

# Biomechanics and Medical Diagnosis of HVI in Adults and Children – An Illustration of the CIREN Model



INOVA REGIONAL  
TRAUMA CENTER

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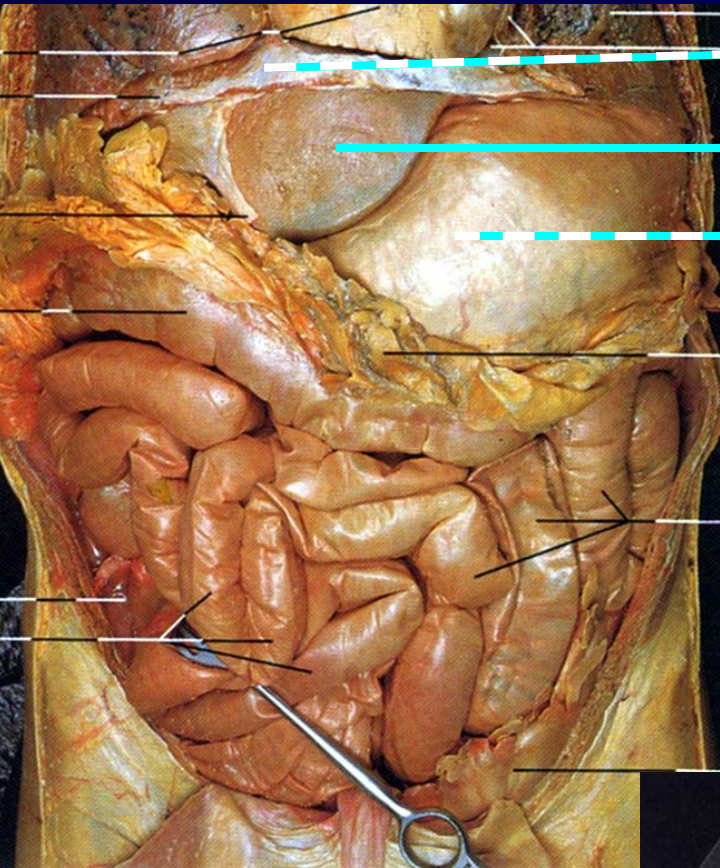
University of  
Virginia

# Introduction

- HVI – Hollow Viscous Injury
- Complicated diagnosis and treatment
- Common injury in automobile crashes
- Children at risk due to smaller anatomy



# Abdominal Anatomy



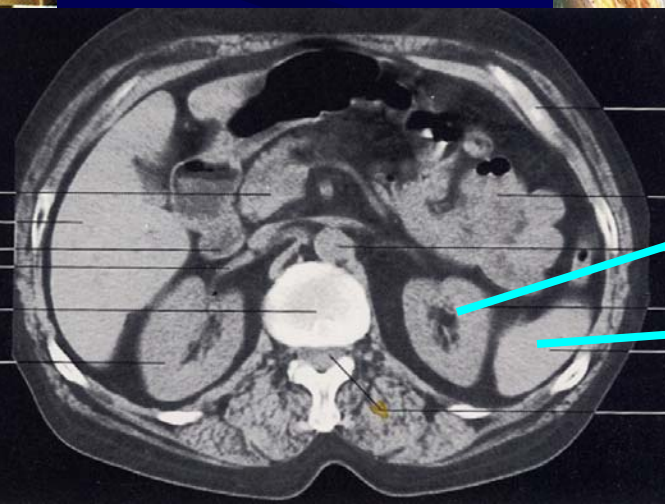
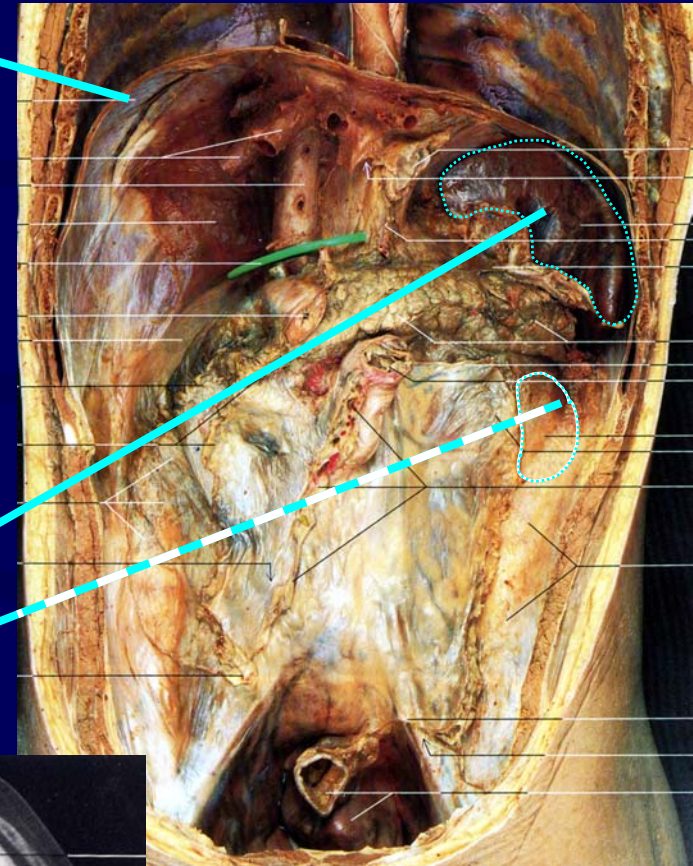
Diaphragm

Liver

Stomach

Spleen

Kidney



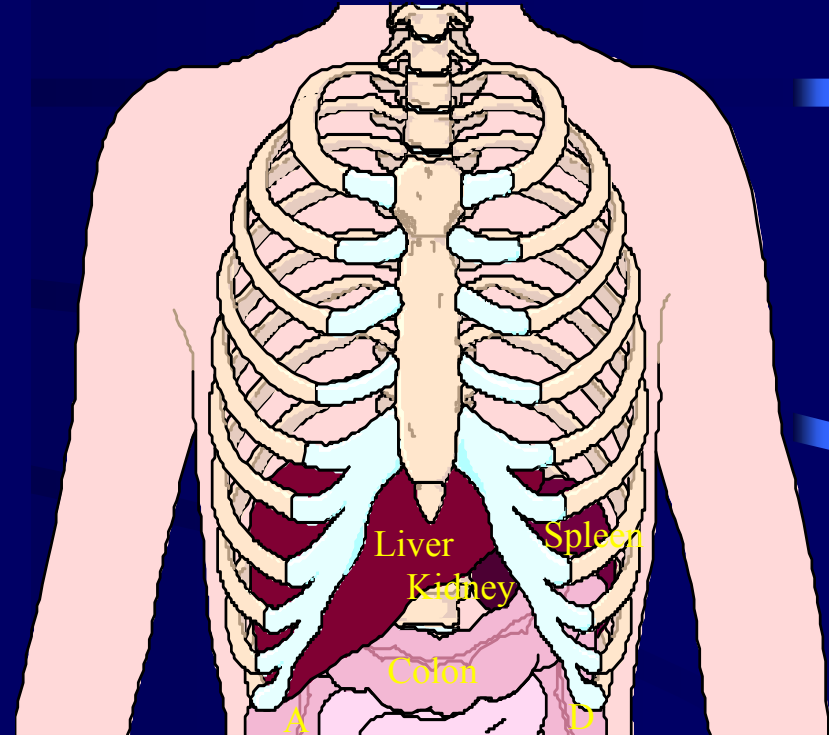
Kidney

Spleen



# Abdominal “Solid” Organs

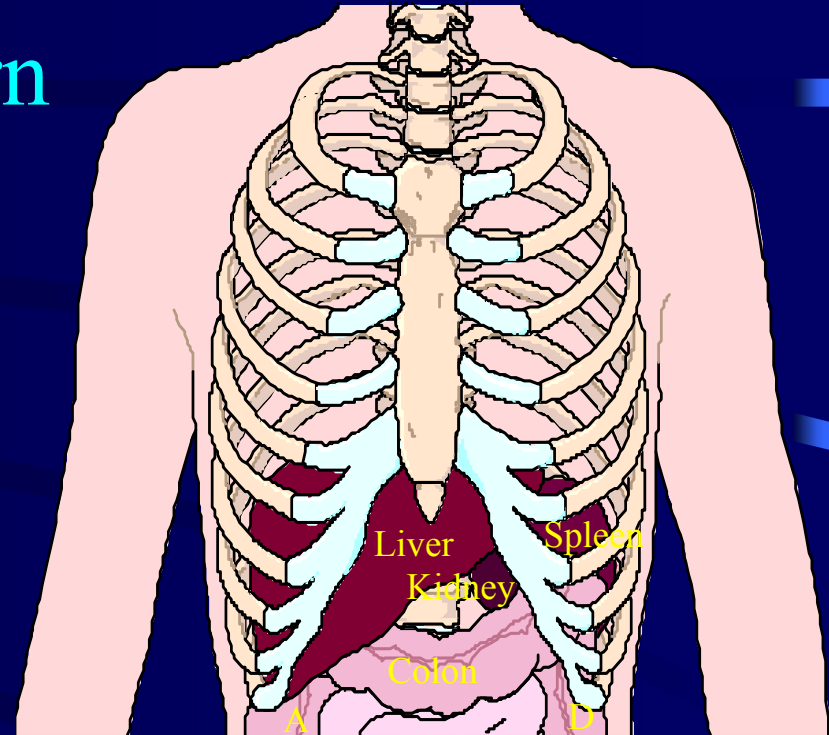
- Liver - 27% of total blood flow
- Spleen- 5% of total blood flow
- Kidneys - 22% of total blood flow
- Pancreas
- Adrenal Glands



# Abdominal “Solid” Organs

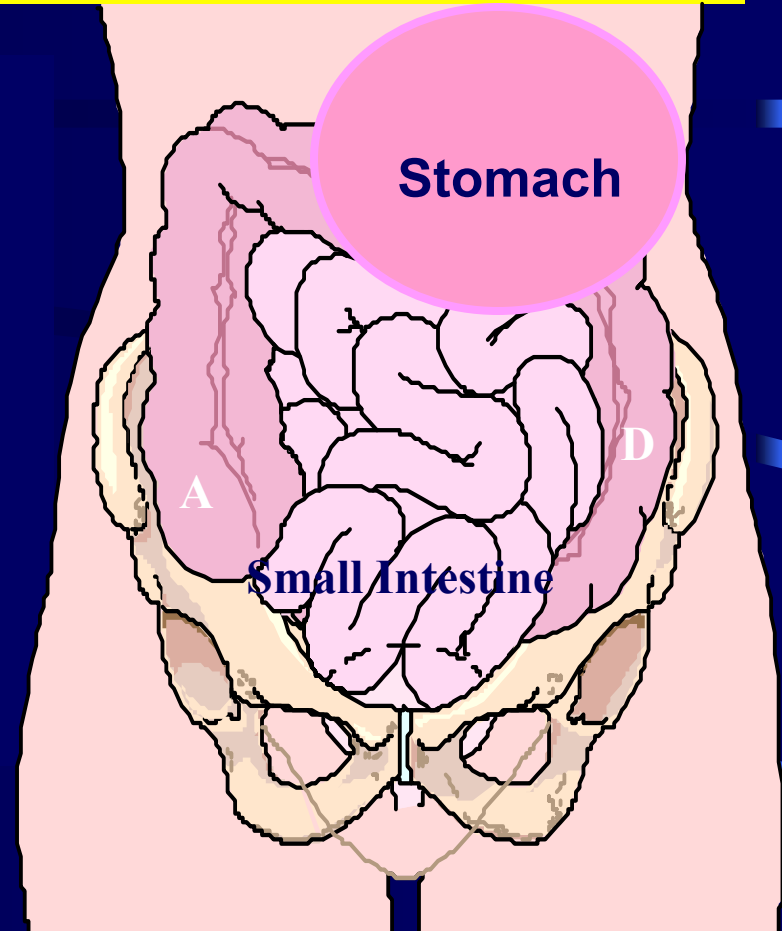
Primary Injury Concern  
Hemorrhage

Diagnosis  
Accurate




# Abdominal “Hollow” Organs

- Stomach
- Small Intestine
  - Duodenum, Jejunum, Ileum
- Large Intestine
  - Ascending, Transverse,
  - Descending, Sigmoid
- Gall Bladder
- Urinary Bladder

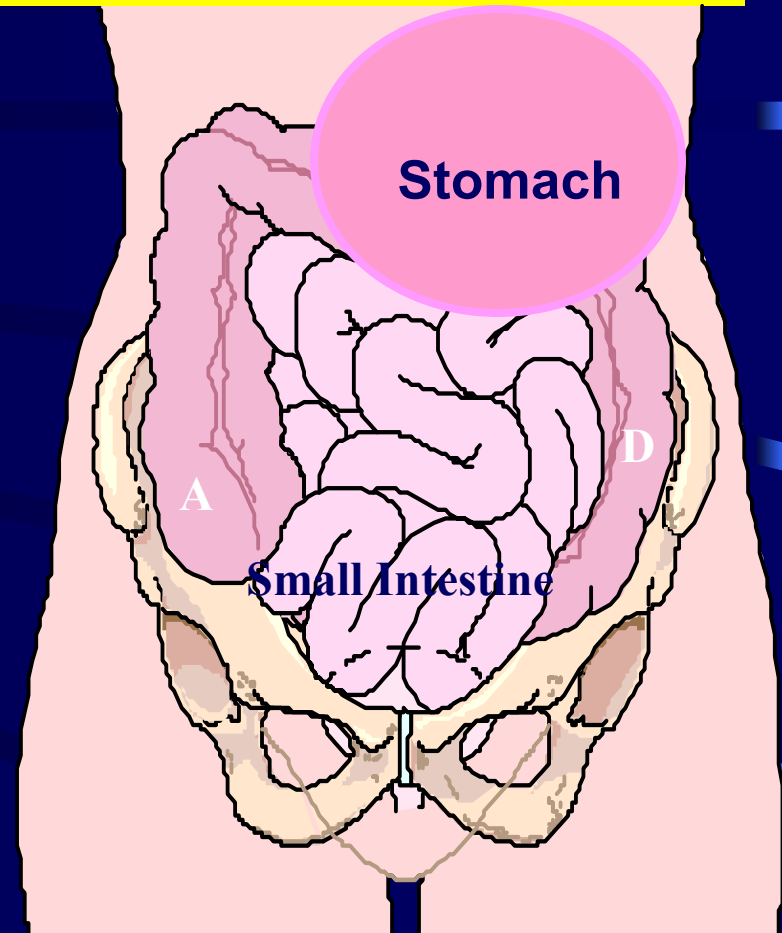


# Abdominal “Hollow” Organs

Primary Injury Concern:  
Spillage of Contents

 Sepsis

Diagnosis  
Inaccurate



# HVI Issues

- Trauma surgeons are increasingly managing blunt abdominal trauma non-operatively
- Intestinal injuries that were previously discovered at laparotomy for solid organ injuries may be missed with non-operative management
- In older reports, delays in diagnosis of less than 12-24 hours were associated with limited morbidity and no mortality
- Longer delays result in significantly increased morbidity and mortality



# Surgeon's Dilemma

- There is no well-publicized consensus among trauma surgeons as to the optimal way to diagnose occult intestinal injury
- Debate over using exploratory surgery as a diagnostic tool focuses on whether or not the risks associated with a non-therapeutic laparotomy outweigh the morbidity and mortality associated with a delay in the diagnosis of small bowel injury

# **Diagnosis and Management of Blunt Small Bowel Injury: A Survey of the Membership of the American Association for the Surgery of Trauma**

**Brownstein, Bunting, Meyer, Fakhry**

**University of North Carolina, Chapel Hill, NC  
and the Inova Regional Trauma Center,  
Falls Church, VA**

# Conclusions

Significant variation exists in the diagnostic approach

- Surgeons underestimated the morbidity of non-therapeutic laparotomy and the mortality associated with a delay in diagnosis
- The lack of consensus regarding the diagnostic approach may have undesirable effects on injured patients

# **Hollow Viscous Injury and Small Bowel Injury in Blunt Trauma:**

*An analysis of 275,557 trauma admissions from the EAST Multi-Institutional Trial*

**EAST Multi-Institutional  
HVI Research Group**

*Watts DD, Fakhry SM et al. J of Trauma, 54:289-294, 2003*

# Conclusions

- Motor Vehicle Crashes (MVC) was the most frequent mechanism of injury in patients with perforating SBI
- Logistic regression models of CT data yielded no useful discriminators in predicting SBI
- Patients from MVCs had a relative risk (RR) of SBI of 1.7
- The non driver position increased the risk of perforating SBI (RR = 1.9, 95% CI 1.6-2.3)
- Use of a seat belt increased the risk of perforating SBI (RR = 2.4 , 95% CI 2.0-2.8)
- Delay in treatment of SBI injuries increased treatment complications



