GTR 7 Informal Working Group
February 12, 2013
Brussels

Preliminary PMHS Injury Risk Curves & Potential Injury Criteria in Rear Impact

Kevin Moorhouse, Ph.D.
NHTSA

Yun-Seok Kang, Ph.D.
Ohio State University

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

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

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

Limitations
Experimental Seat

- **Experimental Seat**
  - Designed for Biofidelity (not injury criteria development)
    - Repeatability, durability, measure occupant loading, allow SB rotation
    - Not designed to represent a real seat

Limitations
Experimental Seat

- **Experimental Seat**
  - Designed for Biofidelity (not injury criteria development)
    - Repeatability, durability, measure occupant loading, allow SB rotation
    - Not designed to represent a real seat
  - Rigid HR with load cells affects UN/LN loads
  - UN/LN loads not accurate after HR contact
    - Uniaxial LCs combined with ramping motion
    - Neck interaction with HR

Limitations
Experimental Seat

- **Experimental Seat**
  - Designed for Biofidelity (not injury criteria development)
    - Repeatability, durability, measure occupant loading, allow SB rotation
    - Not designed to represent a real seat
  - Rigid HR with load cells affects UN/LN loads
  - UN/LN loads not accurate after HR contact
    - Uniaxial LCs combined with ramping motion
    - Neck interaction with HR
  - SB Rotation is more uniform than production SB
    - Large ramping (particularly in moderate-speed test)
      - Neck interaction with HR
      - Lowers effective HR height for PMHS interaction
        - Wrap-around causes large extension in some cases
        - However: peak IV-NIC was still in flexion prior to this

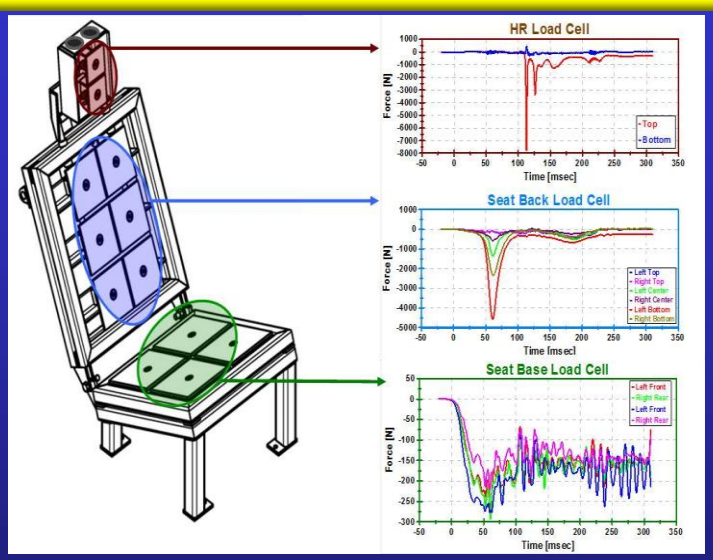
Limitations
Experimental Seat

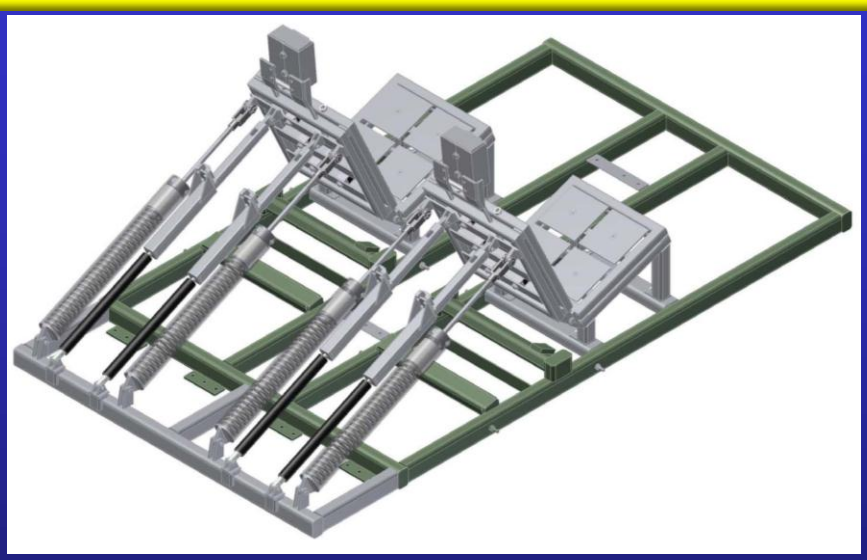
- **Two Biofidelity test conditions (low-speed, mod-speed)**
  - Yields only two BioRIDII data points
  - Can't do traditional correlation study between BioRIDII measures and PMHS injury predictors
  - Need more paired test conditions

Production Seat Testing

- **Strengthen and verify results using real seats**
  - Test PMHS and BioRIDII (multiple paired tests)
    - Production seats (Chevy Cruze, Toyota Camry)
    - Measure HR loads → strain gages on posts
    - Multiple BioRIDII data points for correlation
  - Test Matrix (8 PMHS)
    - First 4 PMHS - 2 seats – varying severities
    - Evaluate injury data
    - Next 4 PMHS – Choose diff pulses, seats, repeats??

Experimental Seat





Test Matrix
Experimental Seat

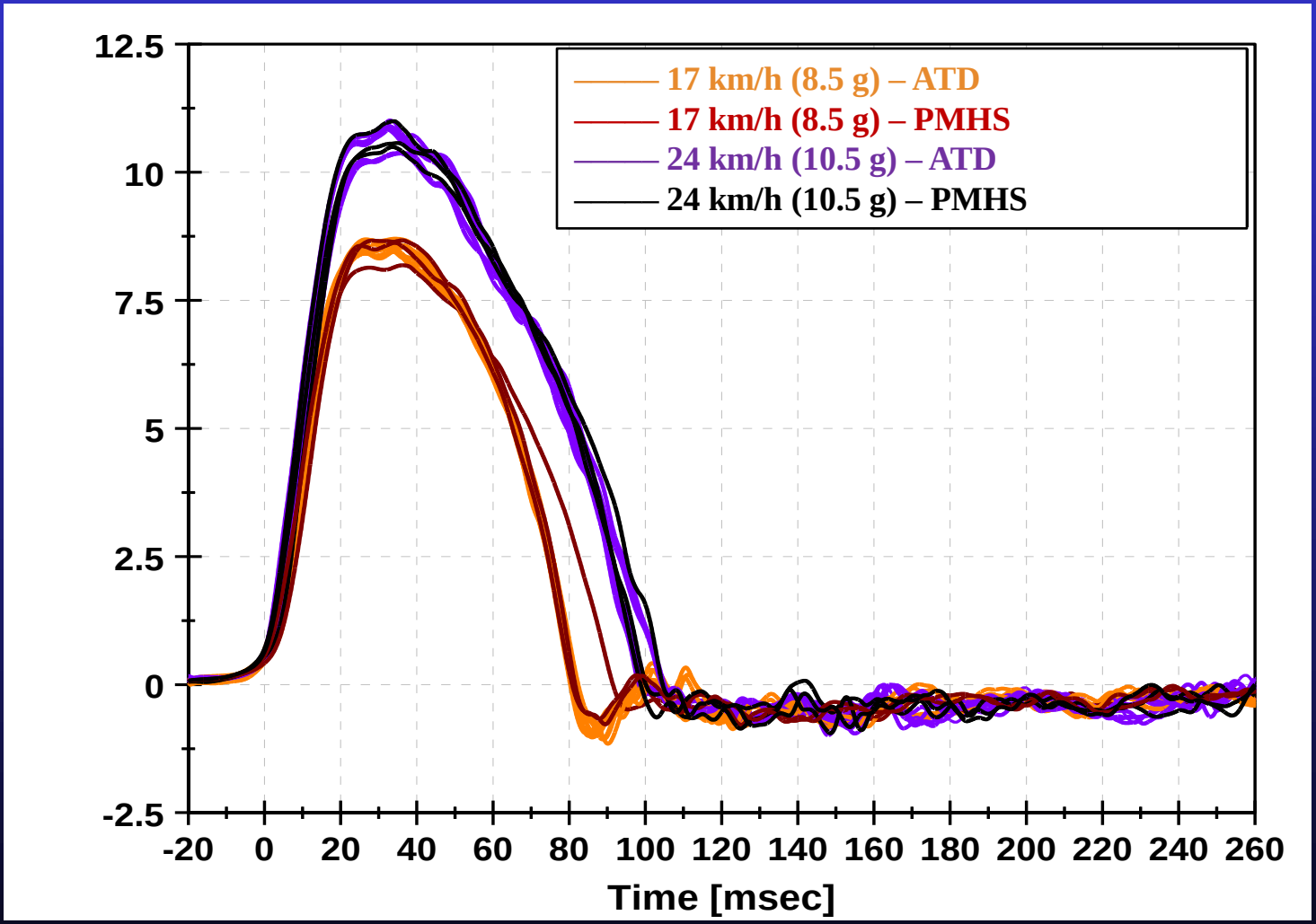
Three repeats at each speed

Dummies			
Test Number	Test Speed	Driver Side Dummy	Passenger Side Dummy
1	L	Hybrid III 50th	BioRID II
2	L	Hybrid III 50th	BioRID II
3	L	RID3D	BioRID II
4	L	RID3D	BioRID II
5	L	RID3D	Hybrid III 50th
6	M	RID3D	Hybrid III 50th
7	M	RID3D	Hybrid III 50th
8	M	RID3D	BioRID II
9	M	RID3D	BioRID II
10	M	Hybrid III 50th	BioRID II

