GTR 7 Informal Working Group
September 10/11, 2013
Gothenburg, Sweden

NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Preliminary PMHS Injury Risk Curves & Potential BioRID Injury Criteria

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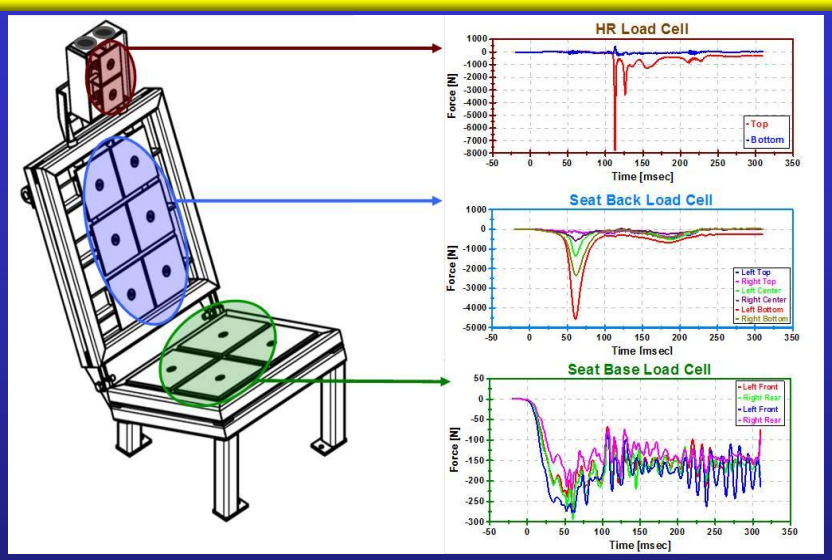
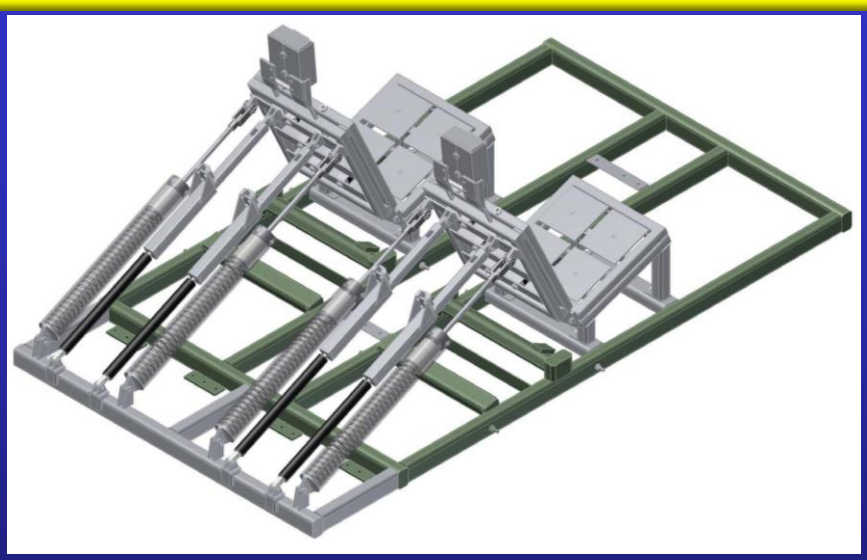
NHTSA

Rear Impact Research Objectives

- **Evaluate biofidelity of available RIDs (BioRID, RID3D, HyIII)**
  - Choose biofidelity test condition
  - Develop experimental seat for rear impact sled testing
  - Conduct sled tests
    - PMHS (Post-Mortem Human Subjects)
    - Dummies (BioRID II, RID3D, Hybrid III)
  - Assess biofidelity and repeatability of dummies
- **Investigate the mechanism of injury**
  - Develop and validate 3-D cervical spine kinematic instrumentation
  - Identify injurious kinematics
- **Relate injury to measured PMHS variables**
  - Assess potential injury criteria for rear impact dummies

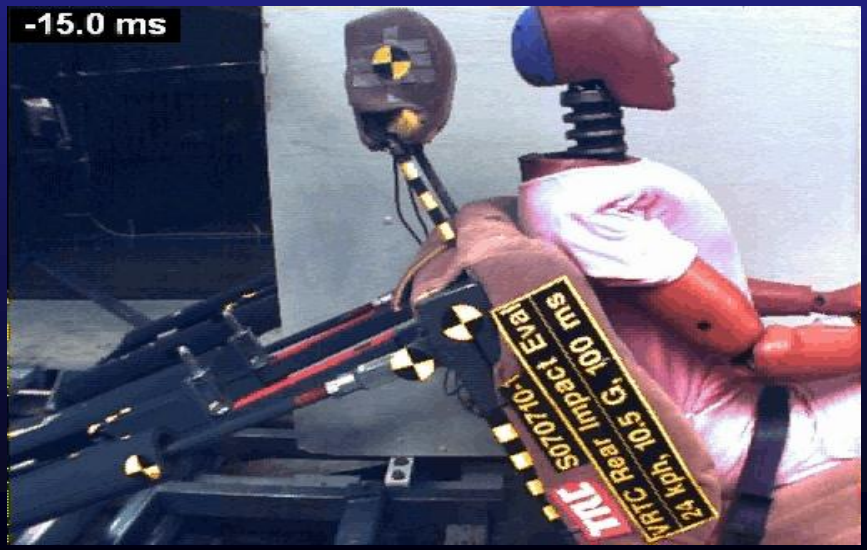
Experimental Seat





Limitations

- Designed for Biofidelity
  - Not to be a real seat
- Rigid HR w/ LCs affects UN loads
- SB Rotation not realistic
  - Large amount of ramping
  - Uni-axial LCs
  - Causes large flexion
- Only two BioRID data points
  - Can't do correlation analysis



Production Seat Testing

- **Test PMHS and BioRIDII (multiple paired tests)**
  - Verify experimental seat measures highly correlated to injury
    - Use only production seat results if possible
  - Test Matrix (8 PMHS)
    - 2 seats (2010 Toyota Camry, 2010 Chevy Cruze)
    - 3 pulses (FMVSS 202a, JNCAP, 24 km/h)
    - Conducted 7/8 tests to date
  - Measure HR loads → strain gages on posts
  - Multiple BioRIDII data points for correlation

Sled Pulses
Production Seats

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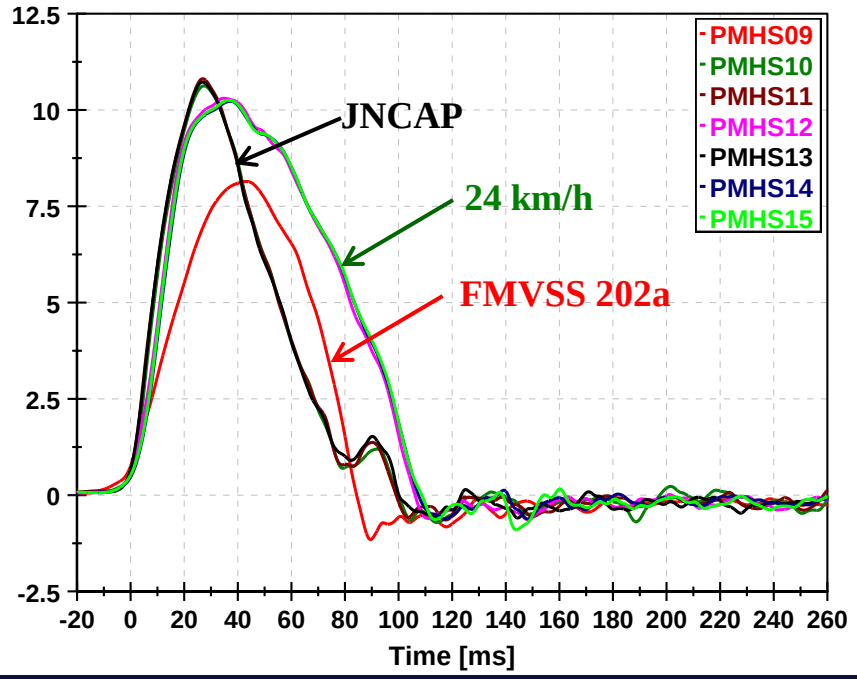
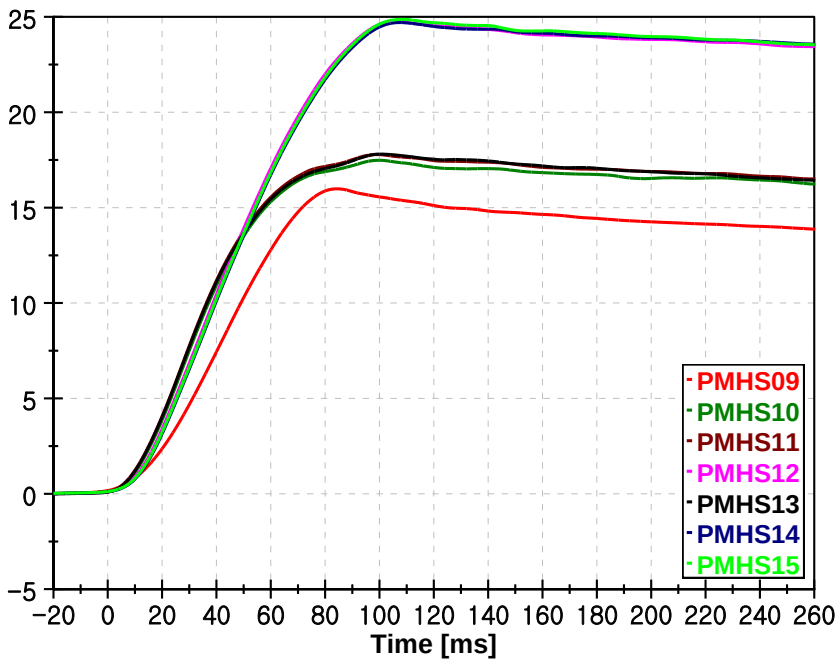
Sled Acceleration



Sled Velocity



Test Matrix Details
Production Seats

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PMHS09

Chevy Cruze
FMVSS 202a

67yo
177cm/83kg

PMHS10

Chevy Cruze
JNCAP

82yo
183cm/79kg

PMHS11

Toyota Camry
JNCAP

66yo
184cm/82kg

PMHS12

Toyota Camry
24 km/h

65yo
184cm/75kg

Test Matrix Details
Production Seats

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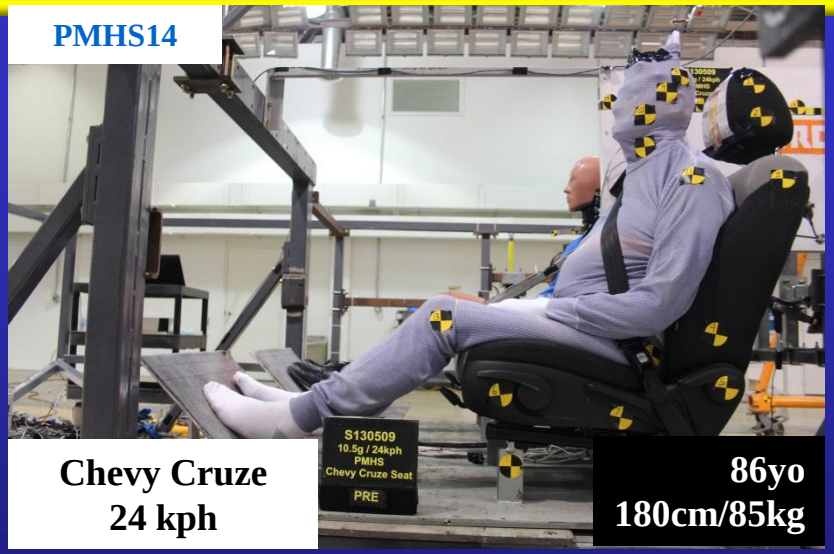
PMHS13

