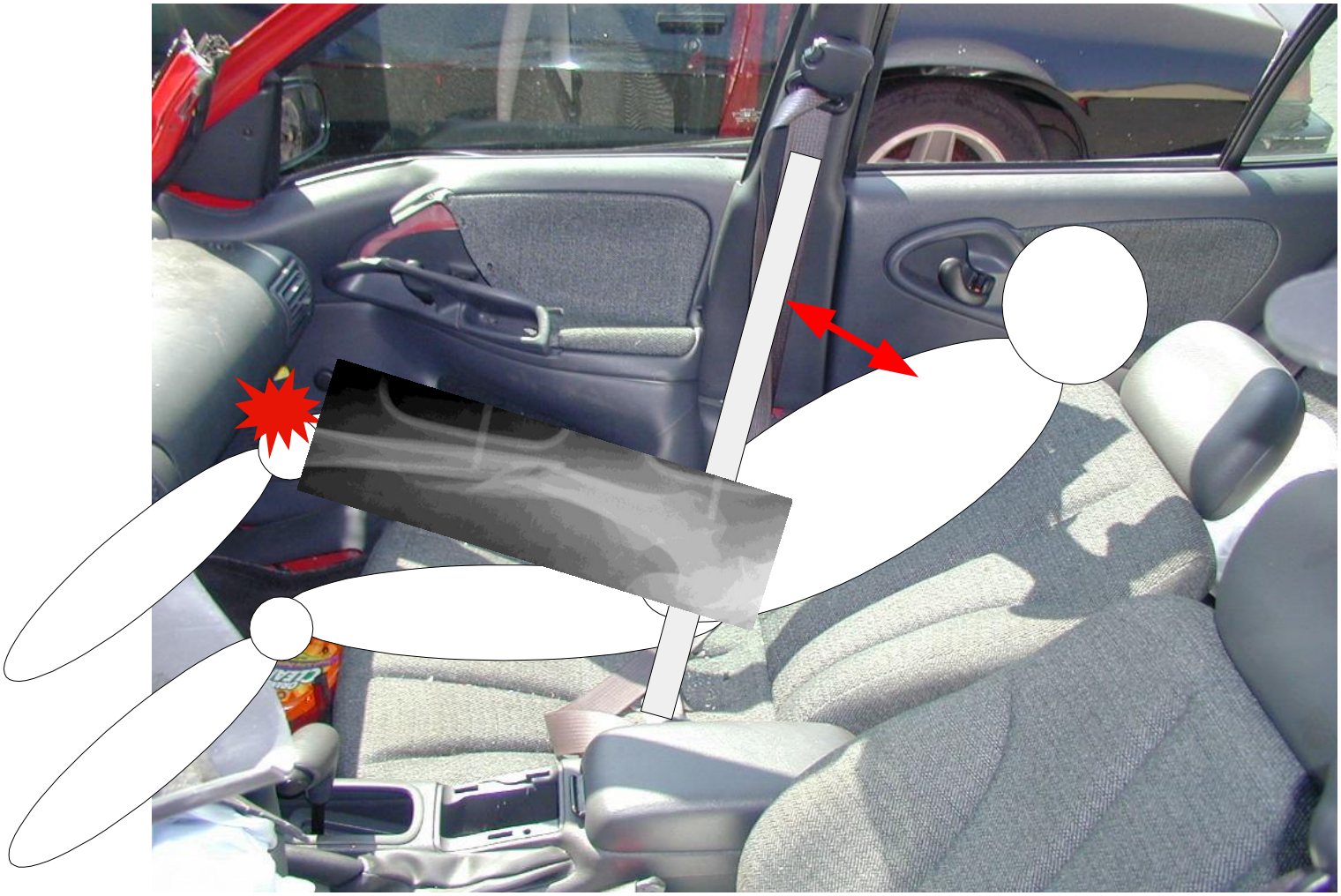
# Seatback Recline

## Case Review 1 – Occupant Kinematics



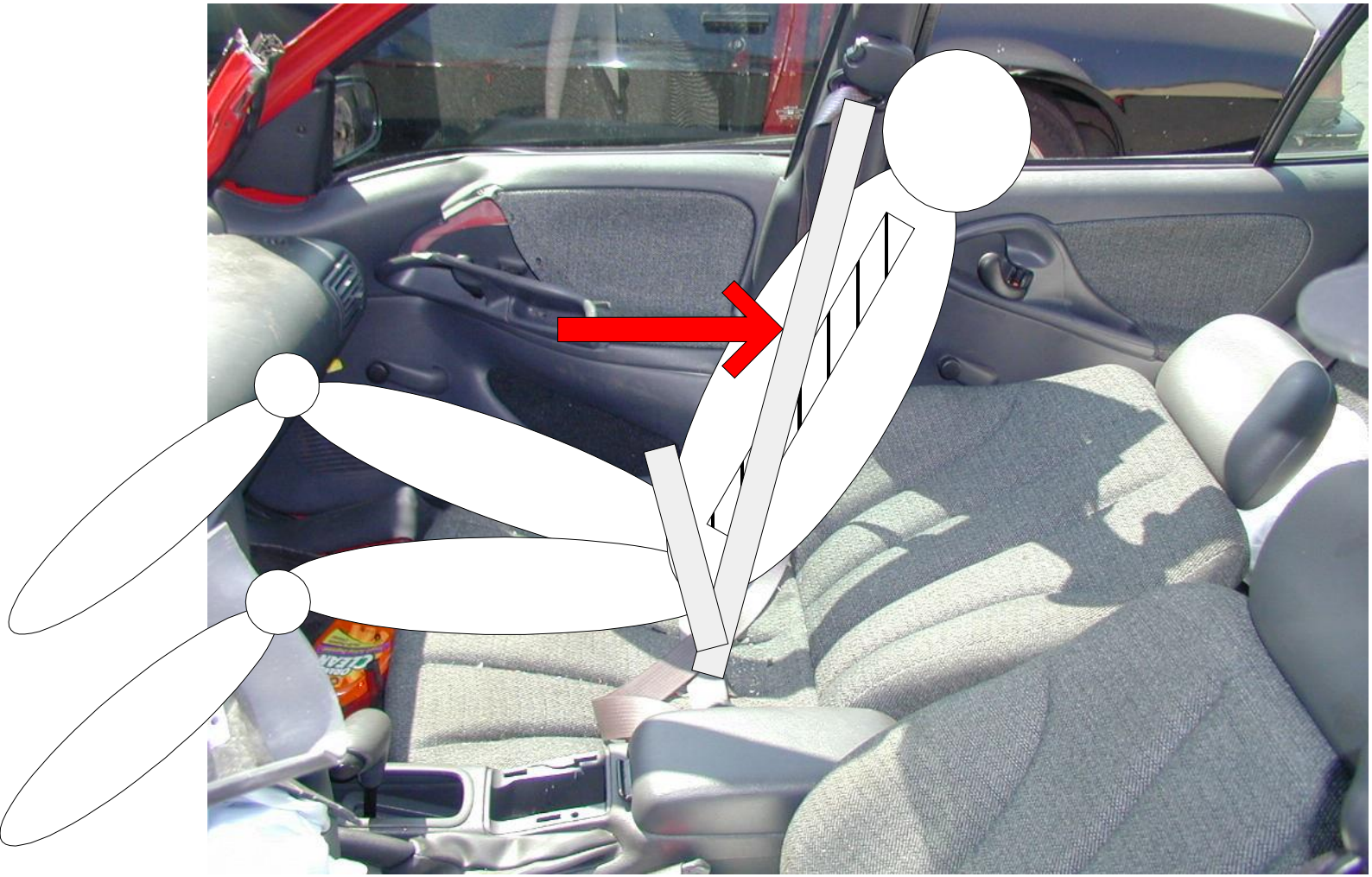
# Seatback Recline

## Case Review 1 – Occupant Kinematics



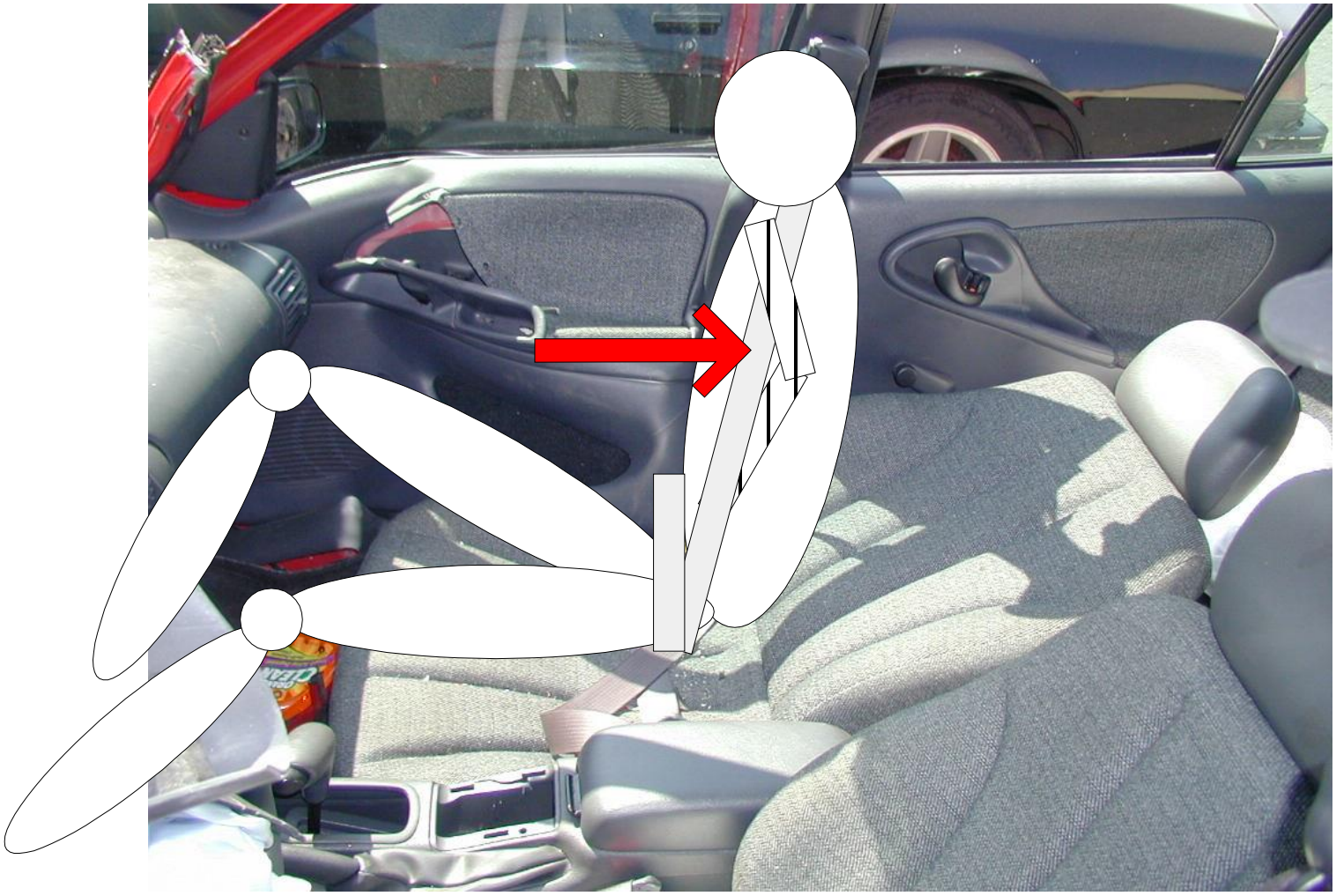
# Seatback Recline

## Case Review 1 – Occupant