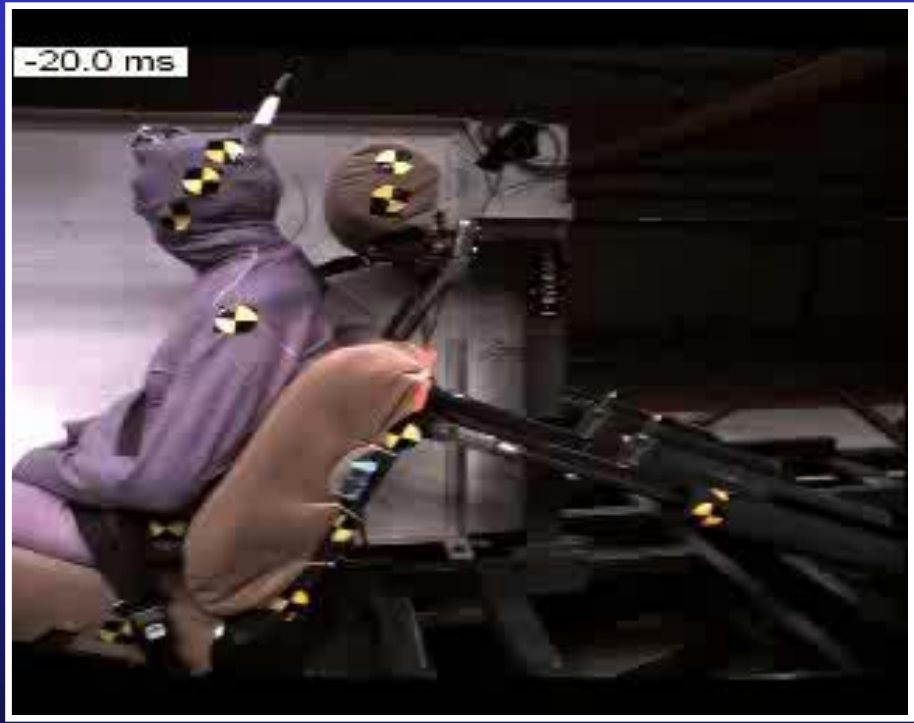
7 PMHS at each speed

PMHS		
Test Number	Test Speed	Driver Side Dummy
1	M	PMHS 01
2	L (4)	PMHS 02
3	L/M	PMHS 03
4	L/M	PMHS 04
5	L/M	PMHS 05
6	L/M	PMHS 06
7	L/M	PMHS 07
8	L/M	PMHS 08

Sled Pulses
Experimental Seat

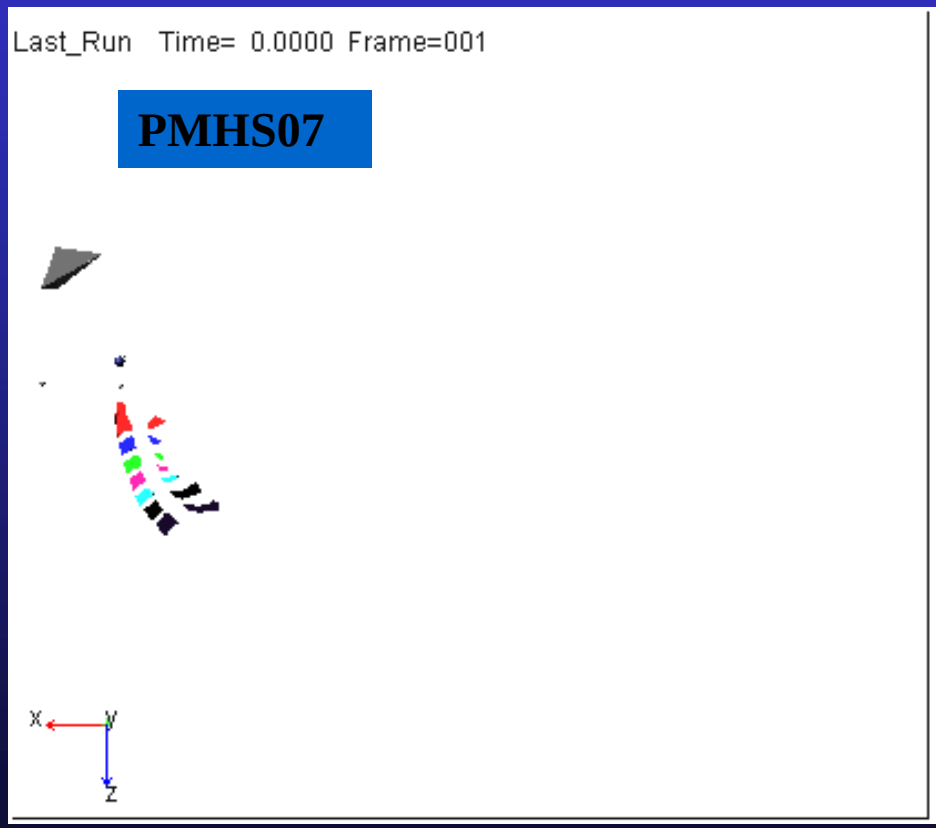


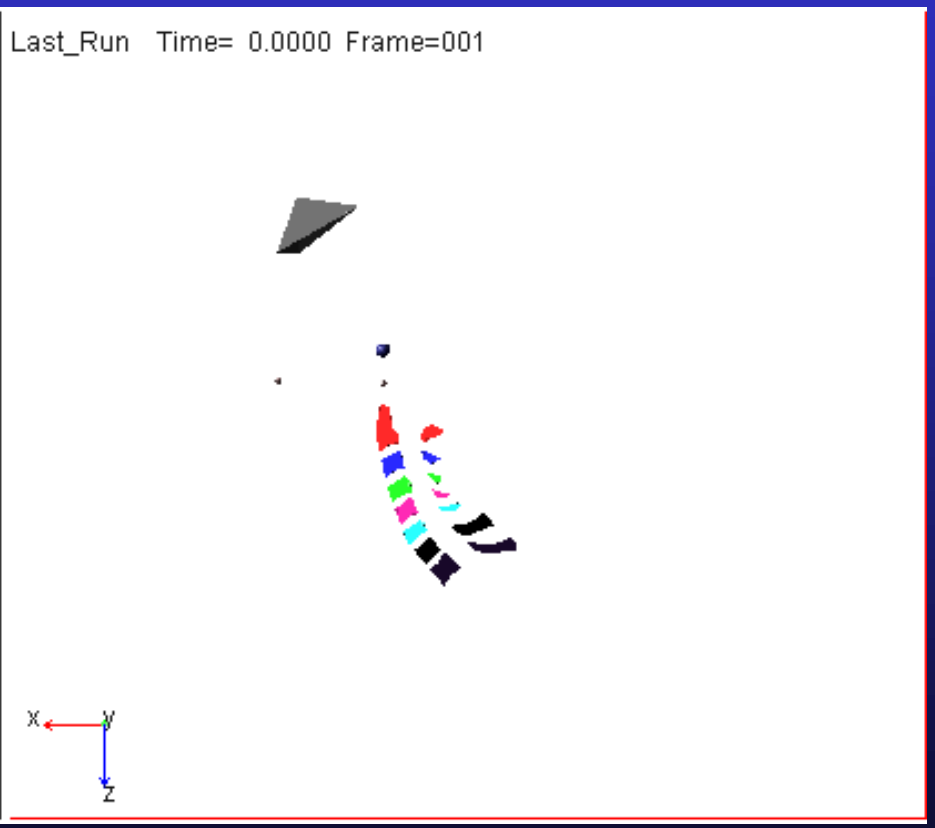
17 km/h; 8.5 g Sled Test
Experimental Seat