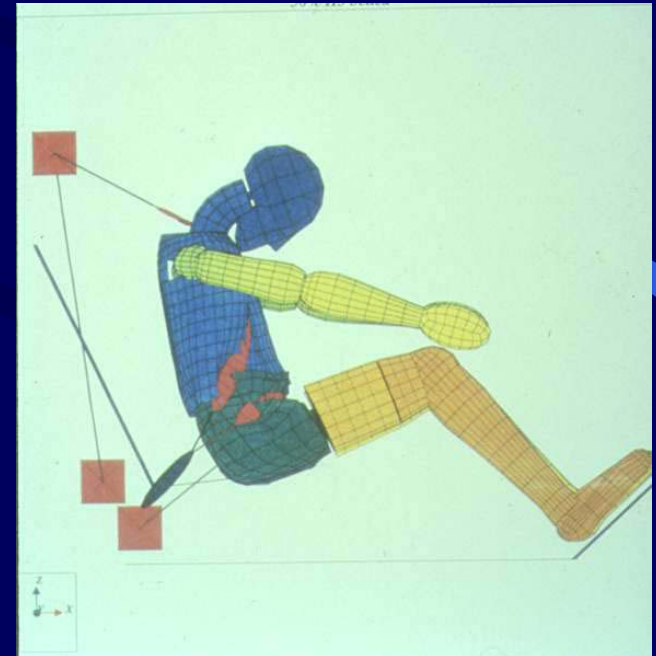
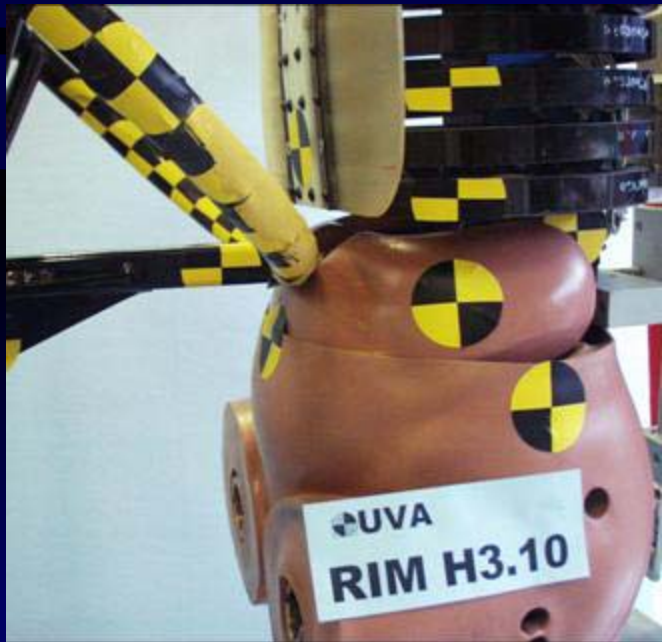
# Risk

The presence of an abdominal seatbelt mark was the most significant risk factor, carrying a 4.7 increase in relative risk (95% CI 3.7 - 5.9)



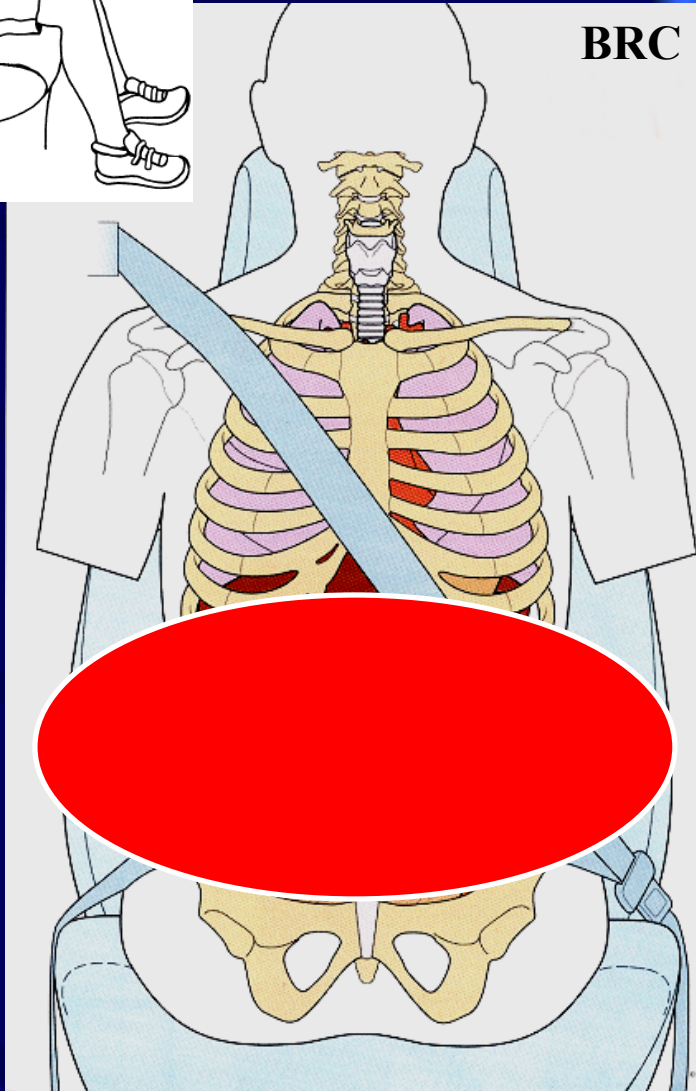
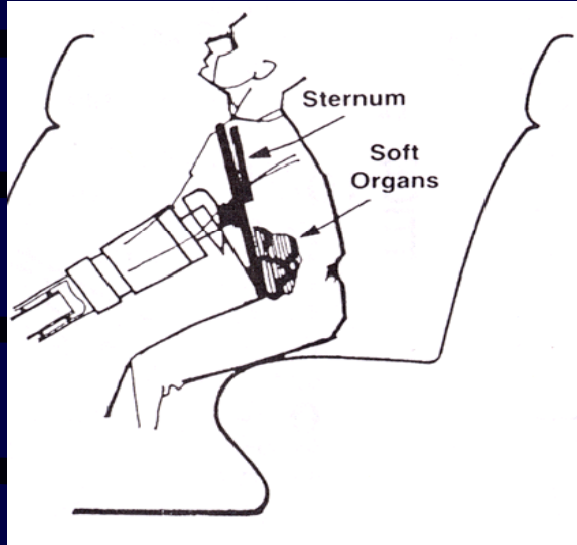
# Biomechanics Research

## Hollow Viscous Organs



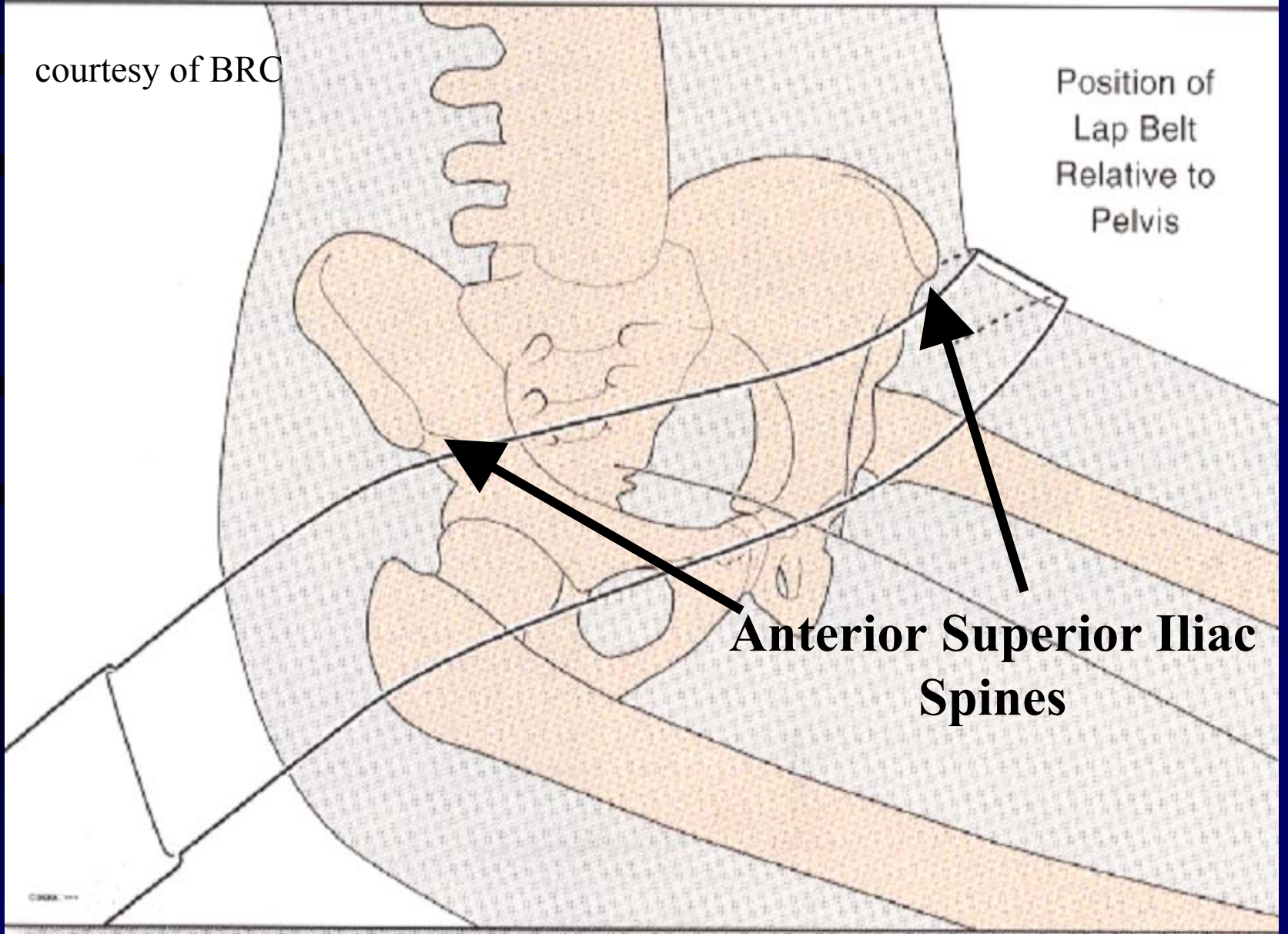
# Frontal Crashes

## Seatbelt, Steering Wheel



courtesy of BRC

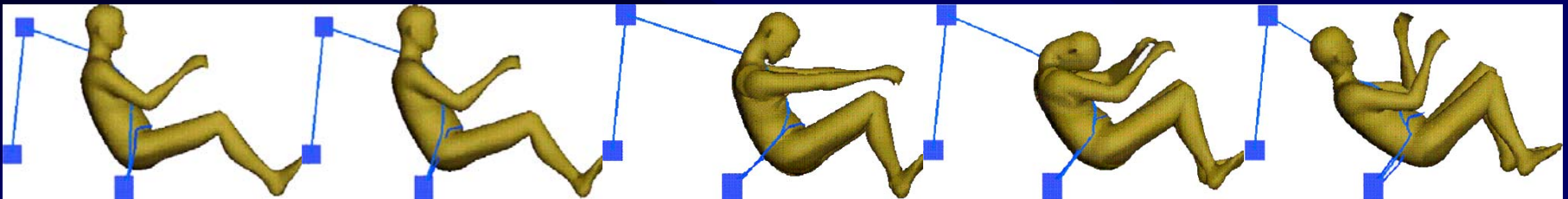
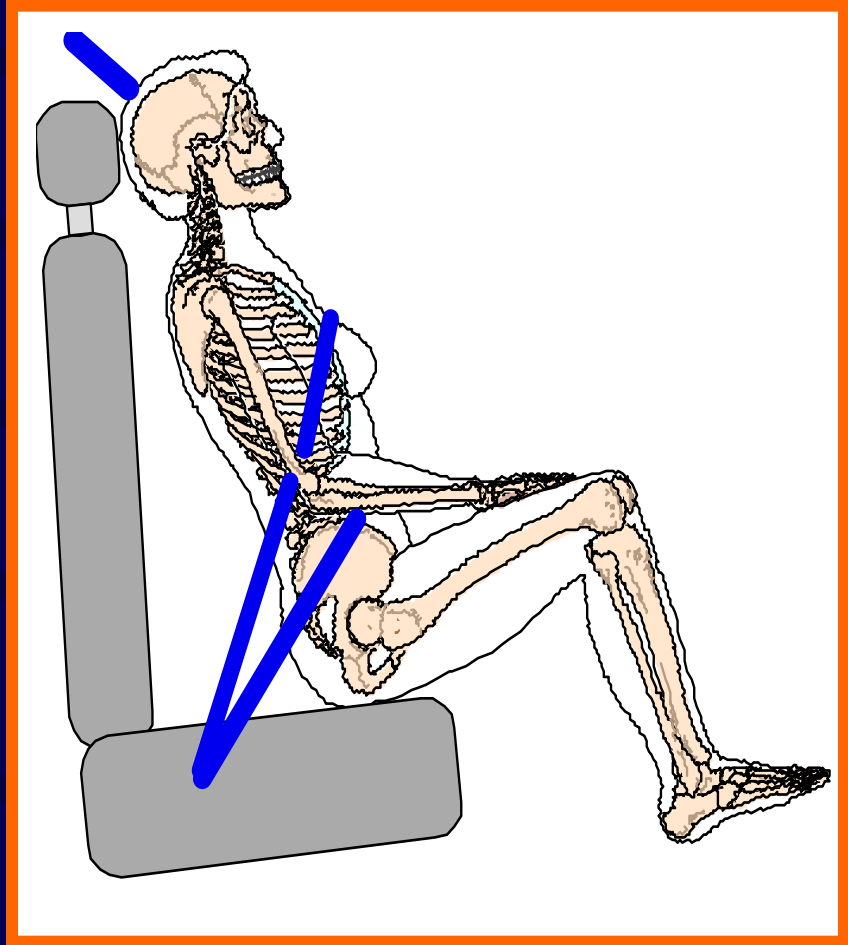
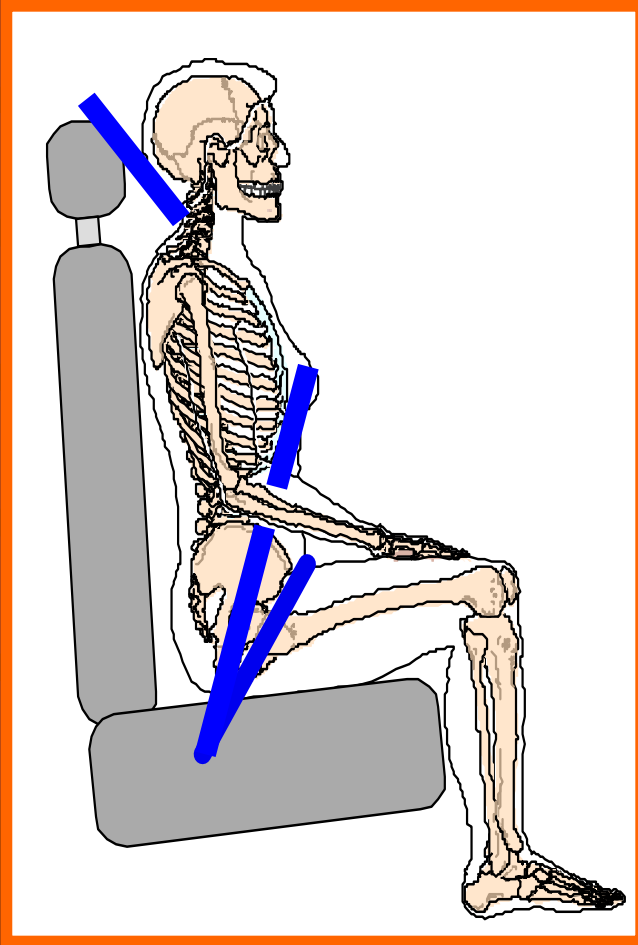
Position of  
Lap Belt  
Relative to  
Pelvis



**Anterior Superior Iliac  
Spines**



# Submarining



courtesy of ESI

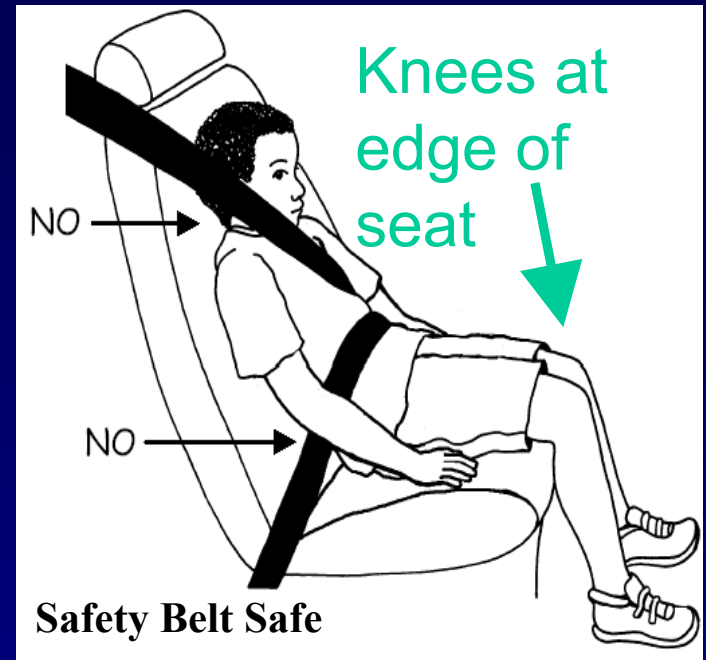




# Reasons for Booster Seats

## Practical concerns

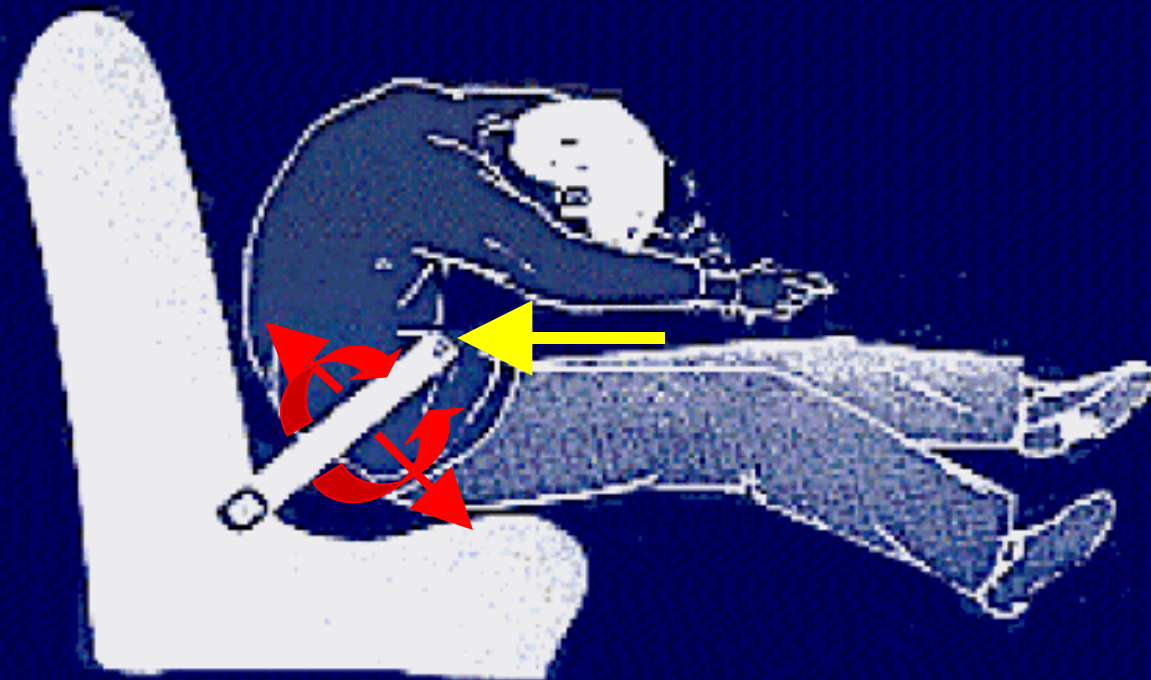
- Prevent slouching due to leg length
- Slouching degrades fit for both lap and shoulder belt
- Reduces misuse of shoulder belt



