Comparison of University of Michigan CIREN Cases to Existing Types of Crash Tests

University of Michigan Program
for Injury Research and Education

UMPIRE

Project Focus

- The key to advancing crash safety is to understand and address serious injuries to motor vehicle crash-involved occupants
- The goals of this study were to:
  - Compare the cases in the U of M - CIREN database to existing industry crash test types
  - Analyze the injuries in these cases in terms of biomechanics, injury assessment methods, and vehicle design enablers

U-M CIREN data

- The U-M CIREN database is a subset of the Crash Injury Research Engineering Network (CIREN) database, which represents seriously injured motor vehicle crash-involved occupants treated at level I trauma centers
- CIREN contains extensive crash reconstruction and medical injury profiles for each case
- CIREN contains the injuries and crashes within its selection criteria that are occurring in spite of advancements of crash safety and need to be addressed to further improve crash safety

CIREN Database Considerations

- The CIREN database does not represent the entire accident-involved population
- The CIREN database includes only relatively seriously injured occupants which makes it difficult to draw conclusions about the effectiveness of current safety and vehicle development practices

$$risk = \frac{\#\,injured}{\#\,exposed} = \frac{\#\,injured}{(\#\,injured + \boxed{\#\,uninjured})}$$

- Consideration must be made to ensure that countermeasures implemented to address serious injuries in the U of M - CIREN database do not increase the potential for injury to currently uninjured occupants and those with only minor injuries

UMPIRE

CIREN Adult Selection Criteria

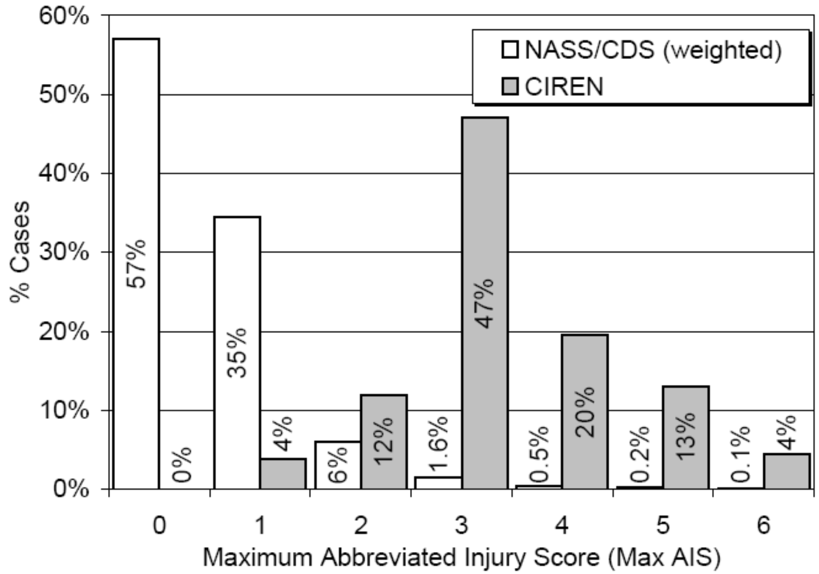
Revised 10/2006

Case Type	Crash Direction	Vehicle Criteria	Restraint Criteria	Occupant	Injury Thresholds
Frontal	10 to 2 o'clock Full frontal Offset Frontal	CY-6 yrs* *(Priority on newest vehicles)*	Air bag, Air bag and 3-point belt	Row 1	AIS≥3 or **
			Must be in 3-point belt and gross misuse **not** documented	Rows 2+	
Side	8 to 10 o'clock 2 to 4 o' clock	CY-6 yrs* *(Priority on newest vehicles)*	Any and all, including unrestrained on struck side and far side	Any	AIS≥3 or **
Rollover	All	CY-6 yrs* *(Priority on newest vehicles)*	Any and all, including unrestrained (EXCEPTION = 100% EJECTION)	Any	AIS≥3 or **
Pregnant Occupant (total enrollment limited)	10 to 2 o'clock Full frontal Offset Frontal	CY-8 yrs* *(Priority on newest vehicles)*	Must be in a 3-point belt and gross misuse **not** documented Avoid out-of-position cases (call NHTSA on non-belted cases for consideration)	Any	AIS2+ AIS1 *(with modedrate to severe impact)*
PI Special Interest ***	Any	Any	Any	Any	Any
Success Case********	Any	CY-6 yrs*	Appropriate restraint usage (belt and/or air bag)	Any	Any
Fire	All	Any	Any and all, including unrestrained	Any	AIS≥2

* Cases where the vehicle is >6 yrs old may be considered for enrollment if the vehicle contained advanced safety components – NHTSA approval required
** AIS of 2 in 2 or more body regions with medical significance (avoid concussive type injury for inclusion)
* *AIS of 2 in the lower extremity with <u>significant</u> articular injury (pilon/talus/calcaneus/Lisfranc/Choparts)
*** Max. PI SI cases allowed per site per year would be 5 based on a 50 case enrollment (10%)
**** Cases must be extraordinary for consideration – NHTSA approval required

UMPIRE

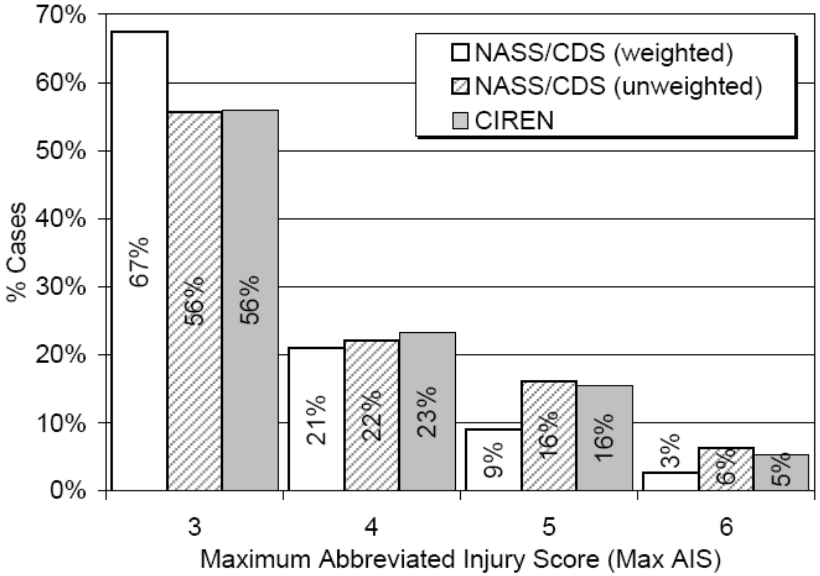
Comparison of CIREN to NASS-CDS



Reference: A Population-Based Comparison of CIREN and NASS Cases Using Similarity Scoring J. Stitzel, et. al. 51st Annual Proceedings Assoc. for the Advancement of Automotive Medicine

- A comparison of NASS-CDS to CIREN cases (2005) shows
  - NASS-CDS contains more than half MAIS 0 crashes because the NASS selection criteria specifies a 'tow-away' crash
  - CIREN contains mostly MAIS 3, 4 and 5 cases

Comparison of CIREN to NASS-CDS



- A comparison of AIS 3+ NASS-CDS to CIREN cases (2005) shows a similar distribution of Maximum AIS

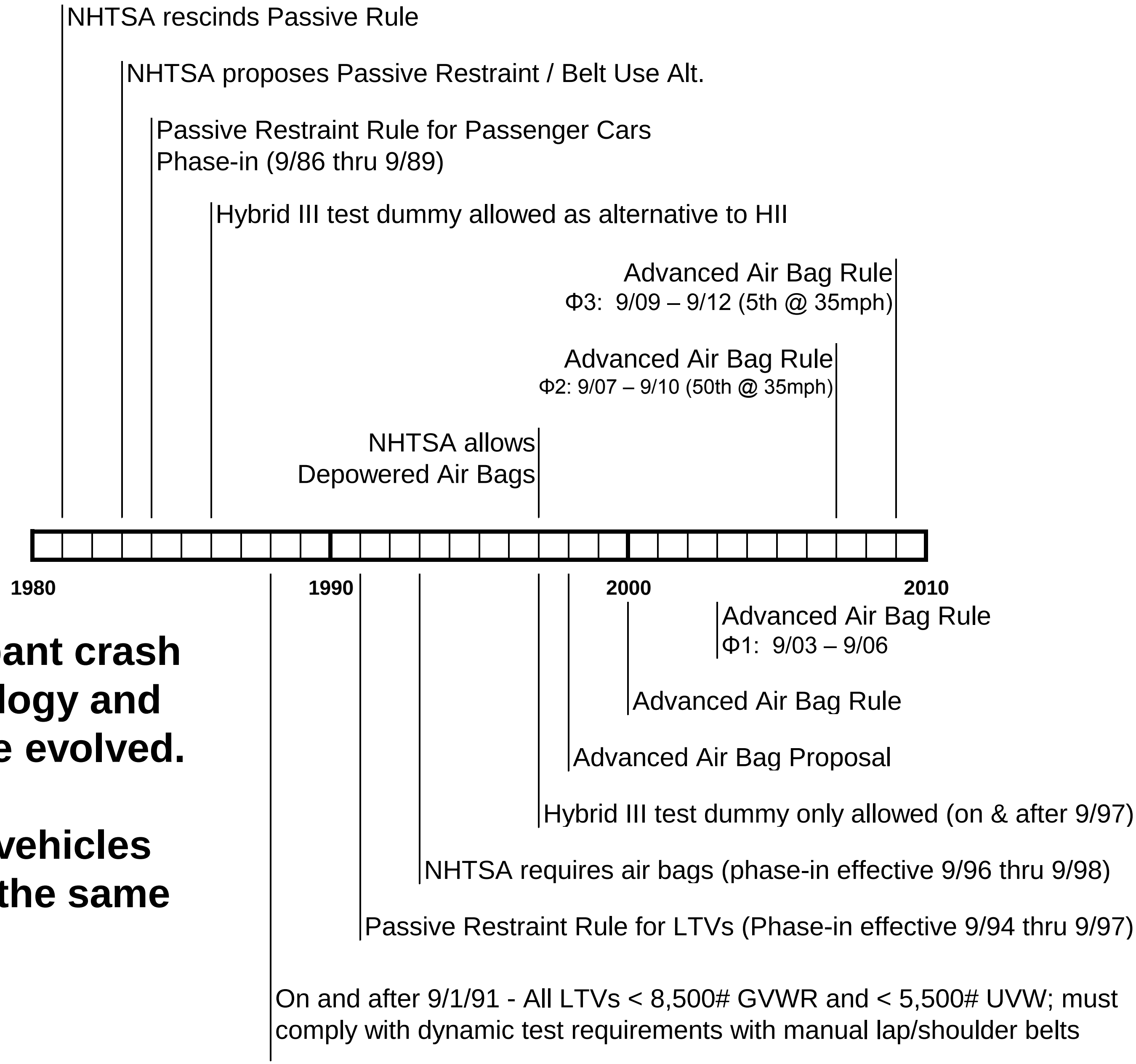
Reference: A Population-Based Comparison of CIREN and NASS Cases Using Similarity Scoring
J. Stitzel, et. al. 51st Annual Proceedings Assoc. for the Advancement of Automotive Medicine

Study Population

- The study included 442 cases from the U of M – CIREN database as of August, 2007
- Injury analysis focused on AIS 3+ injuries

U of M – CIREN Database Demographics – Highlights

- Occupants:
  - 54% female, 46% male
  - Average age of 40 years old
  - Average Body Mass Index (BMI) of 26.5 = Overweight category
  - 71% were drivers, 20% were right front passengers
- Restraints:
  - 68% of women were using 3-point seat belts
  - 55% of men were using 3-point seat belts
- Vehicles:
  - 84% were produced by GM, Ford and Chrysler
  - Vehicle age ranged from 1989-2006 model year with 63% of vehicles from 1995-2000 model years



FMVSS 208 occupant crash protection technology and requirements have evolved.

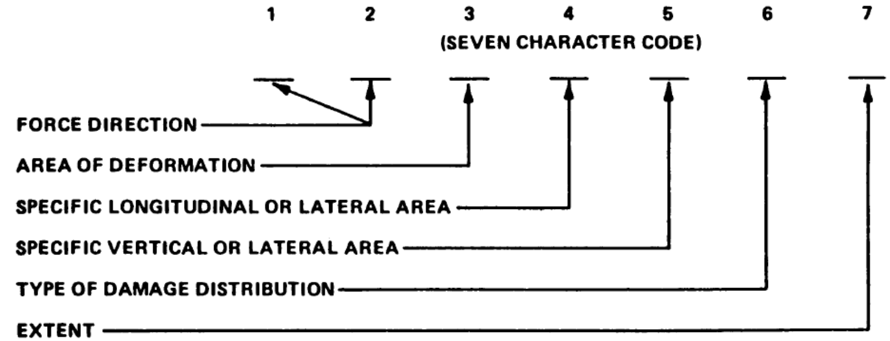
Thus not all case vehicles were designed to the same requirements.

UMPIRE

Assigning CDCs to Crash Test Types

- Collision Deformation Codes (CDCs) were assigned to regulated and other common industry crash tests of
  - Midsize sedans
  - Small sedans
  - Small coupes
  - Large SUVs

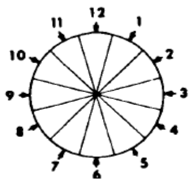
CDC coding:



Columns 1 and 2

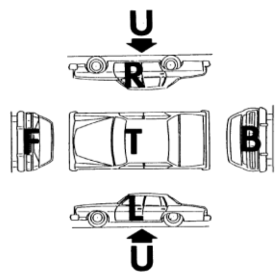
Front

Left



Right

Rear

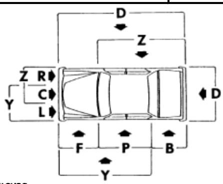


Column 3

- F Front
- R Right Side
- B Back/Rear
- L Left Side
- T Top
- U Undercarriage
- X Unclassifiable

Column 4

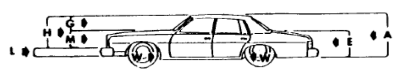
- D Distributed - side or end
- L Left - front or rear
- C Center - front or rear
- R Right - front or rear
- F Side front - left or right
- P Side center section - left or rıgnt
- B Side rear - left or right
- Y F+P or L+C
- Z B+P or R+C



Column 5

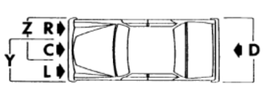
Vert Choices - for front/side rear

- A All
- H Top of frame to top of vehicle
- E Everything below beltline
- G Beltline and above
- M Middle - top of frame to beltline/hood
- L Frame - top of frame to bottom frame
- W Wheels/tires - below undercarriage



Lat Choices - for Top and Undercarriage

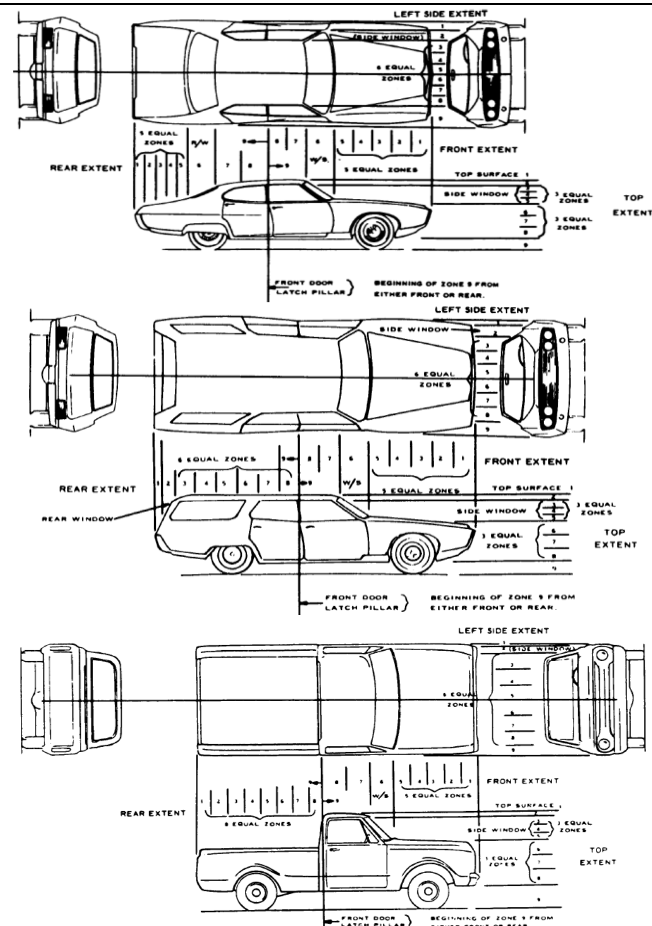
- D Distributed
- L Left
- C Center
- R Right
- Y L and C
- Z R and C



Column 6

- W Wide impact area (>16")
- N Narrow impact area (<16")
- S Sideswipe (0" to 4")
- O Rollover
- A Overhanging structures (inverted step)
- E Corner (from corner to 16"/410mm)
- K Conversion in impact type (mult. CDC)
- U No residual deformation

Column 7



UMPIRE

Reference: SAE Surface Vehicle Standard J224 Collision Deformation Classification, Rev. March, 1980

CDC Extent

- There are many possible measures of crash severity (Delta V, Equivalent Barrier Speed, Extent of Crush, etc.)
- This analysis is based only on CDC extent which is determined by how far the crush extends into the vehicle in the impact direction

U of M - CIREN Case Matching to Crash Test Configurations

- 295 of 442 cases were matched to current crash test configurations (regulated, consumer metric, and development tests) based on CDCs developed from crash test photos (ignoring CDC extent)
- 61 additional cases were matched to current crash test configurations after in-depth case reviews
- 77 cases were assigned to crash configurations without a matching crash test
- 9 cases were so unique that they could not be categorized

In many cases, crash damage closely resembled deformation from crash tests

0 Degree Frontal

<u>Crash Test Photo</u>

<u>Comparable Case Photo</u>

Frontal Center Pole

Crash Test Photo

Comparable Case Photo

UMPIRE

IIHS Side Impact

Crash Test Photo

Comparable Case Photo

In some cases, crash damage within a CDC category varied from crash test deformation.