24 km/h; 10.5 g Sled Test
Experimental Seat

24 km/h; 10.5 g Sled Test
Experimental Seat





Test Matrix
Production Seat

PMHS09

Chevy Cruze FMVSS 202a

67yo 177cm/83kg

PMHS10

Chevy Cruze JNCAP

82yo 183cm/79kg

PMHS11

Toyota Camry JNCAP

66yo 184cm/82kg

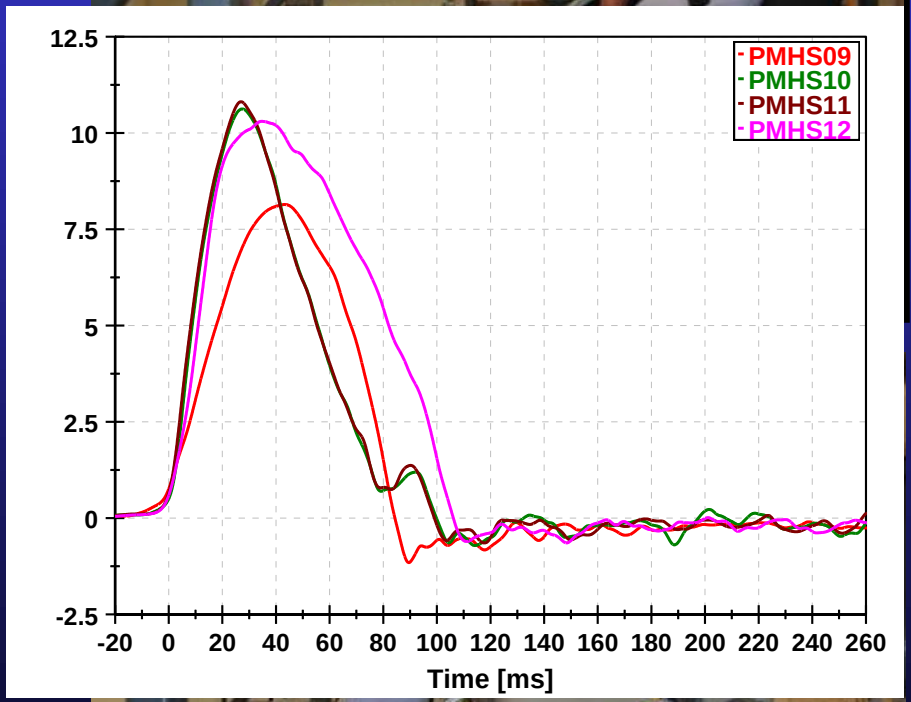
PMHS12

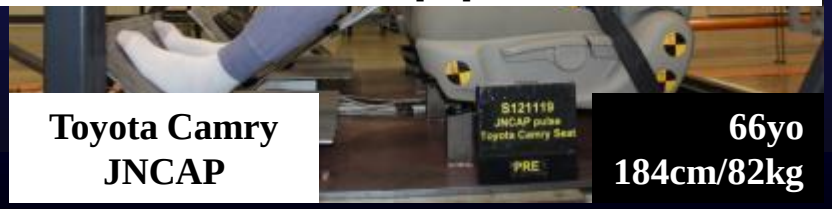
Toyota Camry 24 km/h

65yo 184cm/75kg

Sled Pulses
Production Seat

PMHS09

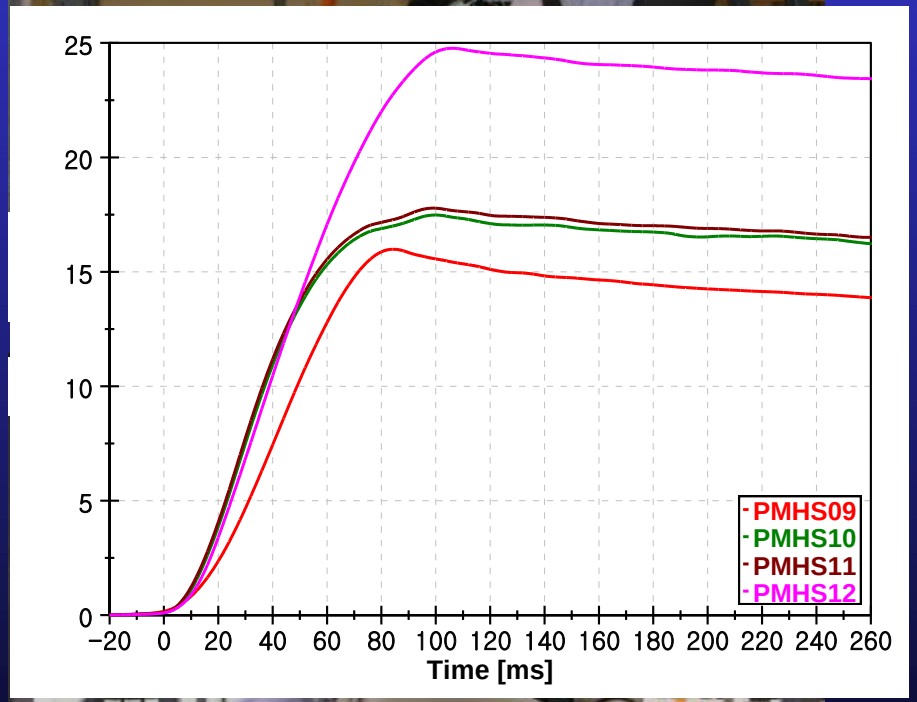


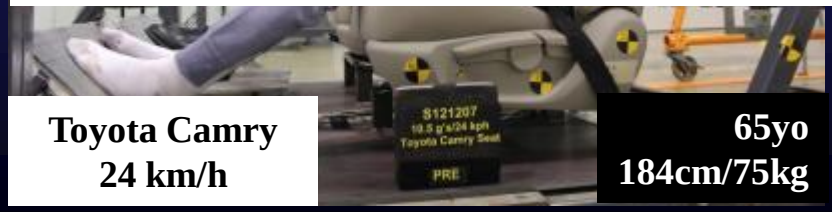