Kinematics



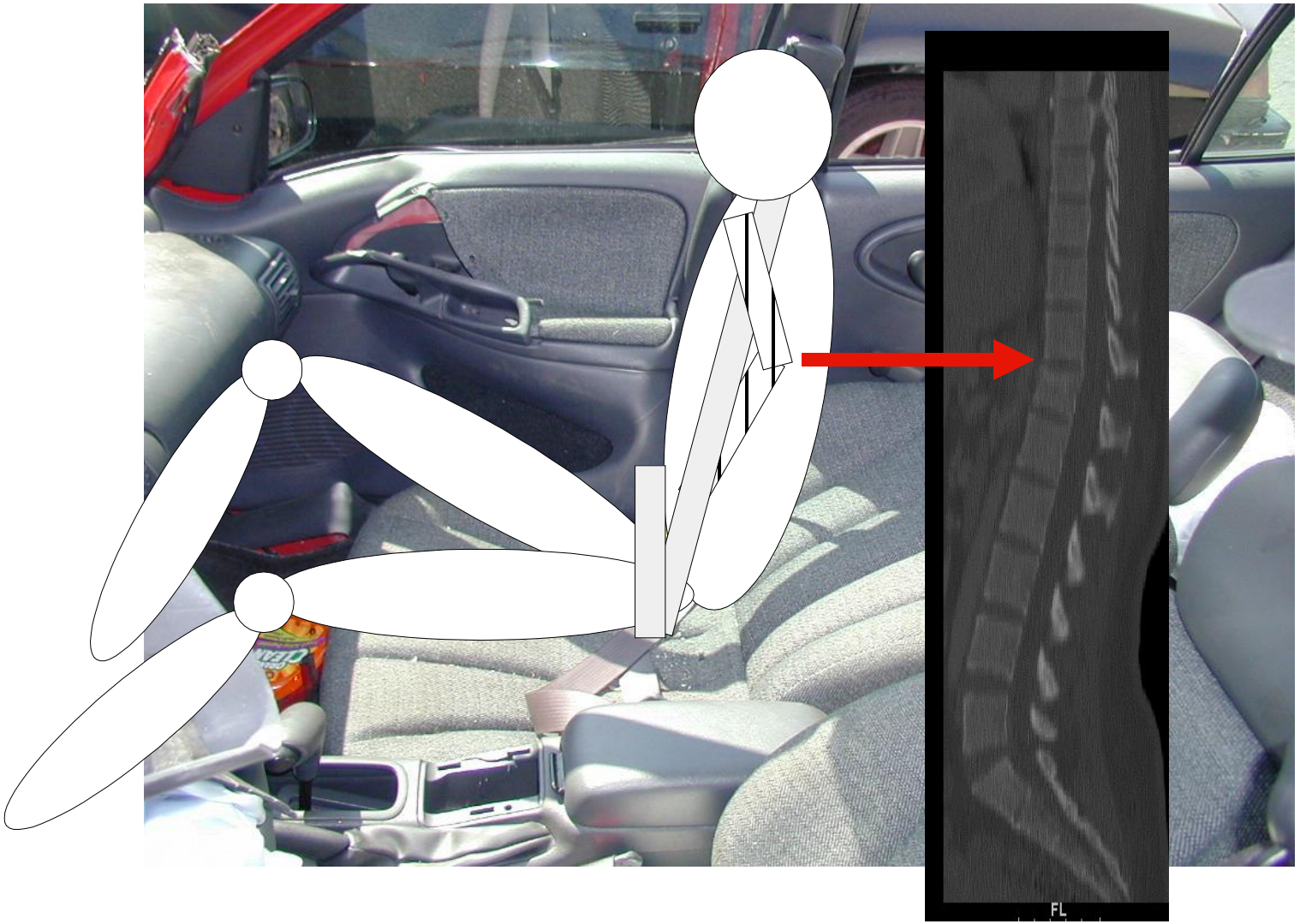
# Seatback Recline

## Case Review 1 – Occupant Kinematics



# Seatback Recline

## Case Review 1 – Occupant Kinematics



T12 Vertebral Body

# Rollovers and Roof Intrusion

# Spinal Cord Injuries and Mortality Associated with