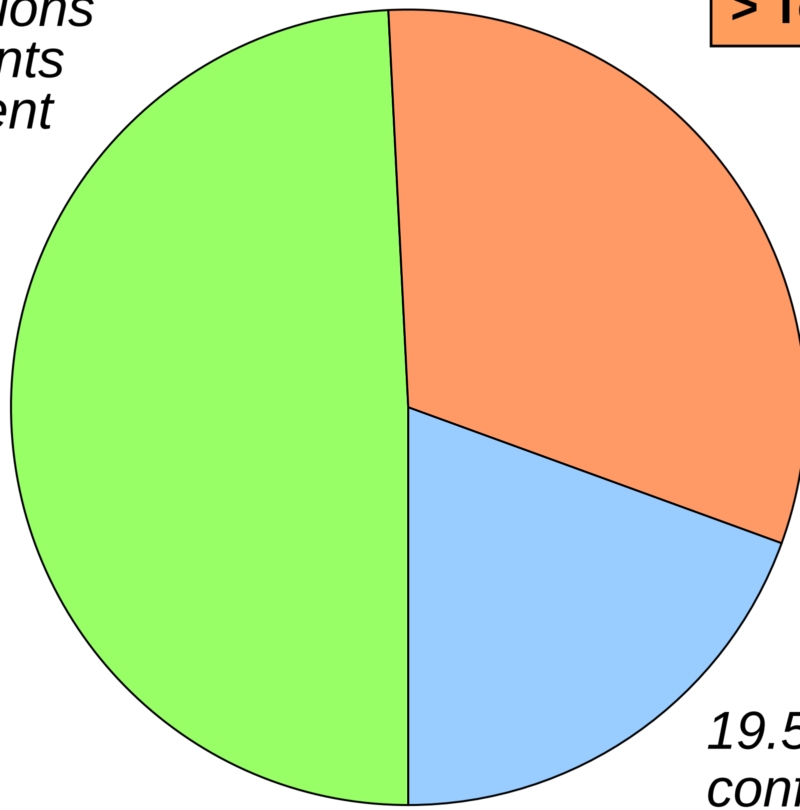
12FYEW3 – Left Angle or Offset

UMPIRE

U-M CIREN
All Cases

= Test Configuration
≤ Test Extent

48.9% of cases had configurations and CDC extents similar to current crash tests



= Test Configuration
> Test Extent

31.7% of cases had similar configurations but greater CDC extents than current crash tests

≠ Test Configuration

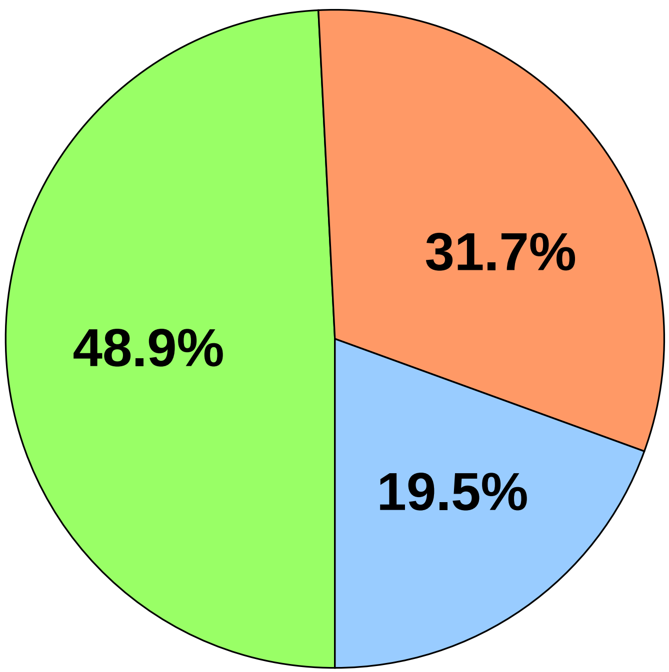
19.5% of cases had configurations that differed from current crash tests

UMPIRE

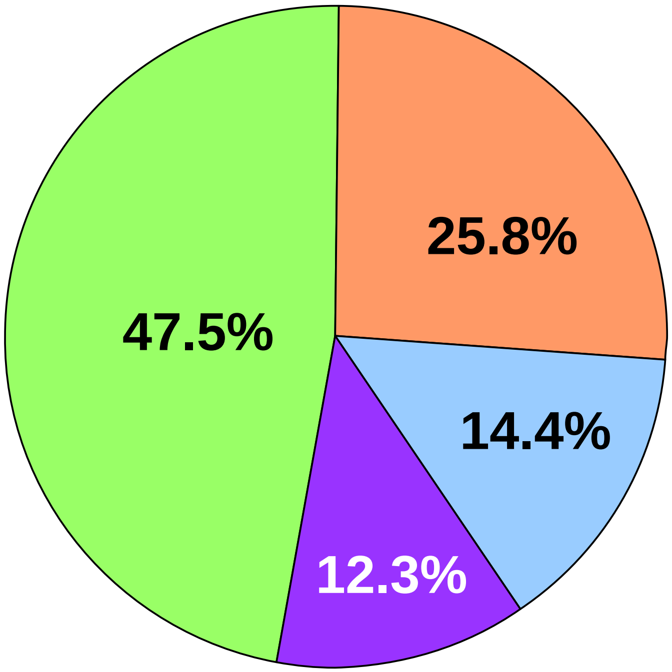
= Test Configuration
≤ Test Extent
= Test Configuration
> Test Extent
≠ Test Configuration