Toyota Camry
JNCAP

78yo
188cm/79kg

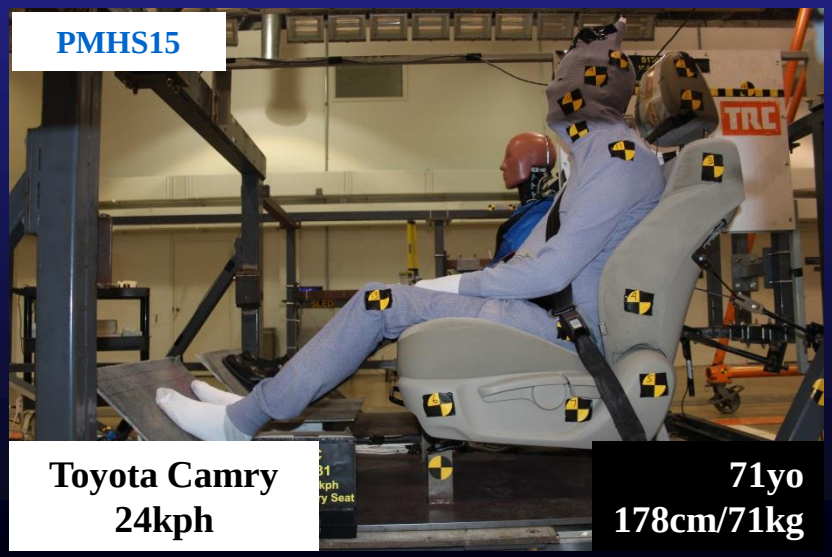
PMHS14



Chevy Cruze
24 kph

86yo
180cm/85kg

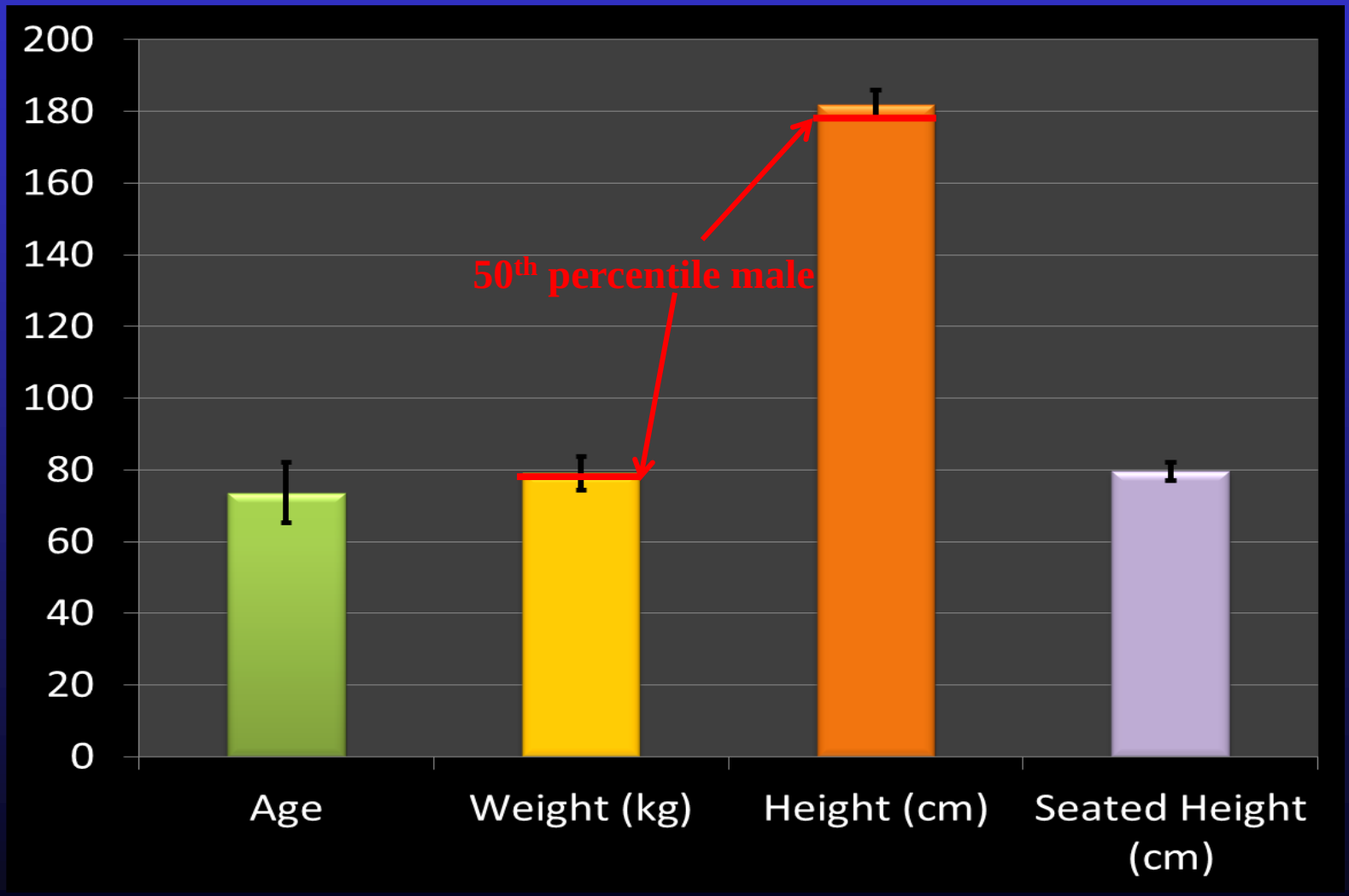
PMHS15



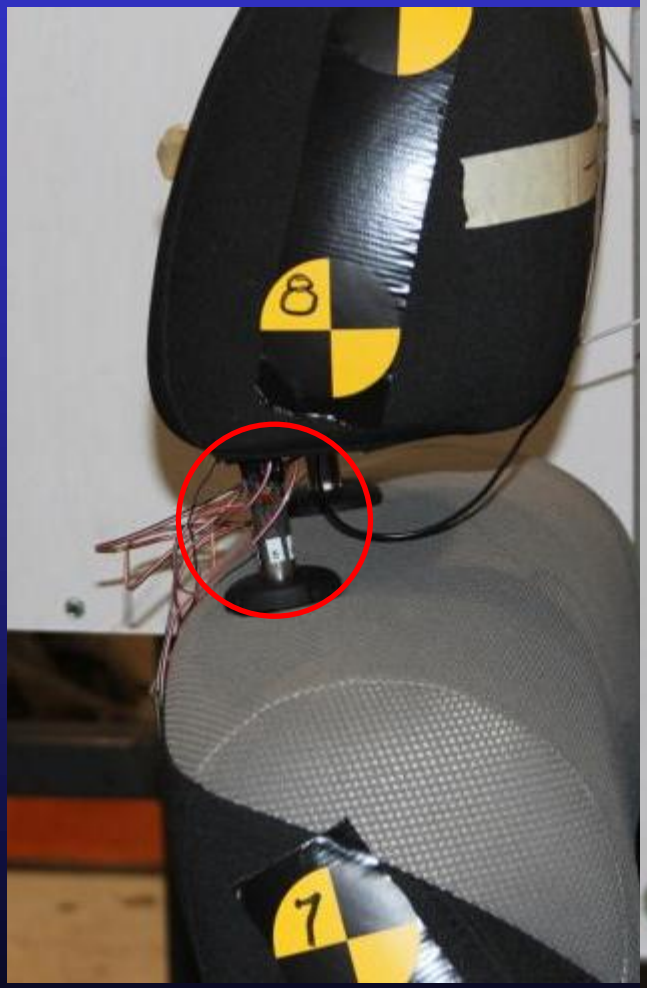
Toyota Camry
24kph

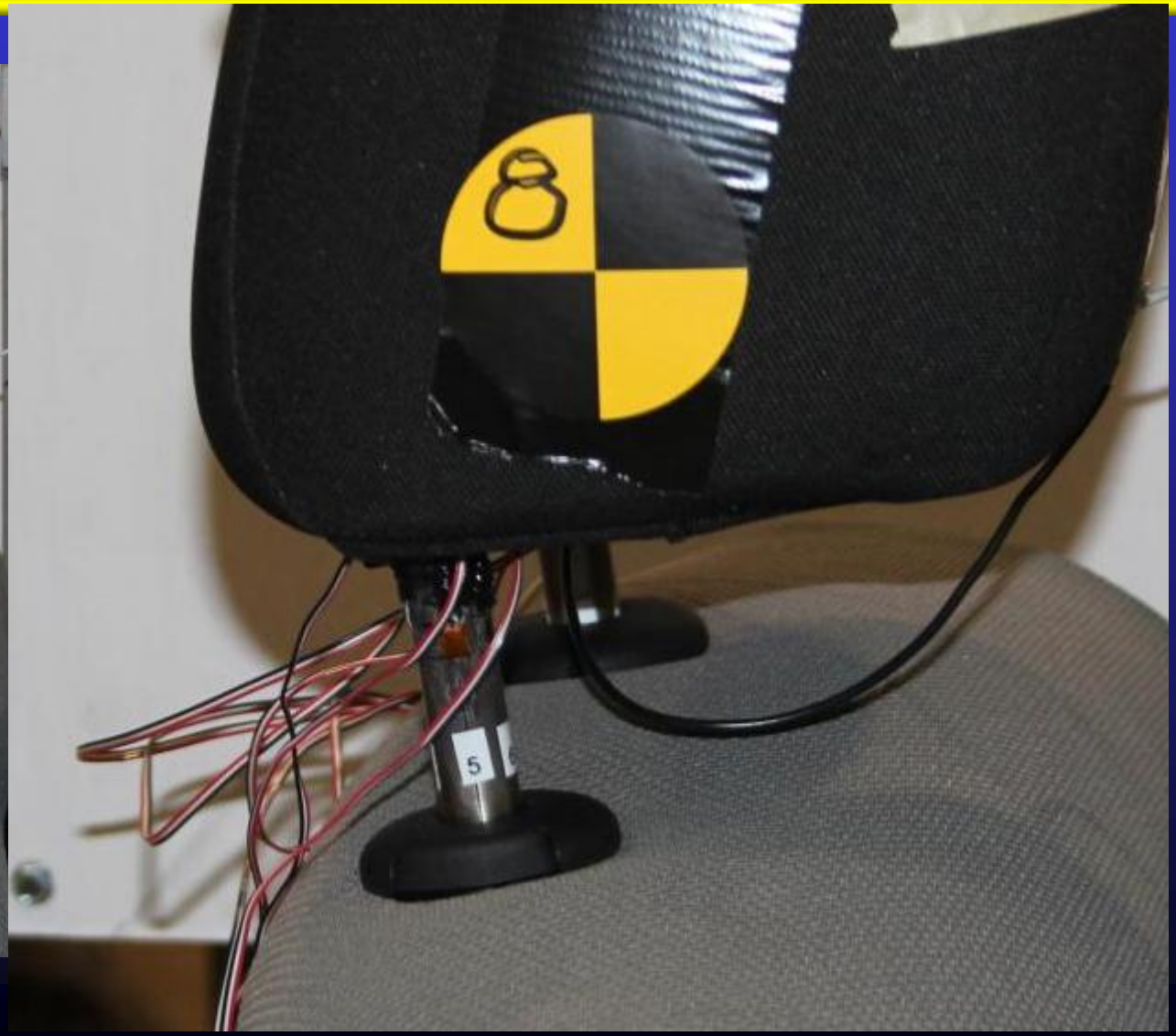
71yo
178cm/71kg

PMHS Anthropometry



Head Restraint Forces