Toyota Camry JNCAP

66yo 184cm/82kg

PMHS10

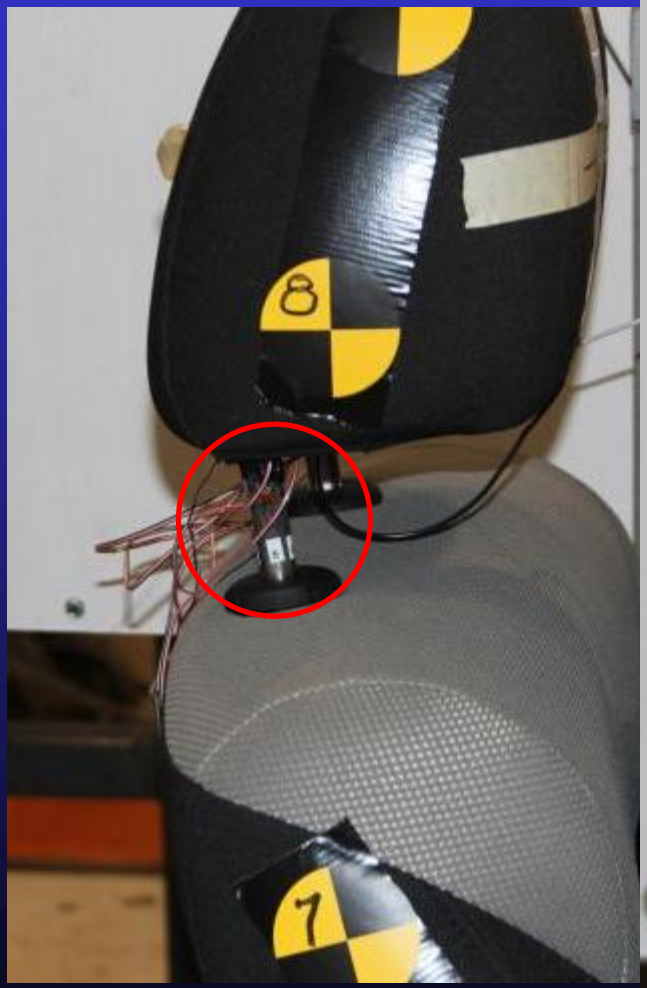


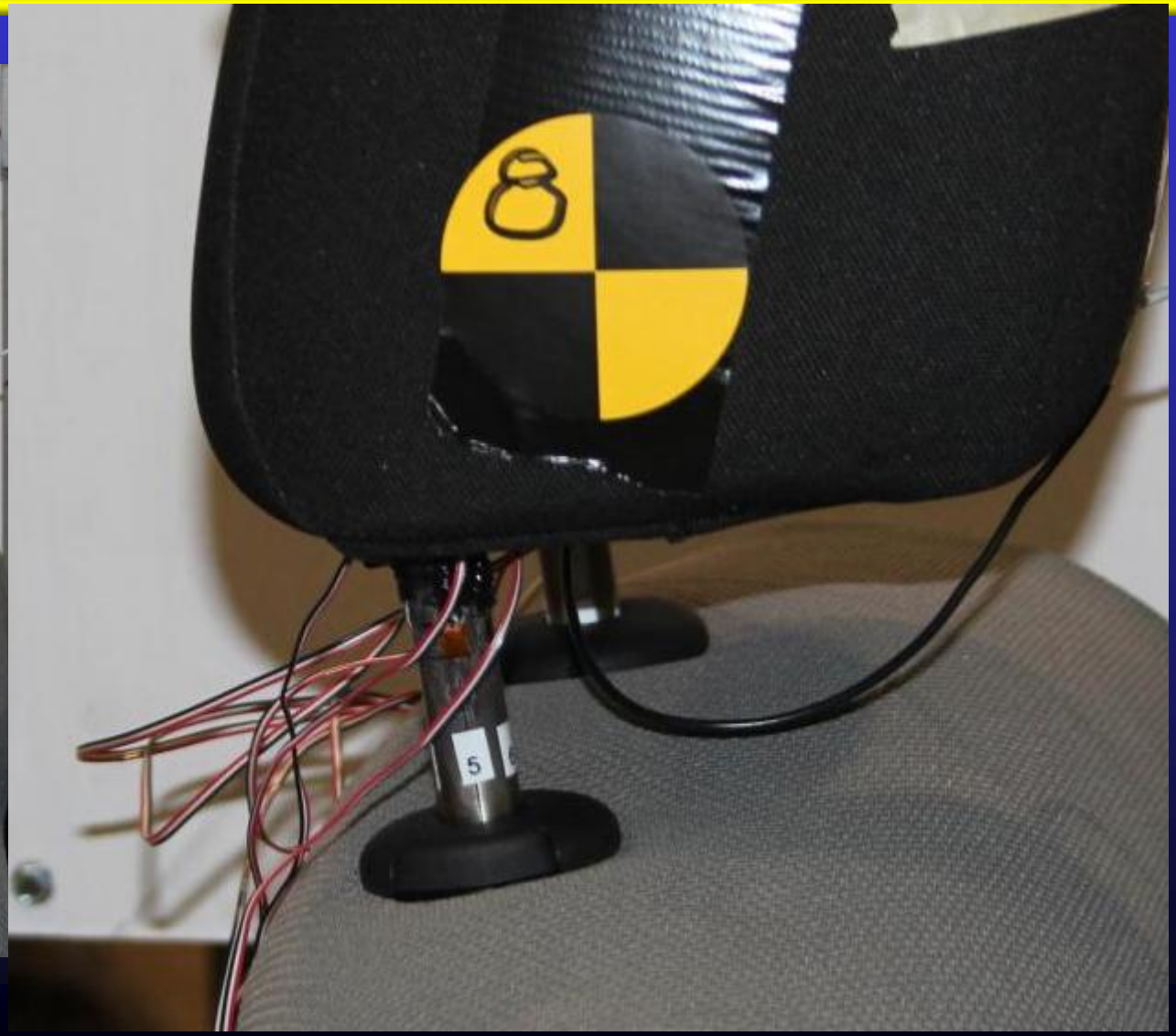


Toyota Camry 24 km/h

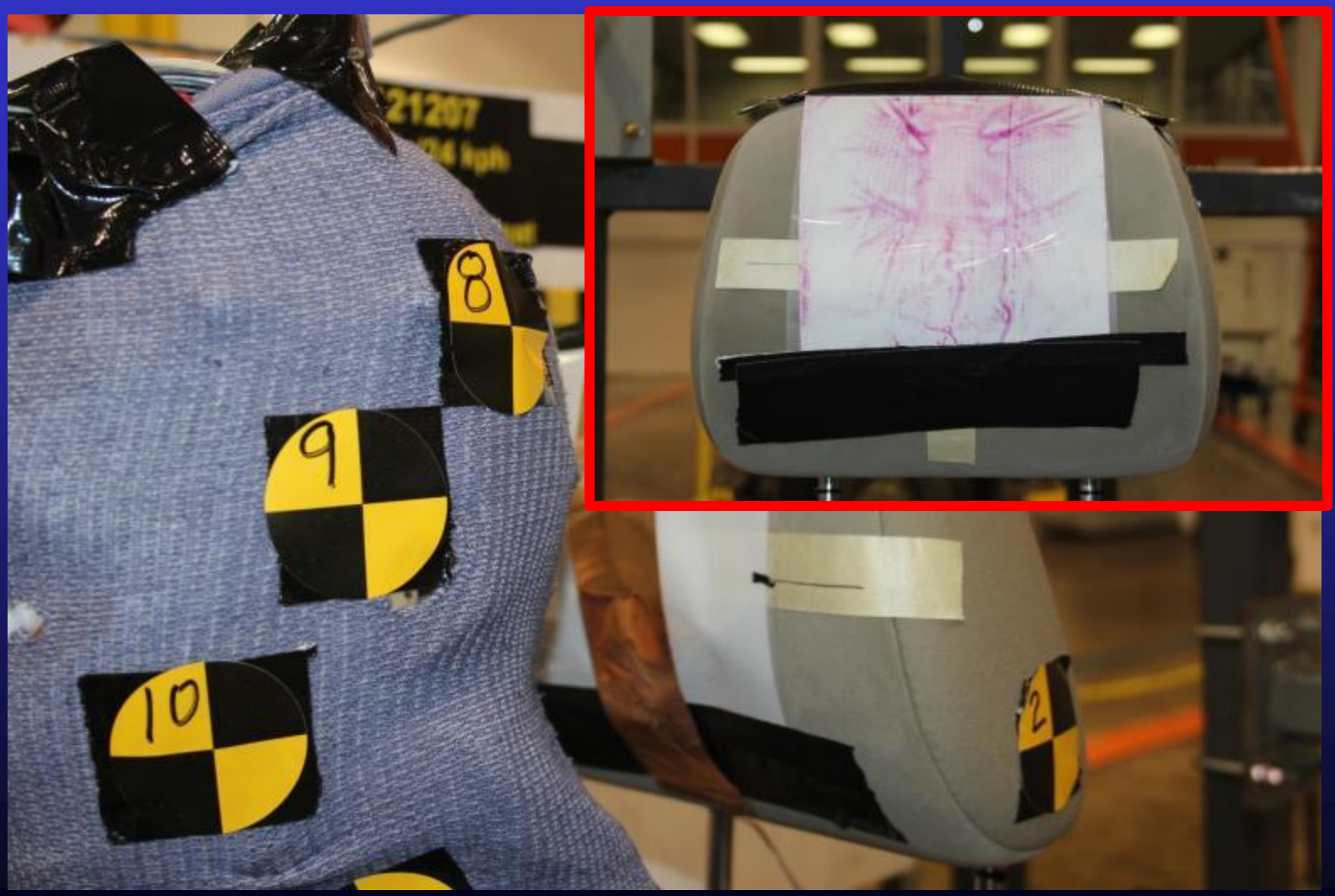
65yo 184cm/75kg

Head Restraint Forces
Production Seat





Head Restraint Forces
Production Seat



Production Seat Sled Tests
Chevy Cruze - FMVSS 202a

Chevy Cruze
FMVSS 202a

Chevy Cruze
FMVSS 202a

PMHS09

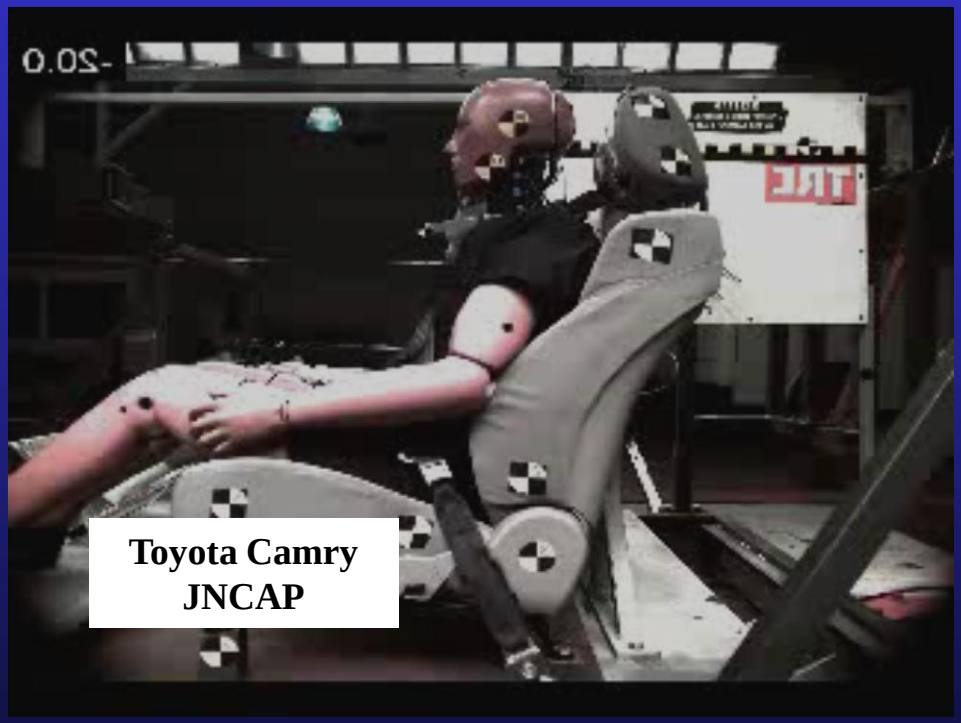
Production Seat Sled Tests
Chevy Cruze - JNCAP