U-M CIREN vs. All CIREN

U-M CIREN n=442



All CIREN n=2089

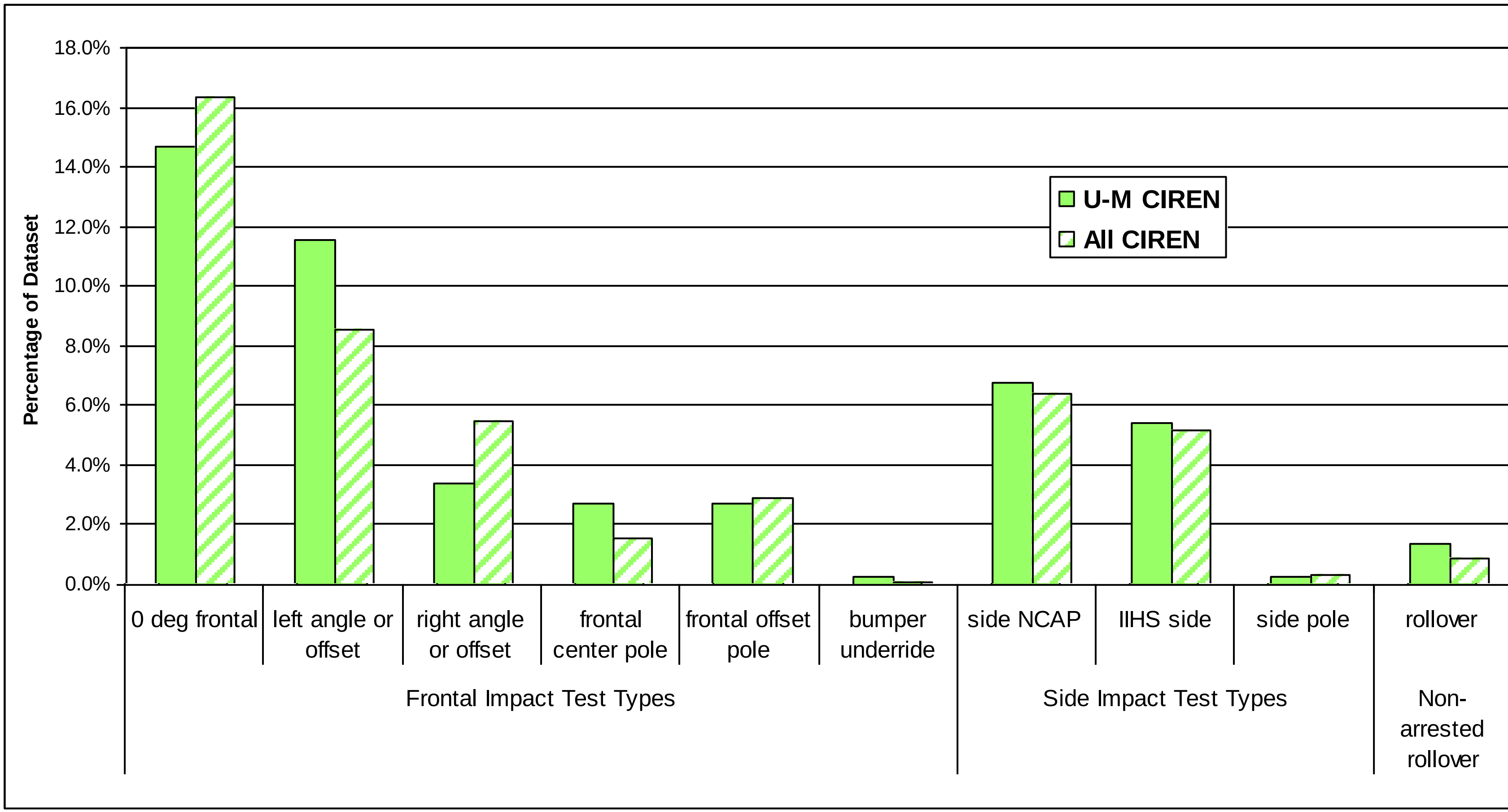


Does not match U-M CIREN CDC

UMPIRE

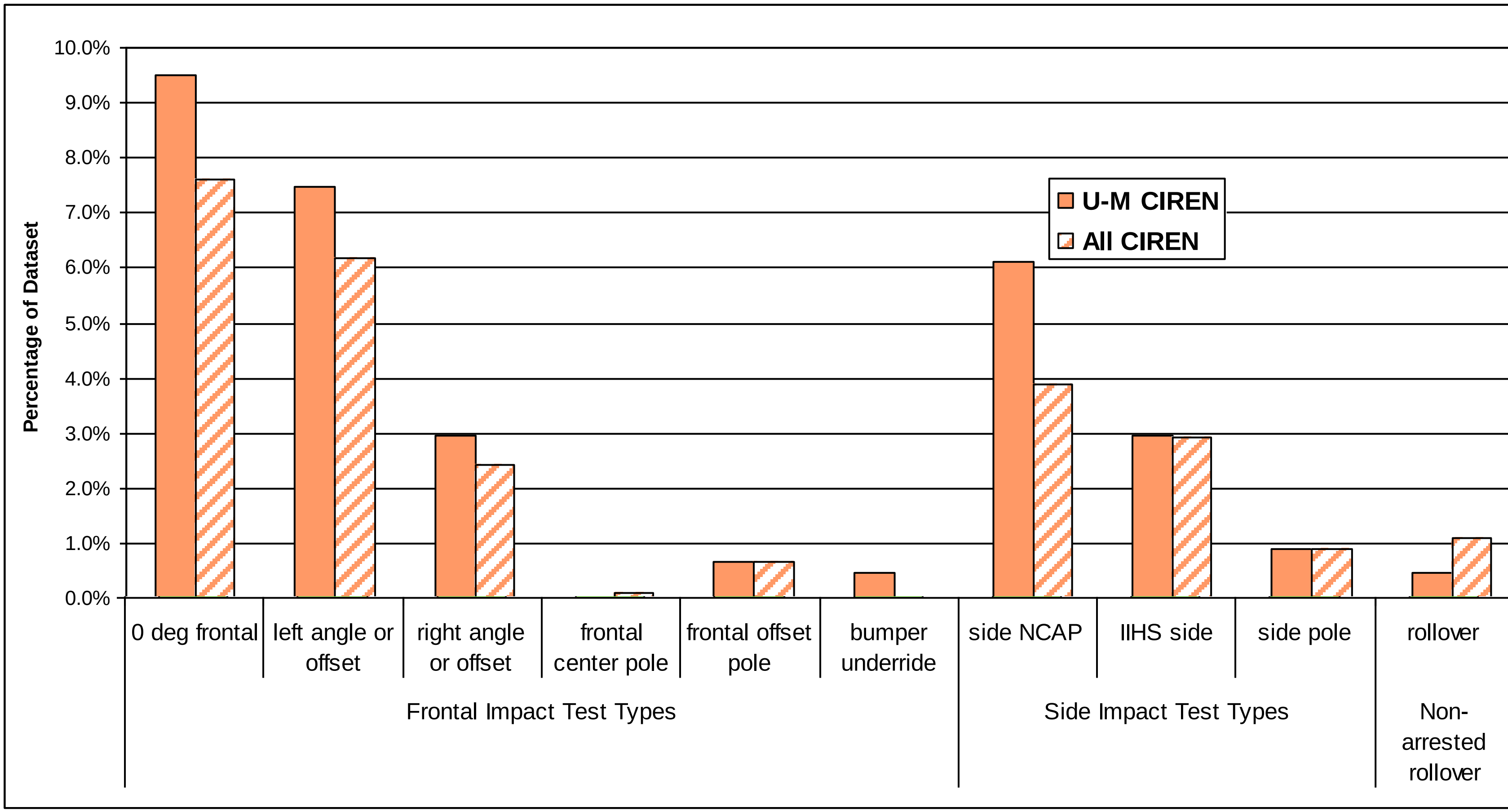
= Test Configuration
≤ Test Extent

= Test Configuration, ≤ Test Extent By Test Type



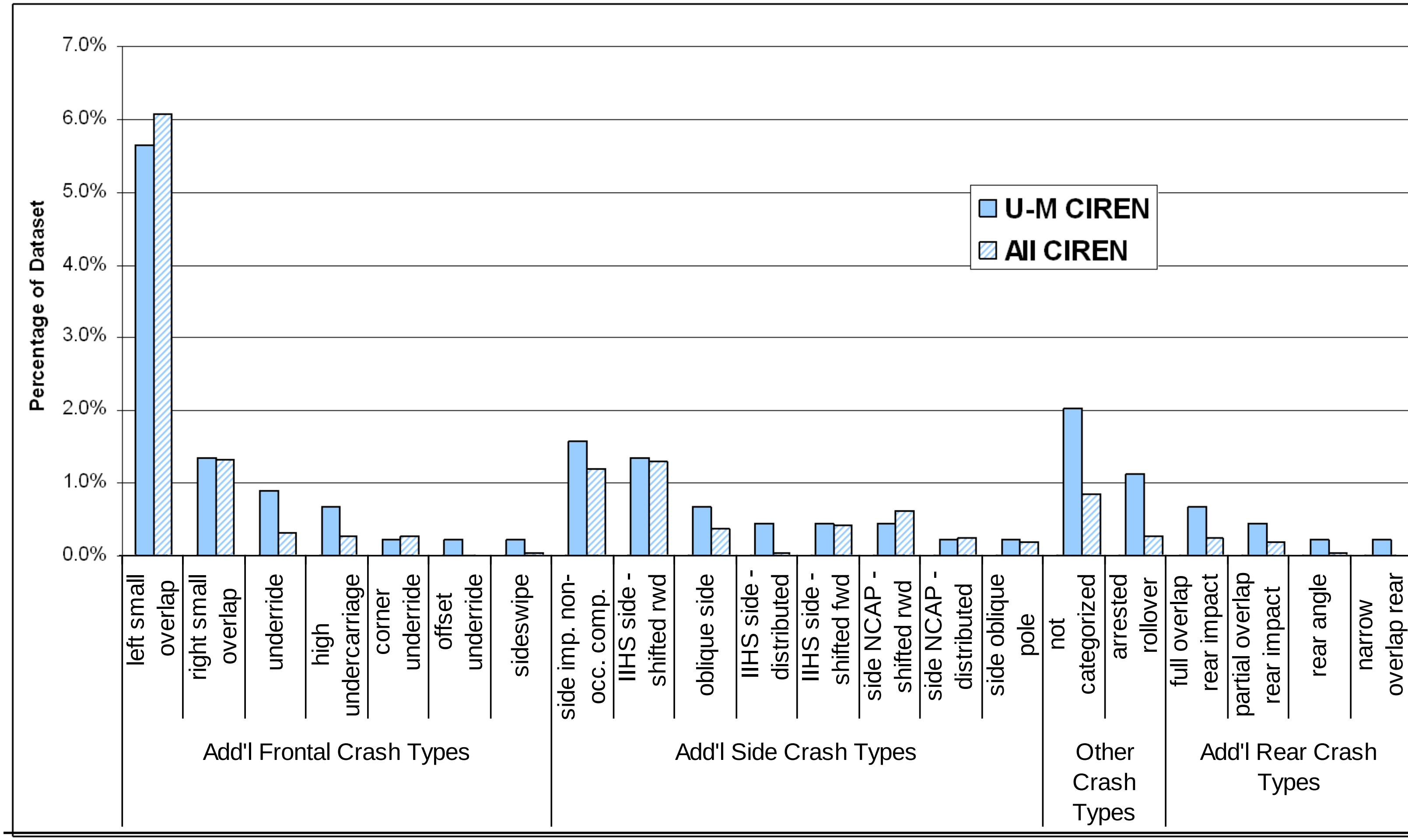
UMPIRE

= Test Configuration, > Test Extent By Test Type



UMPIRE

≠ Test Configuration By Configuration



UMPIRE

= Test Configuration
≤ Test Extent

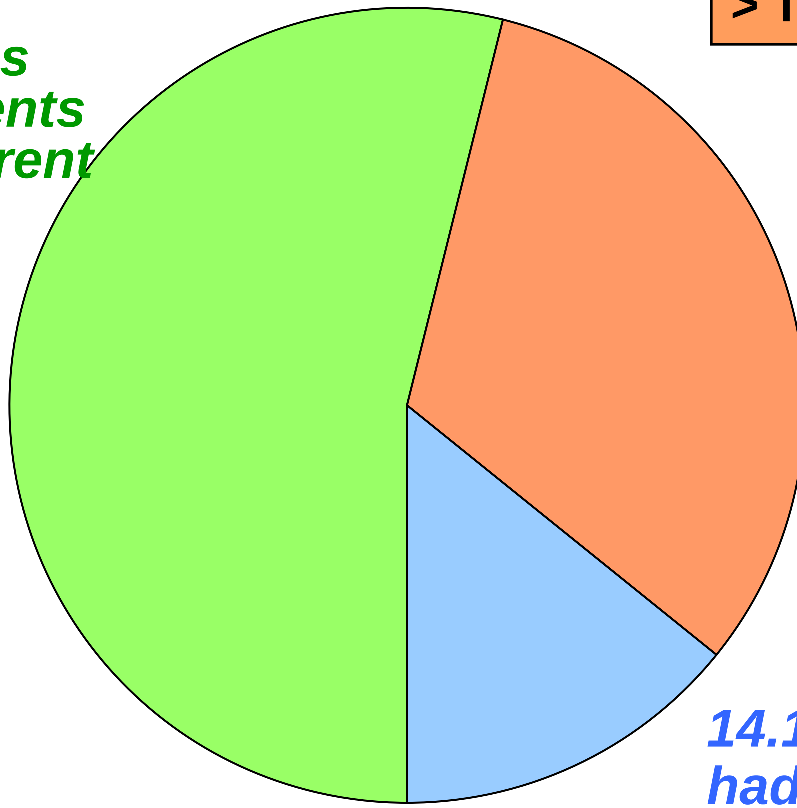
Key Questions
Frontal Crashes

- Why and how were people being seriously injured in U of M - CIREN frontal crashes with configurations and CDC extents similar to current industry tests?
- What was the nature of U of M - CIREN frontal crashes that were different than current industry crash tests in terms of:
  - CDC Extent?
  - Configuration?

U-M CIREN
Frontal Cases

= Test Configuration
≤ Test Extent

53.8% of frontal cases had configurations and CDC extents similar to current crash tests



= Test Configuration
> Test Extent

32.1% of frontal cases had similar configurations but greater CDC extents than current crash tests

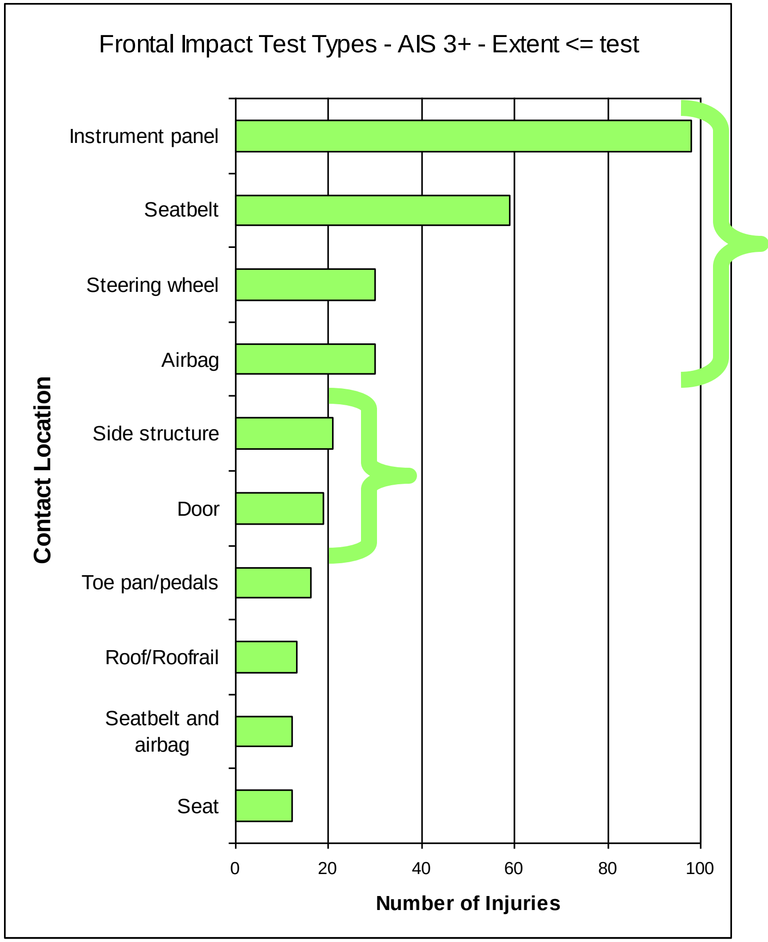
≠ Test Configuration

14.1% of frontal cases had configurations that differed from current crash tests

UMPIRE

= Test Configuration
≤ Test Extent

Top 10 Contact Locations Frontal Crashes



- 65% of injuries were assigned to contact with the instrument panel, seatbelt, steering wheel, and airbag
- 11% of injuries were assigned to contact with the vehicle side structure and door

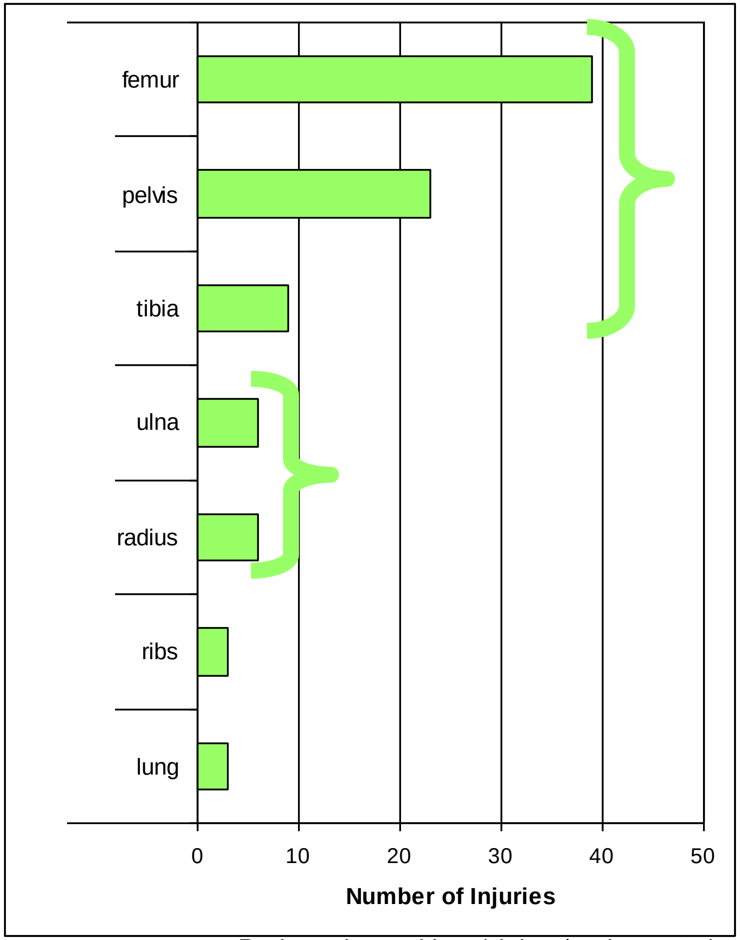
UMPIRE

= Test Configuration
≤ Test Extent

Frontal Crashes Injuries Assigned to Instrument Panel

= Test Configuration
≤ Test Extent

Frontal Crashes
Instrument Panel – Injuries by Body Region



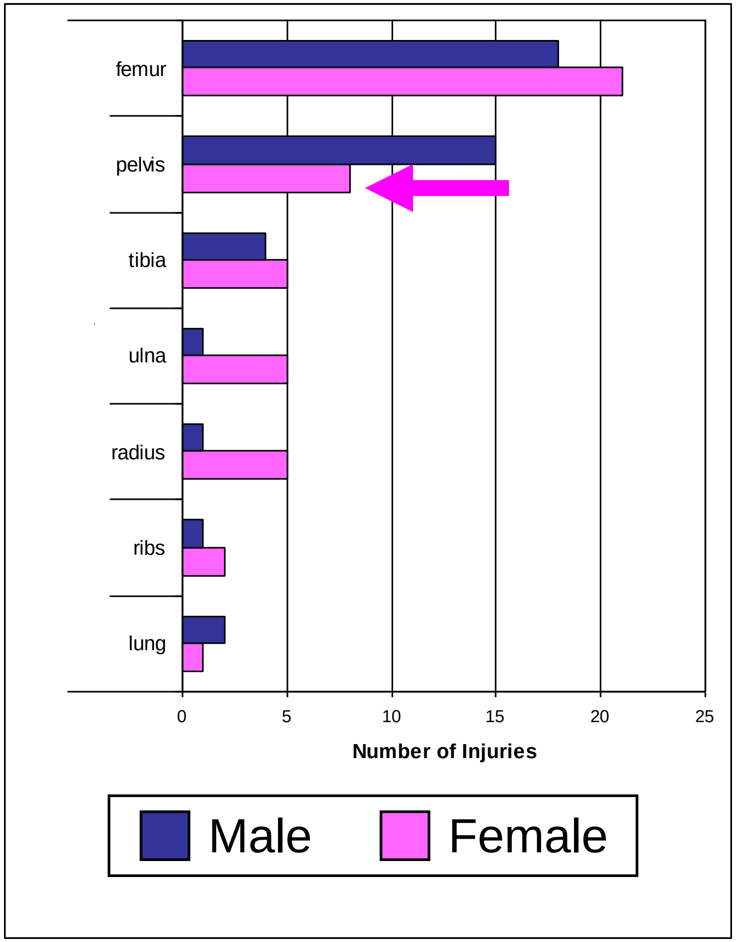
Body regions with ≤ 1 injury/region not shown

- 72% of injuries assigned to the instrument panel were to lower extremities
- 12% were forearm injuries

UMPIRE

= Test Configuration
≤ Test Extent

Frontal Impact Cases
Instrument Panel – Injuries by Gender

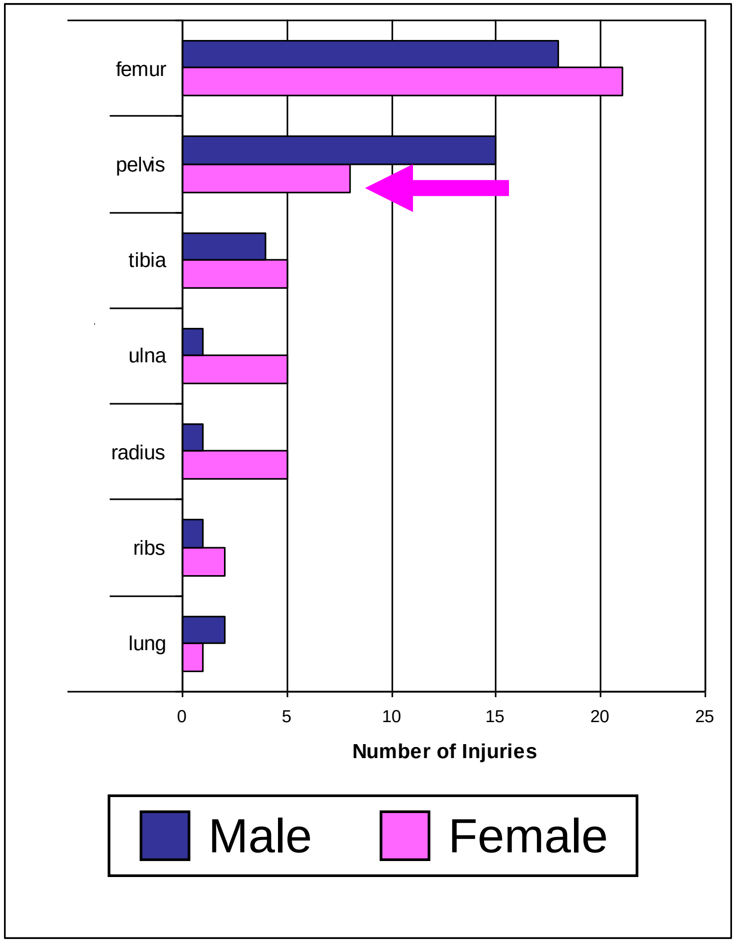


Body regions with ≤ 1 injury/region not shown

- Women had fewer pelvic fractures
  - The difference in belt usage rates alone between men (55%) and women (68%) did not completely account for this

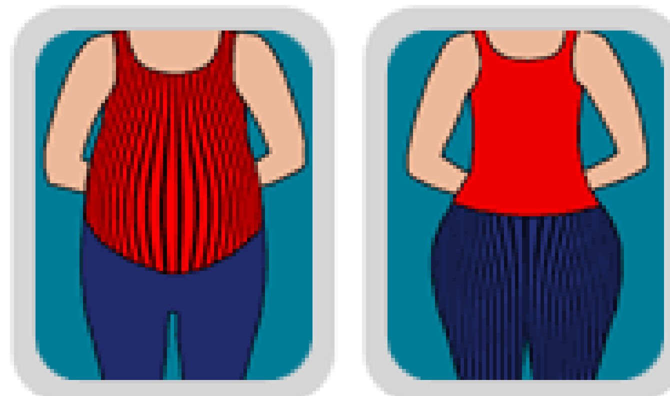
= Test Configuration
≤ Test Extent

Frontal Impact Cases
Instrument Panel – Injuries by Gender



Body regions with ≤ 1 injury/region not shown

- Women had fewer pelvic fractures
  - Pelvic geometry and weight distribution differences are likely responsible.