# Lap Belt Only – Seat Belt Syndrome

**HVI**

**Lumbar Spine**



Gumler et al., 1982

# Side Impact

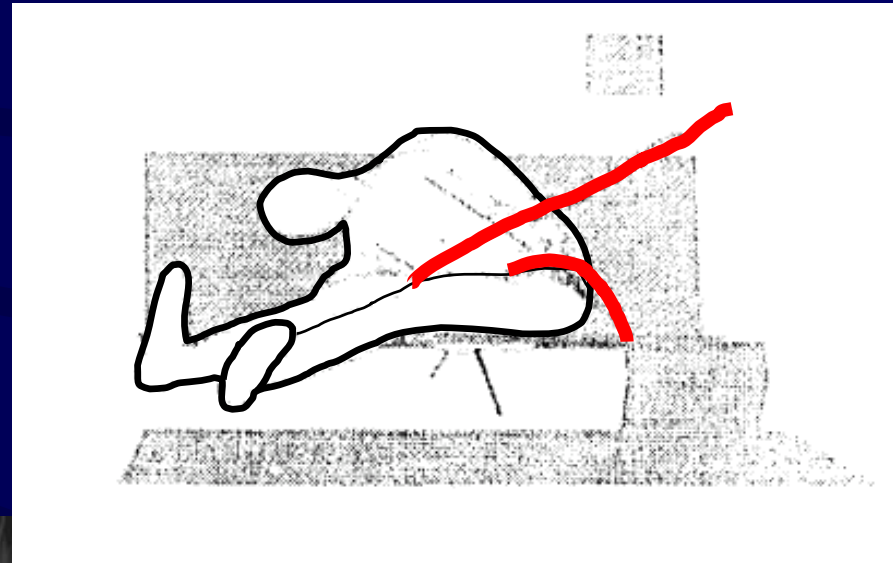
Near Side



Ruptured  
Bladder



Far Side



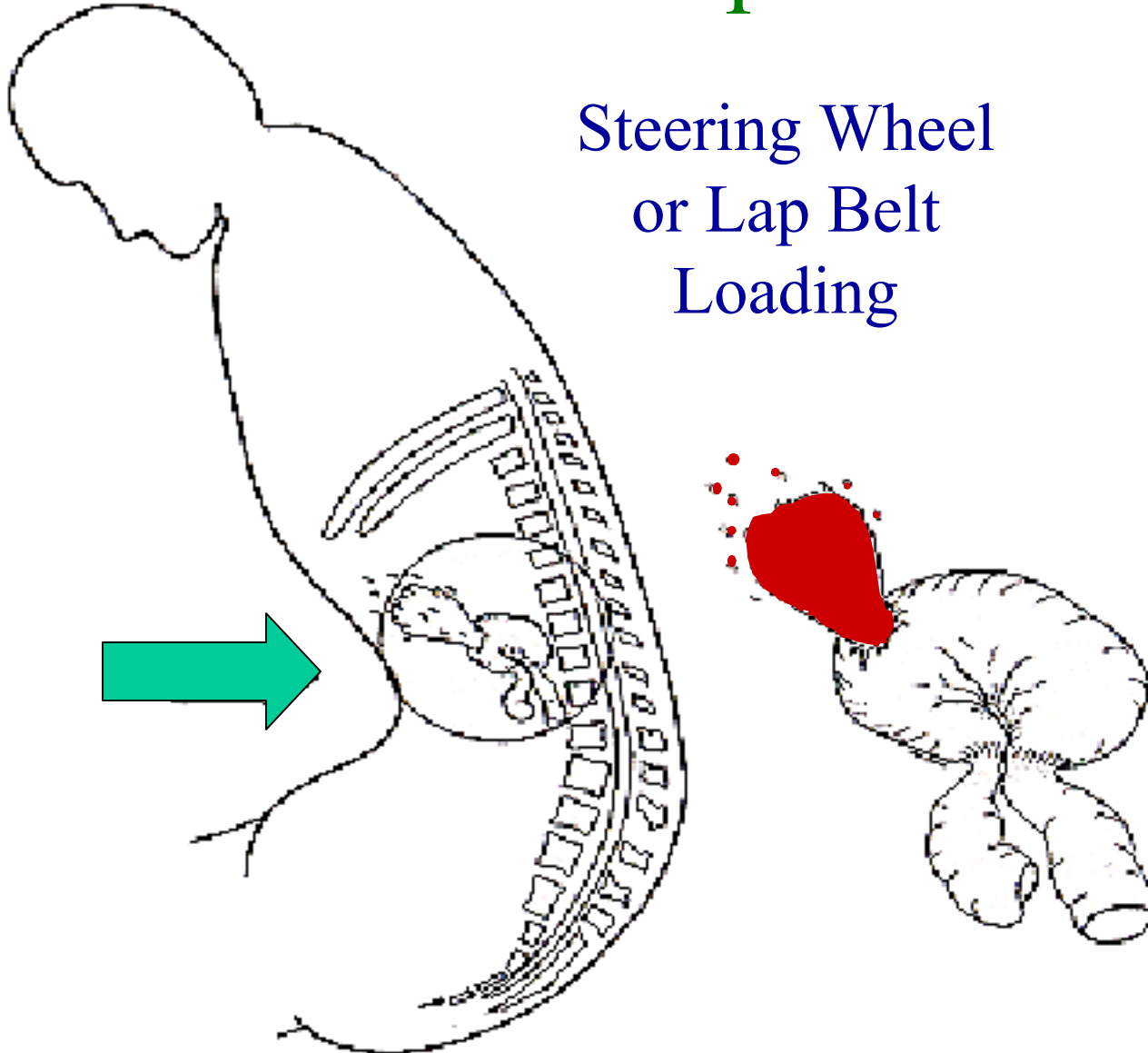
**Belt Loading**

Stolinski et al., 1998

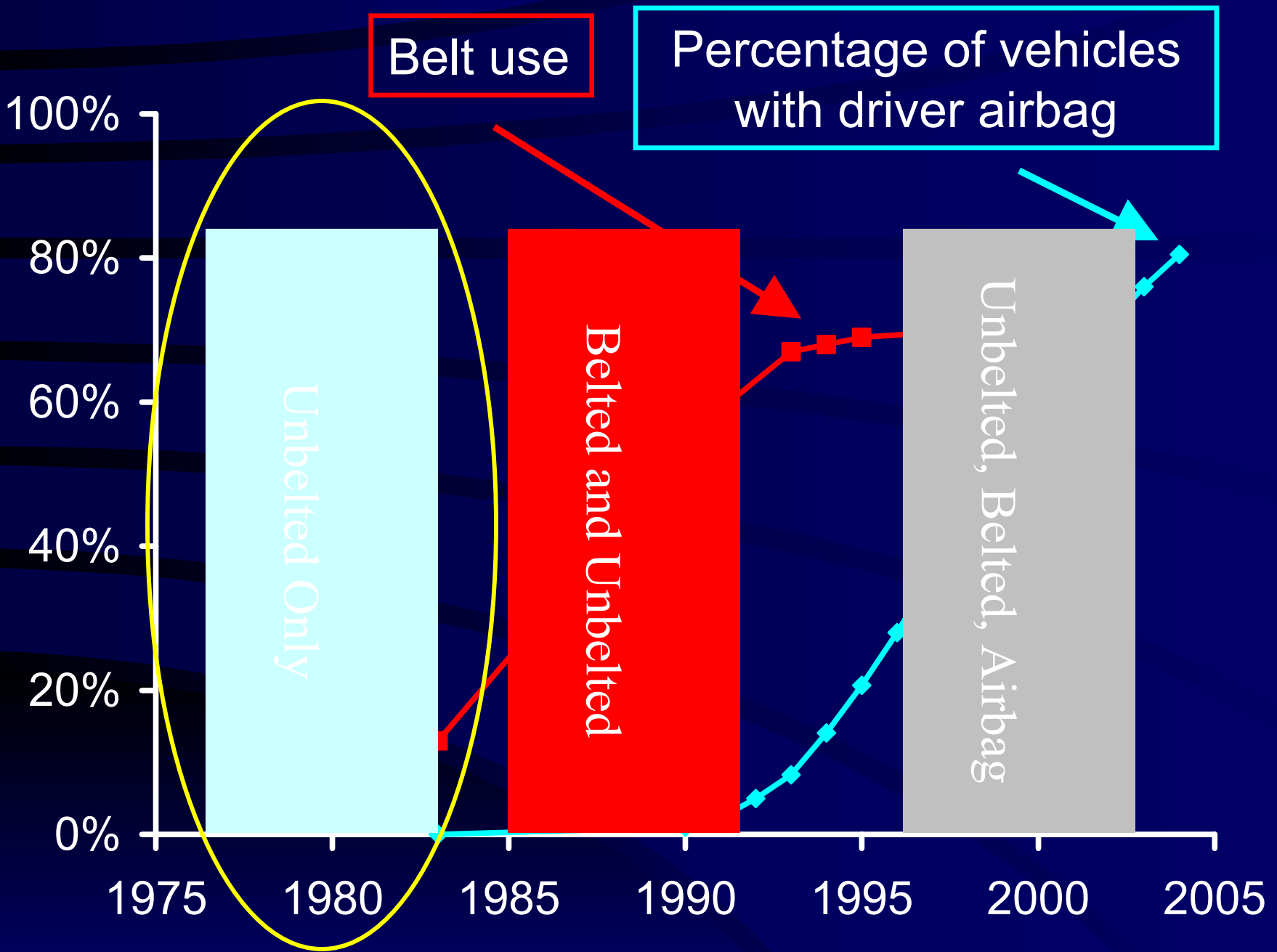
# Injuries

- Contusion, perforations, transections, lesions
- Mechanisms of Injury
  - Increased intraluminal pressure
  - Perforation from rib and pelvic fractures
  - Shearing or crushing against spine
  - Deceleration (relative motion from fixed attachments - mesentery)

# “Blowout” of Intestines caused by high intraluminal pressures







# AIS $\geq$ 2 Hollow Viscous Injury Sources - Frontal Impact

1977-1979

Front:

- Steering Assembly
- Instrument Panel

(52%)

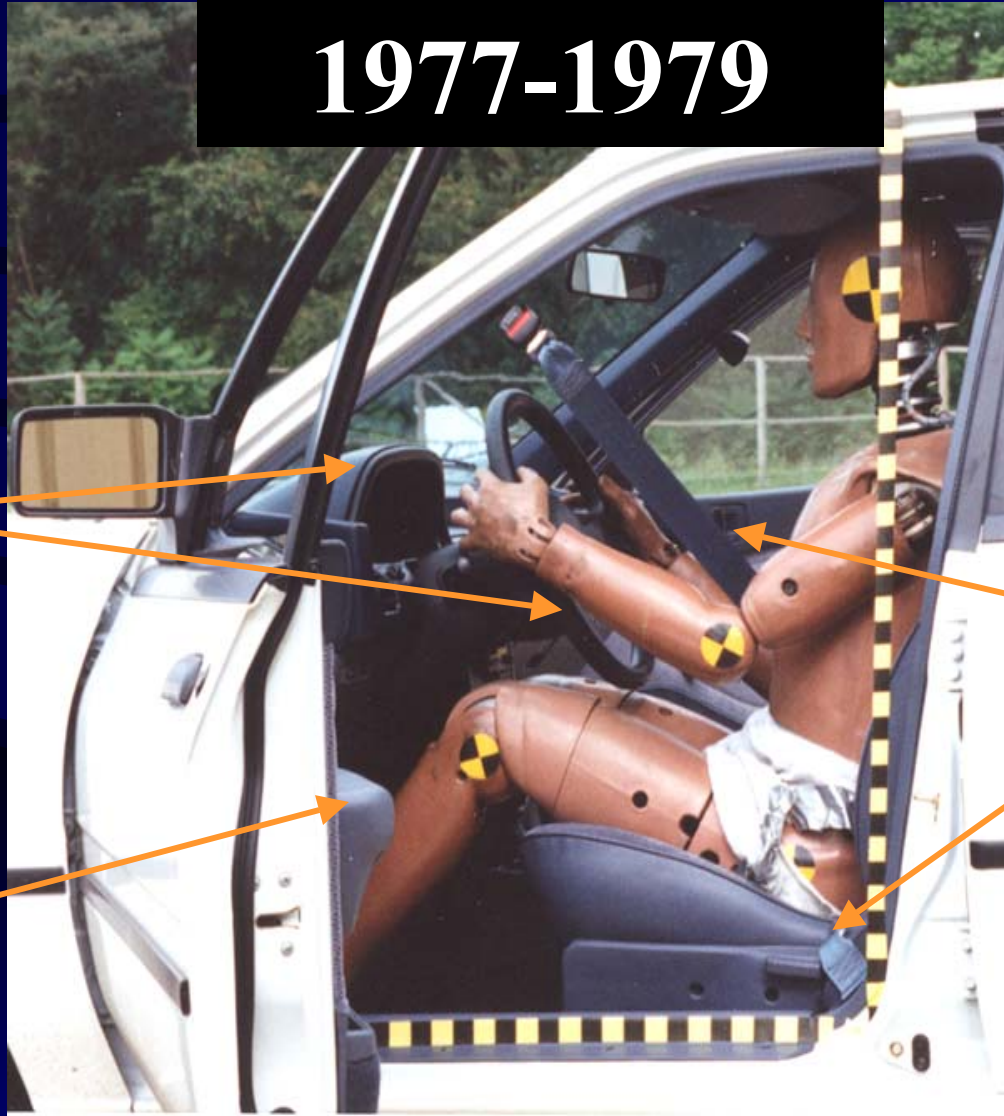
Side Interior:

- Surface
- Armrests

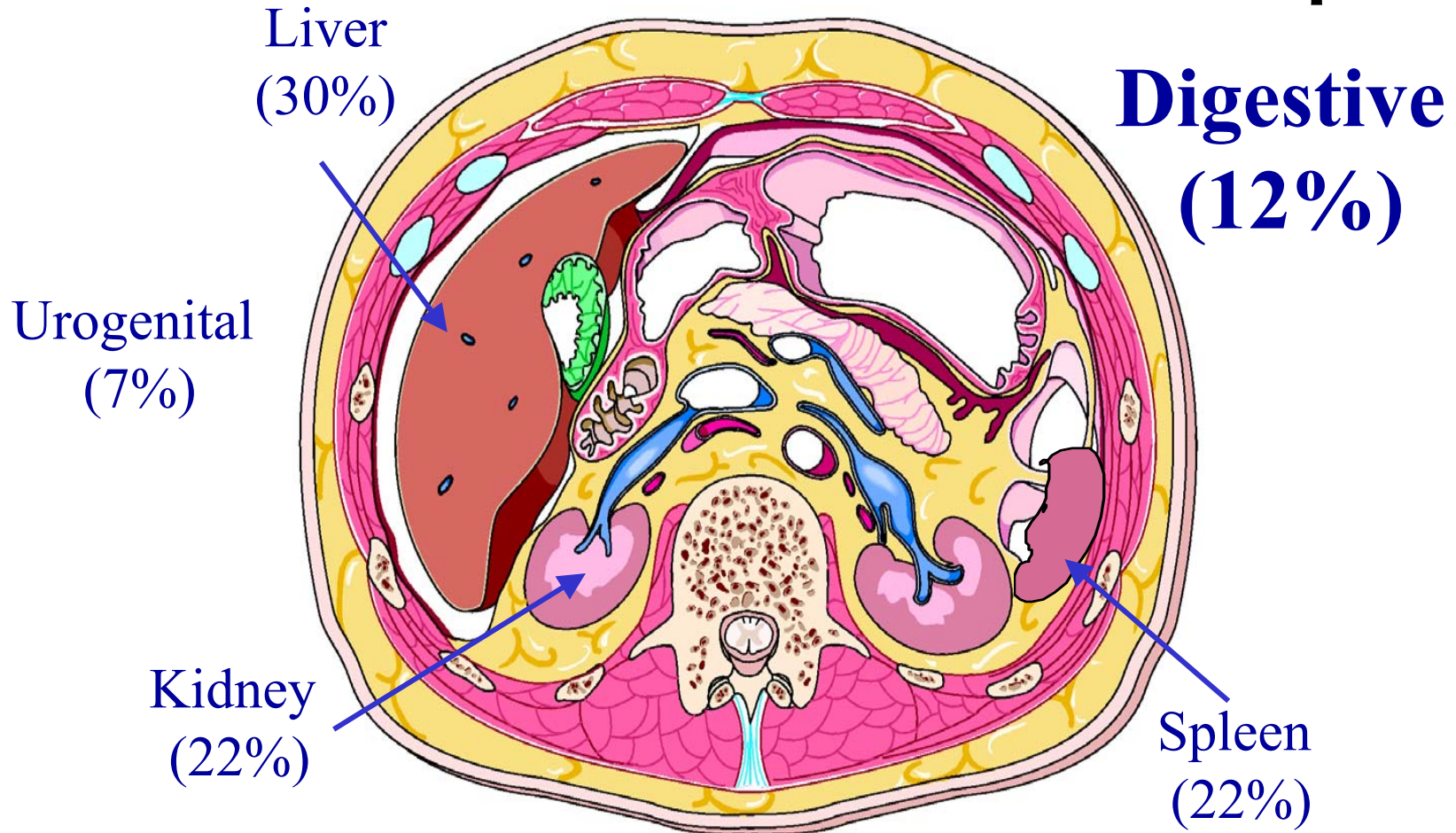
(9%)