Rollover Collisions

Burns S, Mack C, Kaufman R, Bulger E. "Cost Of Spinal Cord Injuries Caused By Rollover Automobile Crashes." *Injury Prevention* 2010;16:74-78.

Mandell S, Kaufman R, Mack C, Bulger E. "Mortality and Injury Patterns Associated with Roof Crush in Rollover Crashes" *Accident Analysis and Prevention* –(2010), doi:10.1016/j.aap.2010.02.013

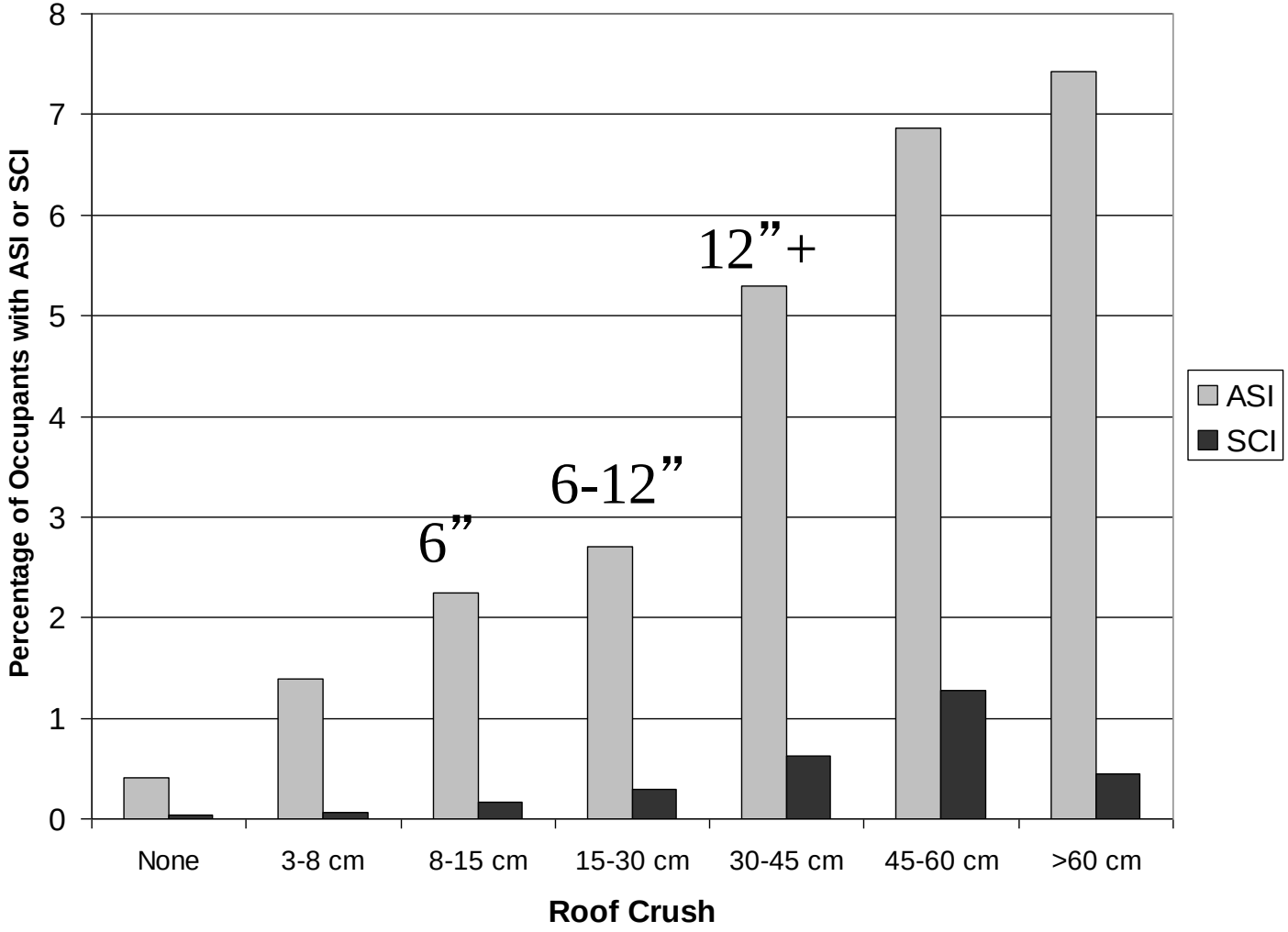
# Rollovers and Body Type

| Rollover Type | Car/Van/Other (%) | SUV/Pickup (%) |
|---|---|---|
| None | 95.03 | 81.60 |
| 1/4 turn | 0.77 | 4.06 |
| 1/2 turn or greater | 4.20 | 14.34 |