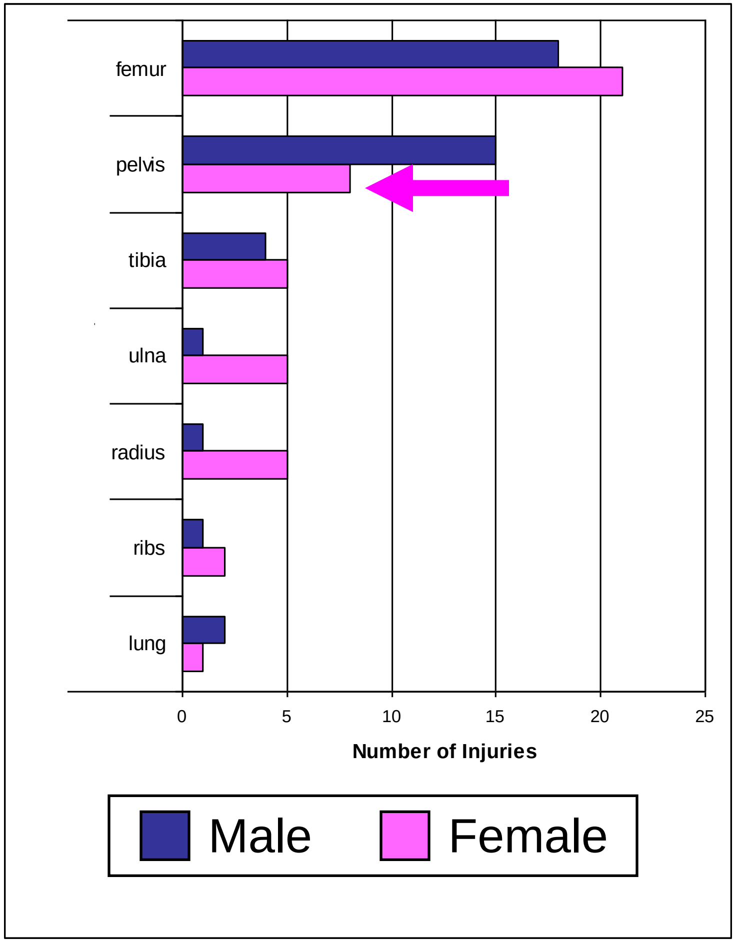
Male **Female**

  - Abdominal weight of men loads through the pelvis during a frontal impact.
  - Hip weight of women is more closely coupled to the thighs and loads the pelvis less during a frontal impact.

UMPIRE

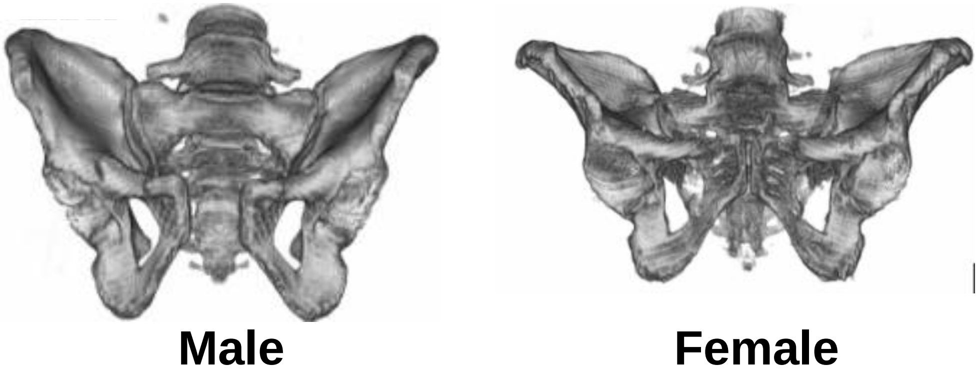
= Test Configuration
≤ Test Extent

Frontal Impact Cases
Instrument Panel – Injuries by Gender



Body regions with ≤ 1 injury/region not shown

- Women had fewer pelvic fractures
  - Pelvic geometry and weight distribution differences are likely responsible.

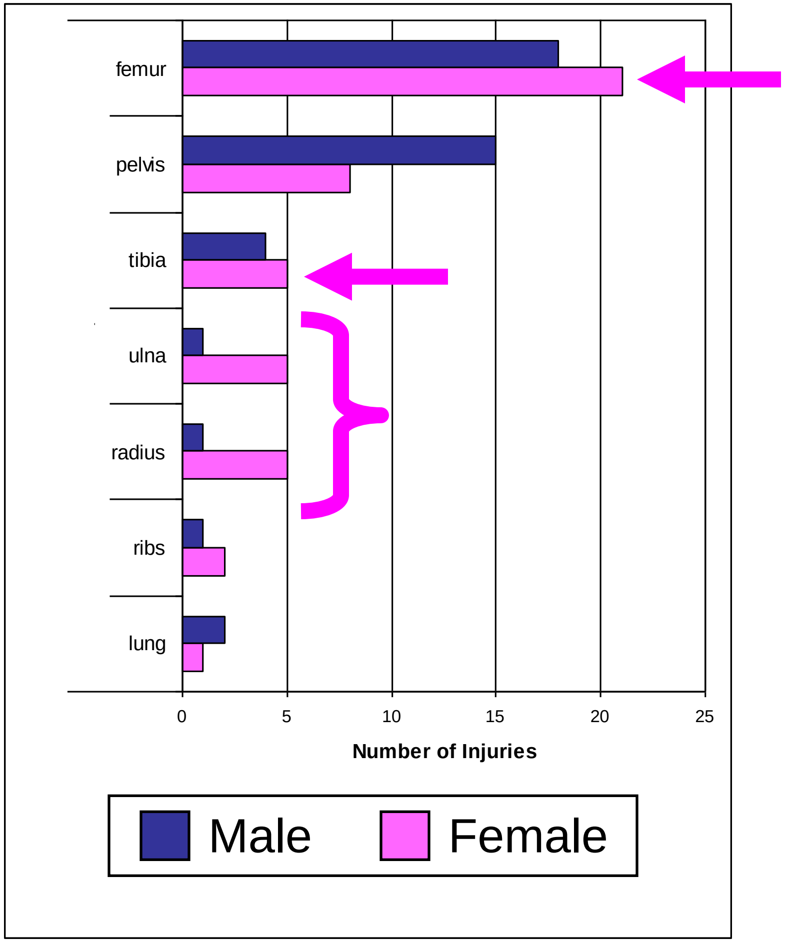


- The male pelvis is generally taller and narrower than the female pelvis
- The cup of the acetabulum is oriented more laterally in the male as opposed to the female
- Thus the male pelvis may be more susceptible to acetabulum fracture

UMPIRE

= Test Configuration
≤ Test Extent

Frontal Impact Cases
Instrument Panel – Injuries by Gender

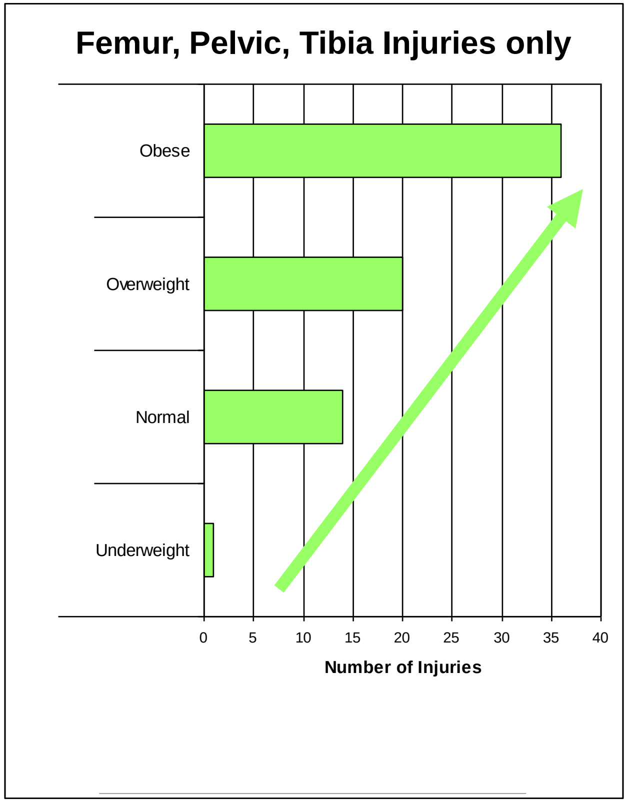


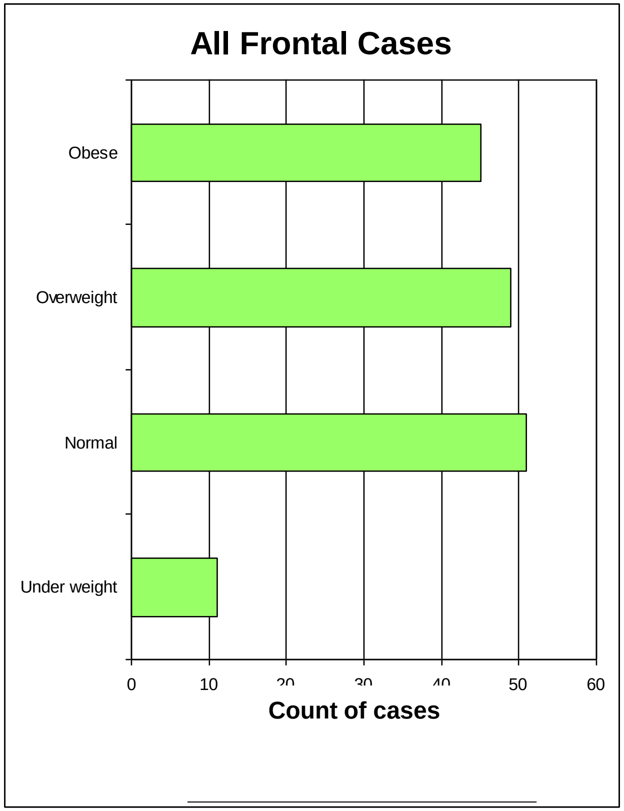
Body regions with ≤ 1 injury/region not shown

- Women appeared to have slightly more femur and tibia fractures.
  - This also may be attributed to the difference in pelvis geometry and weight distribution as well as the proximity to the instrument panel
- Women appeared to have slightly more forearm fractures (may not be statistically significant…)

= Test Configuration
≤ Test Extent

Frontal Impact Cases
Instrument Panel – Injuries by BMI



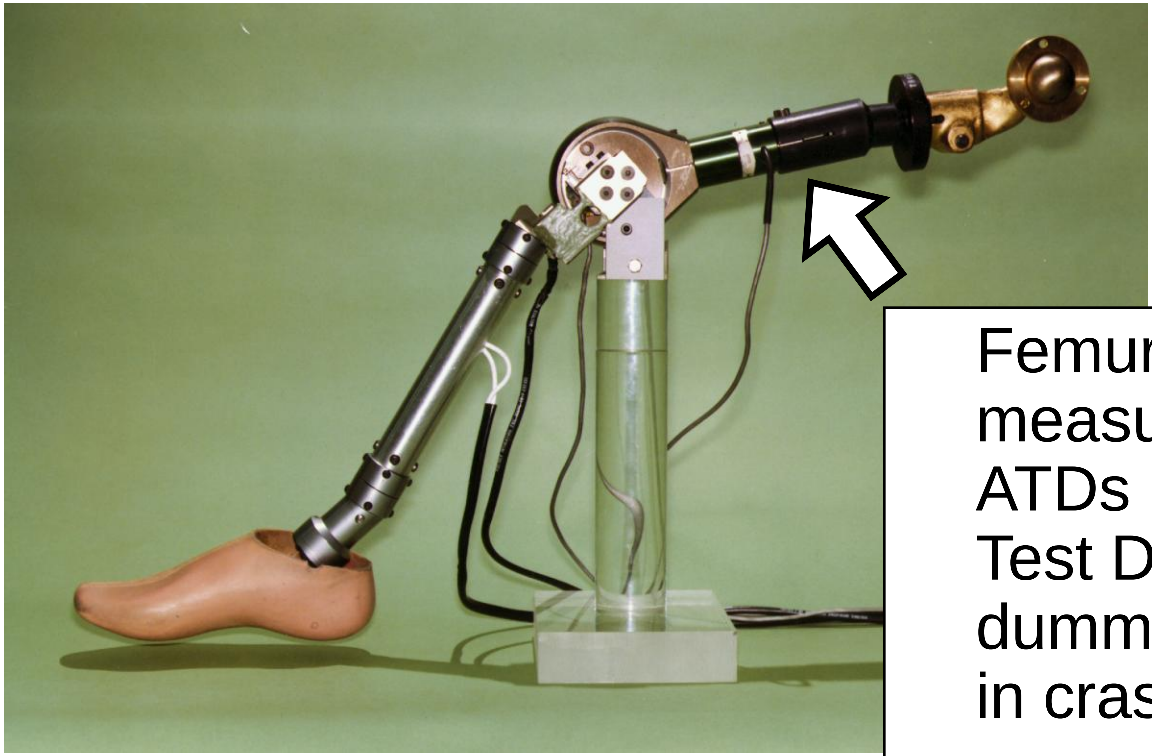


- Femur, pelvic, and tibia injuries increased with BMI
- Increasing BMI provides additional mass which increases occupant energy without an equivalent increase in bone strength

UMPIRE

= Test Configuration
≤ Test Extent

Frontal Impact Cases
Injuries Assigned to Instrument Panel
Engineering Observations

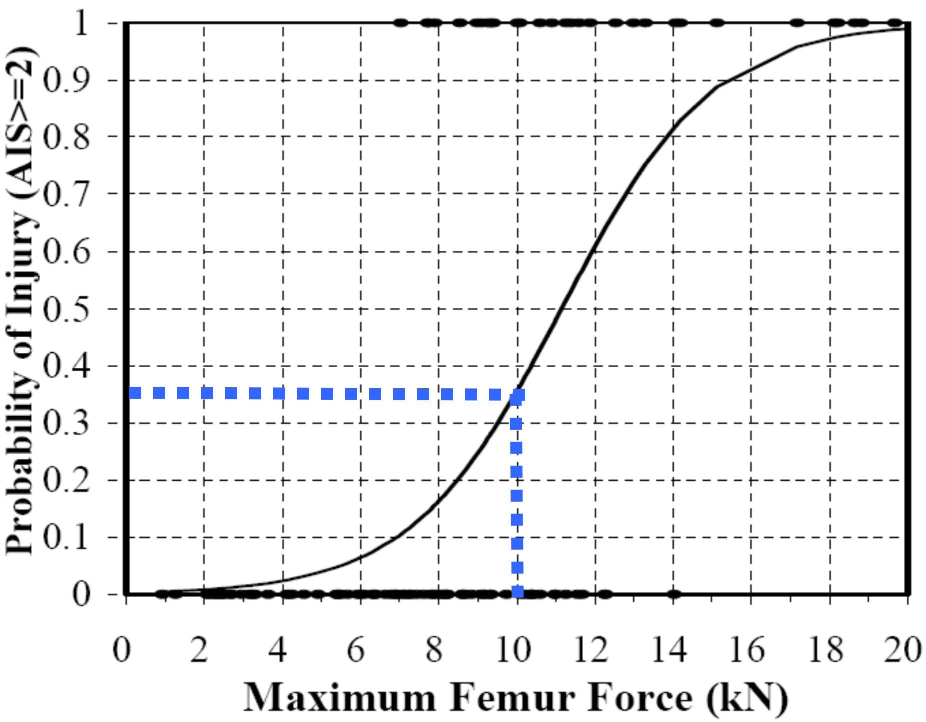


Femur loads are measured in the Hybrid III ATDs (Anthrpomorphic Test Devices or crash dummies) and regulated in crash tests

= Test Configuration
≤ Test Extent

Injury Assessment Reference Value Discussion
Femur Load Tolerance

Injury risk curve – 50th %ile Male[1]



- FMVSS 208 limits represent a 35% risk of a femur/patella fracture[2]
  - 50th Male = 10kN
  - 5th Female = 6.8kN
- Femur fractures are all AIS 3 injuries (AIS 2000)

References: 1 Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems Kippenberger, et. al., 1998