Production Seats





Head Restraint Forces
Production Seats

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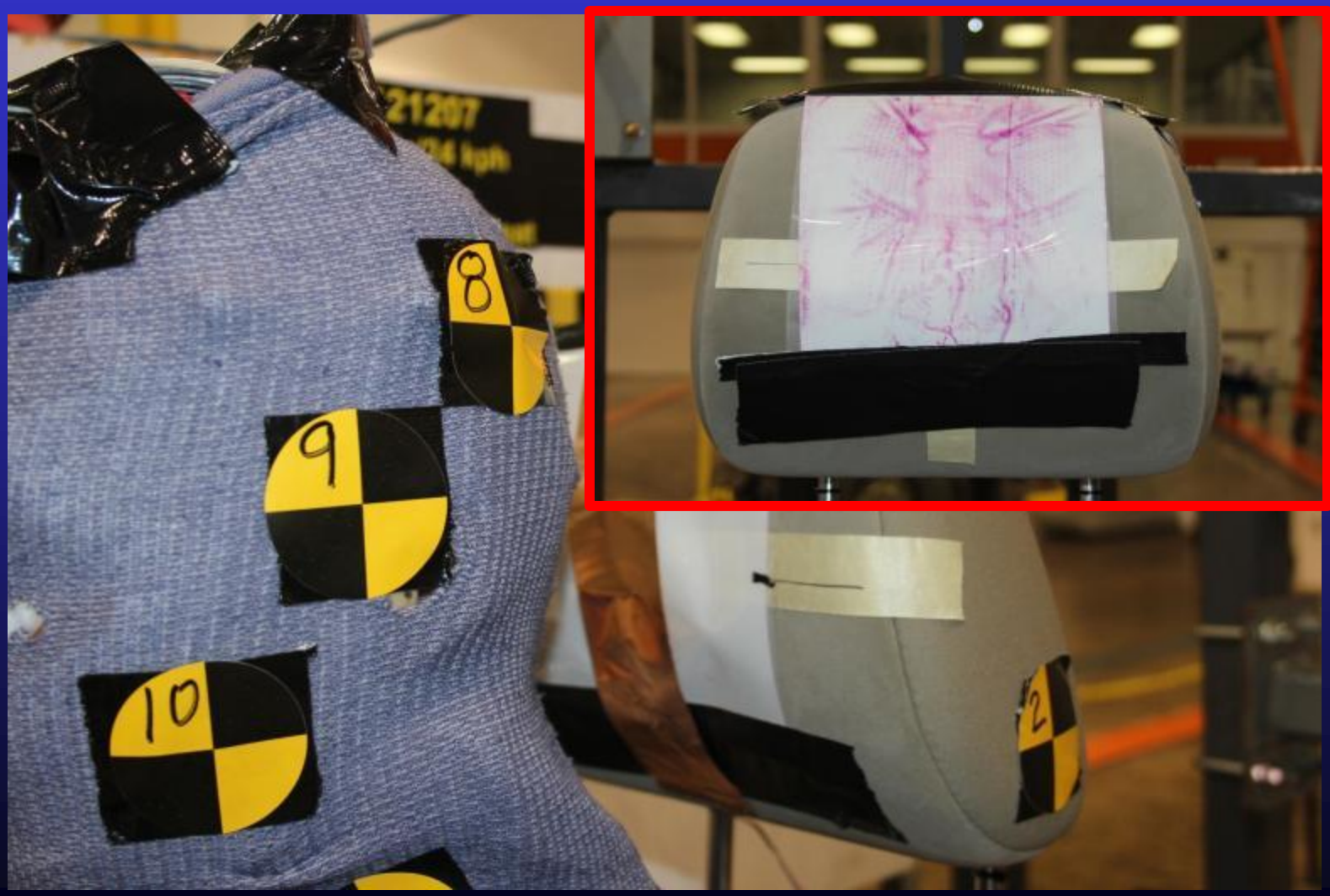


Production Seat Sled Tests
Chevy Cruze - FMVSS 202a

Chevy Cruze
FMVSS 202a

Chevy Cruze
FMVSS 202a

PMHS09

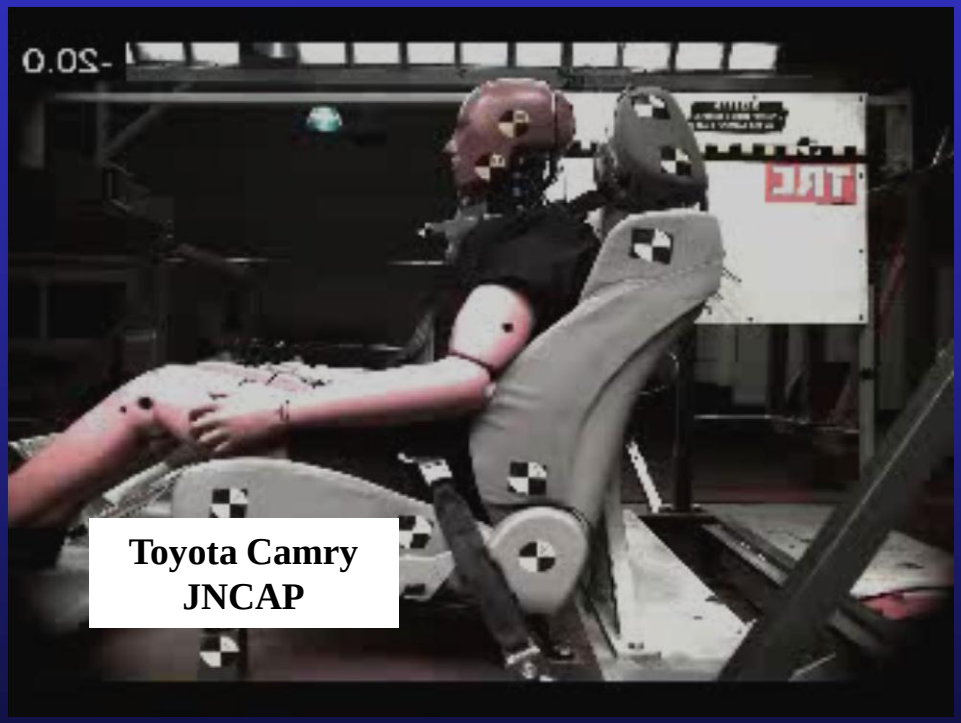
Production Seat Sled Tests
Chevy Cruze - JNCAP