Belt Restraint

(4%)

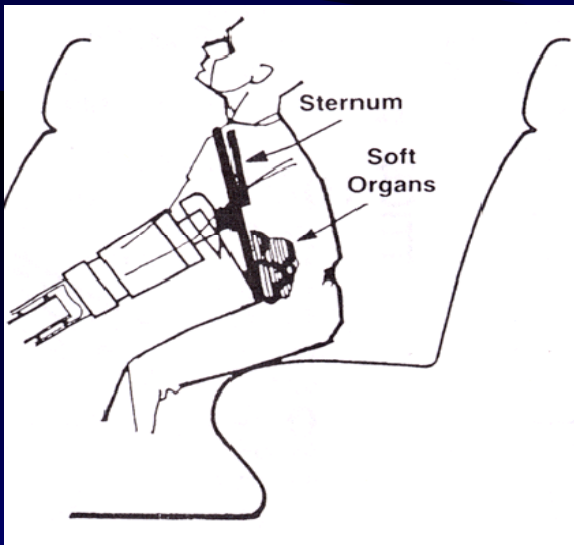


# AIS $\geq 3$ Abdominal Injury Distribution - Frontal Impact

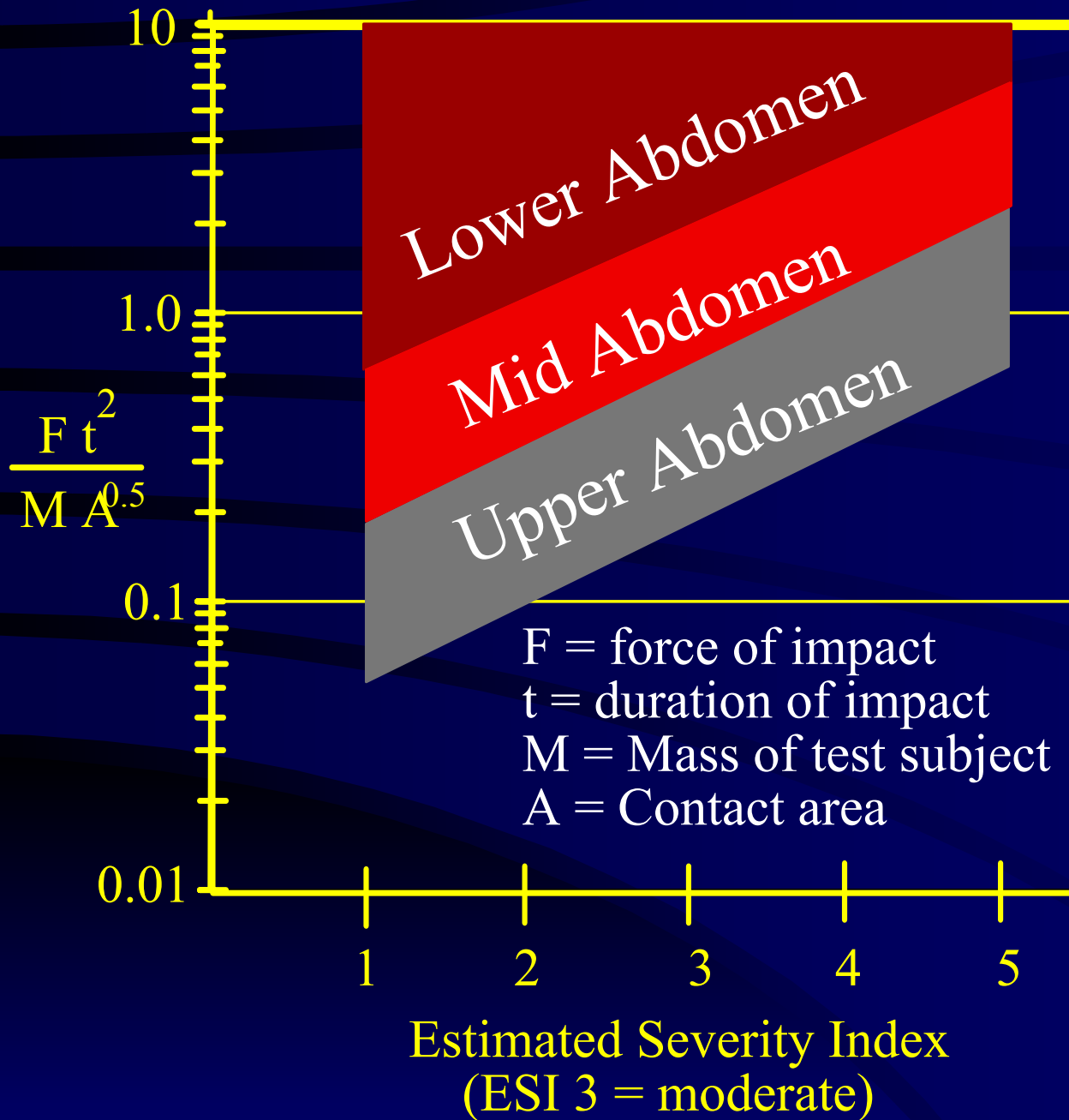




# Early Research Focused on Steering Wheel Contact



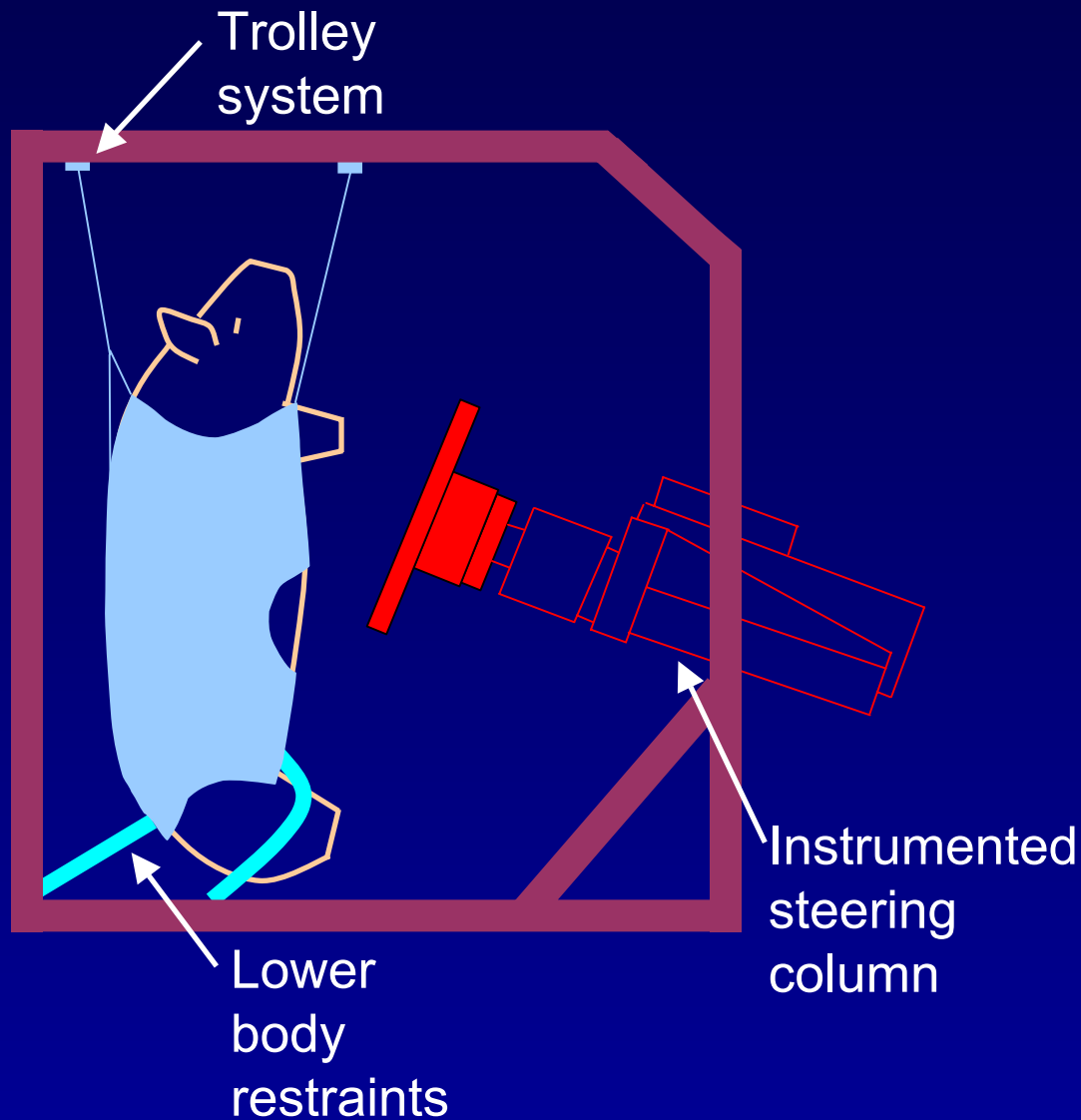
# Abdominal Injury Corridors (Trollope, 1972)



Squirrel Monkeys,  
Rhesus Monkeys,  
Baboons,  
Pigs



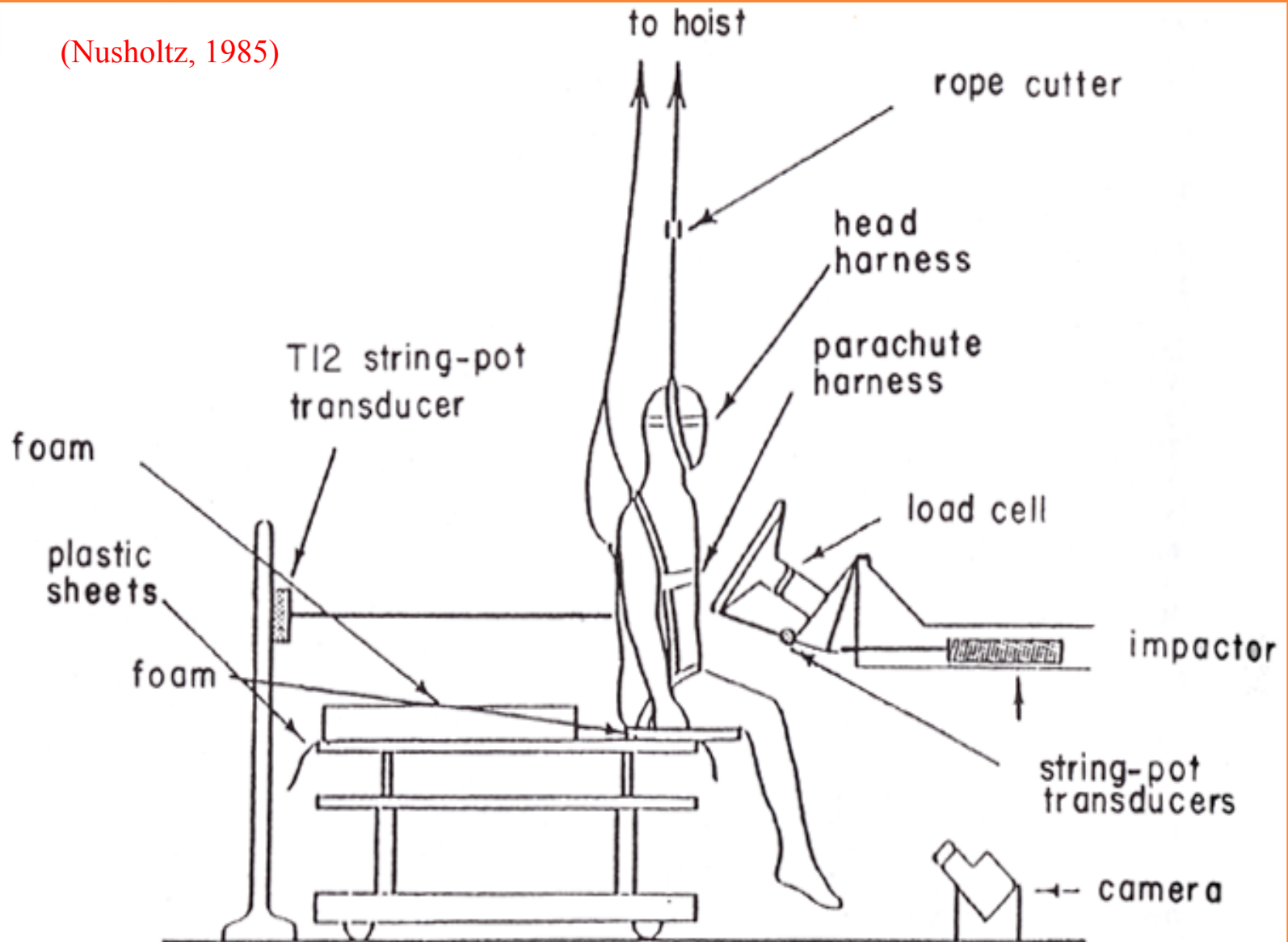
# Porcine Test

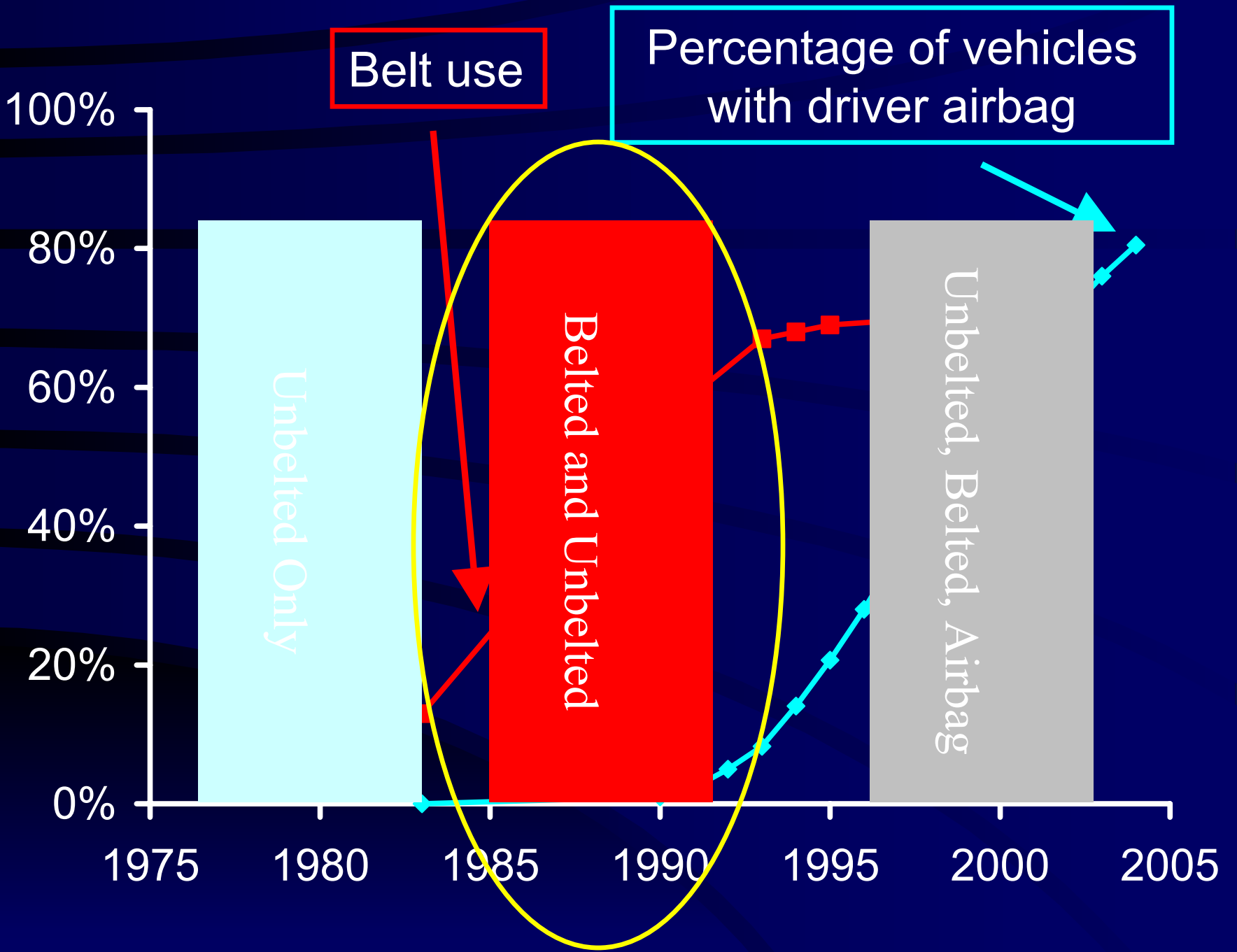


- Test frame mounted on Hyge sled ( $\Delta V=32$  km/h)
- Anesthetized subject supported by suspension suit attached to trolley
- Lower steering wheel rim impacted torso at liver