2 Supplement: Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems – II Eppinger, et. al., 2000

= Test Configuration
≤ Test Extent

Frontal Impact Cases
Instrument Panel Injury
Engineering Observations

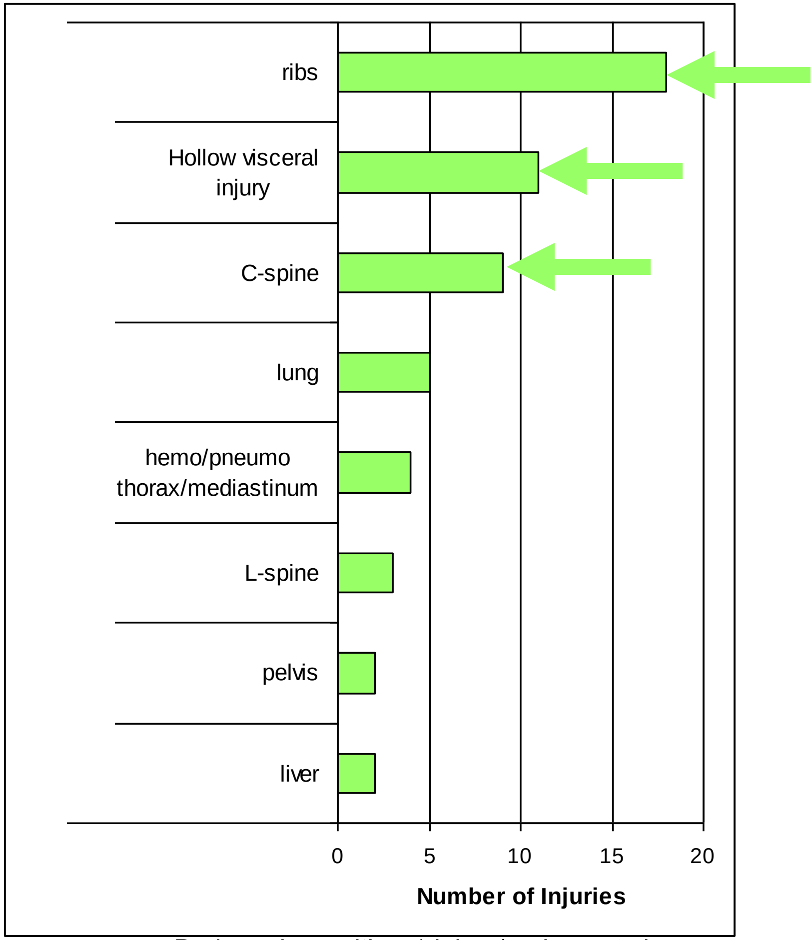
- Current trends in human body mass distribution are not reflected in current ATDs
- Some ATDs have proportionally higher mass in the skeleton than in the flesh as compared to humans

= Test Configuration
≤ Test Extent

Frontal Crashes Injuries Assigned to Seatbelts

= Test Configuration
≤ Test Extent

Frontal Impact Cases
Seatbelt Injuries by Body Region



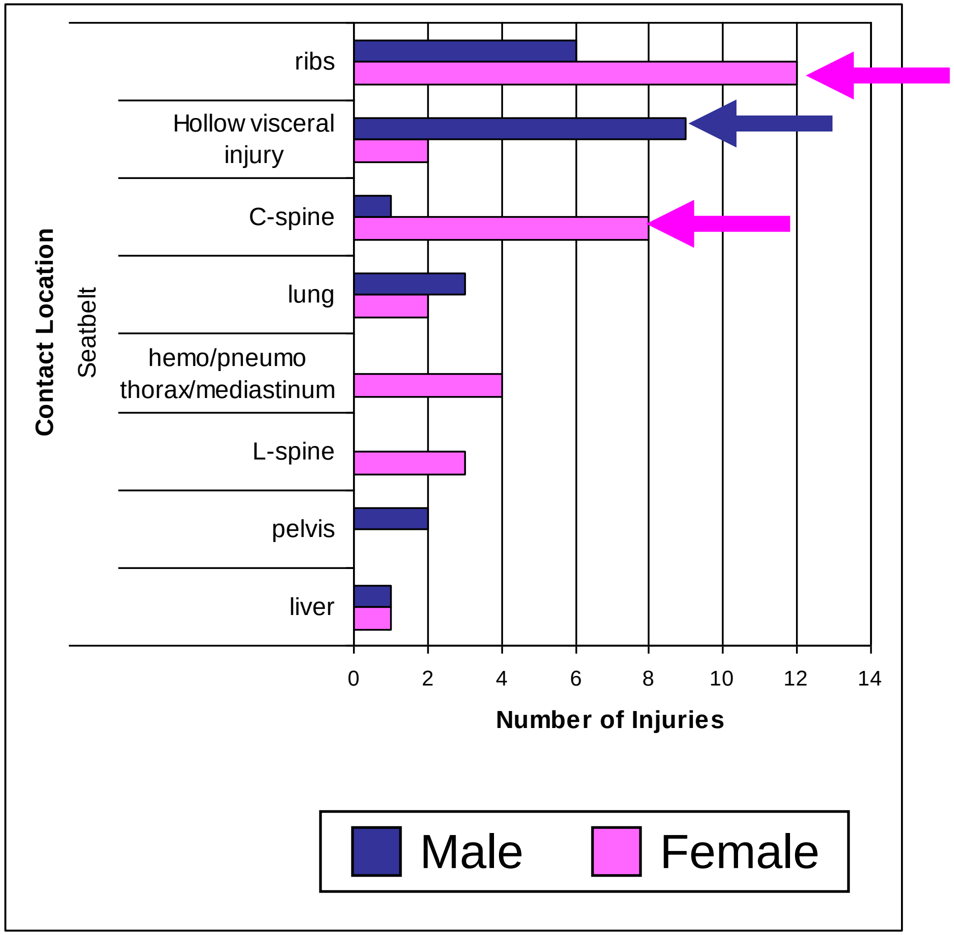
Body regions with ≤ 1 injury/region not shown

- 31% of injuries assigned to the seat belt were rib fractures
- 19% were hollow visceral injury (small bowel, colon, and mesentary)
- 15% were cervical spine injuries (bony and spinal cord)

UMPIRE

= Test Configuration
≤ Test Extent

Frontal Impact Cases
Seatbelt – Injuries by Gender



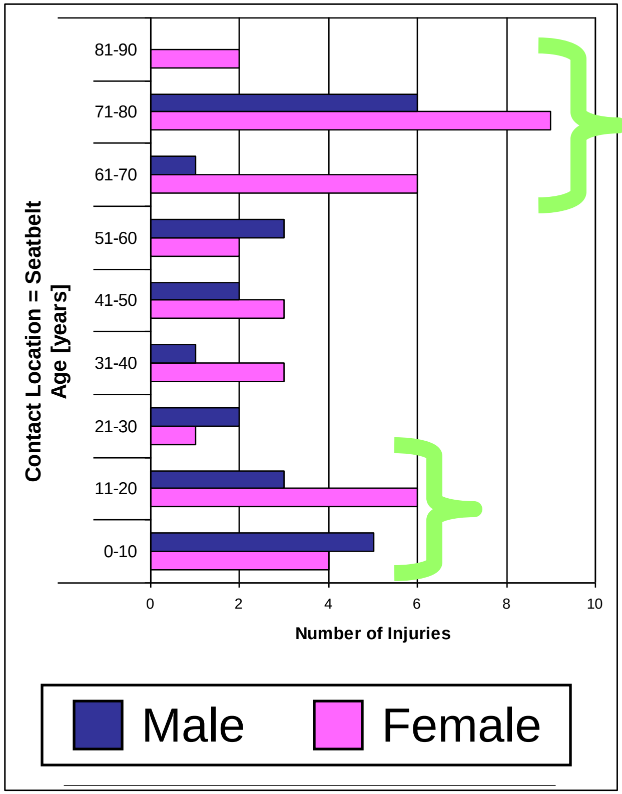
Body regions with ≤ 1 injury/region not shown

- Rib fractures
  - Older women appear to be more susceptible
    - 6 of the 12 were over 70
    - 8 of the 12 were over 50
- Hollow visceral injuries (8 cases)
  - 4 of 5 adult male cases were in the overweight BMI category
  - 3 cases were lap-belt only restrained children
- Cervical spine injuries (7 cases)
  - 5 cases were older adult women (over 56 years old)
  - One case with bony cervical spine injuries involved a 4 year old female

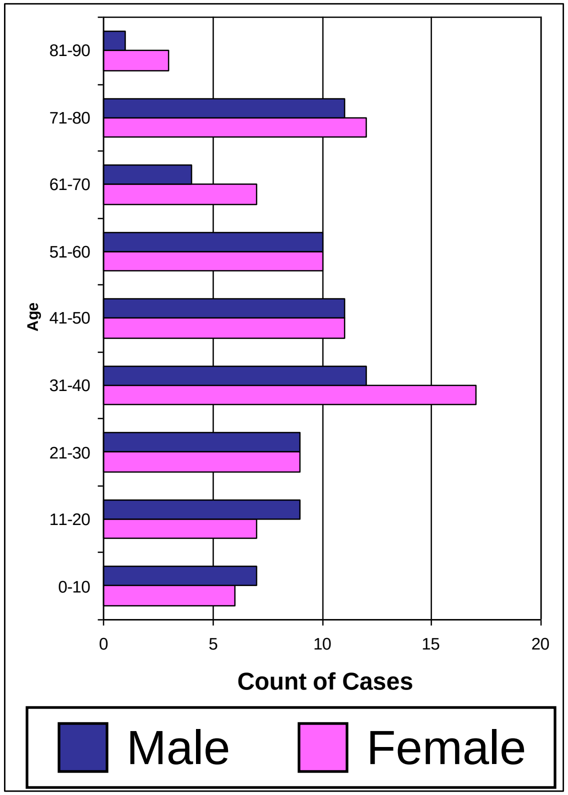
= Test Configuration
≤ Test Extent

Frontal Impact Cases
Seatbelt Injuries by Age and Gender

Assigned to Seatbelt Contact



All Frontal Cases

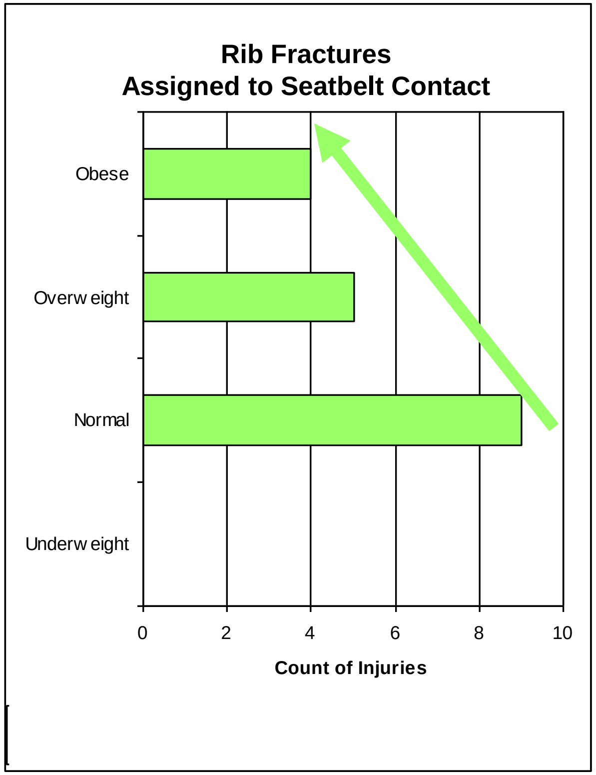


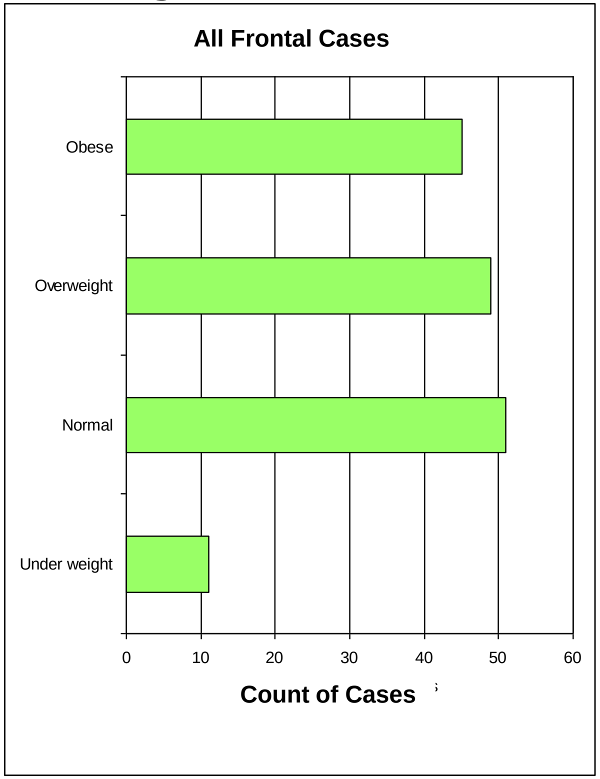
- Seatbelt related injuries appeared to occur more frequently to younger and older occupants
  - Older occupants, especially women, are more likely to be osteoporotic
  - Seatbelt misuse was an issue with some younger occupants in this dataset

UMPIRE

= Test Configuration
≤ Test Extent

Frontal Impact Cases Seatbelt Injuries by BMI



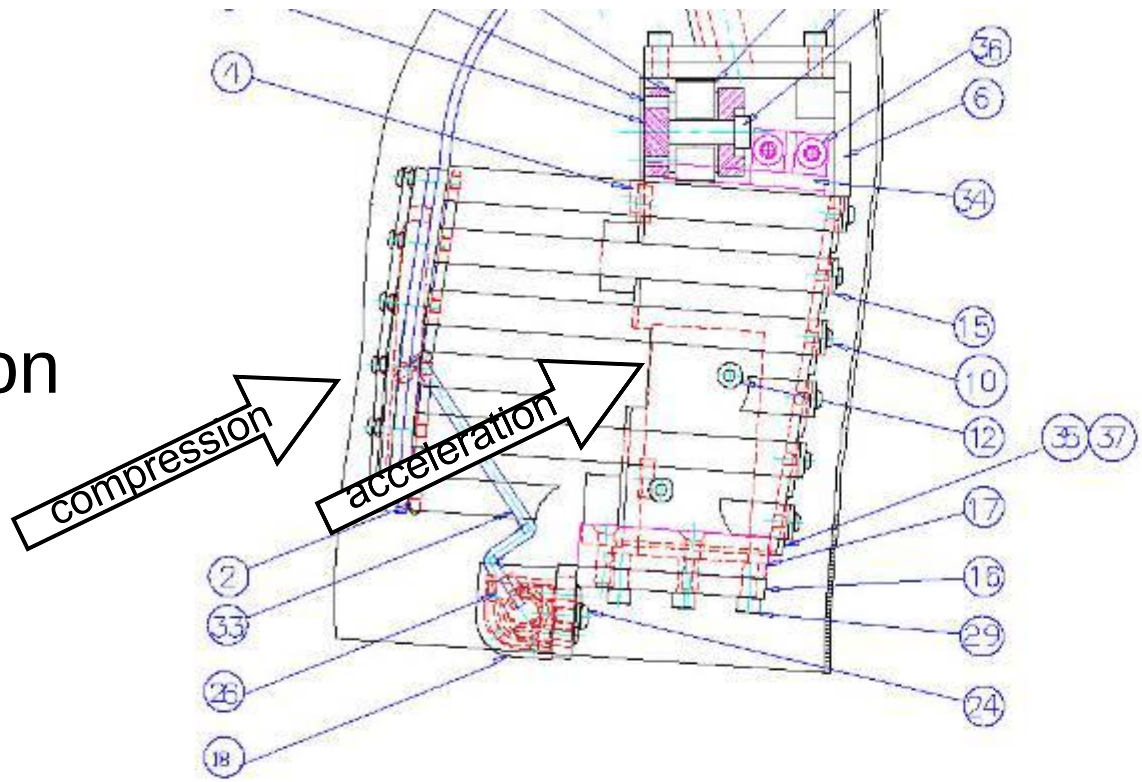


- BMI appears to have the opposite effect on the potential for rib fractures assigned to belt contact as compared to femur, pelvic and tibia fractures assigned to instrument panel contact
- Increased BMI reduced the potential for rib fractures assigned to seat belt contact