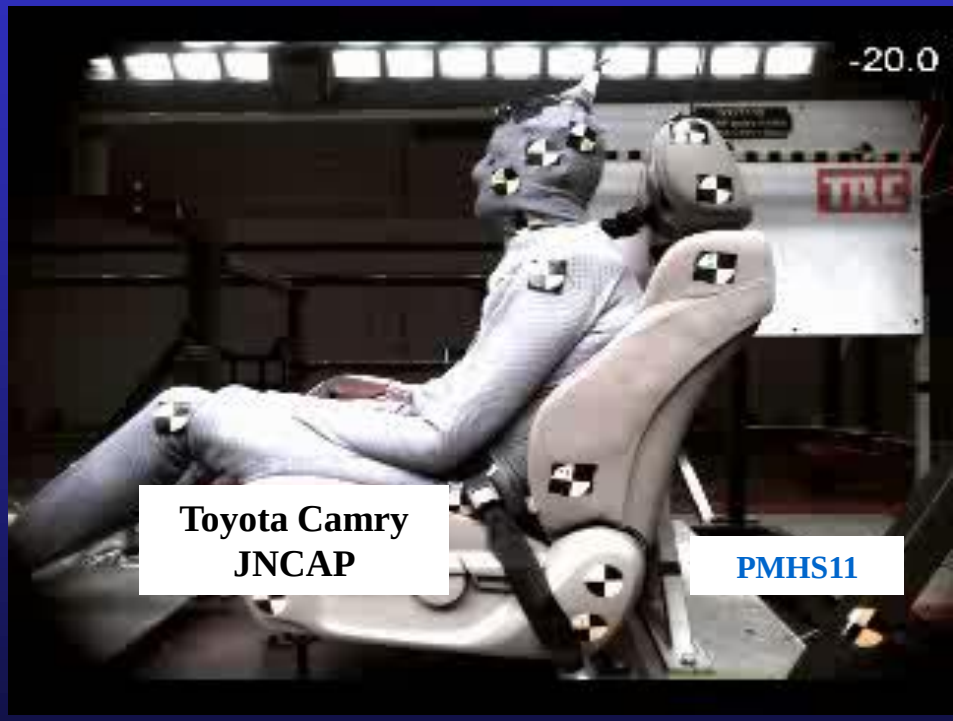
Chevy Cruze
JNCAP

Chevy Cruze
JNCAP

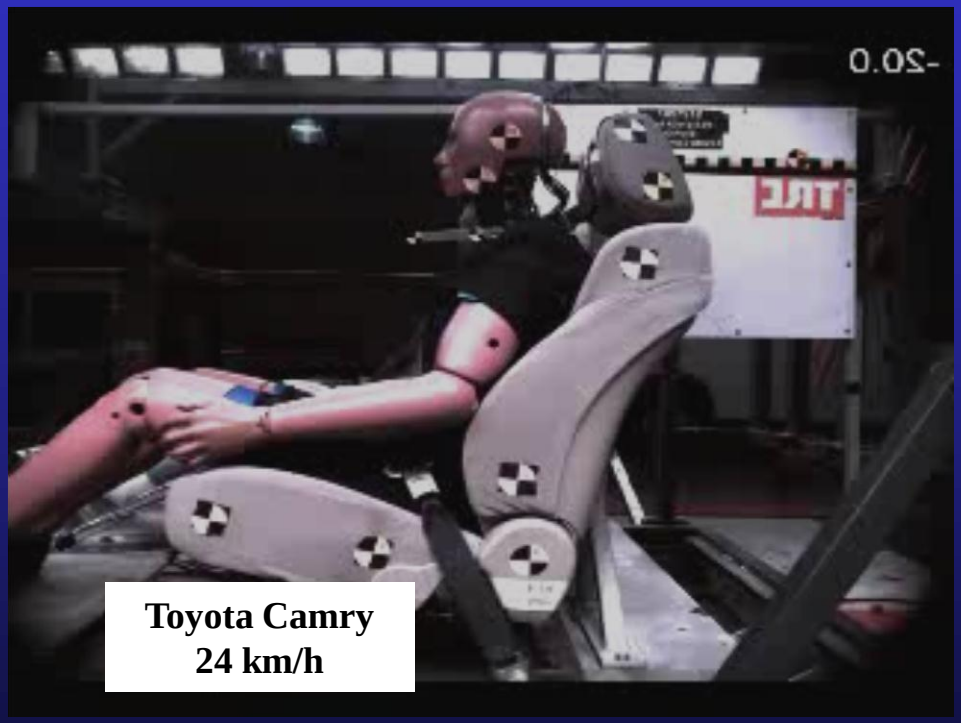
PMHS10

Production Seat Sled Tests
Toyota Camry - JNCAP





Production Seat Sled Tests
Toyota Camry – 24 km/h



Toyota Camry
24 km/h

Toyota Camry
24 km/h

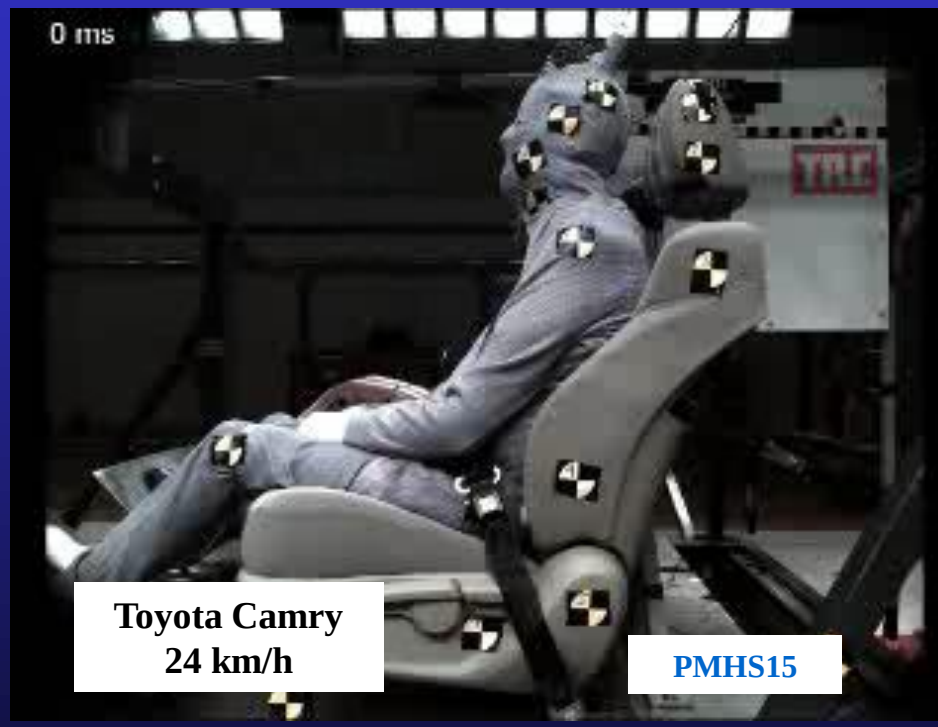
PMHS12

Production Seat Sled Tests
Toyota Camry – JNCAP

Production Seat Sled Tests
Chevy Cruze – 24 km/h

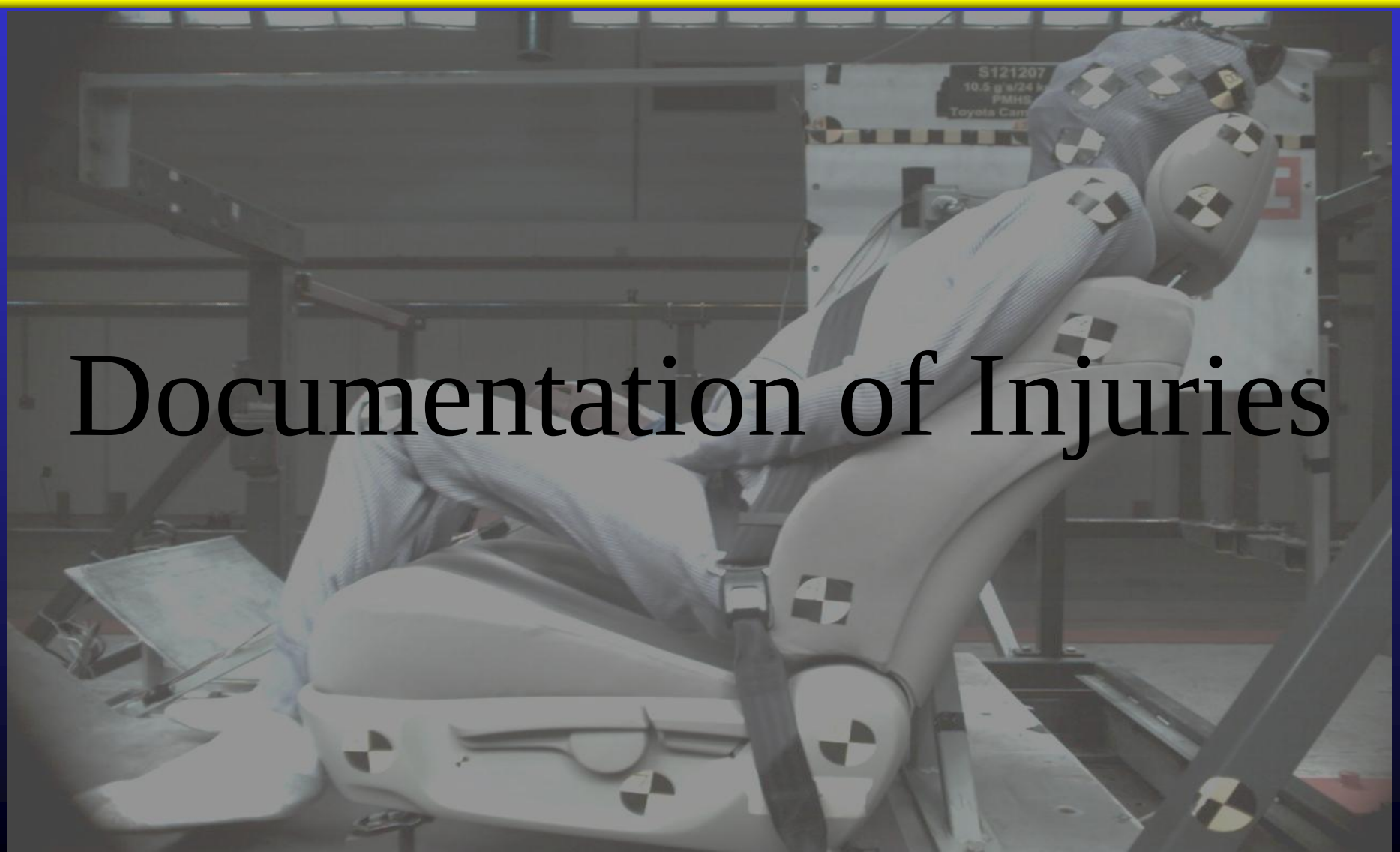
Production Seat Sled Tests
Toyota Camry – 24 km/h

Toyota Camry
24 km/h



Toyota Camry
24 km/h

PMHS15



Documentation of Injuries

Documentation of Injuries
Production Seats

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Injury Documentation							
updated	PMHS09	PMHS10	PMHS11	PMHS12	PMHS13	PMHS14	PMHS15
	FMVSS202	JNCAP	JNCAP	24 km/h	JNCAP	24km/h	24 km/h
C2/C3							Subluxation
C3/C4				Subluxation			
C4/C5	Subluxation		Subluxation	Subluxation			
C5/C6		Subluxation	Subluxation			Subluxation	
C6/C7		Subluxation			Subluxation	Subluxation	Subluxation

Injury Criteria Analysis

PMHS Injury Analysis

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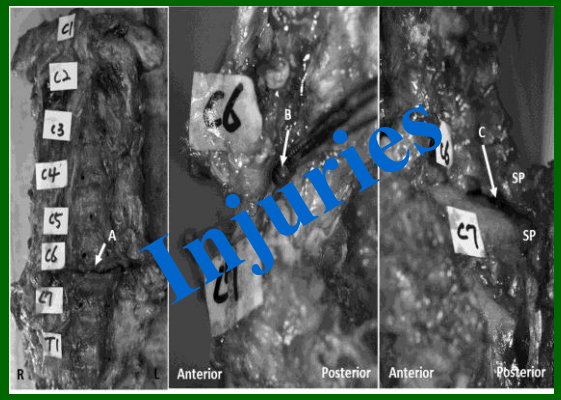
PMHS

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Correlation?



Normalization?

Step 2

Best injury predictors

Correlation?

Kinetics/kinematics

Current/potential injury criteria

PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics

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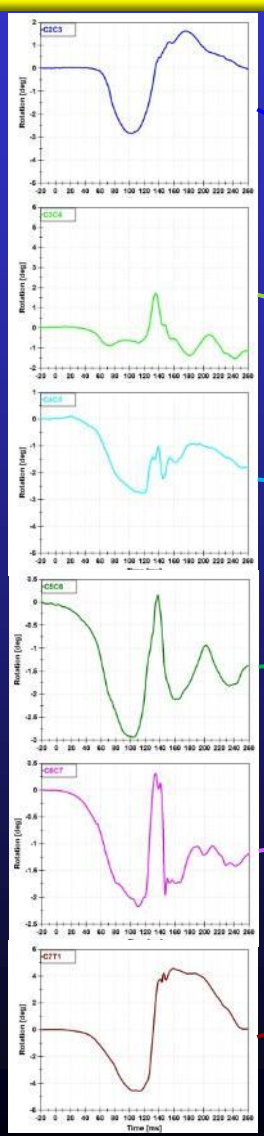
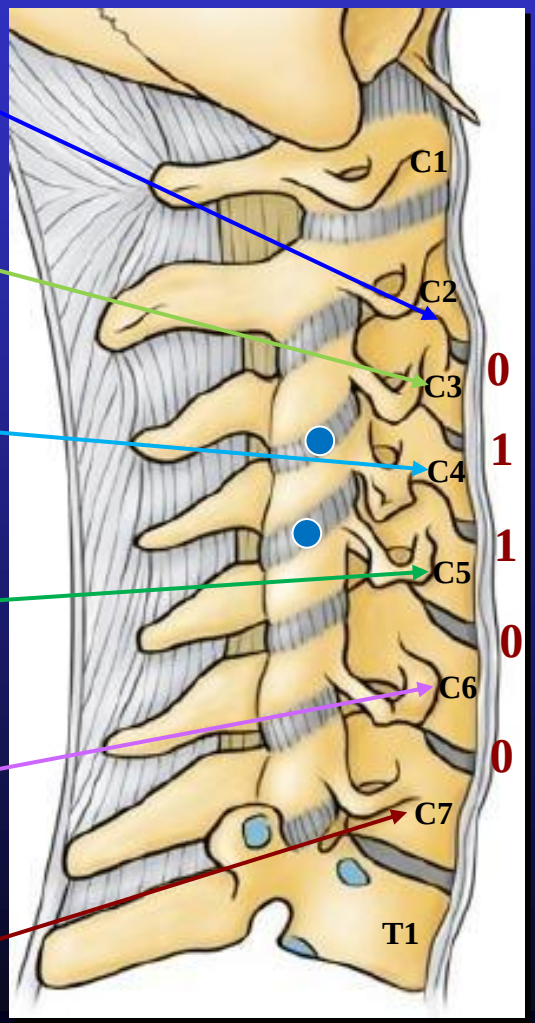
Intervertebral kinematics

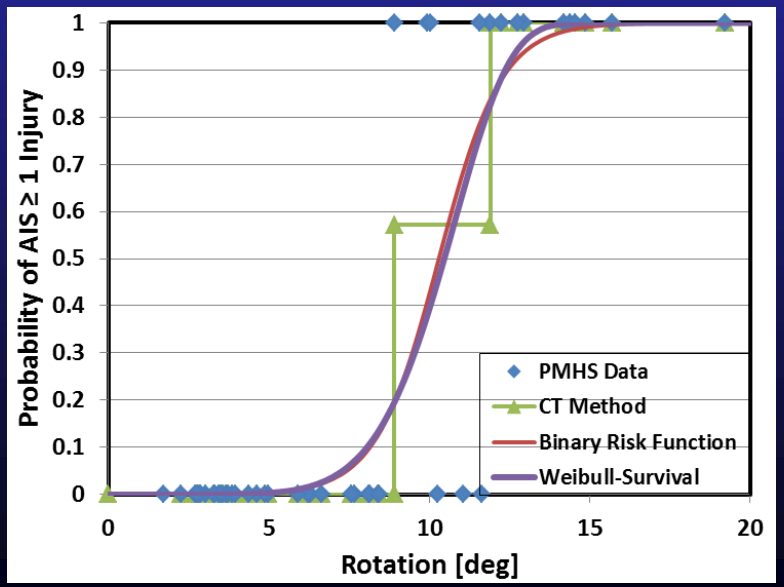


Injuries @ intervertebral levels



- C2/C3 – C6/C7: 5 levels
- 5 data points per test
- n =~85 (50 exp / 35 prod)