# Abdominal Impact Tests

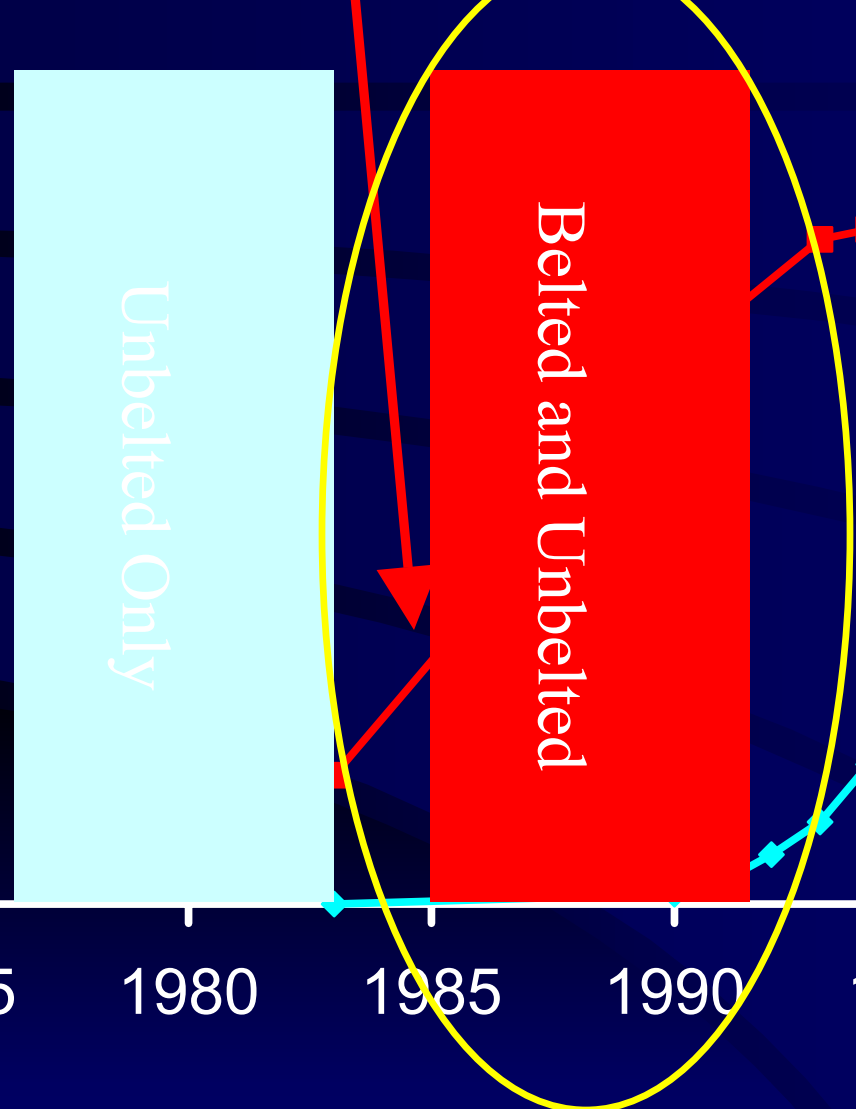
(Nusholtz, 1985)





Belt use

Percentage of vehicles with driver airbag



Unbelted Only

Belted and Unbelted

Unbelted, Belted, Airbag

# AIS $\geq$ 3 Hollow Viscous Injury Sources - Frontal Impact

1988-1994

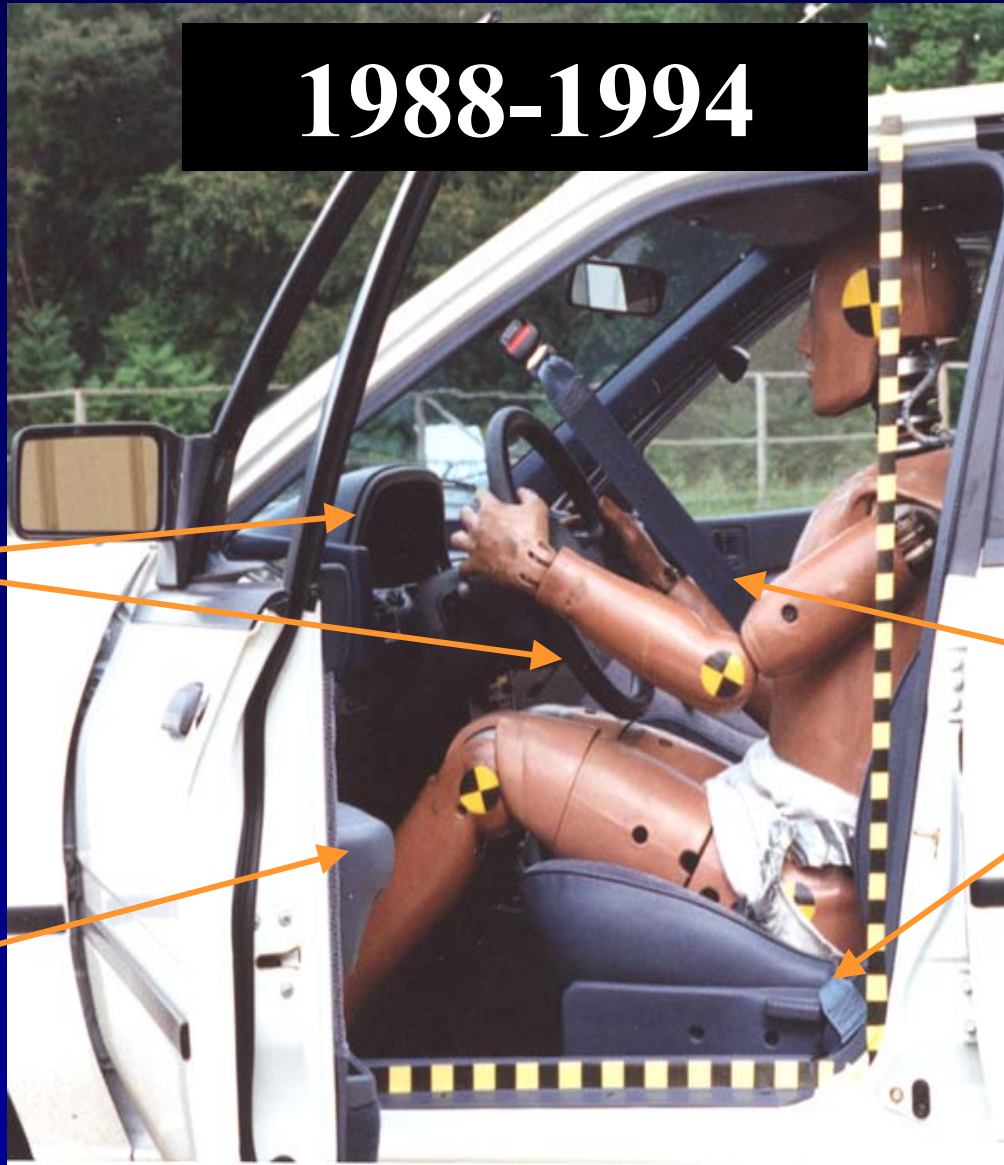
Front:

-Steering Assembly  
(39%)

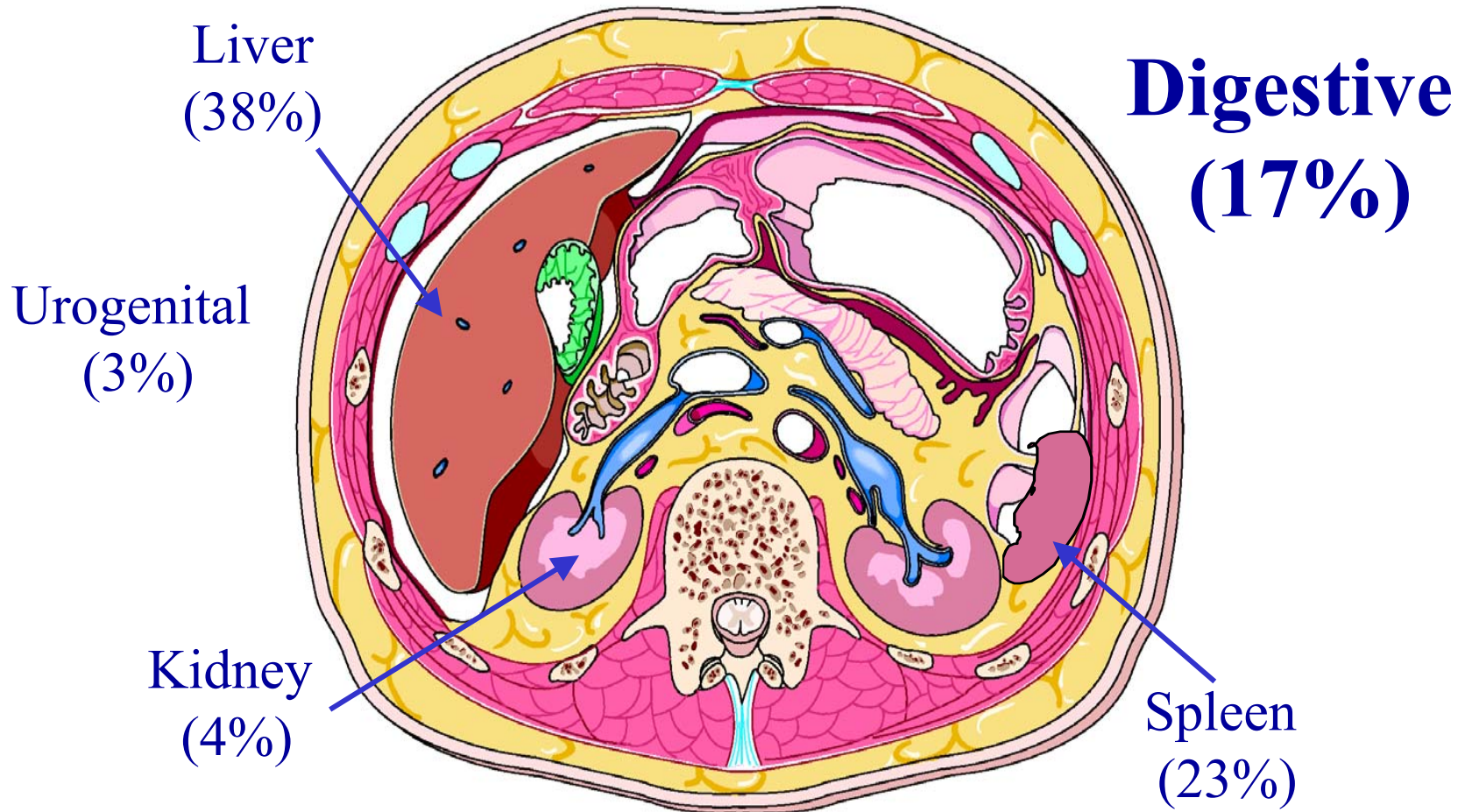
Belt Restraint  
(56%)

Side Interior:

-Surface  
-Armrests  
(5%)



# AIS $\geq 3$ Abdominal Injury Distribution - Frontal Impact



# Seatbelt Loading of Abdomen

## Injuries

Mesentery

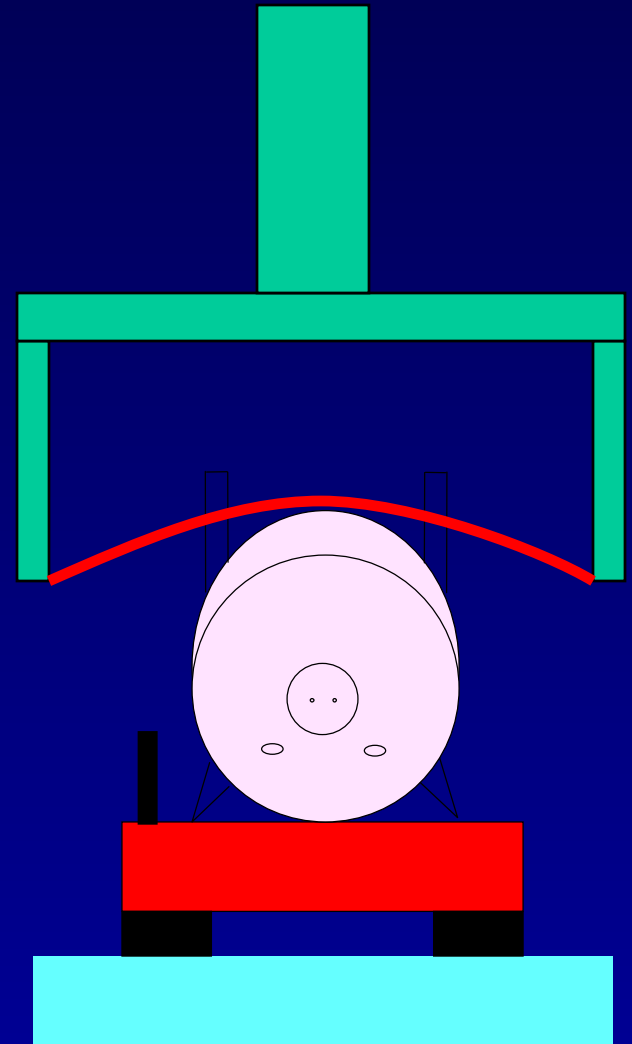
Duodenum

Small bowel

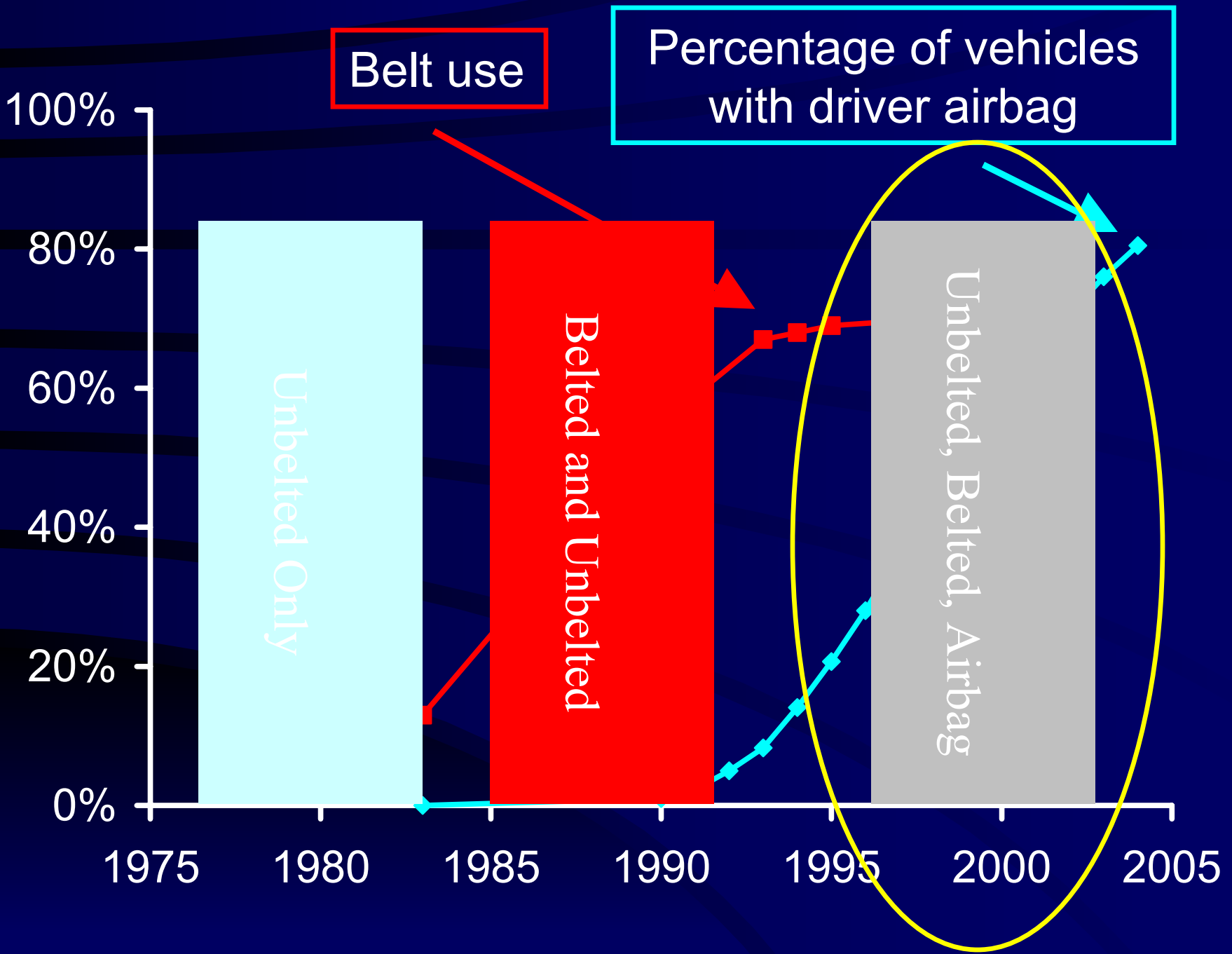
Large bowel

Cecum

Miller (1988)







# AIS $\geq 2$ Hollow Viscous Injury Sources - Frontal Impact

1993-1997

Front:

- Steering Assembly
- Instrument Panel

(27%)