= Test Configuration
≤ Test Extent

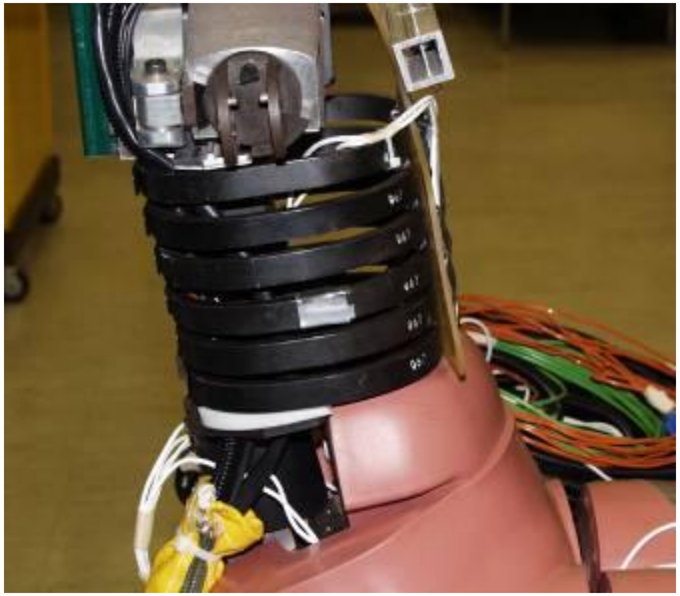
Frontal Impact Cases
Seat Belt Injury
Engineering Observations

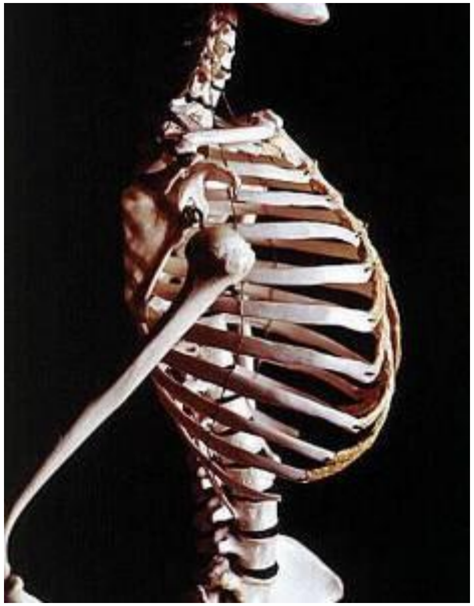
Hybrid III ATDs measure chest acceleration and chest compression



= Test Configuration
≤ Test Extent

Frontal Impact Cases
Seat Belt Injury
Engineering Observations



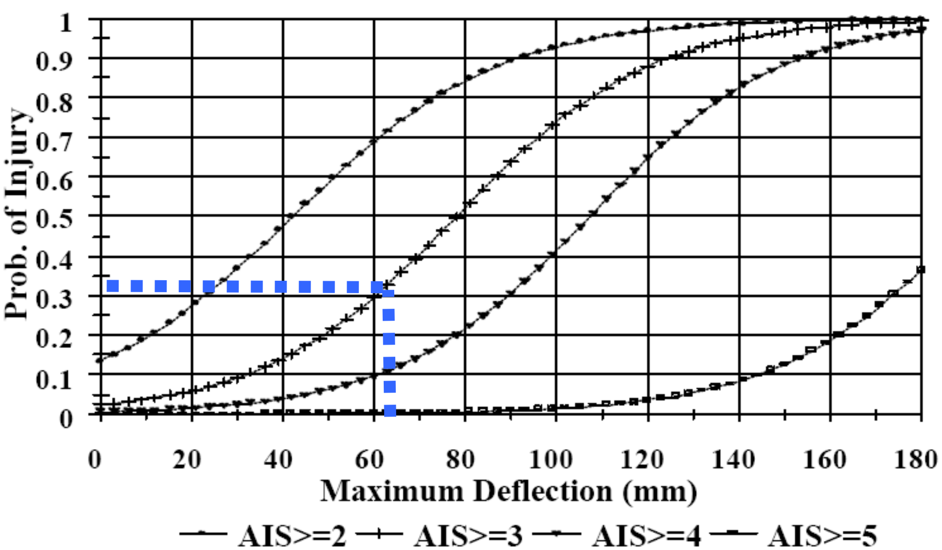


- An ATD must be a repeatable and durable crash test instrument, therefore, differences exist between the dummy’s and a human’s rib cage

= Test Configuration
≤ Test Extent

Injury Assessment Reference Value Discussion Chest Deflection Tolerance

Injury risk curve – 50th %ile Male



- FMVSS 208 limits represent a 33% risk of an AIS≥3 injury
  - 50th Male = 63mm
  - 5th Female = 52mm
- >3 rib fractures on one side or 1 to 3 fractured ribs and a hemo/pneumo thorax is coded as an AIS 3 chest injury (AIS 2000)

Reference: Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems - II Eppinger, et. al., 1999

Frontal Impact Cases
Seat Belt Injury
Engineering Observations

- Chest acceleration has been regulated in crash tests since the 1970s
- Chest compression has more recently been regulated in crash tests
  - The mid-sized male Hybrid III has been required since the 1998 model year but was previously allowed
  - Recently, the small female was regulated and the mid-sized male chest compression requirements were made more stringent

= Test Configuration
≤ Test Extent

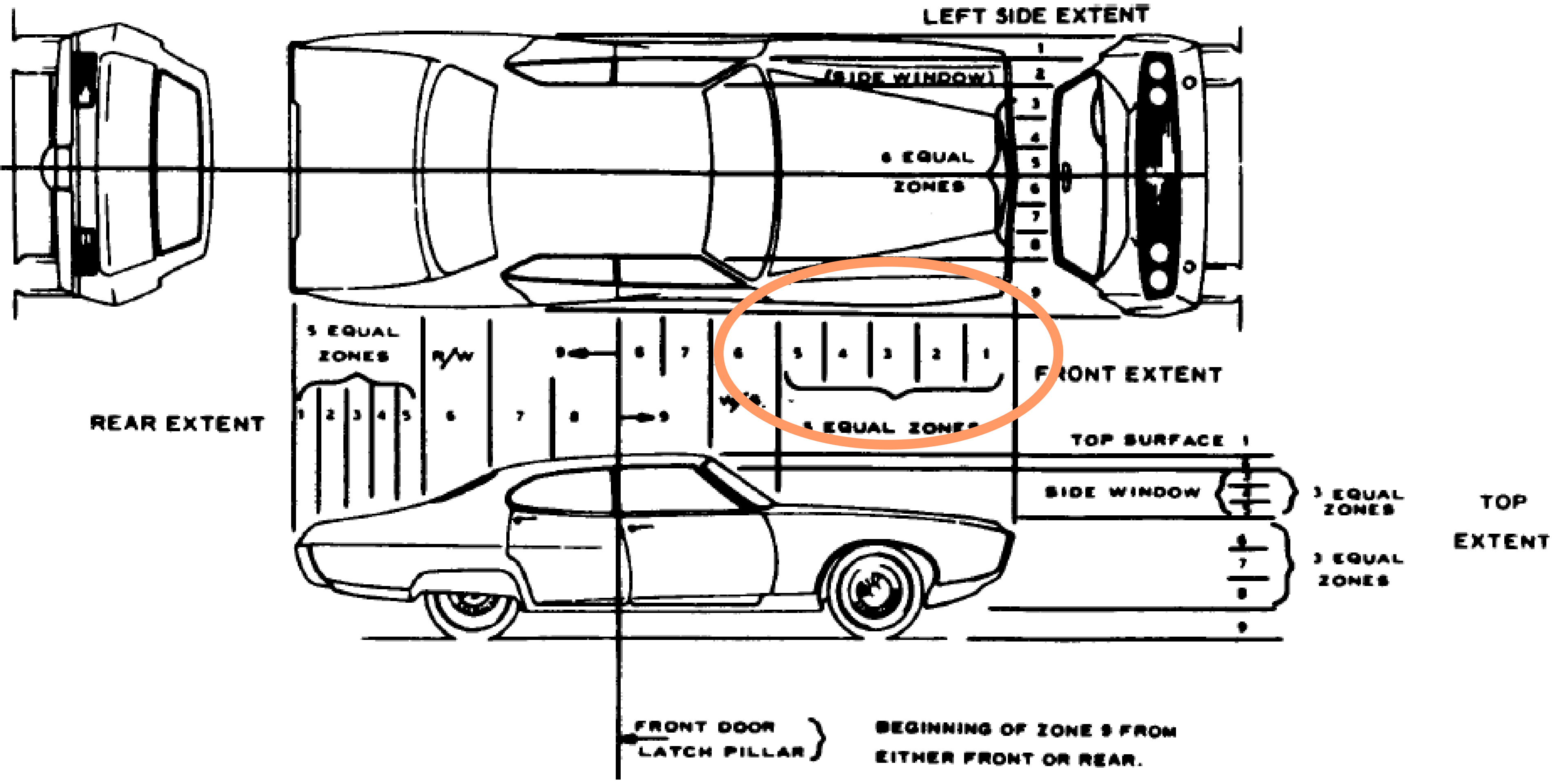
Frontal Impact Cases Summary

- Femur, pelvic, and tibia injuries increased with BMI while chest injuries decreased in cases with similar configurations and extents to industry crash tests
- Pelvic and femur injury patterns differed between men and women
- Rib injuries assigned to seatbelts appeared to occur more frequently to older and younger occupants
- Test dummies can not account for all of the variation seen in the human population because they must be repeatable and durable test devices

Key Questions
Frontal Crashes

- Why and how were people being seriously injured in U of M - CIREN <u>frontal</u> crashes with configurations and CDC extents similar to current industry tests?
- What was the nature of U of M - CIREN <u>frontal</u> crashes that were different than current industry crash tests in terms of:
  - CDC Extent?
  - Configuration?

CDC Position 7: Extent



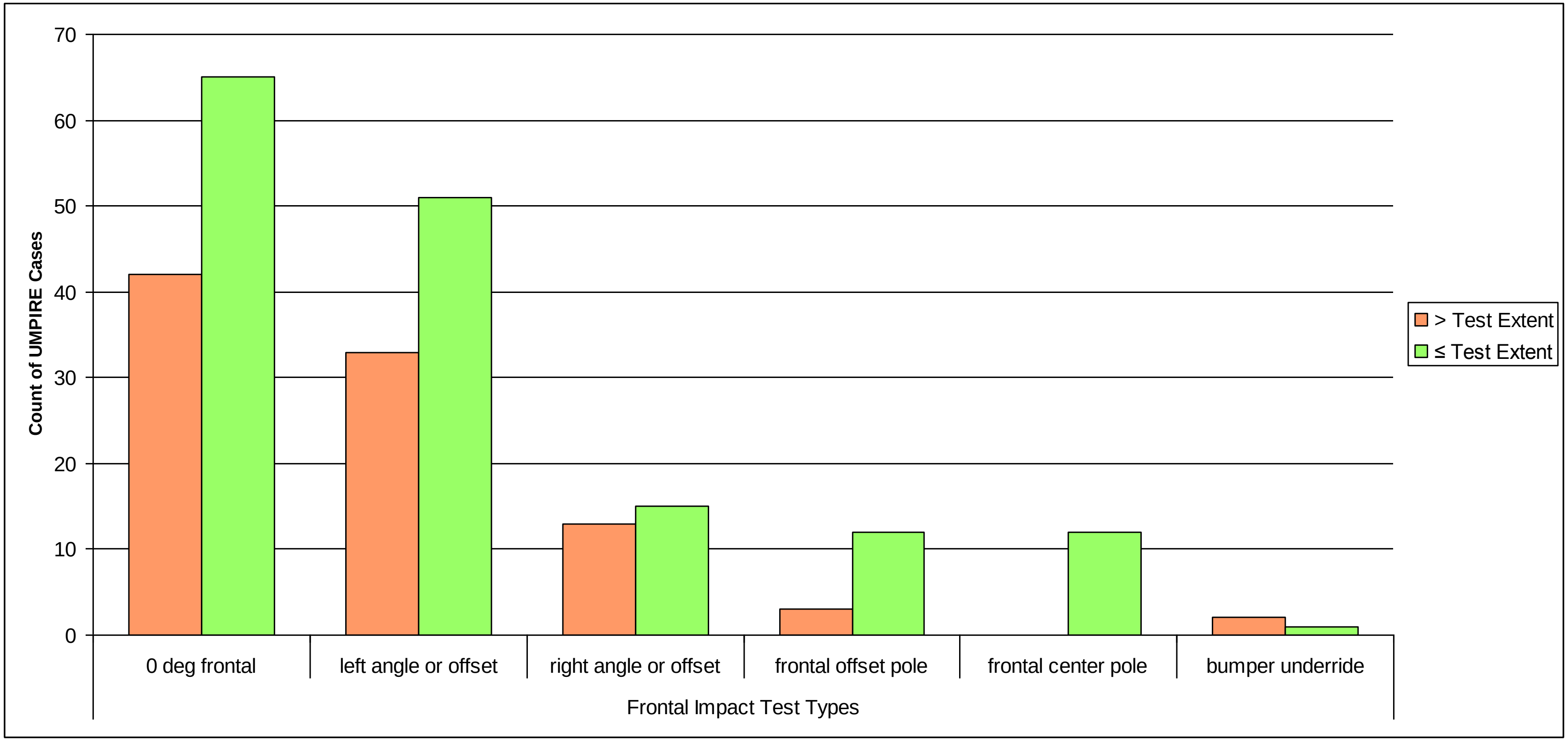
UMPIRE

Reference: SAE Surface Vehicle Standard J224 Collision Deformation Classification, Rev. March, 1980

= Test Configuration
> Test Extent

= Test Configuration
≤ Test Extent

Frontal Impact Cases with Configurations Similar to Current Test Types CDC Extent Comparison

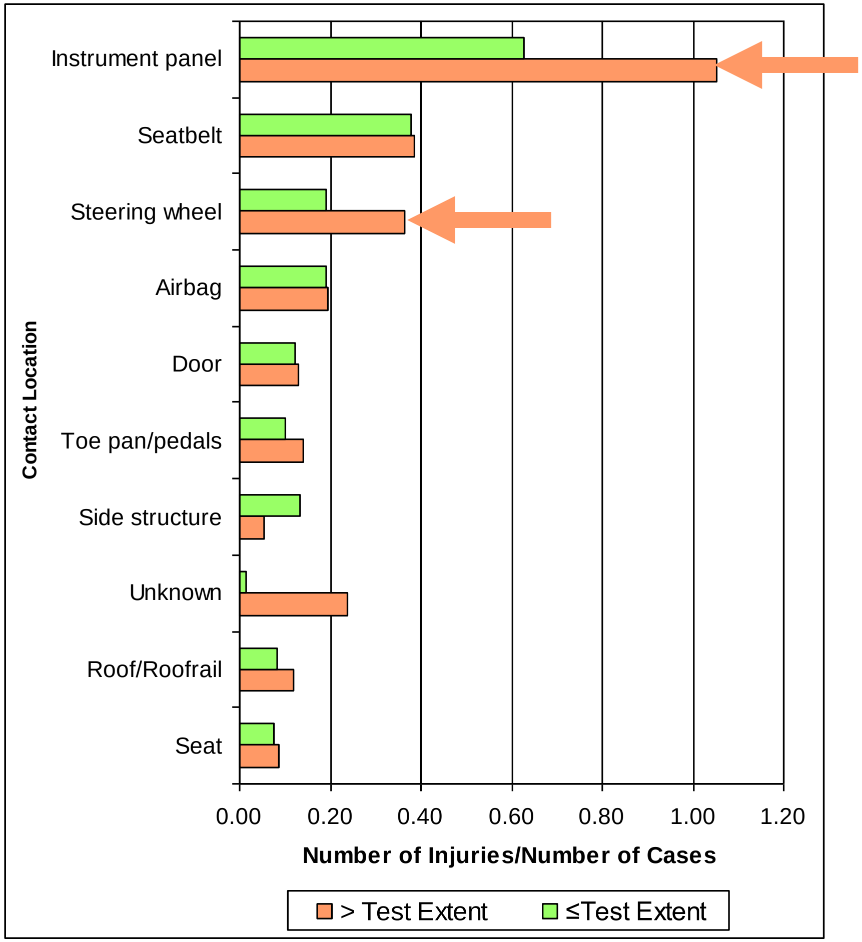


UMPIRE

= Test Configuration
> Test Extent

= Test Configuration
≤ Test Extent

Frontal Impact Case Occupant Injuries by Assigned Contact Location and Extent



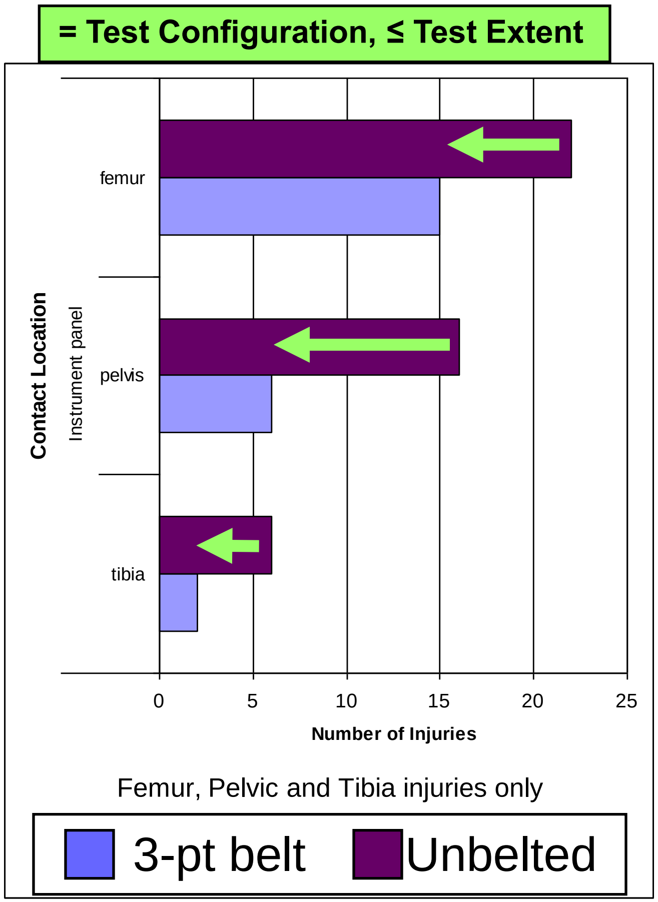
- Data above and below current test CDC extents were normalized by dividing the number of injuries by the number of cases
- Injuries assigned to instrument panel and steering wheel contact increased with higher extents, however those assigned to seatbelt and airbag contact did not increase