Injury Risk Curves



PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics
Production Seats Only

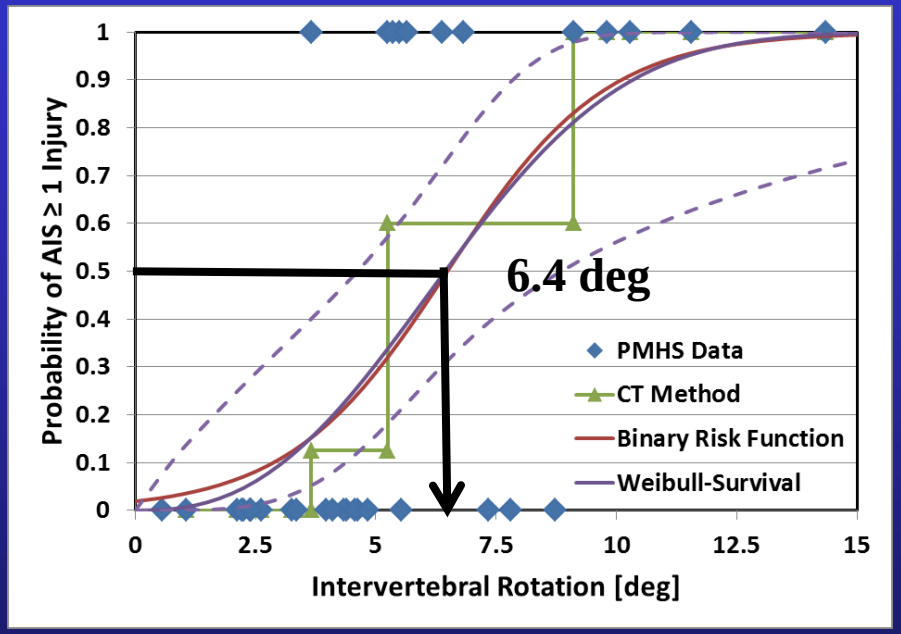
Intervertebral kinematics		Log-Likelihood P-value	Goodman-Kruskal Gamma
Acceleration x	(+)	0.026	0.54
	(-)	0.531	0.17
	Max	0.038	0.54
Acceleration z	(+)	0.016	0.46
	(-)	0.003	0.60
	Max	0.001	0.62
Velocity x	(+)	0.477	0.23
	(-)	0.132	0.33
	Max	0.104	0.35
Velocity z	(+)	0.531	0.21
	(-)	0.447	0.10
	Max	0.395	0.19
Angular velocity y	(+)	0.323	0.14
	(-)	0.003	0.53
	Max	0.002	0.56
Rotation y	**(-)**	**0.000**	**0.76**
Facet JT Slide	**(+)**	0.058	0.40
Facet JT Slide Rate	Max	0.083	0.36
Facet JT Axial	Max	0.005	0.59
Facet JT Axial Rate	**(-)**	0.001	0.66

(+) : positive peak, (-): negative peak, Max: maximum peak

P-value < 0.005 , Goodman-Kruskal Gamma > 0.7

Best correlation and prediction

PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics
Production Seats Only



Intervertebral Rotation	Log-Likelihood P-value	Goodman-Kruskal Gamma	AUROC
Intervertebral Rotation y	0.000	0.76	0.85

PMHS Injury Analysis

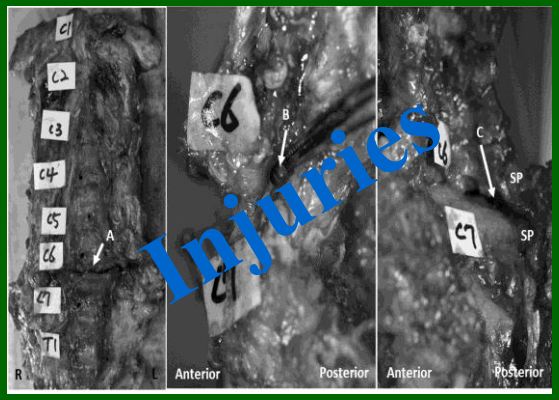
PMHS

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Correlation?



Normalization?

Step 2

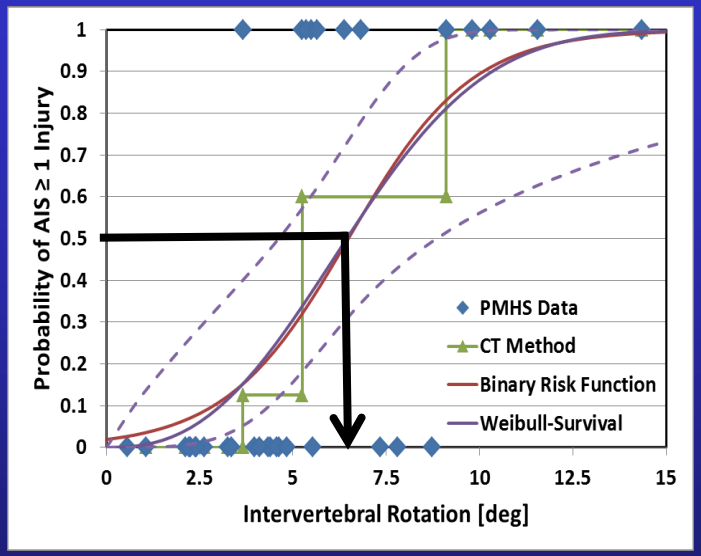
Best injury predictors

Correlation?

Kinetics/kinematics

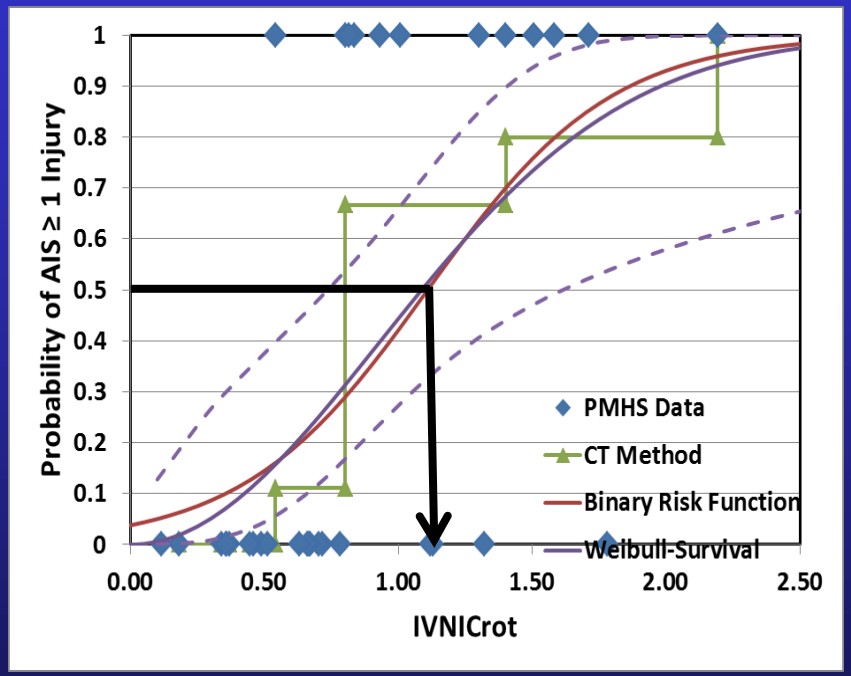
Current/potential injury criteria

PMHS Injury Analysis
Injury Risk Curves – IV-NICrot
Production Seats Only



6.4 deg rotation

$$IV-NIC_i = \frac{\Theta_{trauma,i}}{\Theta_{physiological,i}}$$



IV-NIC = 1.1

Normalized Intervertebral Rotation	Log-Likelihood P-value	Goodman-Kruskal Gamma	AUROC
IVNICrot	0.001	0.71	0.86

PMHS Injury Analysis

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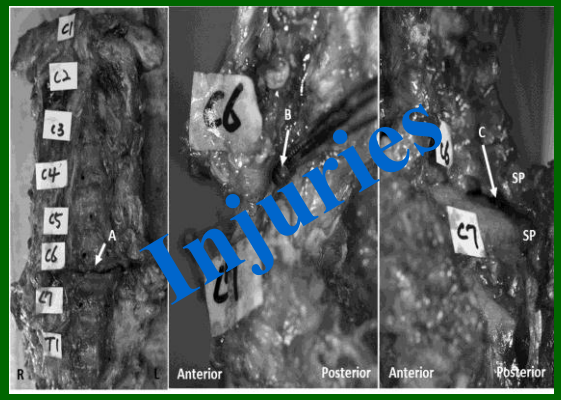
PMHS

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Correlation?



Normalization?

Step 2

Best injury predictors

Correlation?

Kinetics/kinematics

Current/potential injury criteria

PMHS Injury Analysis
IV-NIC vs. Current/Potential Injury Criteria

- **Correlation between IV-NIC rotation and existing injury criteria**

$IV-NICrot$ ⟷ **Correlation?**

Yes ↓

Potential PMHS/BioRID Injury Criteria

$$NIC = 0.2 \times a_{rel} + v_{rel}^{2}$$

$$N_{km} = \frac{F_x}{F_{int}} + \frac{M_y}{M_{int}}$$

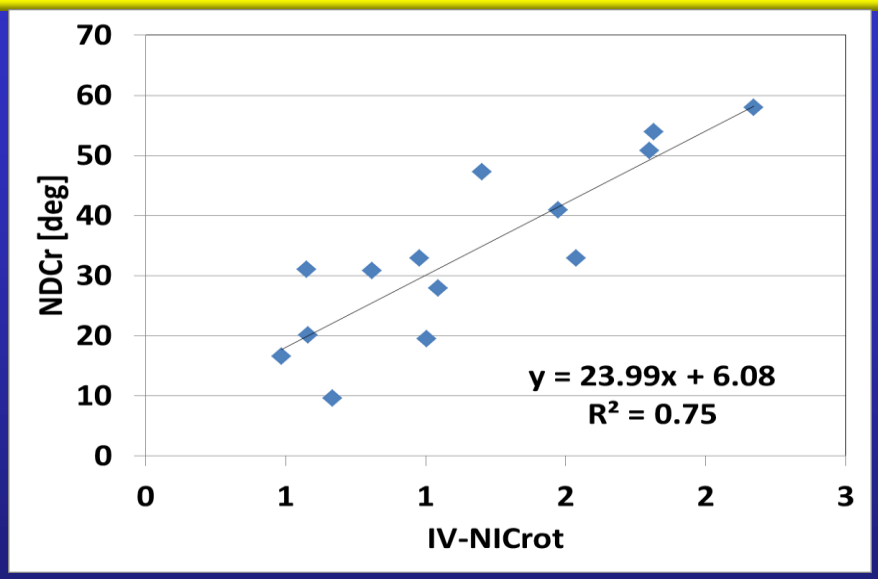
NDC, Nij
Head-to-T1 Rotation
Upper/Lower Fx, Fz, My
Other physical parameters

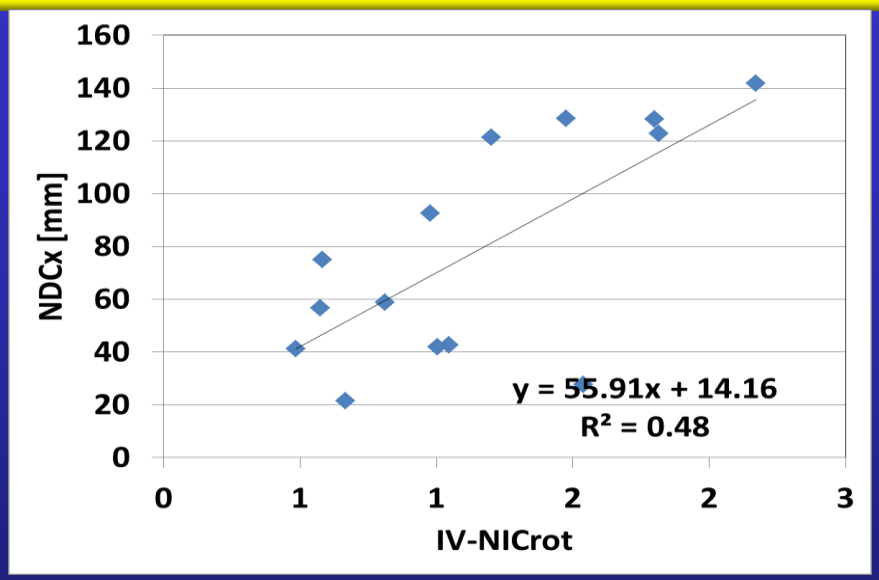
$$LNL-index(t) = \left| \frac{\sqrt{My_{lower}(t)^2 + Mx_{lower}(t)^2}}{C_{moment}} \right| + \left| \frac{\sqrt{Fx_{lower}(t)^2 + Fy_{lower}(t)^2}}{C_{shear}} \right| + \left| \frac{Fz_{lower}(t)}{C_{tension}} \right|$$