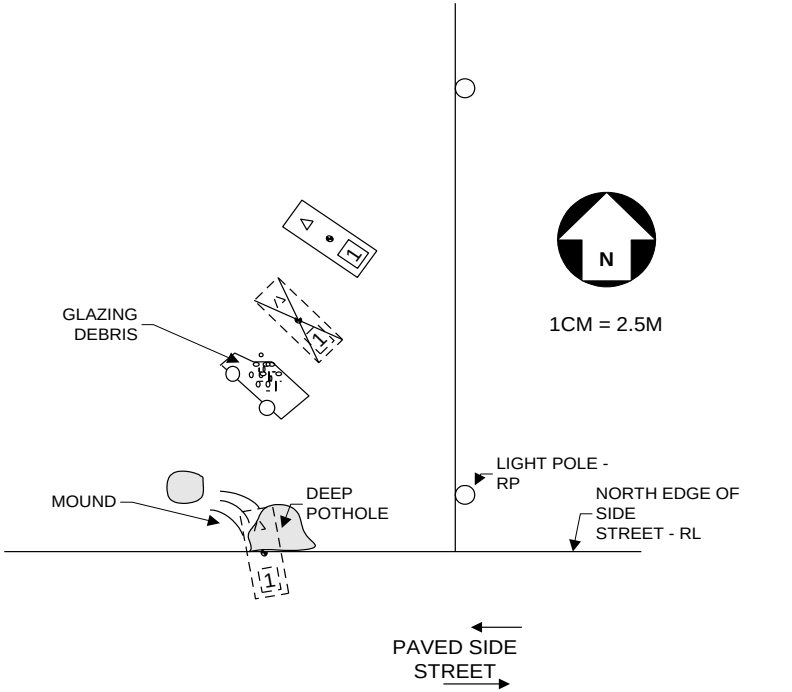
LTV body types were 3.7 times more likely to experience any degree of a rollover (1/4 turn or greater)