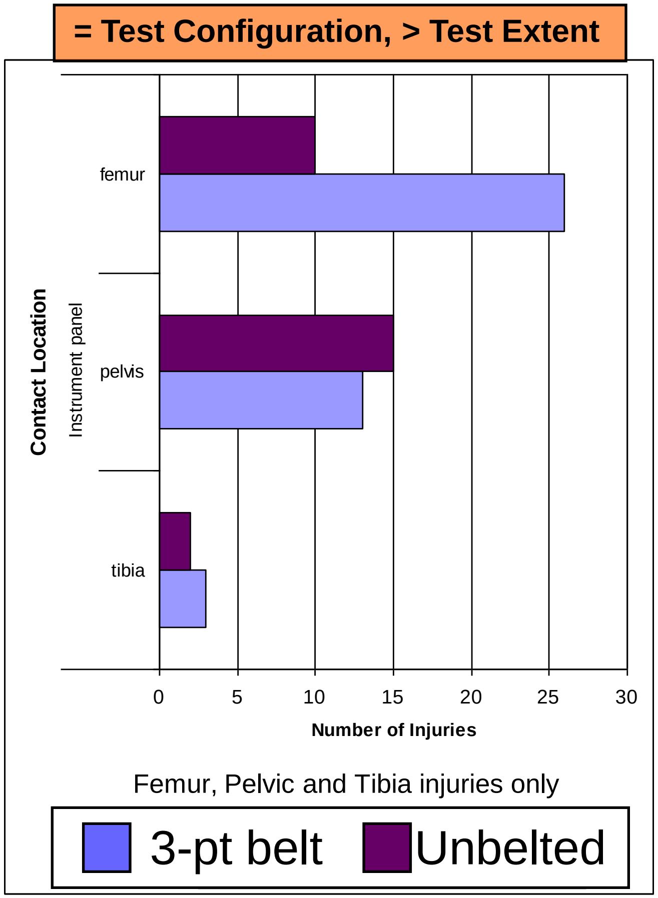
UMPIRE

= Test Configuration
> Test Extent

= Test Configuration
≤ Test Extent

Frontal Impact Case Occupant Injuries Instrument Panel Injuries by Body Region, Belt Use, and Extent





- Belts appeared to be more effective in reducing femur, pelvic and tibia injuries in crashes with lower CDC extents

UMPIRE

= Test Configuration
> Test Extent

= Test Configuration
≤ Test Extent

Frontal Impact Cases
CDC Extent
Engineering Observations

- Injuries assigned to instrument panel and steering wheel contact increased with higher extents however those assigned to seatbelt and airbag contact did not increase, possibly due to
  - Load limiting seat belts
  - Load sharing between the seatbelt and the airbag
  - Loading other components, once the restraint capacity of the seatbelt and the airbag was exceeded

= Test Configuration
> Test Extent

= Test Configuration
≤ Test Extent

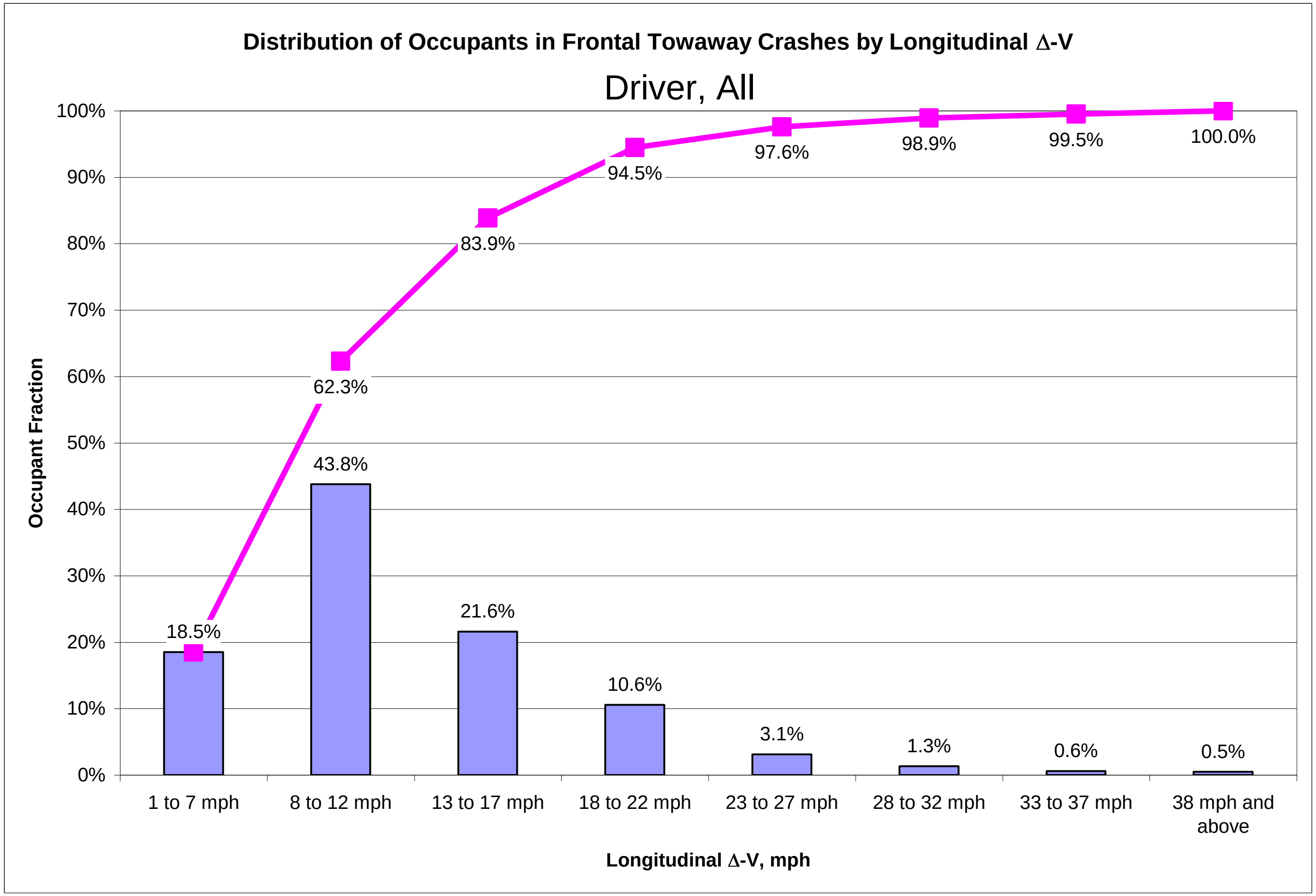
Frontal Impact Cases
CDC Extent
Engineering Observations

- There are many possible measures of crash severity (Delta V, Equivalent Barrier Speed, Extent of Crush, etc.)
- This analysis is based only on CDC extent
- Increasing crash test severities requires consideration of possible consequences that may increase injuries to people not currently being injured in more frequent / lower severity crashes

= Test Configuration
> Test Extent

Crash Severity Distribution

1997-2006 NASS CDS



UMPIRE

High Severity Crash Test Requirements

drives

Stiffer Vehicle Crush Zones

drives

- Aggressive airbags
- Stiffer restraint systems

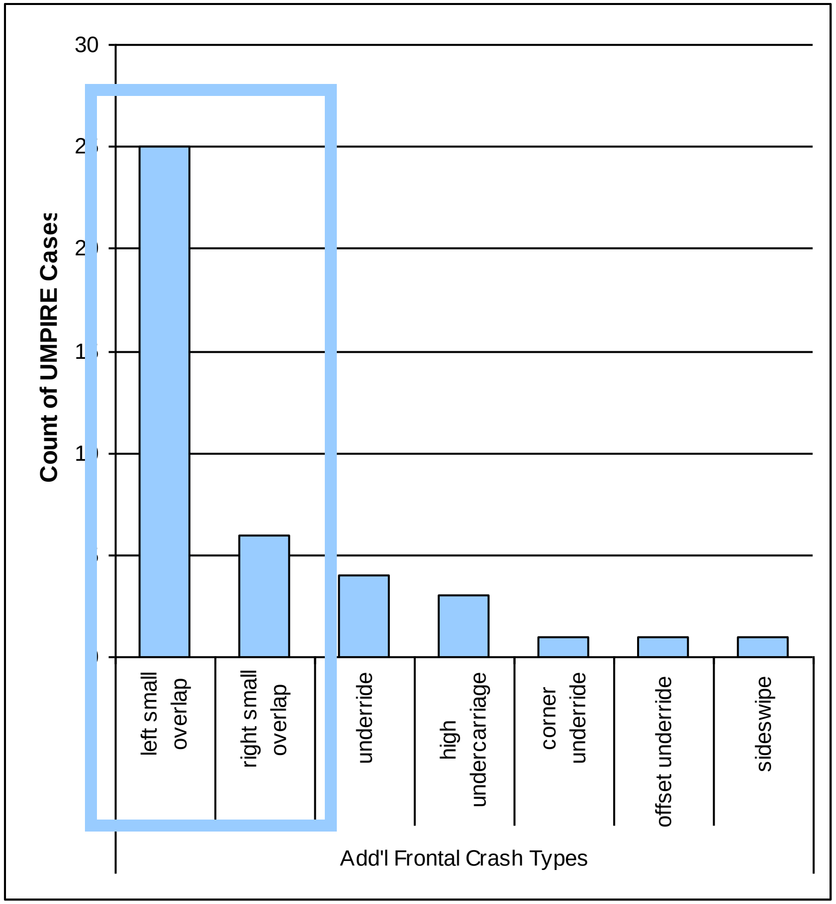
These changes may benefit some occupants in <u>infrequent</u> high severity crashes…

…but increase risk to occupants in <u>more frequent</u> moderate severity crashes by increasing the loads on the occupants.

Key Questions
Frontal Crashes

- Why and how were people being seriously injured in U of M – CIREN frontal crashes with configurations and CDC extents similar to current industry tests?
- What was the nature of U of M - CIREN frontal crashes that were different than current industry crash tests in terms of:
  - CDC Extent?
  - Configuration?

Cases with Frontal Crash Configurations Different from Current Test Types



- Small overlap crashes comprised the majority of frontal crashes with configurations different than current test types
- Small overlap crashes comprised 10.7% of frontal cases in the U-M CIREN database

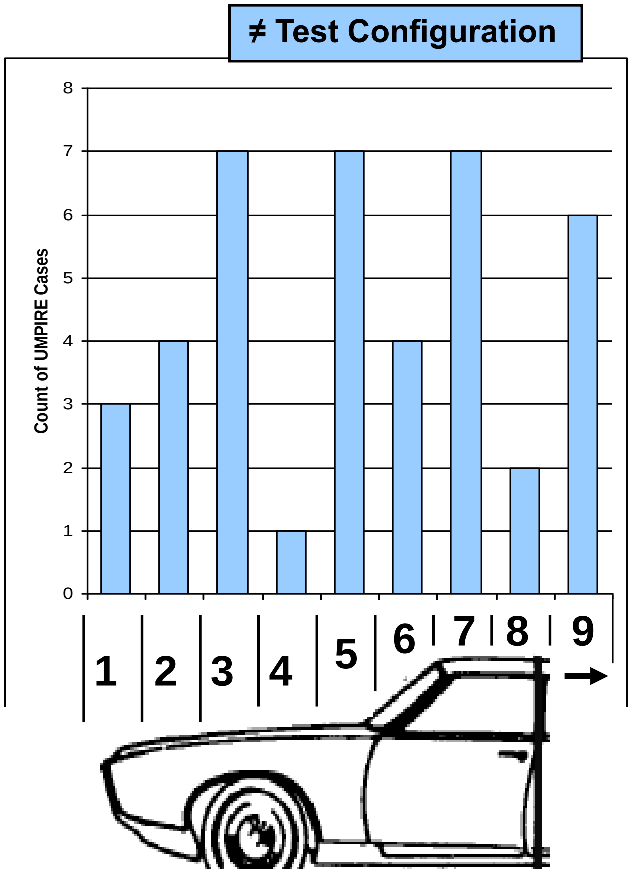
≠ Test Configuration

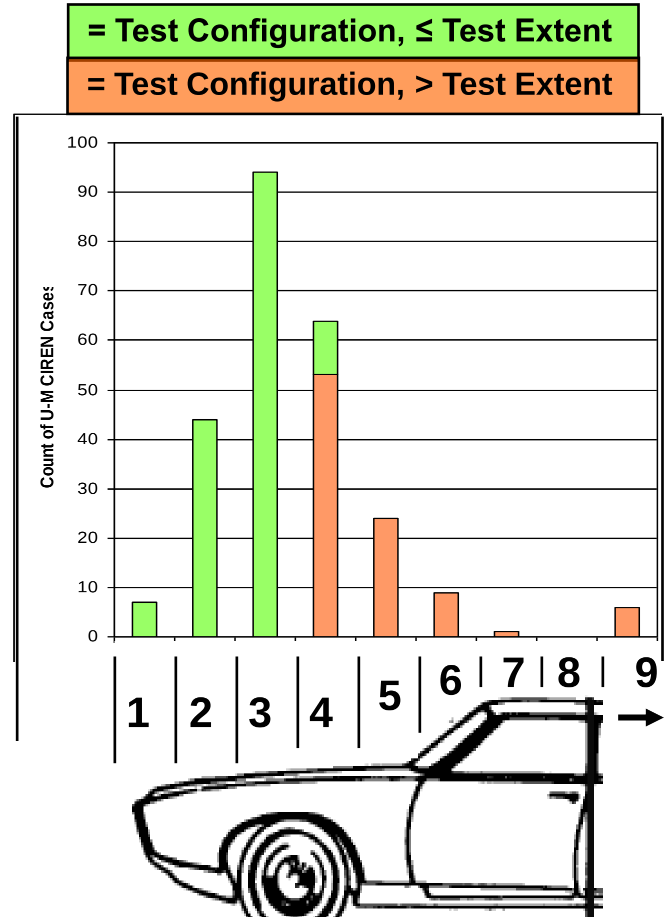
Small Overlap Examples

UMPIRE

≠ Test Configuration

Cases with Frontal Crash Configurations Different from Current Test Types - Extent Discussion