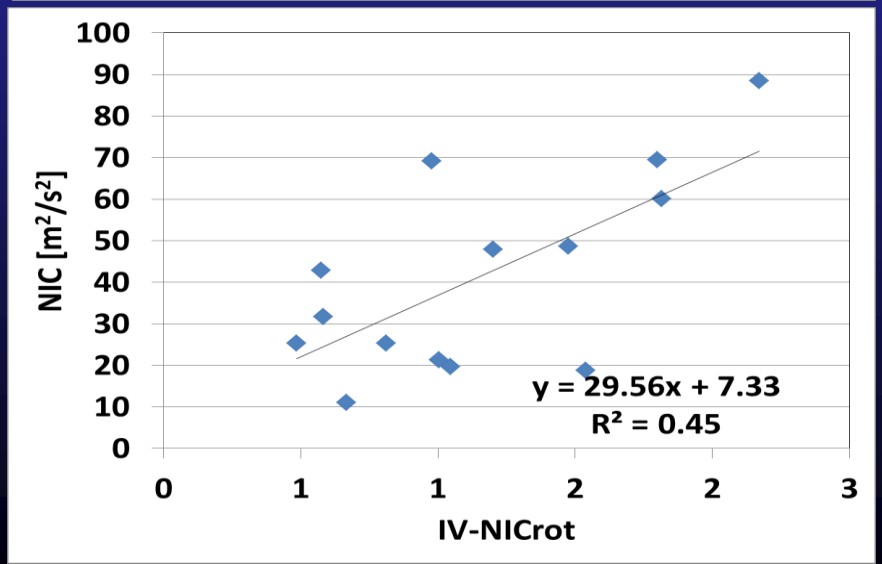
PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria

	IV-NICrot
	R^2 - value
NDCrot	0.75
NDCx	0.48
NDCz	0.14
NIC	0.45

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria







- 50 % chance of AIS 1+ injuries
  - **IV-NICrot : 1.1**
  - NDCrot : 32.5 deg (flexion)
  - NDCx: 75.1 mm
  - NIC: 39.6 m^2/s^2

Potential BioRID Injury Criteria

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BioRIDII

Potential BioRID Injury Criteria

Step 3

PMHS		BioRIDII
Best injury predictors 	linear regression	Current/potential injury criteria 
Best injury predictors 	linear regression	Intervertebral kinematics 
Injury risk curves 	Scaled Risk curves	Injury risk curves 

Potential BioRID Injury Criteria
Intervertebral Rotations

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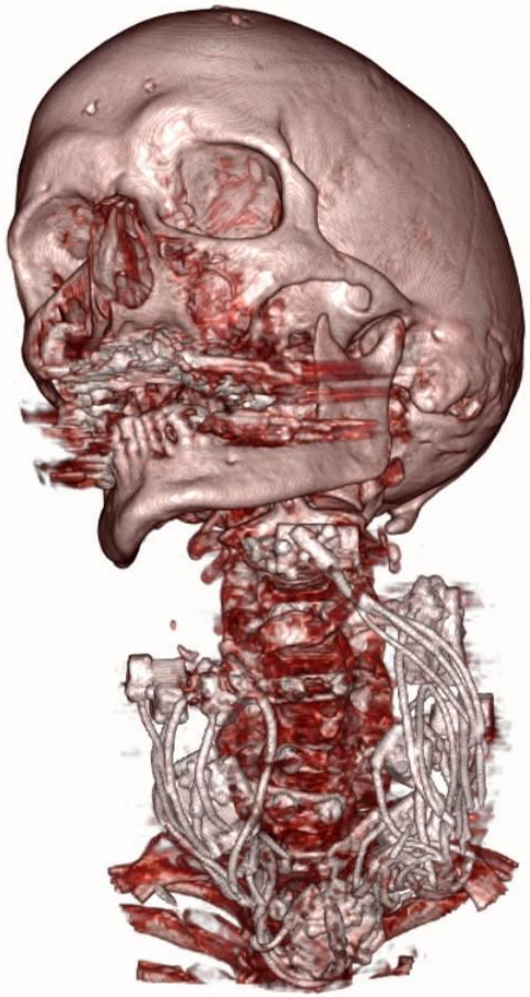
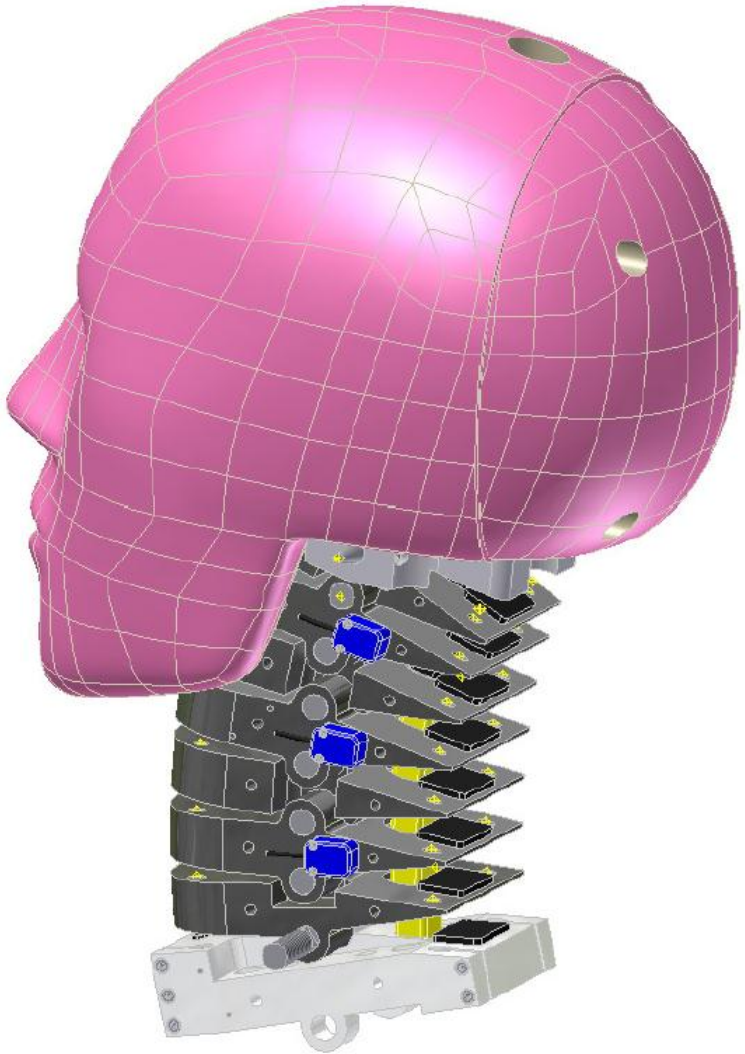
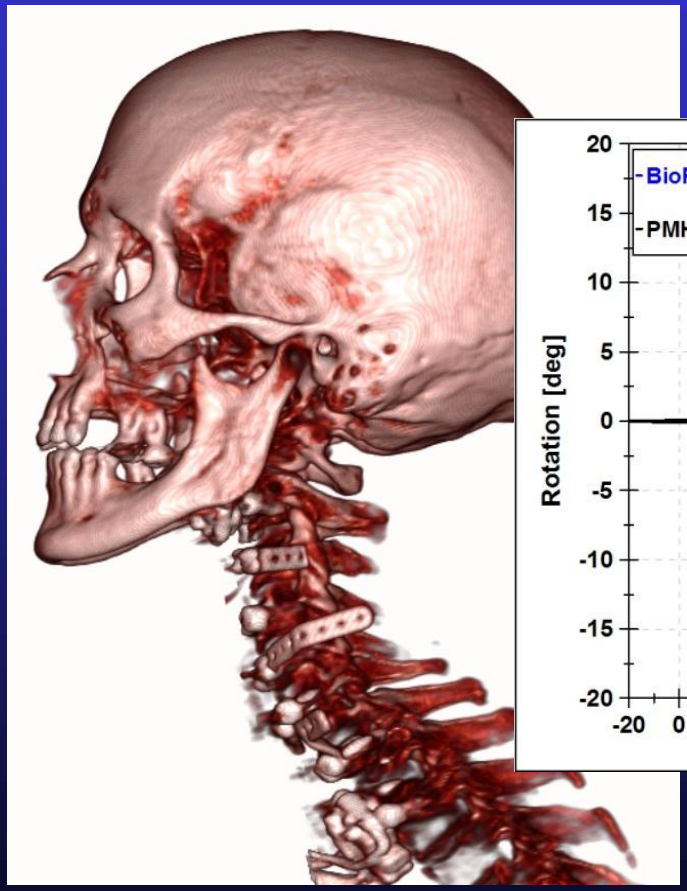
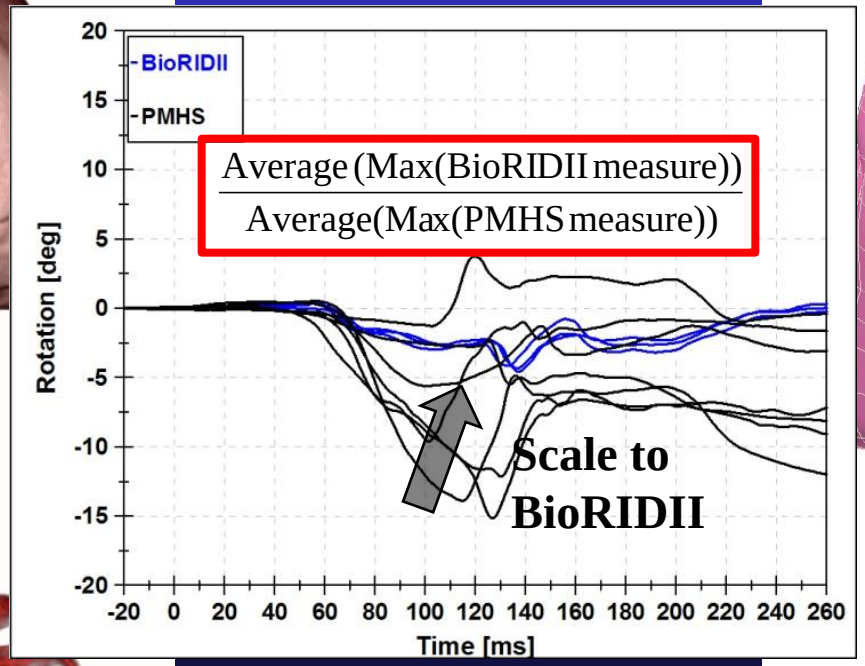
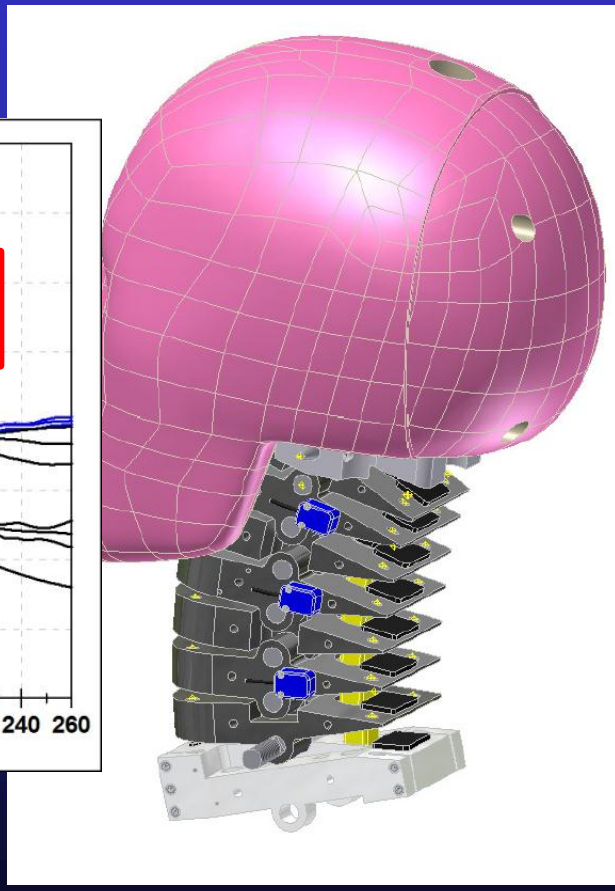