Source: NASS-CDS

# Roof Crush and ASI-SCI



# Rollover CIREN Case Reviews with ASI-SCI



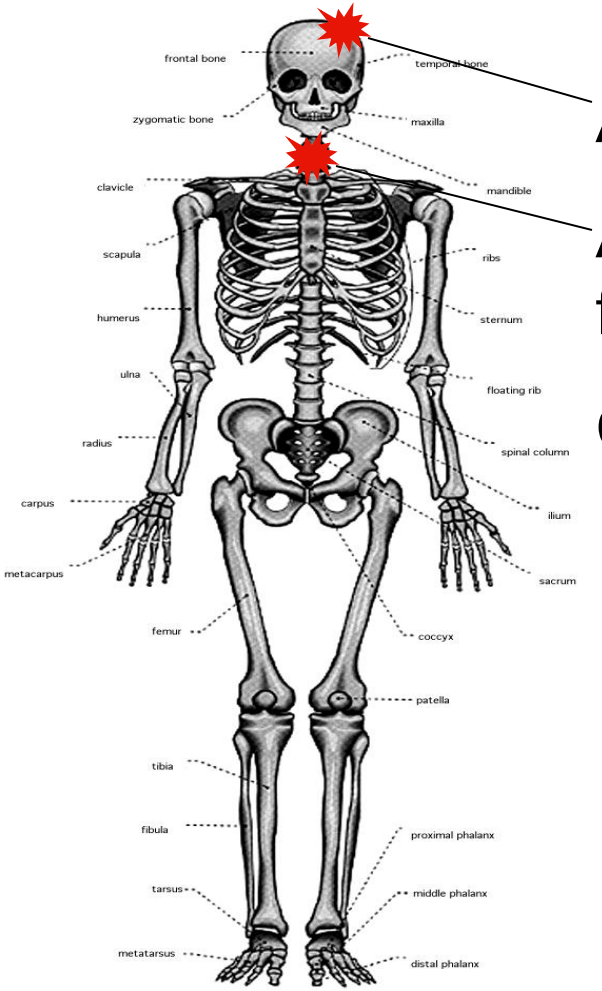

2000 Chevrolet Trail Blazer

Front Right Passenger

Lap/shoulder restrained

21 yr. – Male 6’, 175lbs

# Injuries

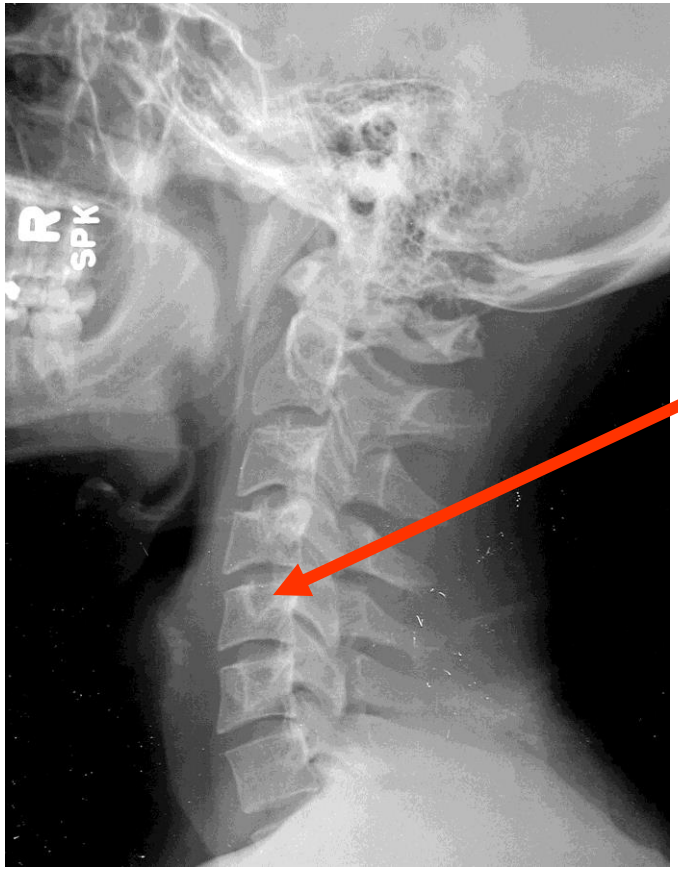


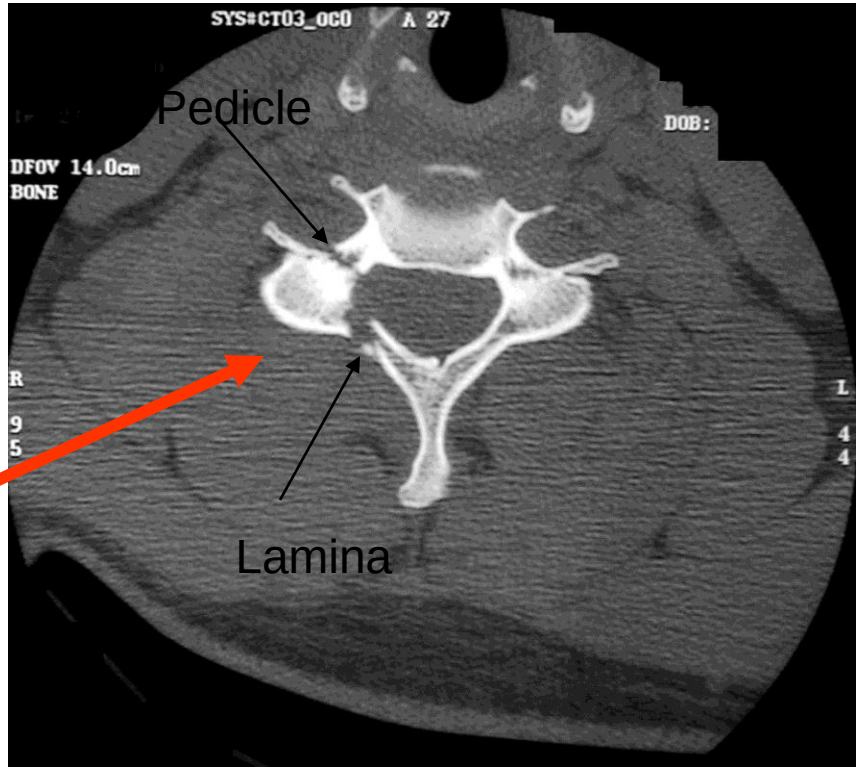

AIS 2 – Complex left scalp laceration

AIS 4 – Incomplete cord contusion and fractures

C5 Lamina and Pedicle Fractures

# C-spine Fractures

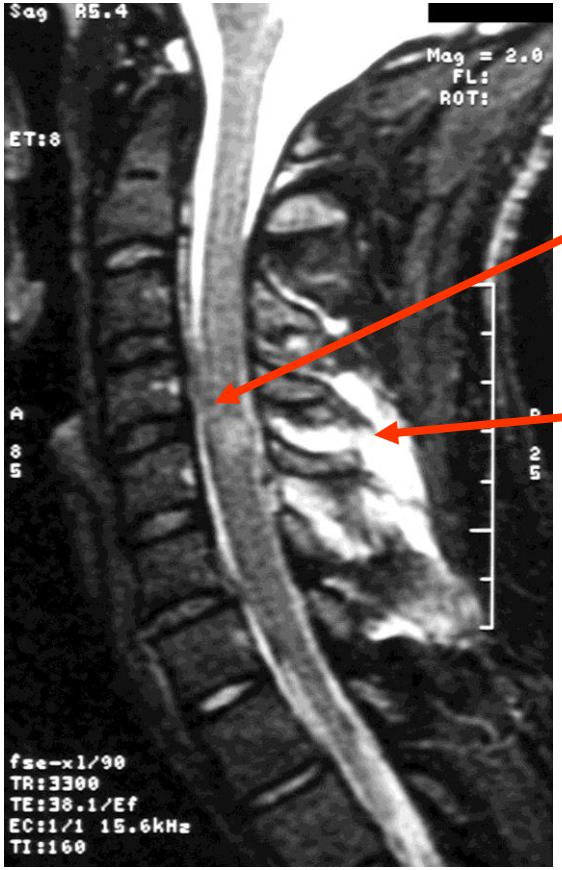