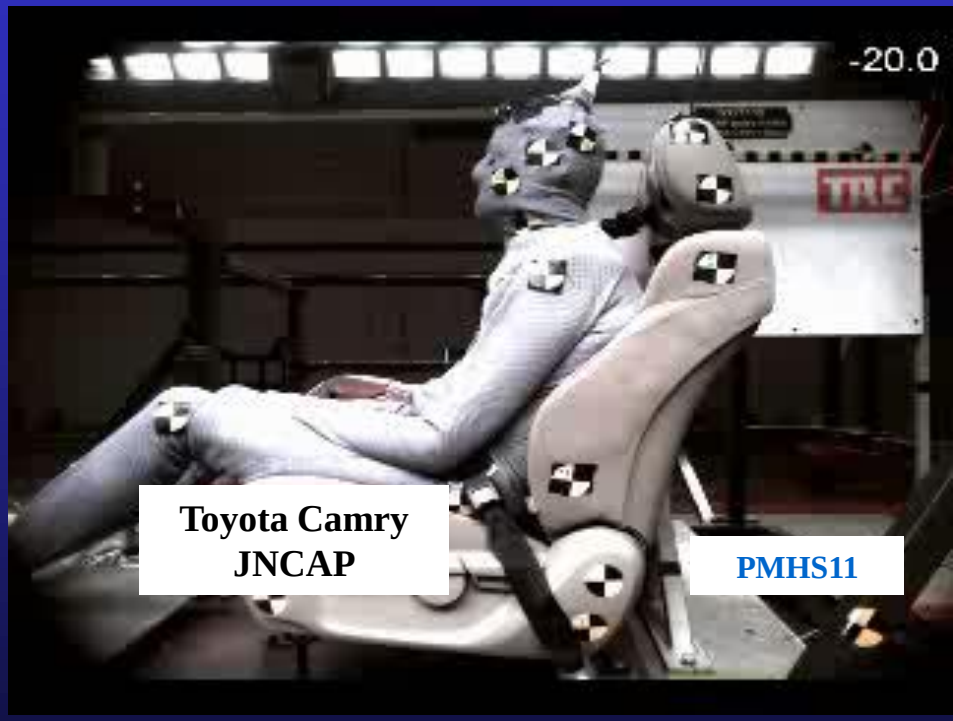
Chevy Cruze
JNCAP

Chevy Cruze
JNCAP

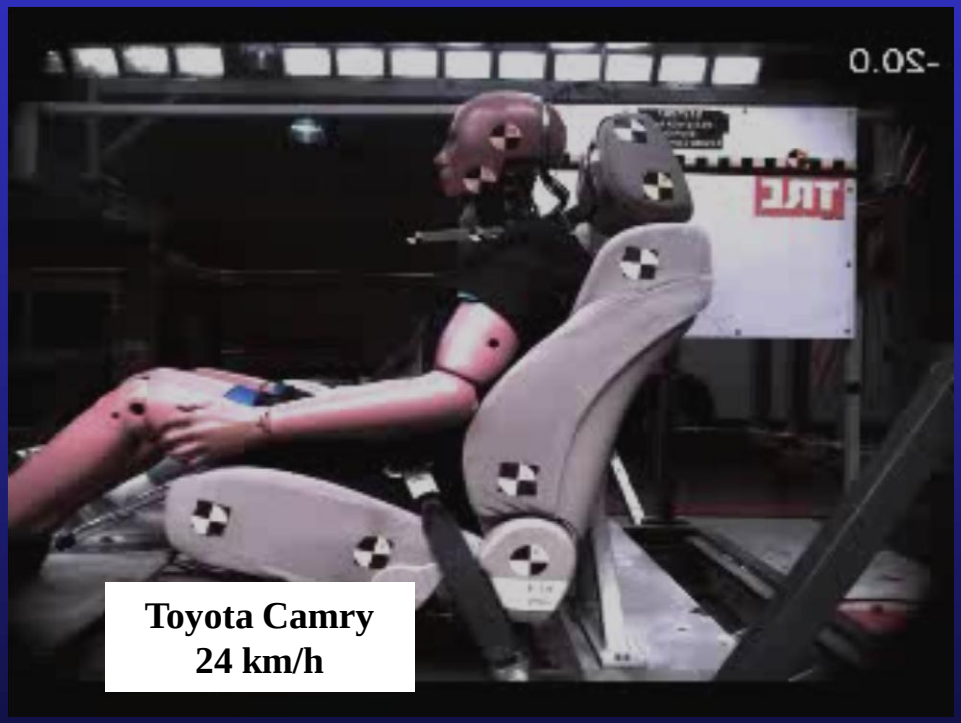
PMHS10

Production Seat Sled Tests
Toyota Camry - JNCAP





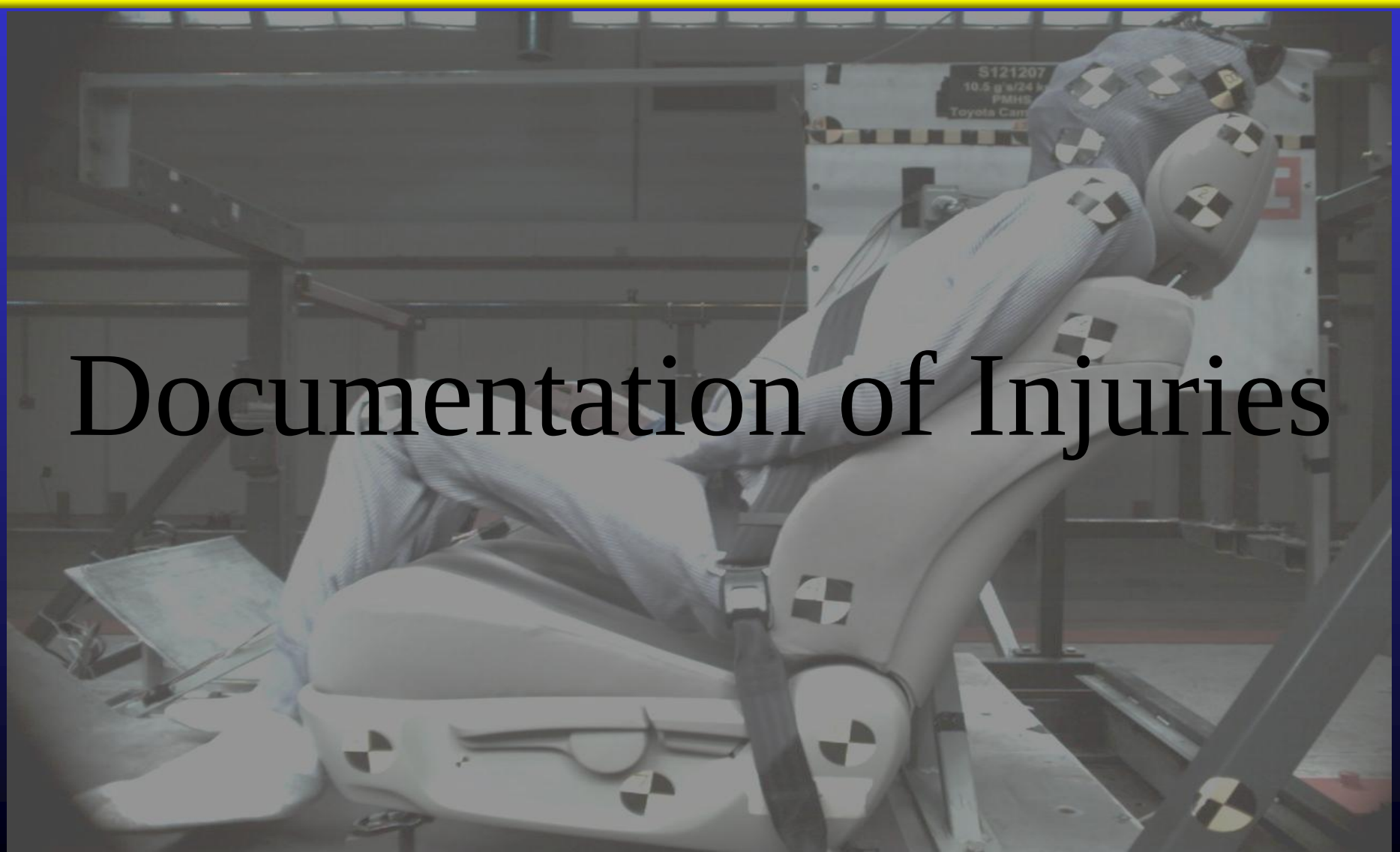
Production Seat Sled Tests
Toyota Camry – 24 km/h



Toyota Camry
24 km/h

Toyota Camry
24 km/h

PMHS12



Documentation of Injuries

Documentation of Injuries
Experimental Seat

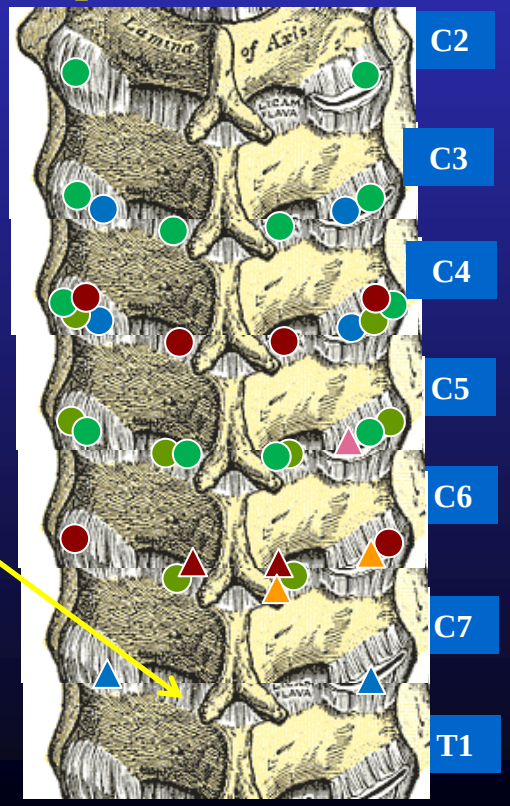
: disc rupture

: subluxation (represents WAD)

: laceration (tear)

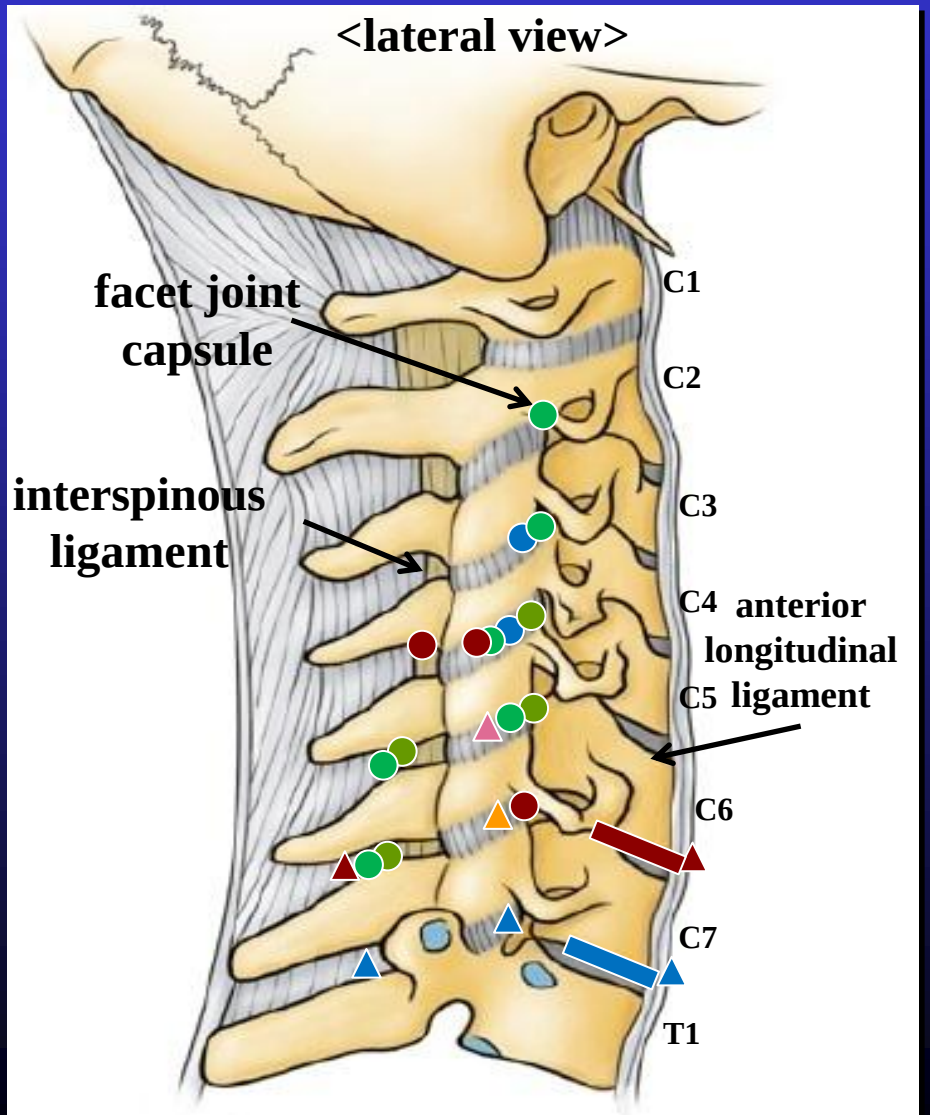
PMHS03
PMHS04
PMHS05
PMHS06
PMHS07
PMHS08

<posterior view>



ligamentum flavum

<lateral view>



Documentation of Injuries
Experimental Seat

Injury Documentation						
	PMHS03	PMHS04	PMHS05	PMHS06	PMHS07	PMHS08
C2/C3	No injury	No injury	Subluxation	No injury	No injury	No injury
C3/C4	Subluxation	No injury	Subluxation	No injury	No injury	No injury
C4/C5	Subluxation	Subluxation	Subluxation	No injury	Subluxation	No injury
C5/C6	No injury	Subluxation	Subluxation	Subluxation	No injury	No injury
C6/C7	No injury	Subluxation	Subluxation	No injury	Subluxation/ligament tear/disc injury	Subluxation