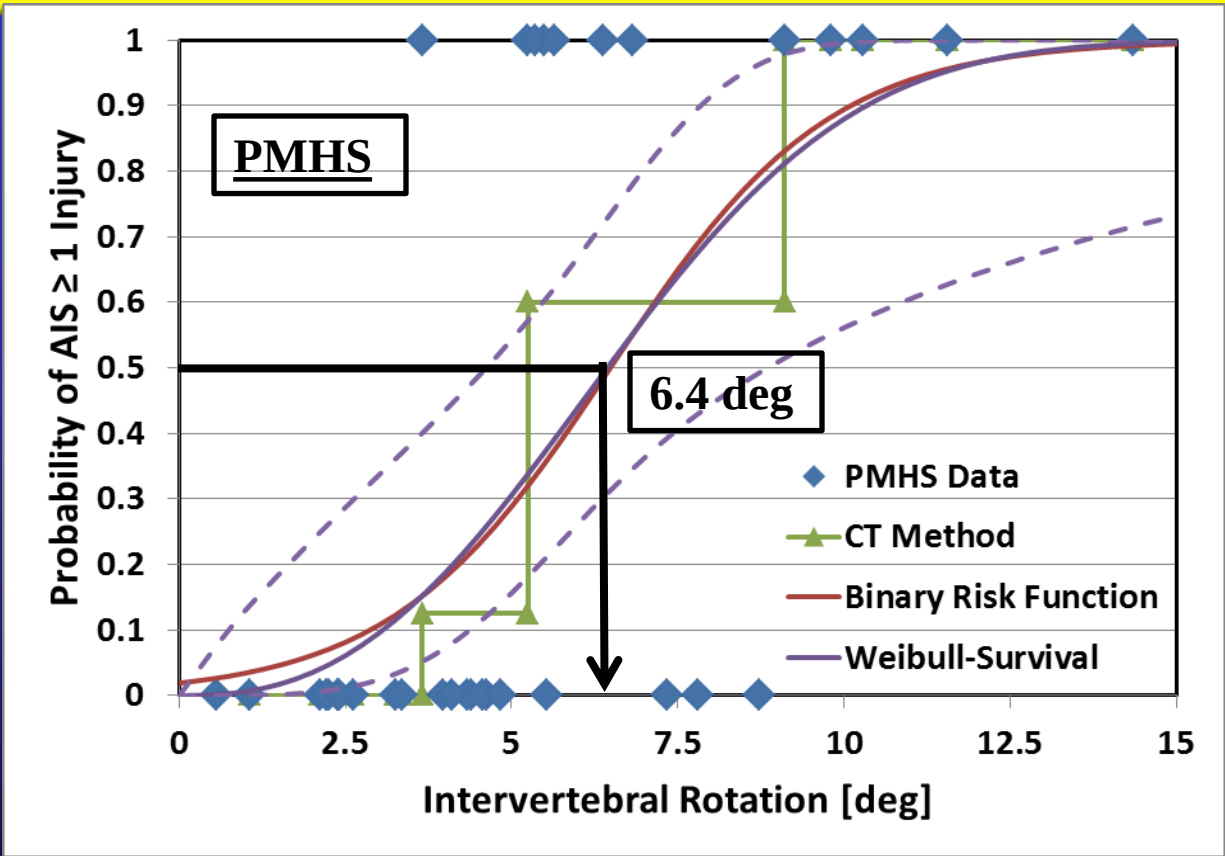
Potential BioRID Injury Criteria





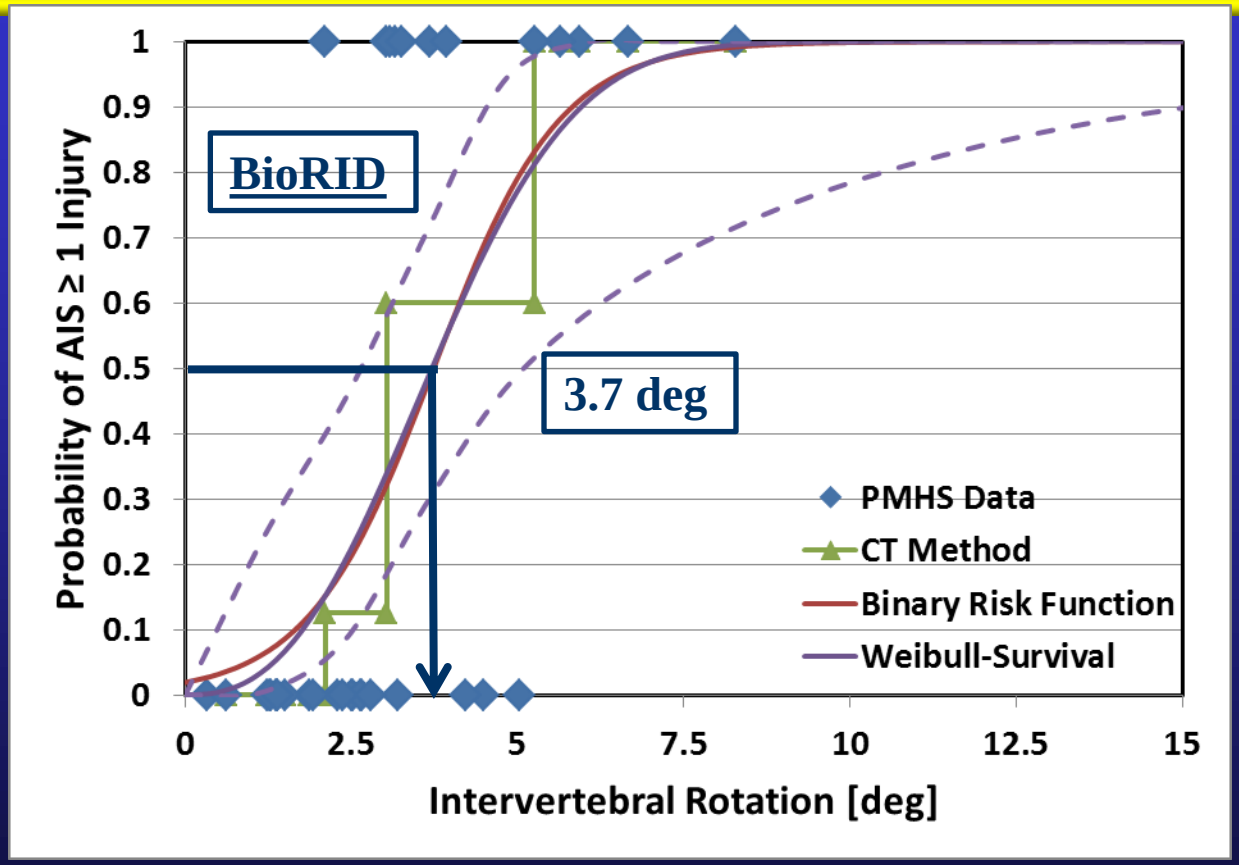


Potential BioRID Injury Criteria
Intervertebral Rotations
Production Seats Only



Intervertebral Rotation	Log-Likelihood P-value	Goodman-Kruskal Gamma	AUROC
Intervertebral Rotation y	0.000	0.76	0.88

Potential BioRID Injury Criteria
Intervertebral Rotations
Production Seats Only



Intervertebral Rotation	Log-Likelihood P-value	Goodman-Kruskal Gamma	AUROC
Intervertebral Rotation y	0.000	0.76	0.88

Potential BioRID Injury Criteria
Intervertebral Rotations
Production Seats Only

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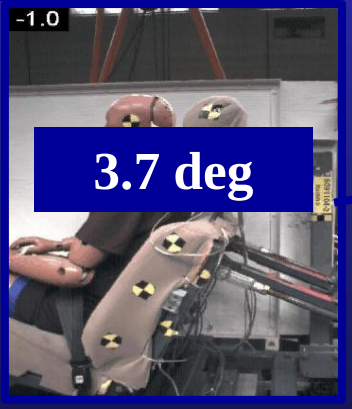
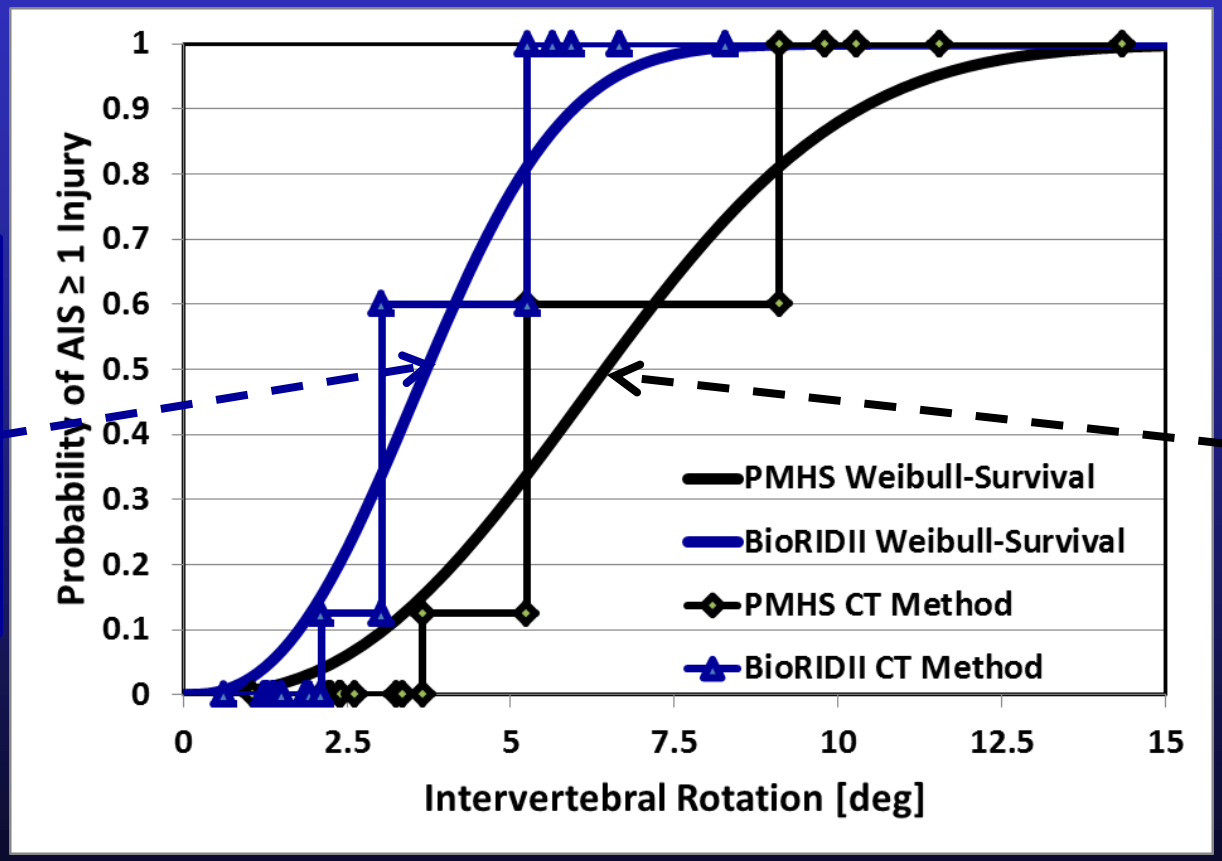
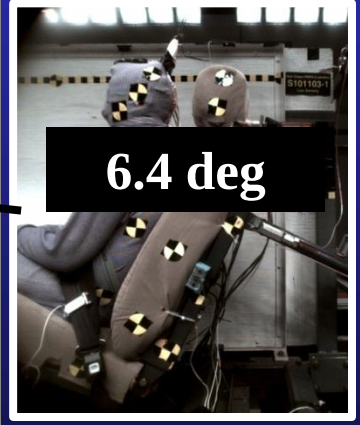
BioRIDII/PMHS Injury Risk Curve for Intervertebral Rotation