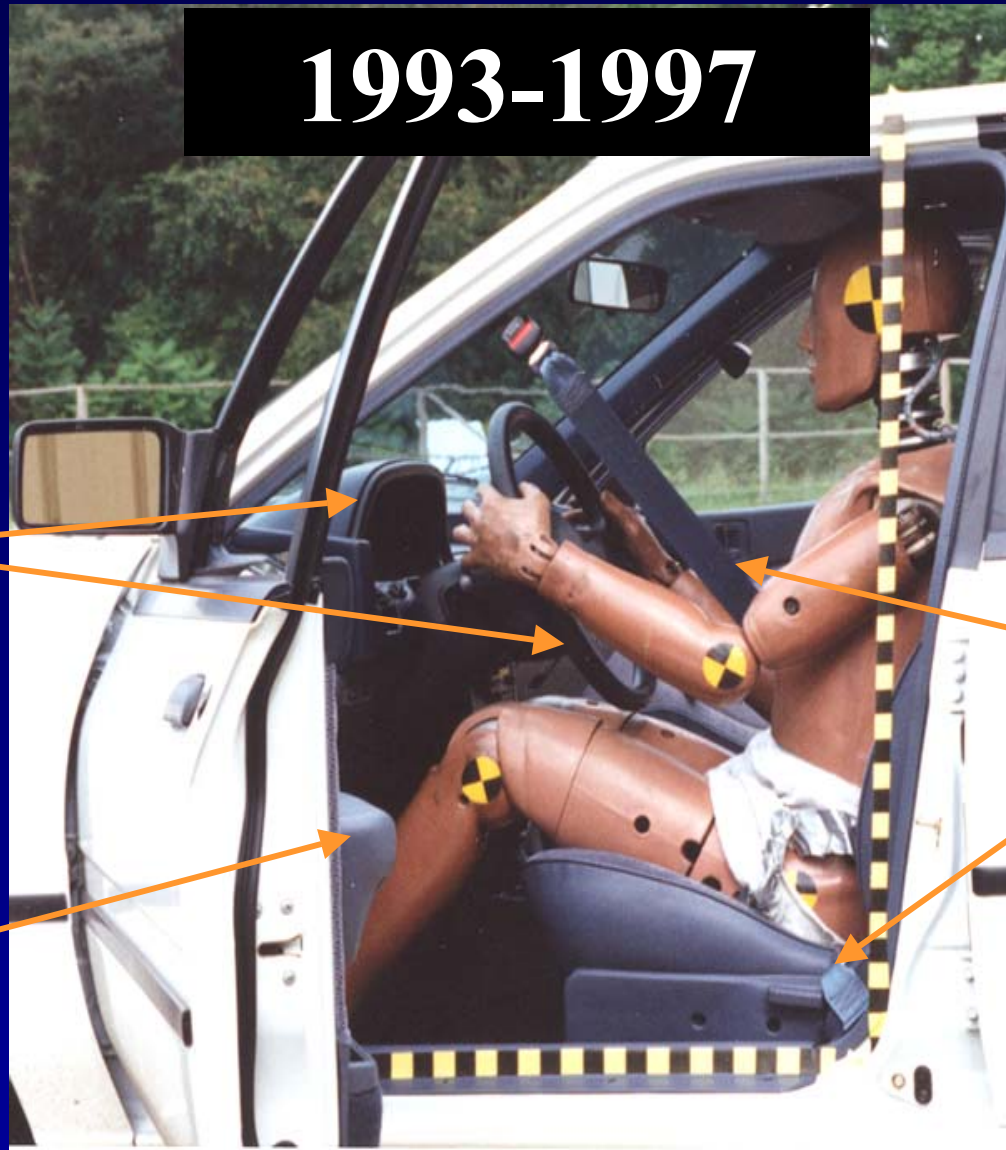
Side Interior:

- Surface
- Armrests

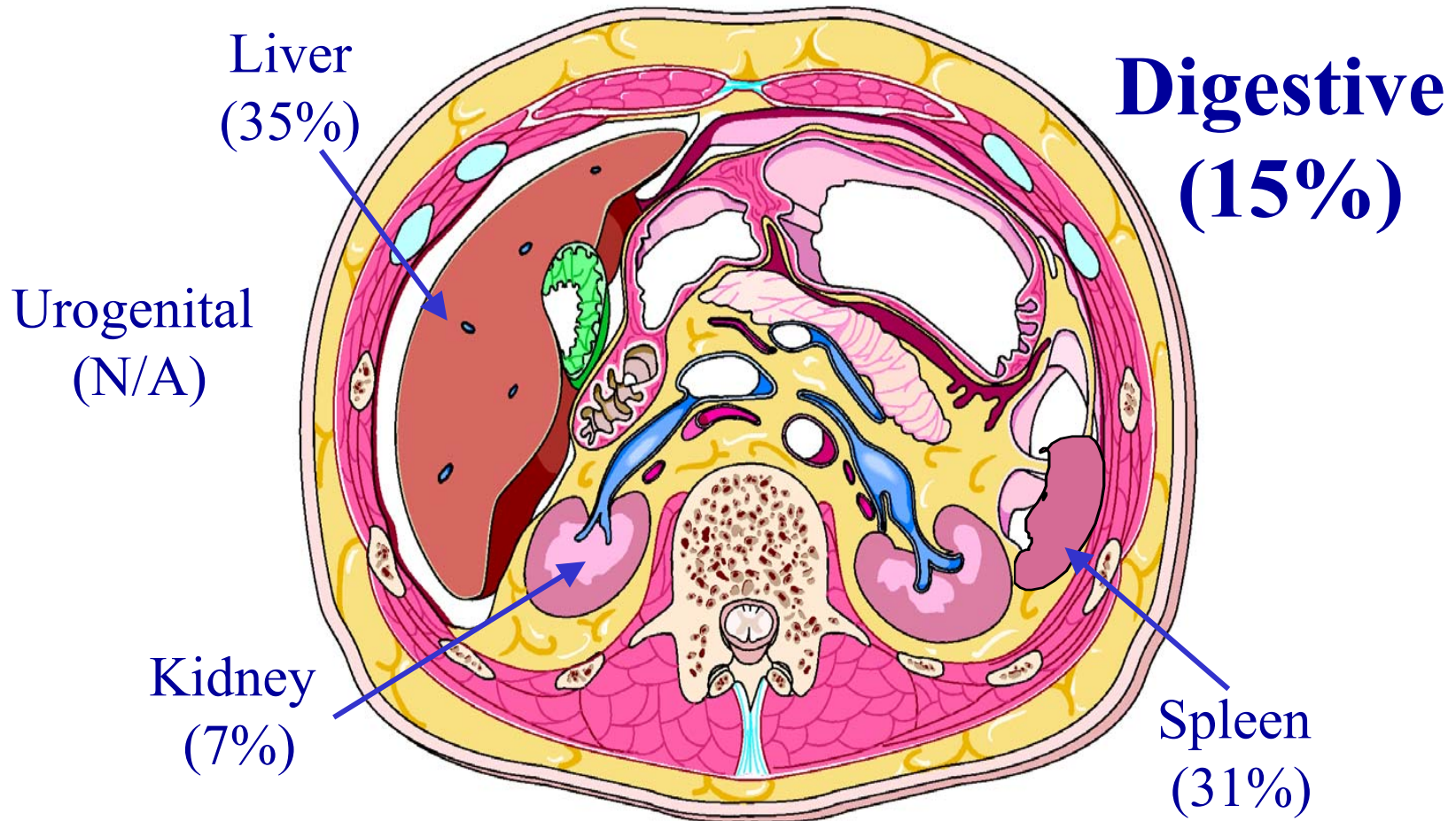
(15%)

Belt Restraint

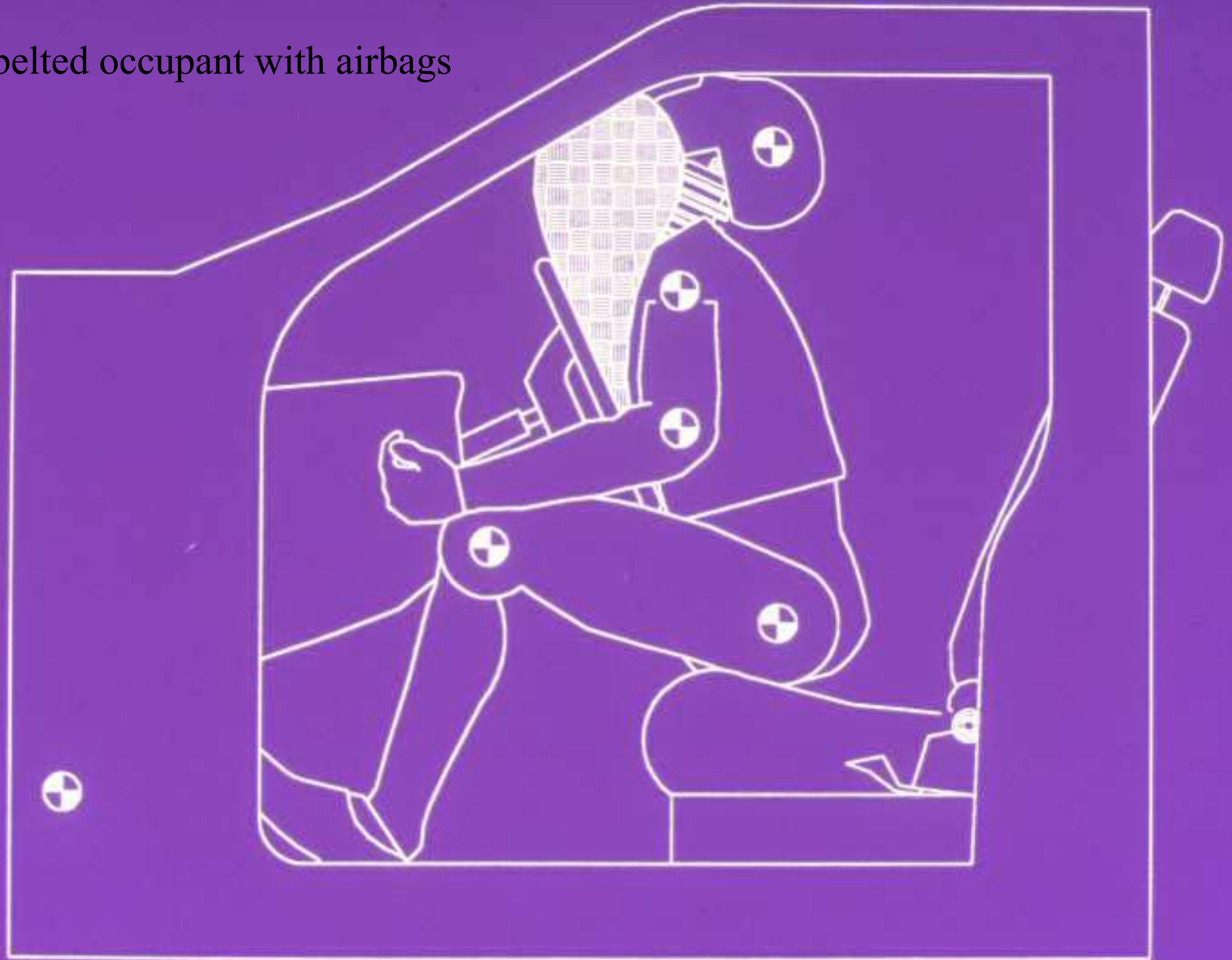
(59%)



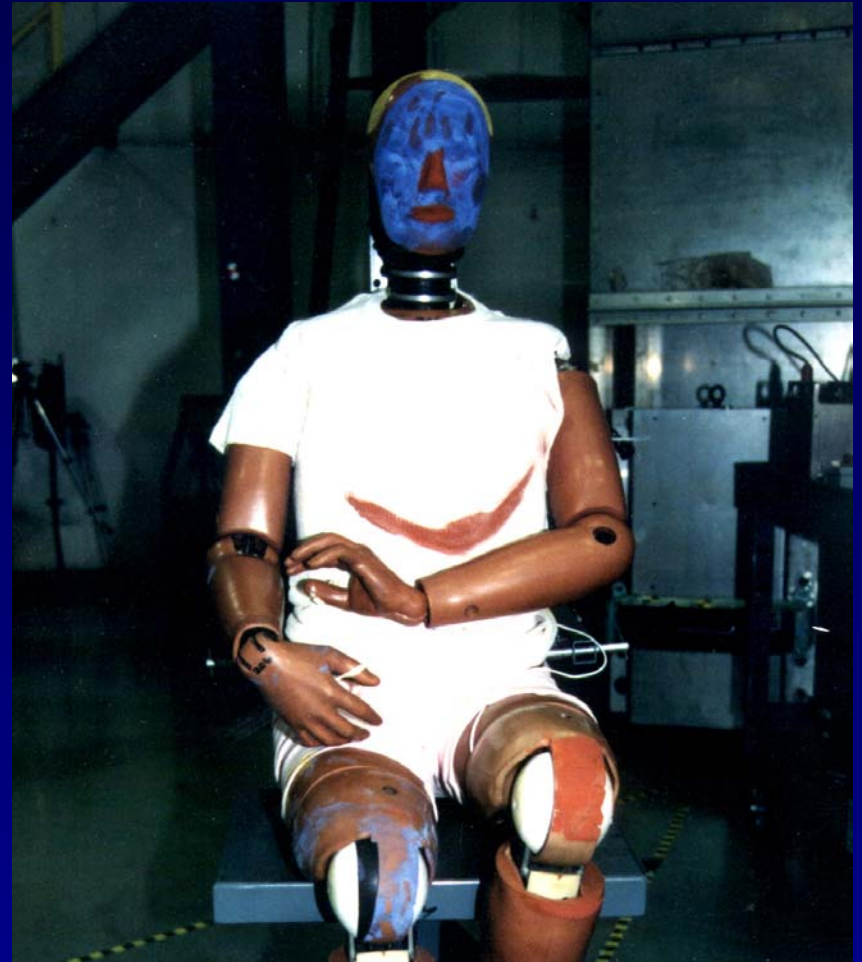
# AIS $\geq 3$ Abdominal Injury Distribution - Frontal Impact



Unbelted occupant with airbags







**Steering Wheel Contact Despite Airbag**

# Airbag Loading of Abdomen



Cadaveric tests with loading to abdomen  
Hardy et al. (2001)

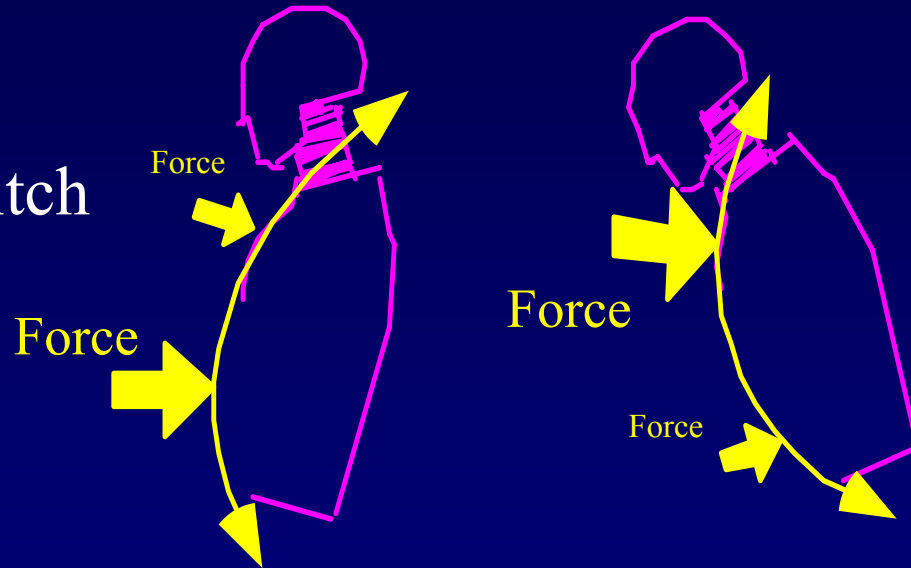
**Injuries**  
**Colon, Mesentery, Peritoneum**



# Recent Advances

Force Limiter

Improve torso pitch



Lap belt pretensioners

Reduce slack and submarining

Trosseille et al. (2002)