Documentation of Injuries
Production Seat

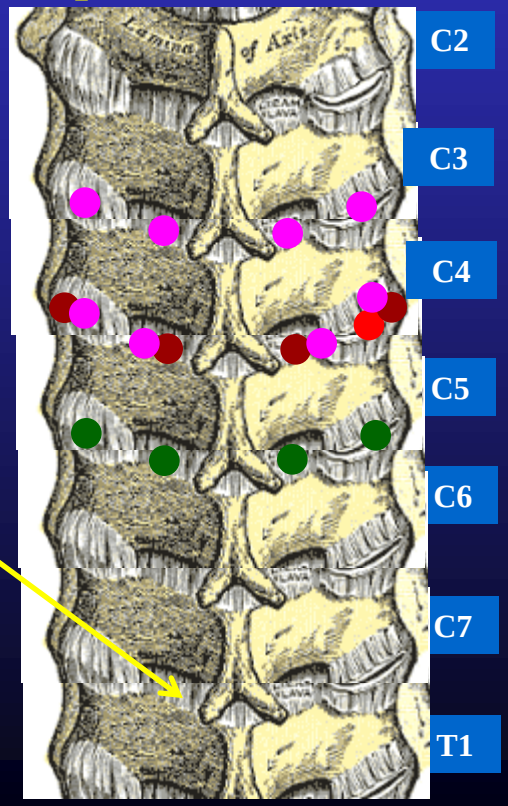
: disc rupture

: subluxation (represents WAD)

: laceration (tear)

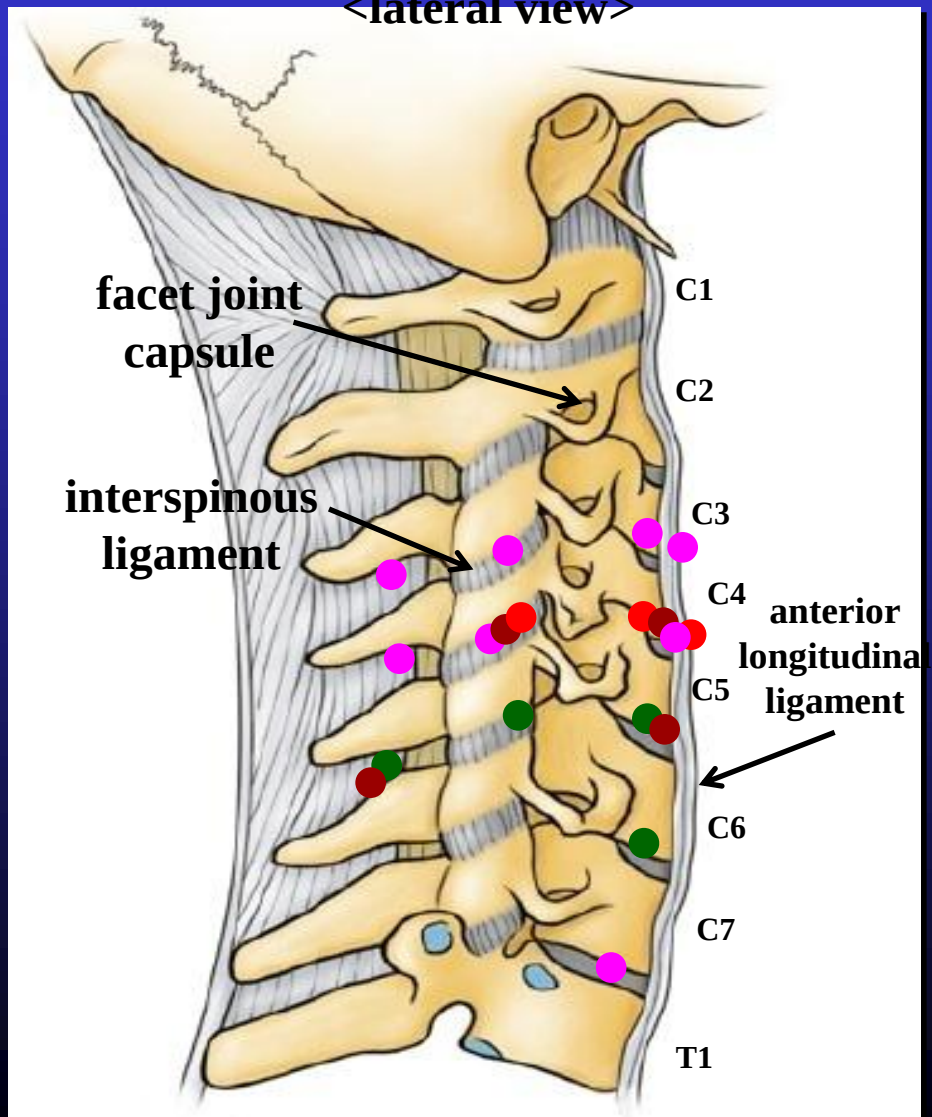
PMHS09
PMHS10
PMHS11
PMHS12

<posterior view>



ligamentum flavum

<lateral view>



Documentation of Injuries
Production Seat

IV-NICrot (Rotation)				
updated	PMHS09	PMHS10	PMHS11	PMHS12
	FMVSS202	JNCAP	JNCAP	24 km/h
C2/C3	No injury	No injury	No injury	No injury
C3/C4	No injury	No injury	No injury	Subluxation
C4/C5	Subluxation	No injury	Subluxation	Subluxation
C5/C6	No injury	Subluxation	Subluxation	No injury
C6/C7	No injury	Subluxation	No injury	No injury

Injury Criteria Analysis

PMHS Injury Analysis

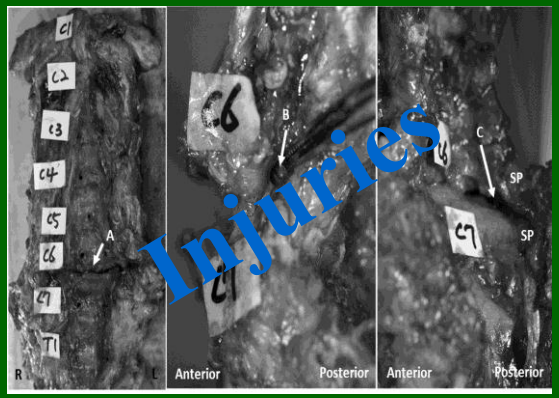
PMHS

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Correlation?



PMHS Injury Analysis

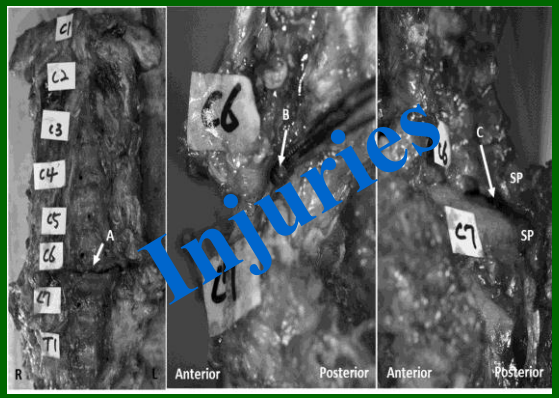
PMHS

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Correlation?



Normalization?

PMHS Injury Analysis

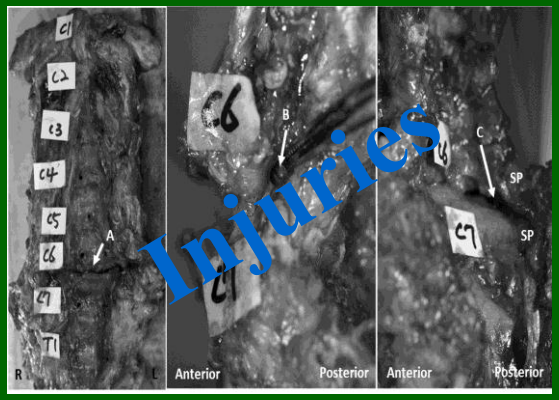
PMHS

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

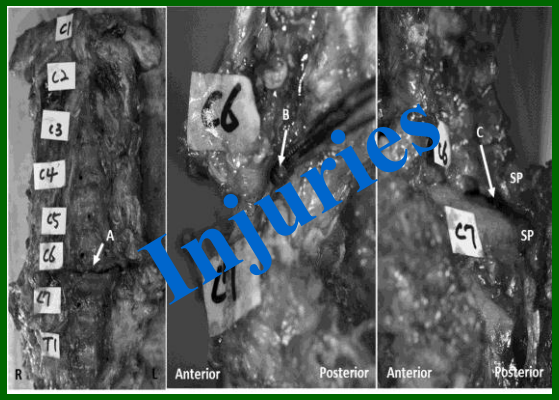
PMHS

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Correlation?



Normalization?