C5 Lamina, Pedicle fx

Compression Lateral bending to R

# Incomplete SCI -Cord Contusion



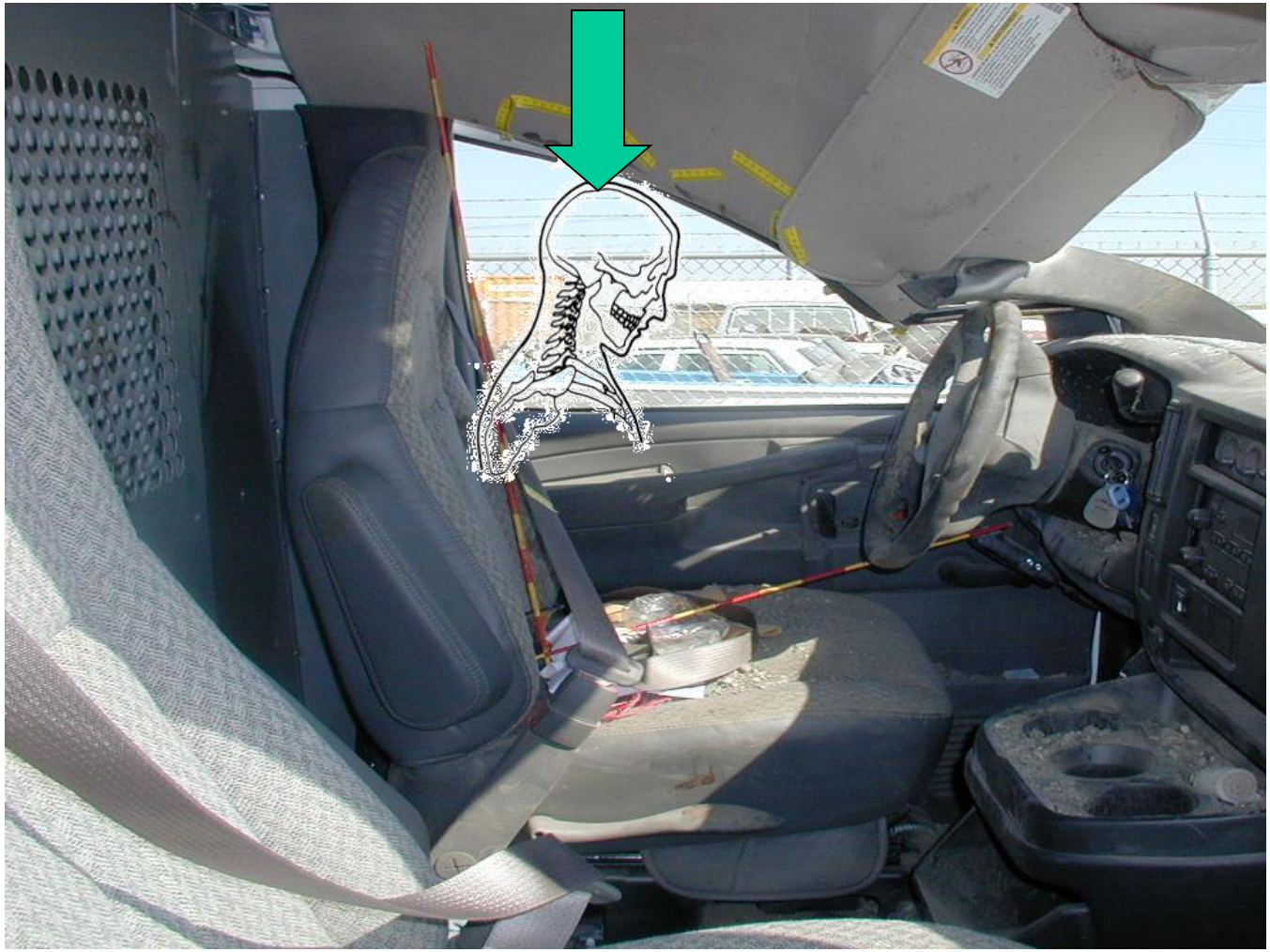

Cord Contusion Echoes

Posterior soft tissue edema

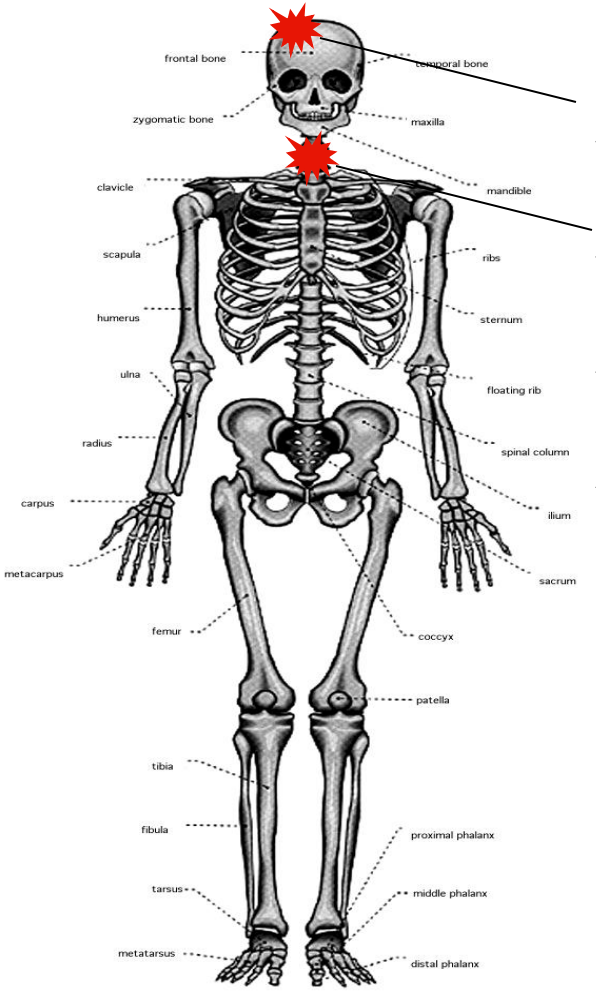
# Roof Crush and Intrusion

40 CM roof Intrusion into driver position

# Compression- Flexion



# Injuries



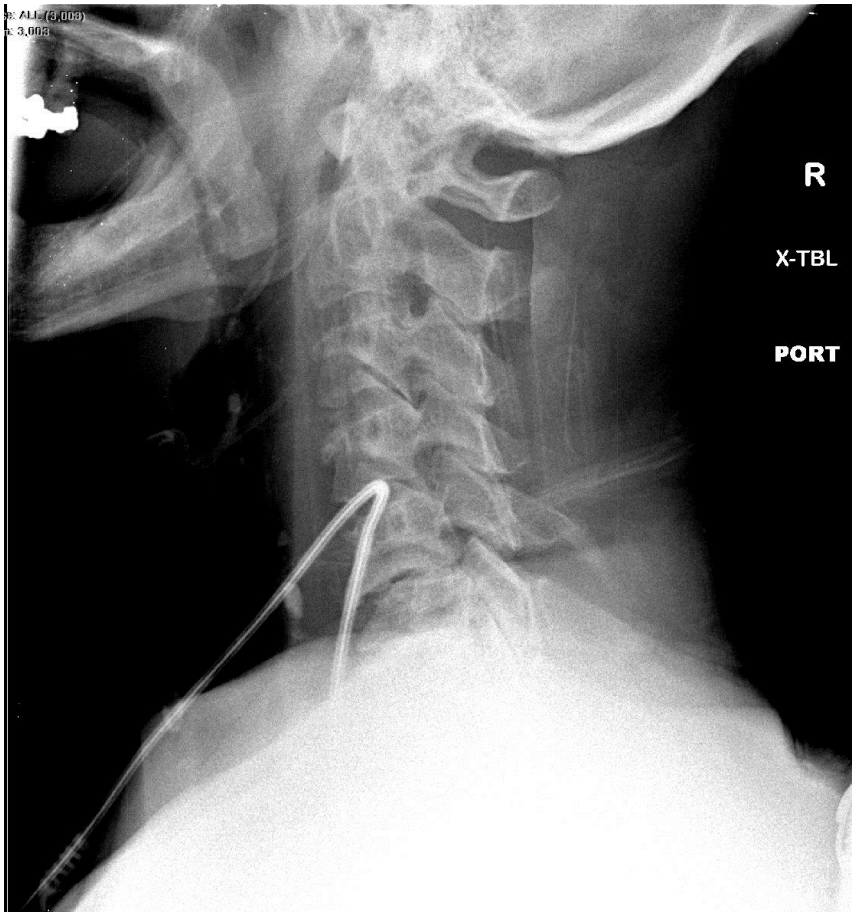

AIS 1 – Scalp abrasion,laceration

AIS 3 – C5-C6 dislocation

AIS 3 – C5 lamina fracture

AIS 3 – C4 and C6 TP fractures

# Radiology



# Summary

- Side Impact
  - Door intrusion reflects injury patterns
  - Raised center console: bilateral pelvic fractures
  - Side airbags protective
  - Children greater risk TBI Booster seats are key
- Frontal Impact
  - Restraint systems critical
  - Knee-Hip-Thigh loads
  - Toe pan intrusion

# Summary

- Rollovers
  - Intrusion associated with head/neck injuries
- Other factors associated with injury
  - Consider loose cargo
  - Other unrestrained passengers
  - Seatback intrusion
  - Seat position: reclined is bad

# Questions?