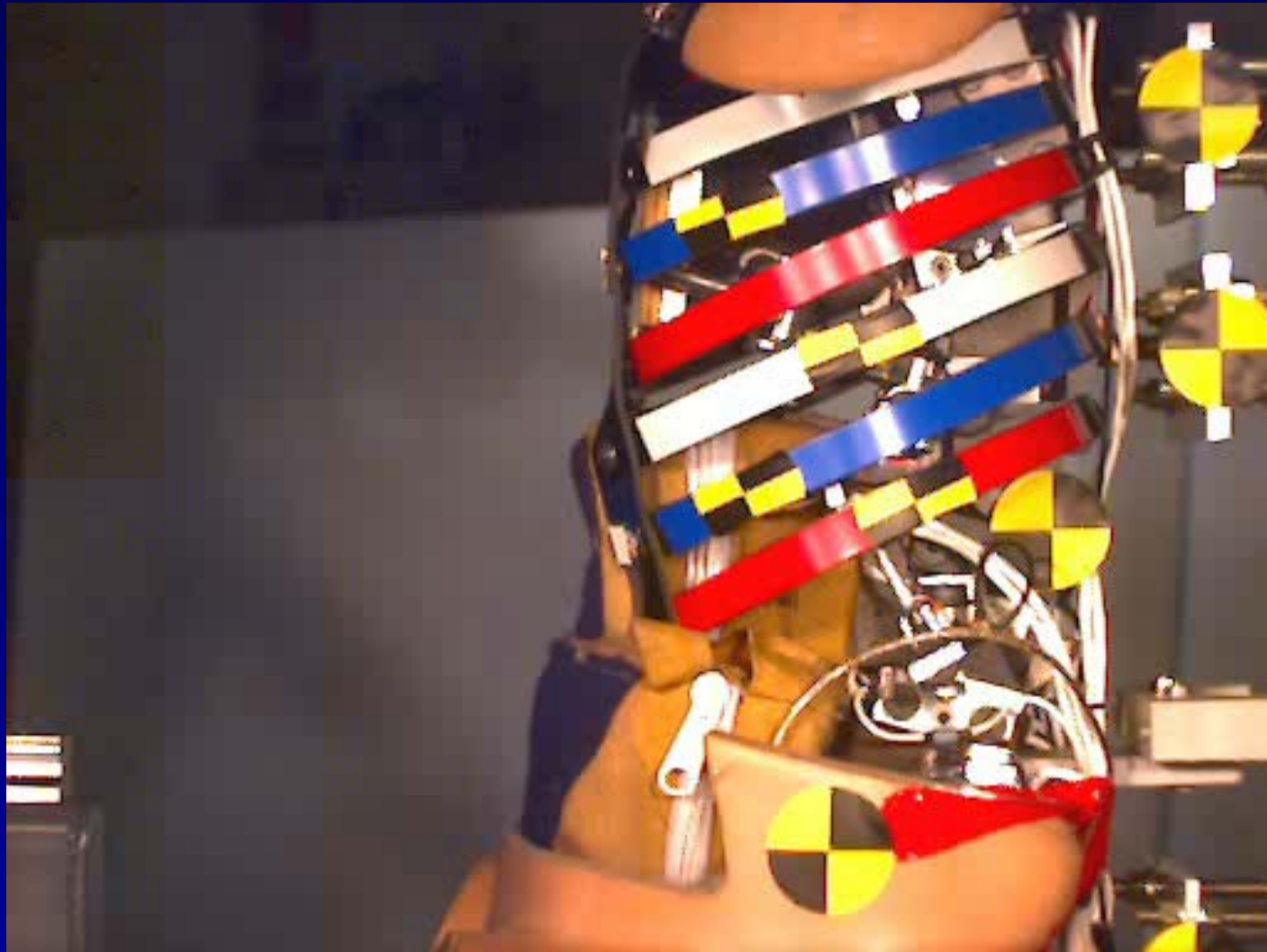
Steffan et al. (2002)



# Steering wheel impacts to abdomen

## Dummy and cadaver

Shaw et al. (2004)

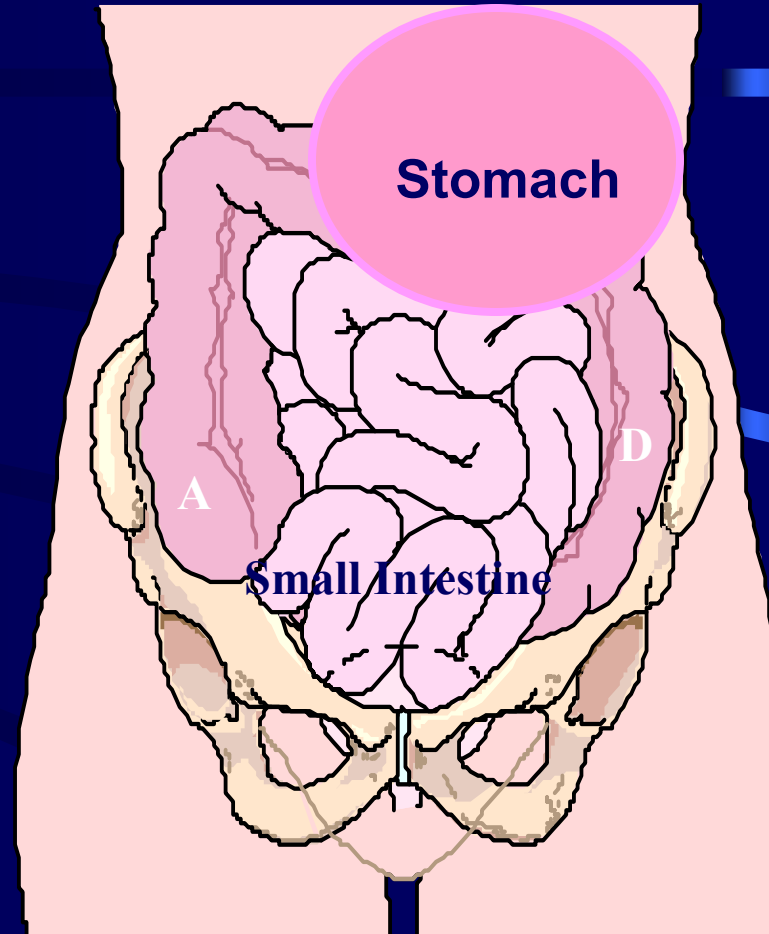




# **Hollow Viscous Injury Analysis of CIREN Data**

# CIREN Query

- Hollow Viscous Injury
- No rollovers
- No ejections
- 16 years and older
- Driver and Front Right Passenger



- 61% of HVI in Frontal Crash with PDOF 330-30
- 33% in Right (30-150) or Left (210-330)

**61%**



**33%**



# Demographics of CIREN HVI Cases

## FRONTAL CRASHES

- Incidence      39 / 856 drivers had HVI (4.6%)  
                    12 / 224 pass had HVI (5.4%)
- Injuries        62 injuries - 39 drivers  
                    25 injuries - 12 passengers
- 39 drivers – 50% Belted, 50% Unbelted
- 12 pass – All Belted



# Demographics of CIREN HVI Cases

## SIDE CRASHES

- Incidence
  - 18/348 NEAR Side had HVI (4.6%)
  - 9 / 132 FAR Side had HVI (6.8%)
- Injuries
  - 24 injuries - 18 NEAR Side
  - 23 injuries - 9 FAR Side
- 18 NEAR Side – 72% Belted, 18% Unbelted
- 9 FAR Side – 55% Belted, 45 % Unbelted

# Frontal Crashes

	Driver		Passenger	
	N	% all HVI	N	% all HVI
Colon	13	<b>21</b>	7	<b>28</b>
Mesentery	27	<b>44</b>	5	<b>20</b>
Small Bowel	12	<b>19</b>	6	<b>24</b>
Bladder	4	<b>6</b>	0	<b>0</b>
Duodenum	1	<b>2</b>	3	<b>12</b>
Gallbladder	3	<b>5</b>	0	<b>0</b>
Stomach	1	<b>2</b>	4	<b>16</b>
Omentum	1	<b>2</b>	0	<b>0</b>

Driver Injury Source – **53% SW (11 belt, 22 unbelt)**

36% Belt

Pass Injury Source – 80% Belt

# Side Crashes

	Near Side		Far Side	
	N	% all HVI	N	% all HVI
Colon	5	<b>21</b>	7	<b>30</b>
Mesentery	8	<b>33</b>	8	<b>35</b>
Small Bowel	1	4	6	<b>26</b>
Bladder	8	<b>33</b>	1	4
Duodenum	0	0	0	0
Gallbladder	0	0	0	0
Stomach	1	4	0	0
Omentum	1	4	1	4

Near Side Injury Source – 50% Interior, Belt 21%

Far Side Injury Source – 83% Belt

**All Crash Types, AIS 2+ HVI**  
**Bondy 1977-79 – 7% belted**  
**CIREN 1996-2003 – 64% belted**

<b>Crash Type</b>	<b>Frontal</b>	<b>Side</b>
<b>Bondy</b>	<b>63 %</b>	<b>24.4 %</b>
<b>CIREN</b>	<b>65 %</b>	<b>34.6 %</b>

<b>Injury Source</b>	<b>SW</b>	<b>Belt</b>	<b>Side</b>	<b>Unknown</b>
<b>Bondy</b>	<b>46 %</b>	<b>4 %</b>	<b>18 %</b>	<b>33 %</b>
<b>CIREN</b>	<b>25 %</b>	<b>50 %</b>	<b>11 %</b>	<b>13 %</b>

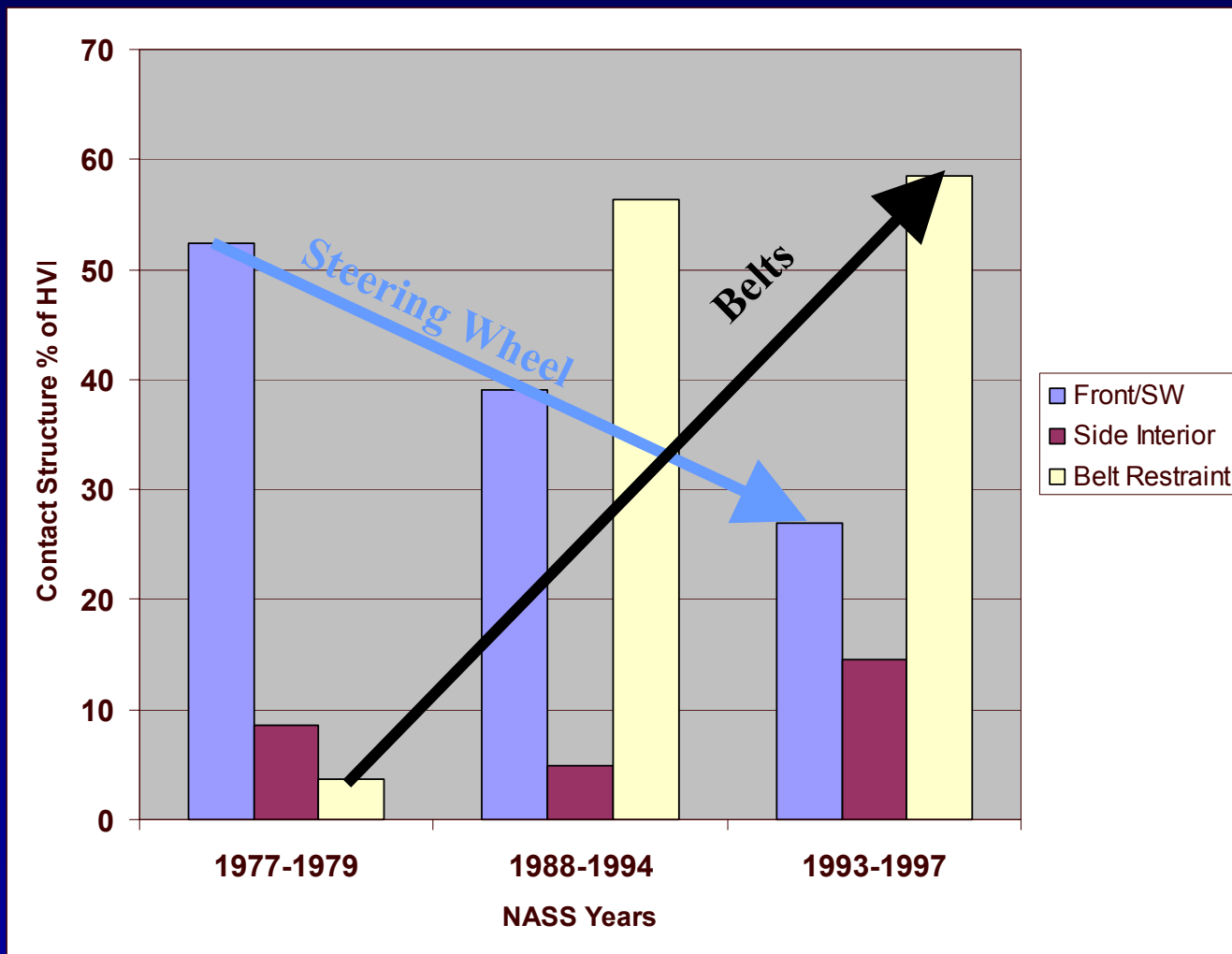
## Frontal Crashes

Elhagediab & Rouhana 1988-94 – AIS 3+

CIREN 1996-2003 – AIS 2+

	Unbelted No Airbag	Belted No Airbag	Unbelted <b>Airbag</b>	Belted <b>Airbag</b>
<i>Elhagediab</i>	40 %	60 %	0 %	0 %
<i>CIREN</i>	15 %	14 %	21 %	51 %

# HVI Injury Source Changes Over Time

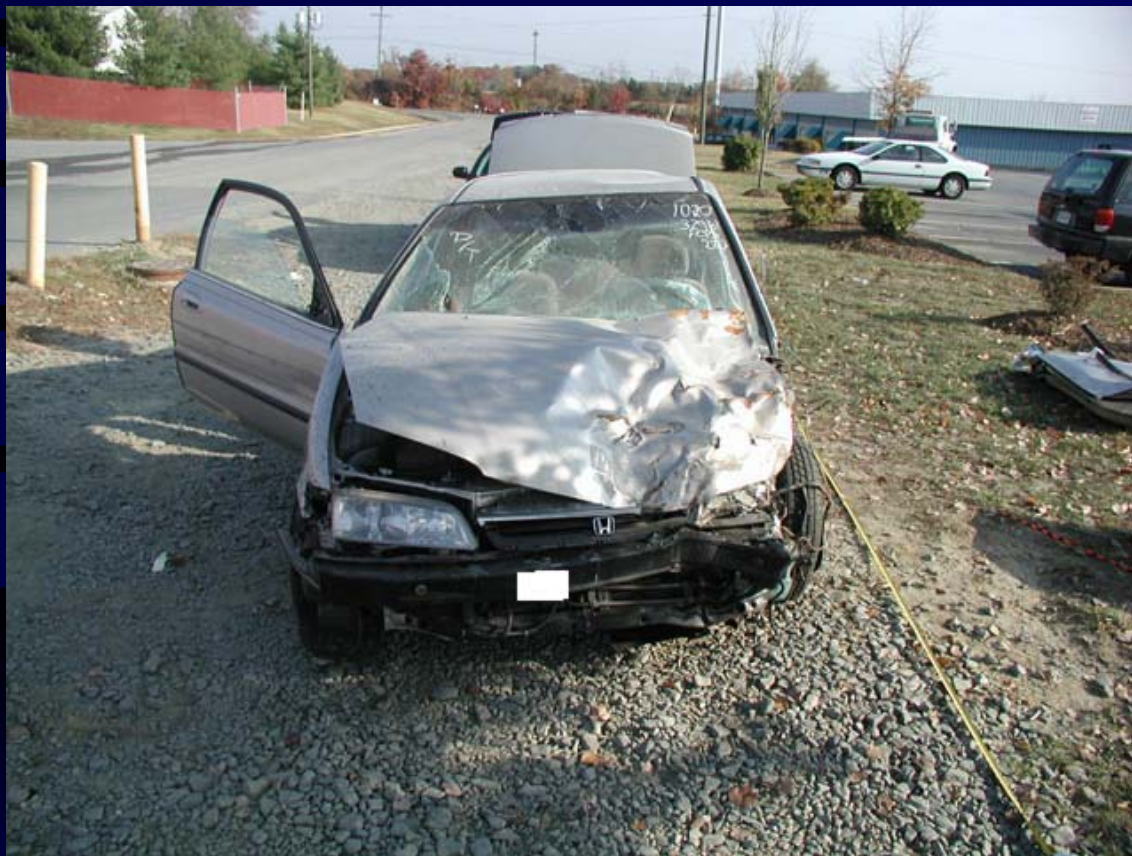






# CIREN Case Examples

# Case # 1 – Frontal Crash Belted Adult in Rear Seat

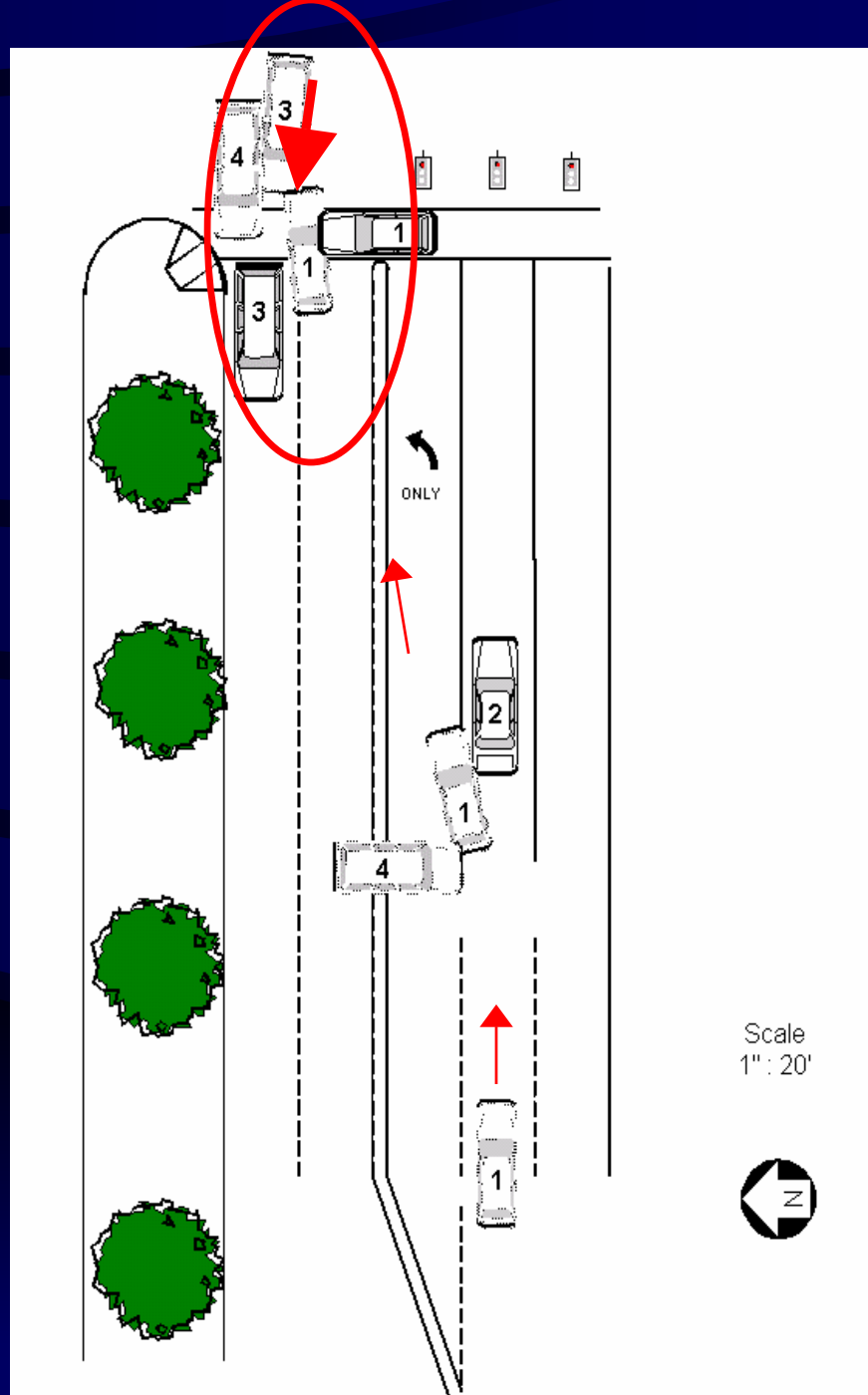


**1997 Honda Accord**

**CDC: 12FYEW3**

**PDOF: 10 degrees**

**$\Delta V$ : 33 km/h/21 mph**



Scene Diagram  
Showing Point of  
Impact

Clavicle fx

**Jejunal perforation**

Age: 53  
Gender: Female  
Position: Right Rear  
Weight: 120 lbs.  
Height: 5'4"  
Safety Device: 3-point restraint