BioRIDII





PMHS



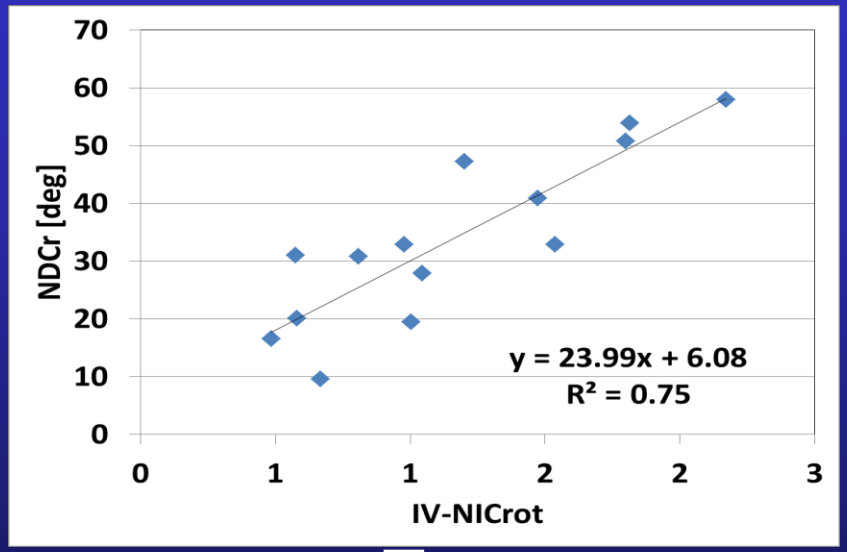
Potential BioRID Injury Criteria
Global Measures
Production Seats Only

	Correlations with IV-NICrot	
		R^2 - value
NDCrot	32.5 deg	0.75
NDCx	75.1 mm	0.48
NIC	39.6 m^2/s^2	0.45

Scale to convert to BioRID values

Potential BioRID Injury Criteria
Global Measures (NDCrot)
Production Seats Only

PMHS Regression model



50 % chance of AIS 1+ injuries for PMHS

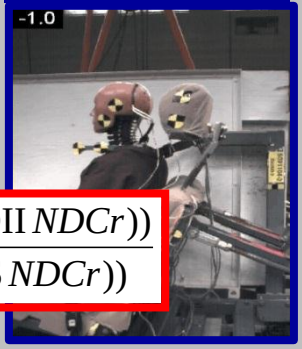
NDCrot = 32.5 deg (flexion)

50 % chance of AIS 1+ injuries for BioRIDII

NDCrot : 12.2 deg (flexion)

PMHS

BioRIDII



Scaling

$$\frac{\text{Average}(\text{Max}(\text{BioRIDII } NDCr))}{\text{Average}(\text{Max}(\text{PMHS } NDCr))}$$

Potential BioRID Injury Criteria
Global Measures (NDCx)
Production Seats Only

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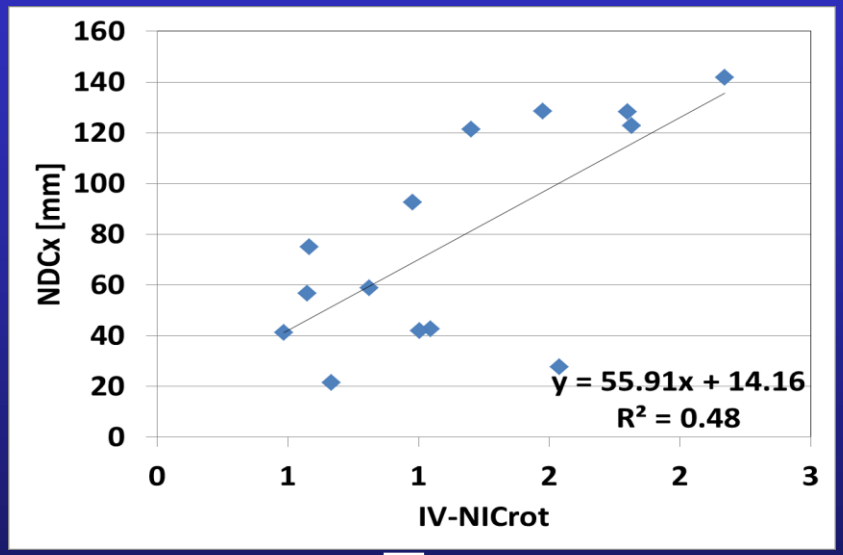
PMHS Regression model



50 % chance of AIS 1+ injuries for PMHS

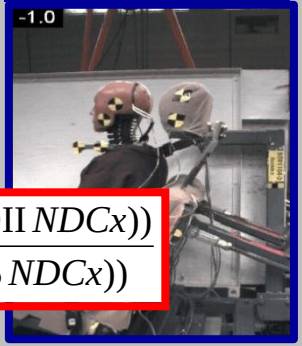
NDCx = 75.1 mm

50 % chance of AIS 1+ injuries for BioRIDII

NDCx : 117.8 mm

PMHS

BioRIDII

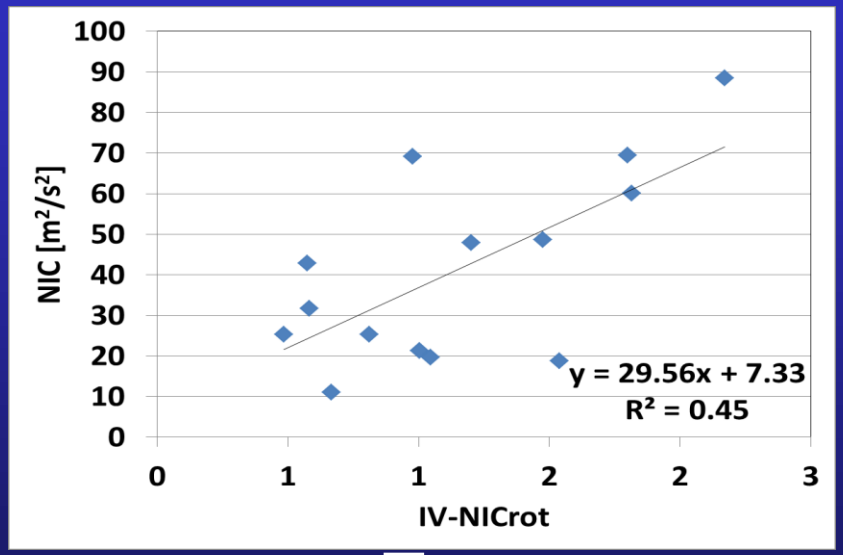


Scaling

$$\frac{\text{Average}(\text{Max}(\text{BioRIDII } NDCx))}{\text{Average}(\text{Max}(\text{PMHS } NDCx))}$$

Potential BioRID Injury Criteria
Global Measures (NIC)
Production Seats Only

PMHS Regression model



50 % chance of AIS 1+ injuries for PMHS

NIC = 39.6 m^2/s^2

50 % chance of AIS 1+ injuries for BioRIDII

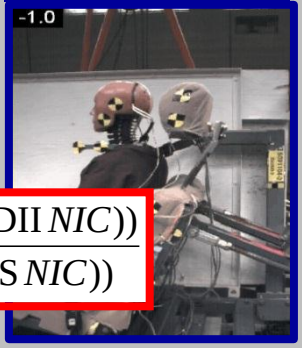
NIC : 29.7 m^2/s^2

PMHS

Scaling

$$\frac{\text{Average}(\text{Max}(\text{BioRIDII } NIC))}{\text{Average}(\text{Max}(\text{PMHS } NIC))}$$

BioRIDII



Summary

- **Best PMHS injury predictor**
  - IV-NICrot
    - 50% chance of AIS 1+ injury = 1.1

- **Most promising BioRID injury criteria**
  - IV Rotation, NDCrot
    - 50% chance of AIS 1+ injury:
      - IV Rotation = 6.4 deg (flex) PMHS, 3.7 deg BioRID (flex)
        NDCrot = 32.5 deg (flex) PMHS, 12.2 deg (flex) BioRID

USA & Japan Collaboration

- **Best injury predictor**
  - USA → IV-NICrot
  - Japan → IV-NICrot (well correlated with Strain & Strain Rate)
- **Potential "global" injury criteria**
  - USA: IV-NICrot → NDCrot, NDCx, NIC
  - Japan: IV-NICrot → NIC, UNFx, UNMy, LNFx, LNMy
- **Common ground:**
  - NIC
  - USA: Still investigating UNFx, UNMy, LNFx, LNMy, Nkm
    - Inverse Dynamics an issue after HR contact
      - Use direct correlation of BioRID measures??
  - Japan: Still investigating NDCrot, NDCx

USA & Japan Collaboration

- **BioRID Injury Criteria**
  - USA:
    - Approach: Experimental
      - Direct link to PMHS injury
      - Incorporates BioRID response through paired testing
  - Japan:
    - Approach: Head/neck model, Volunteer testing, accident reconstruction
      - Allows for calculation of Strains/Forces/Moments
      - Measures from model applied directly to BioRID
  - Merge two methods to agree on appropriate criteria
    - First draft of criteria in next presentation by Dr. Ono

Work left to do in current test series

- **Conduct one more paired PMHS/BioRID test**
  - Finalize decision about inclusion of NIC and NDCx
    - NDCx kinematics need to be transformed from CG to OC
      - Requires video analysis of targets
    - Can use Head-to-T1 rotation instead of NDCrot (if no NDCx)
  - Make decision about IV rotation versus global measures
  - Continue to investigate direct BioRID correlations

- **Finish analysis of kinetic measures to compare with Japan**

Future Work and outlying questions

- **Conduct sled series again with two BioRID dummies**
  - Certify and upgrade BioRID dummies
    - Design changes that improved reproducibility?
  - Conduct all 8 tests in one week
  - Improve direct correlations and intervertebral kinematics?
  - Two dummies to evaluate reproducibility

Future Work and outlying questions

- **NDCr is for flexion. What about extension?**
  - Rely on Japan kinetic criteria?
  - Put 12 deg head-to-T1 criterion in brackets?

- **Conduct paired BioRID/Hybrid III sled tests**
  - 12 deg Hybrid III extension = ?? deg BioRID
    - Range of seats using 202a pulse;
    - Include some seats with active HR
    - Other pulses?
    - No HR or large backset?
      - Limited extension achieved with BioRID in previous NHTSA testing presented to GTR by Ed Probst

Questions??

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