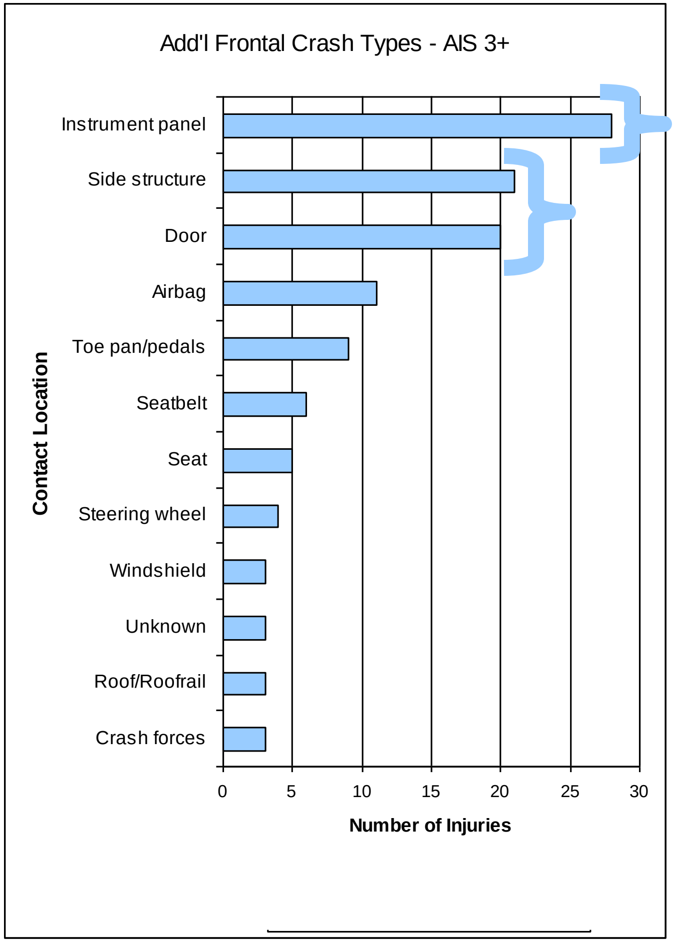




- Frontal crash configurations different from current test types tended to involve localized vehicle deformation that produced higher CDC extents
- Other measures of crash severity are less likely to show the same level of increase

UMPIRE

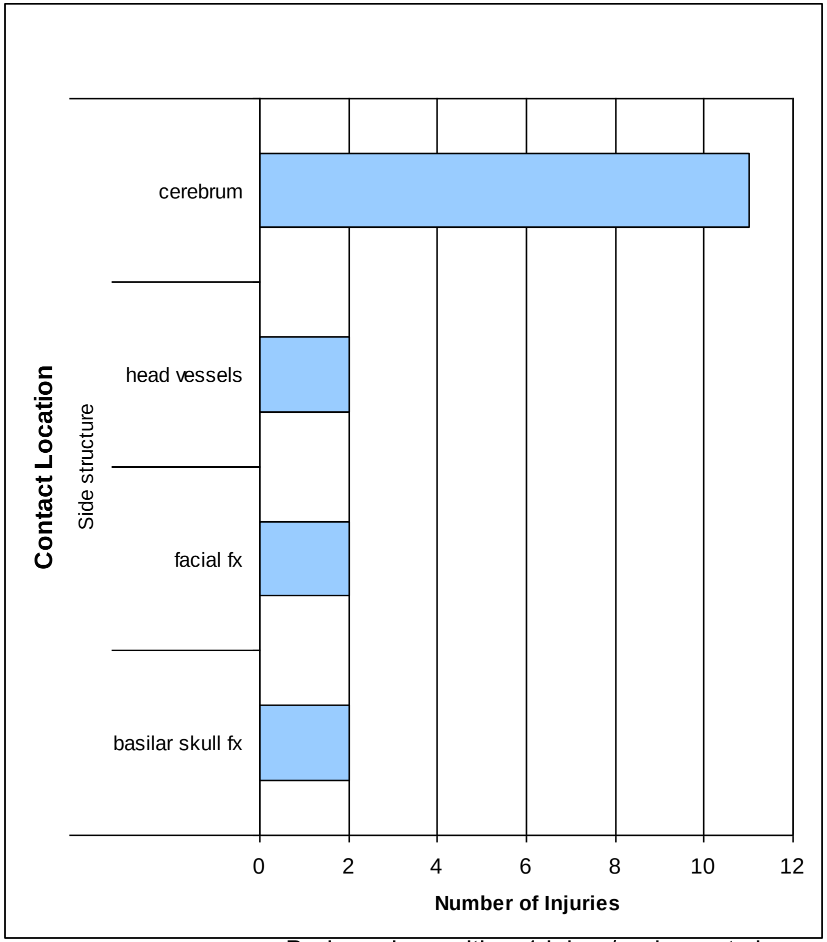
Cases with Frontal Crash Configurations Different from Current Test Types
Top 10 Contact Locations



- Injuries assigned to instrument panel contact were still the most frequent
- Injuries assigned to side structure and door contact were more frequent than in cases with existing test configurations
  - Small overlap crashes involve lateral occupant motion as well as lateral intrusion

UMPIRE

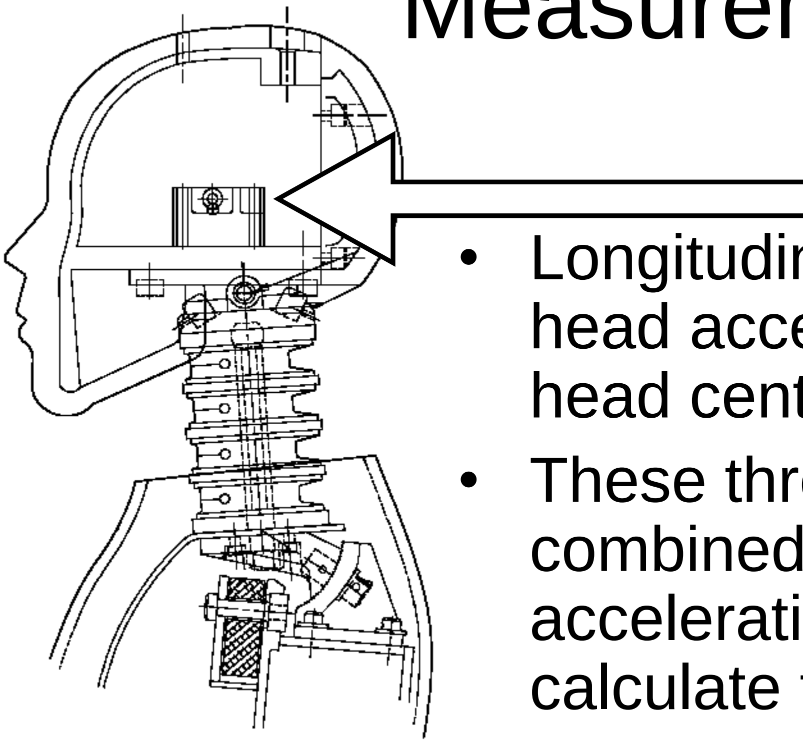
Frontal Impact Case Occupant Injuries
Side Structure Injuries



Body regions with ≤ 1 injury/region not shown

- Injuries assigned to side structure contact in this category were all attributed to head contact with the A-pillar in 5 small overlap crashes

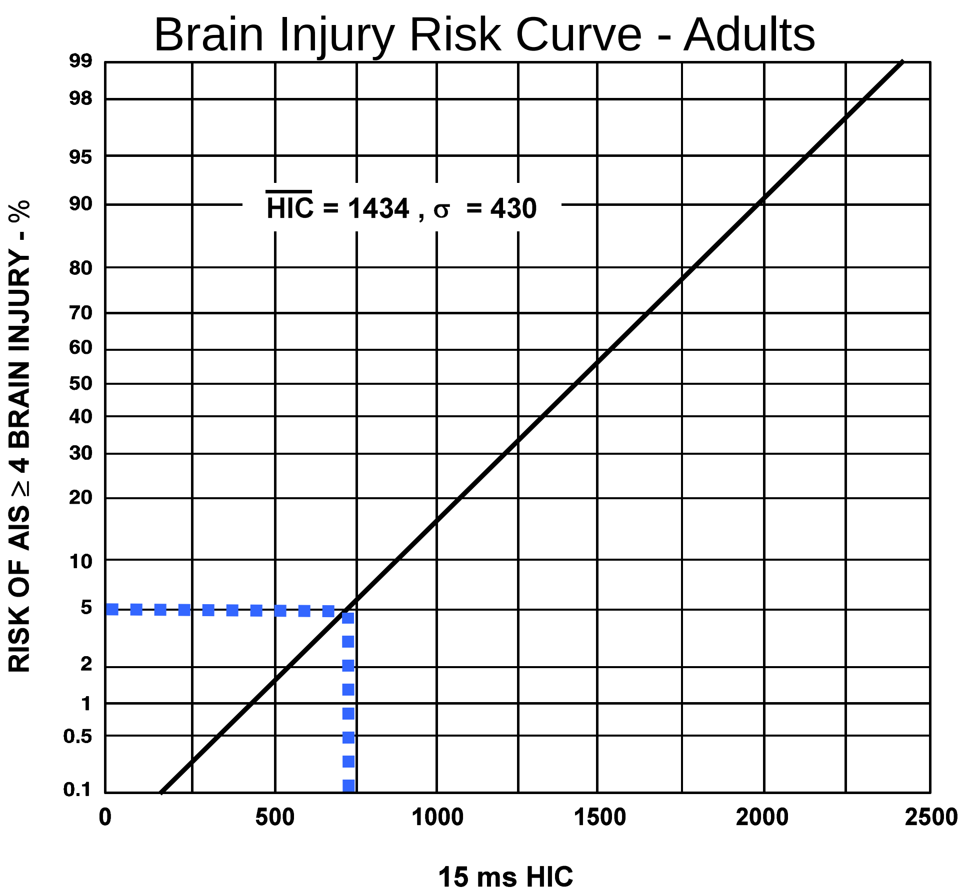
Hybrid III Crash Dummy Head Measurement



- Longitudinal, Lateral, and Vertical head acceleration is measured at the head center of gravity.
- These three measurements are combined to calculate a resultant head acceleration (a) which is used to calculate the Head Injury Criteria:

$$\mathrm{HIC} = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a\,dt \right]^{2.5} (t_2 - t_1)$$

Injury Assessment Reference Value Discussion 15 ms Head Injury Criteria (HIC) Tolerance



- FMVSS 208 limit of 700 HIC represents a 5% risk of an AIS≥4 brain injury
- Brainstem and diffuse axonal injuries are examples of AIS 4 head injuries

Reference: Biomechanical Scaling Bases for Frontal and Side Impact Injury Assessment Reference Values
Mertz, et. al., 2003

Frontal Impact Cases
≠ Test Configuration
Engineering Observations

- Small overlap crashes were the most frequent crash type in the ≠ Test Configuration:
  - Head injuries assigned to A-pillar contact were attributed to lateral occupant motion and A-pillar displacement rearward in the vehicle

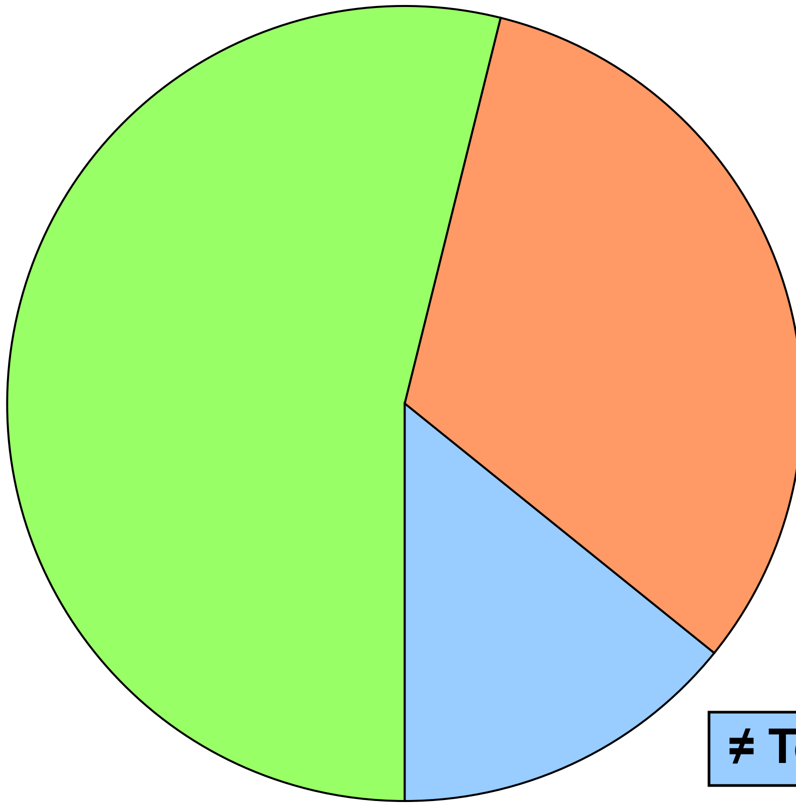
Summary

- Every field crash is unique and crash tests represent general categories, therefore judgment was used to group cases and match with crash tests
- About 53% of U-M CIREN frontal cases had crash configurations and CDC extents similar to industry crash tests

U-M CIREN Frontal Cases

= Test Configuration
≤ Test Extent

53.8% of frontal cases had configurations and CDC extents similar to current crash tests



= Test Configuration
> Test Extent

32.1% of frontal cases had similar configurations but greater CDC extents than current crash tests

≠ Test Configuration

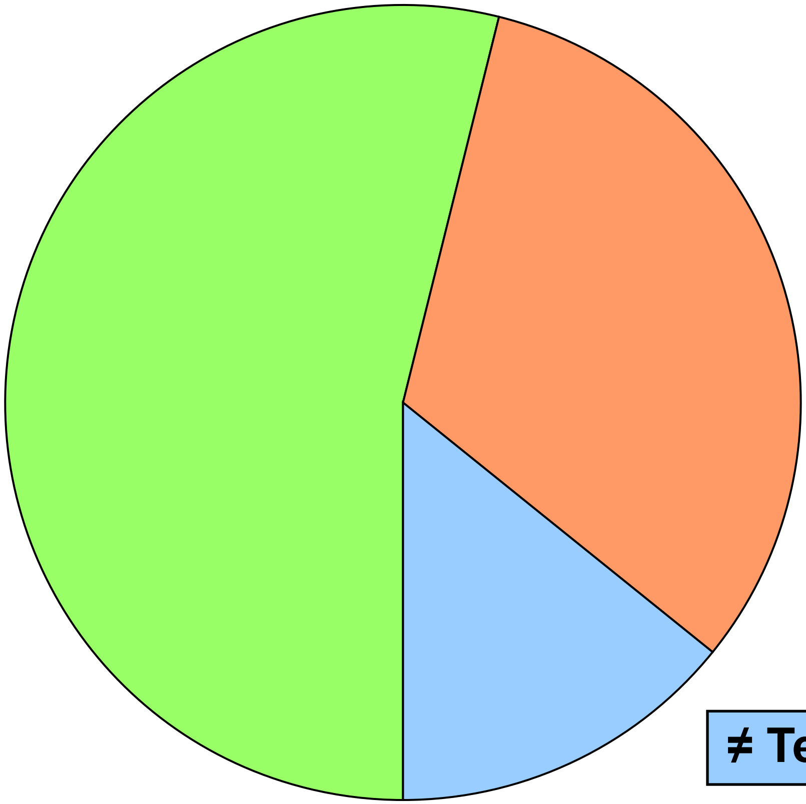
14.1% of frontal cases had configurations that differed from current crash tests

U-M CIREN Frontal Cases

= Test Configuration
≤ Test Extent

Injuries occur in cases that are similar to existing crash tests

Injury trends were identified that may help in improving data measurement and data interpretation from existing tests



= Test Configuration
> Test Extent

Trends in injuries between greater and lesser CDC extents were observed

Any changes to further improve higher extent crash performance need to be balanced with performance in more frequent lower CDC extent crashes

≠ Test Configuration

Small overlap crashes were the most common crash type in this category

Conclusions

- The majority of injuries in this study occurred in crash configurations similar to existing crash tests, therefore, improvements in crash test data measurement and data interpretation may be beneficial in reducing injuries
- Small overlap frontal crashes were the most common configuration not represented by current crash tests, however, they represented only 10.7% of all frontal crashes in the U-M CIREN database
- Any consideration of increasing test severity must be addressed in a way that does not increase the risk to the current uninjured population