<b>Injuries (ICD)</b>	<b>AIS Severity</b>	<b>Info Source</b>	<b>Aspect</b>	<b>Contact Area</b>
Jejunal perforation (863.20)	541424.3	Surgery	Right	SB
Flank contusion (922.8)	590402.1	Exam	Left	SB





# Case # 2 – Frontal Crash Belted Adult Driver



1999 Kia Sportage SUV

CDC: 12FDEW4

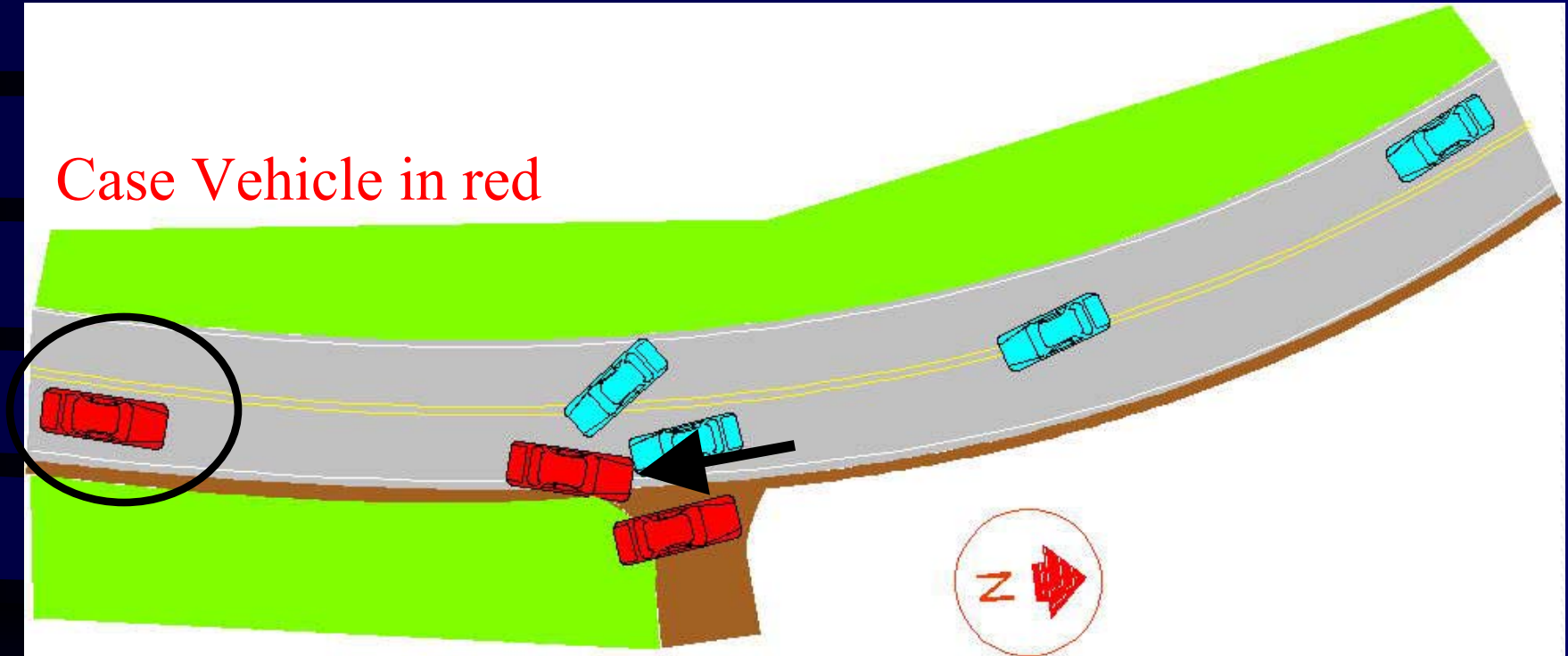
PDOF: 350

$\Delta V$ : 37 kmph/23 mph





# Scene Diagram Showing Point of Impact



Age: 32  
Gender: Male  
Position: Driver  
Weight: 340 lbs.  
Height: 6'2"

Safety Devices:

3-point restraint  
Pretensioner  
Airbag  
Knee Airbag



# Steering Wheel Contact

340 pound driver



Concussion

Liver contusion  
**Mesentery, Duodenum  
Lacerations**

Bilateral Femur fractures

Metatarsal, navicular,  
cuboid fxs



# Case # 3 – Frontal Crash Misuse of Shoulder Belt, Child



2001 Toyota 4Runner SUV

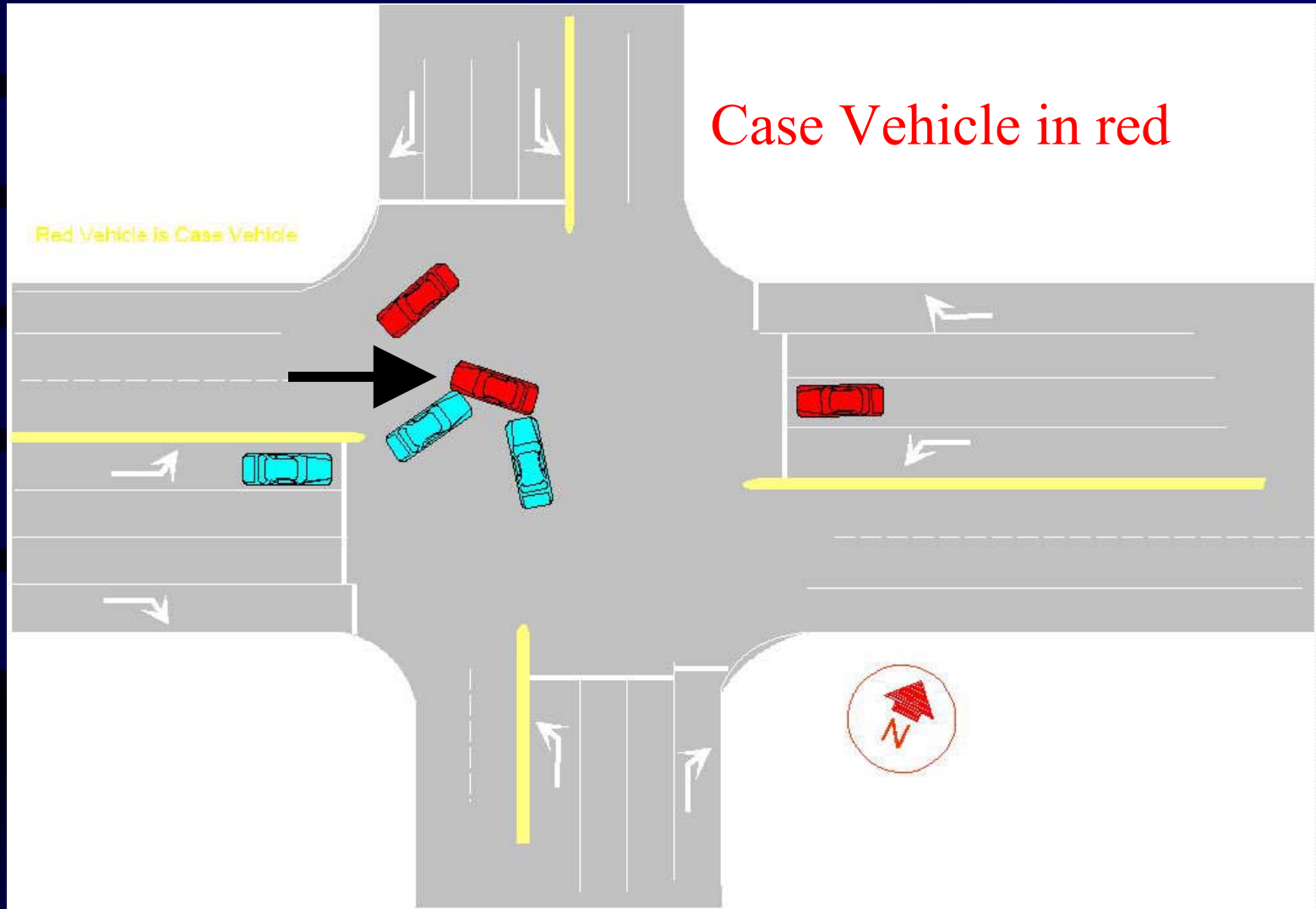
CDC: 11LYEW44

PDOF: 330

$\Delta V$ : 34 kmph/21 mph



# Scene Diagram Showing Point of Impact







**Lap  
Belt**

Age: 6  
Gender: Male  
Position: Right Rear  
Weight: 42 lbs.  
Height: 42"

Safety Device:

**3-point restraint with  
shoulder belt worn  
behind back**

Jejunum serosal laceration  
Mesentery contusion  
Colon contusion  
Retroperitoneal hematoma



# Case # 4 – Side Crash Belted Far Side Adult



1998 Toyota Camry

CDC: 02RYAW3

PDOF: 50

$\Delta V$ : 44 kmph/27 mph





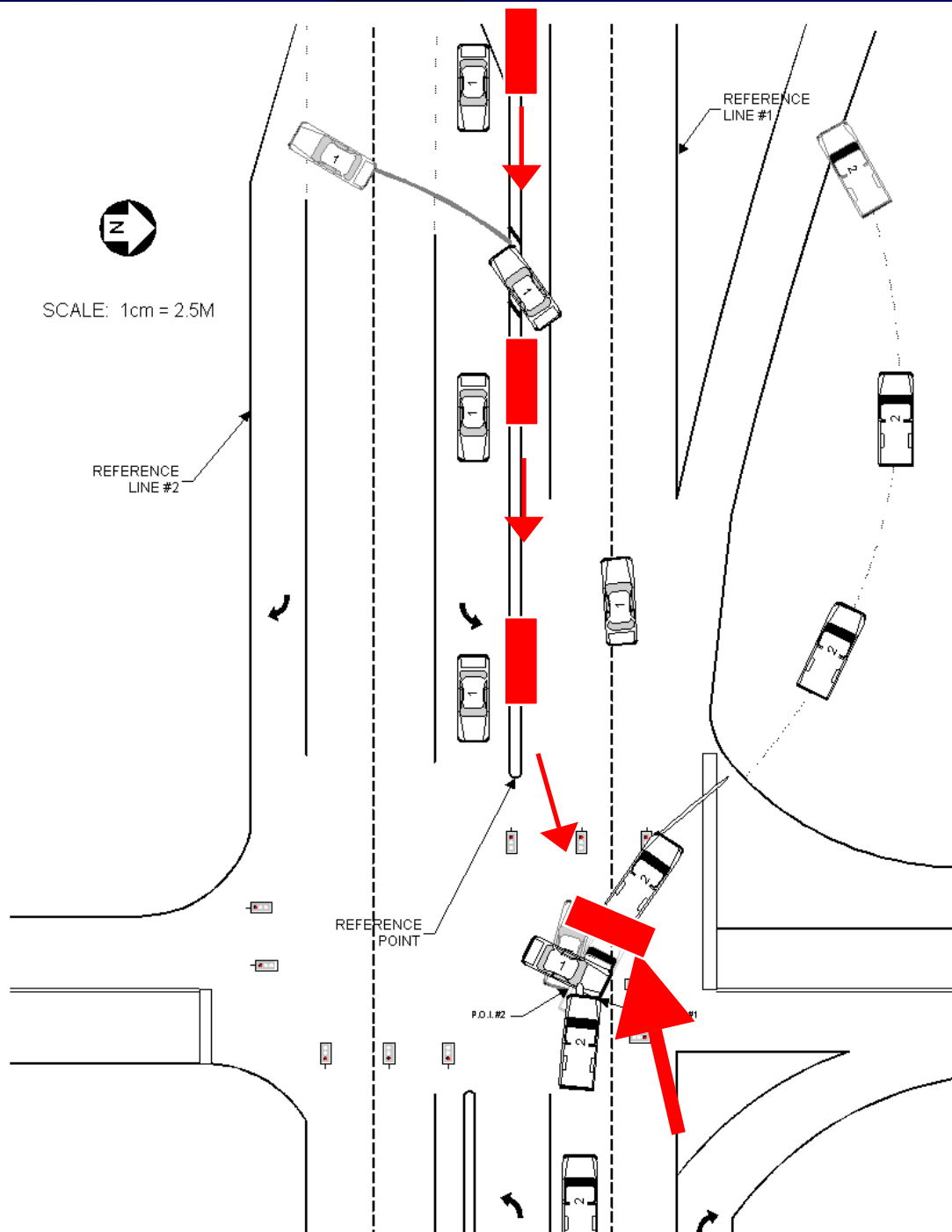
SCALE: 1cm = 2.5M

REFERENCE  
LINE #2

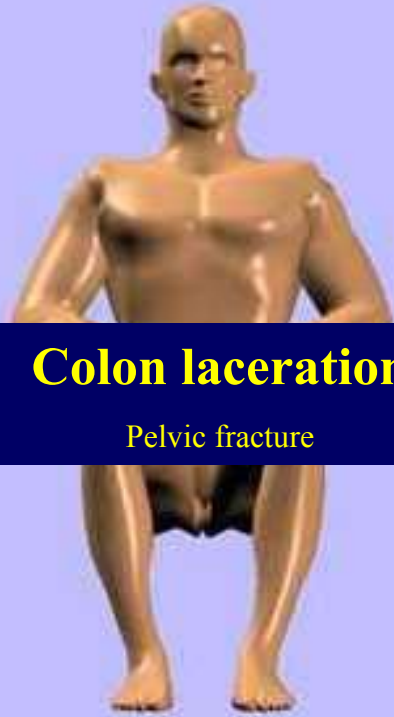
REFERENCE  
LINE #1

REFERENCE  
POINT

P.O.I.#2



Scene  
Diagram  
Showing  
Point of  
Impact

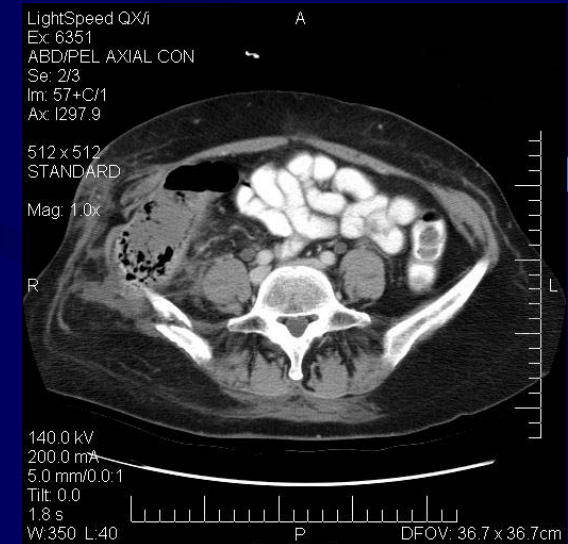
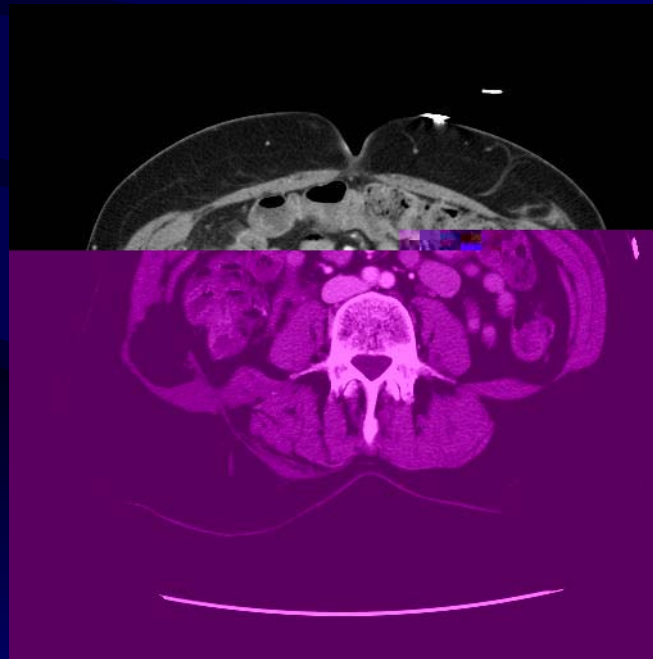


**Colon laceration**

Pelvic fracture

Age: 56  
Gender: Female  
Position: Driver  
Weight: 146 lbs.  
Height: 5'4"  
Safety Device: 3-point restraint

## Belt Load on Abdomen



# Questions?