Step 2

Best injury predictors

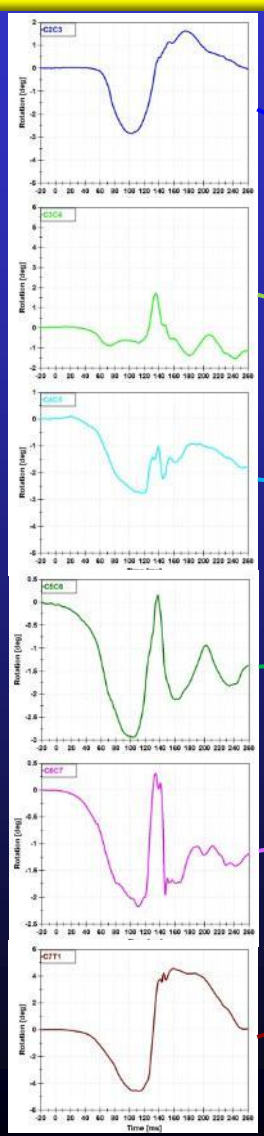
Correlation?

Kinetics/kinematics

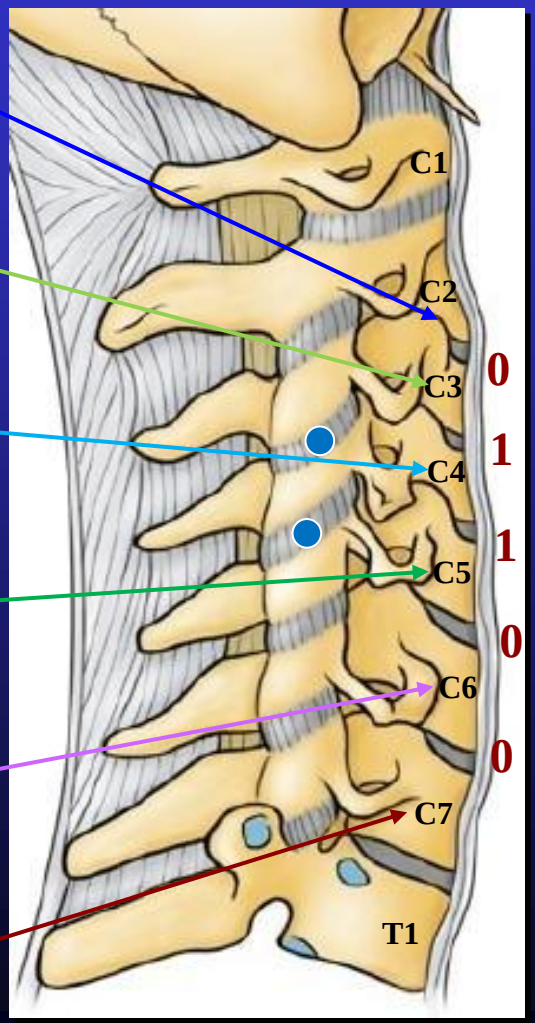
Current/potential injury criteria

PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics

Intervertebral kinematics

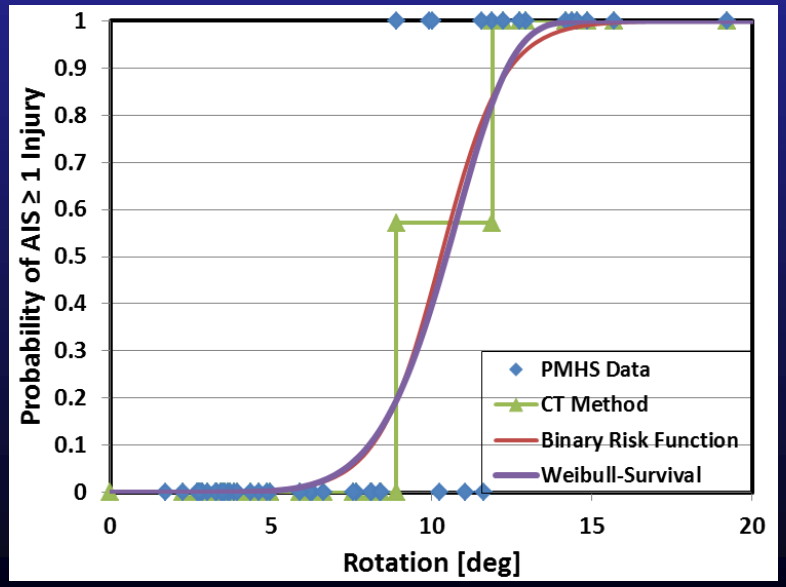


Injuries @ intervertebral levels



- C2/C3 – C6/C7: 5 levels
- 5 data points per test
  - PMHS02-non injurious 4 multiple tests
- n =~70 (50 exp / 20 prod)

Injury Risk Curves



PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics
Experimental Seat Only

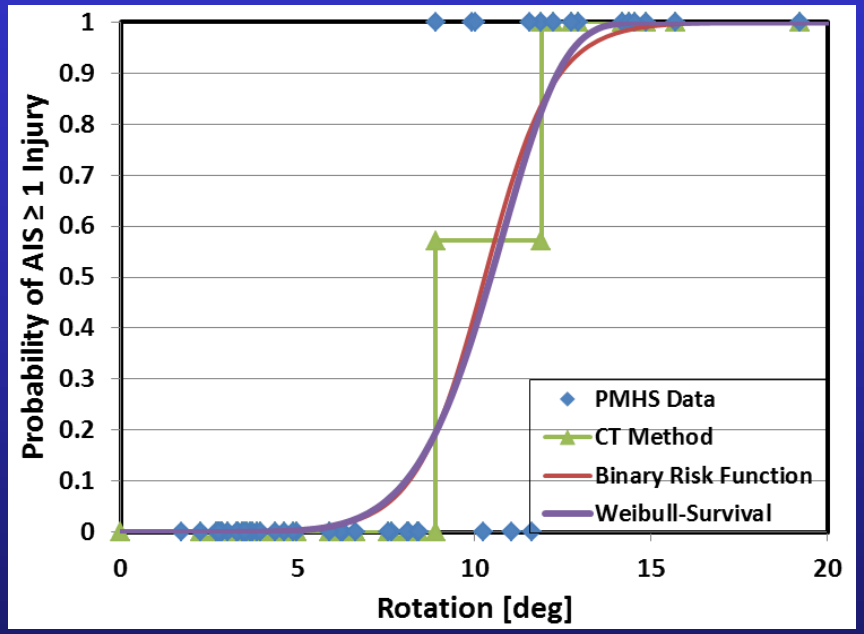
Intervertebral kinematics		Pseudo R^2	Nagelkerke R^2	Log-Likelihood	P-value	Goodman-Kruskal Gamma
Acceleration x	(+)	0.05	0.08	-30.38	0.07	0.49
	(-)	0.17	0.25	-26.74	0.00	0.72
	Max	0.09	0.14	-29.14	0.02	0.59
Acceleration z	(+)	0.17	0.26	-26.58	0.00	0.62
	(-)	0.10	0.15	-28.96	0.01	0.59
	Max	0.12	0.19	-28.18	0.01	0.58
Velocity x	(+)	0.04	0.07	-30.61	0.09	0.34
	(-)	0.20	0.29	-25.79	0.00	0.54
	Max	0.20	0.29	-25.80	0.00	0.54
Velocity z	(+)	0.01	0.01	-31.86	0.53	-0.05
	(-)	0.12	0.18	-28.31	0.01	0.47
	Max	0.04	0.06	-30.91	0.13	0.14
Angular velocity y	(+)	**0.30**	**0.43**	**-20.70**	**0.00**	**0.83**
	(-)	0.05	0.08	-33.20	0.07	0.42
	Max	0.17	0.26	-28.84	0.00	0.70
Rotation y	Max	**0.72**	**0.83**	**-8.24**	**0.00**	**0.96**
Facet JT Slide	Max	**0.38**	**0.52**	**-18.53**	**0.00**	**0.77**
Facet JT Slide Rate	Max	0.13	0.20	-30.39	0.00	0.49
Facet JT Axial	Max	0.06	0.10	-32.71	0.04	0.28
Facet JT Axial Rate	Max	0.05	0.09	-32.95	0.06	0.38

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

Pseudo R^2 > 0.2, Nagelkerke R^2 > 0.4, P-value < 0.05 , Goodman-Kruskal Gamma > 0.6

Best correlation and prediction

PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics
Experimental Seat Only



Intervertebral kinematics		Pseudo R^2	Nagelkerke R^2	Log-Likelihood	P-value	Goodman-Kruskal Gamma
Intervertebral Rotation y	Max	0.72	0.83	-8.24	0.000	0.96

Pseudo R^2 > 0.2, Nagelkerke R^2 > 0.4, P-value < 0.05 , Goodman-Kruskal Gamma > 0.6

Best correlation and prediction

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

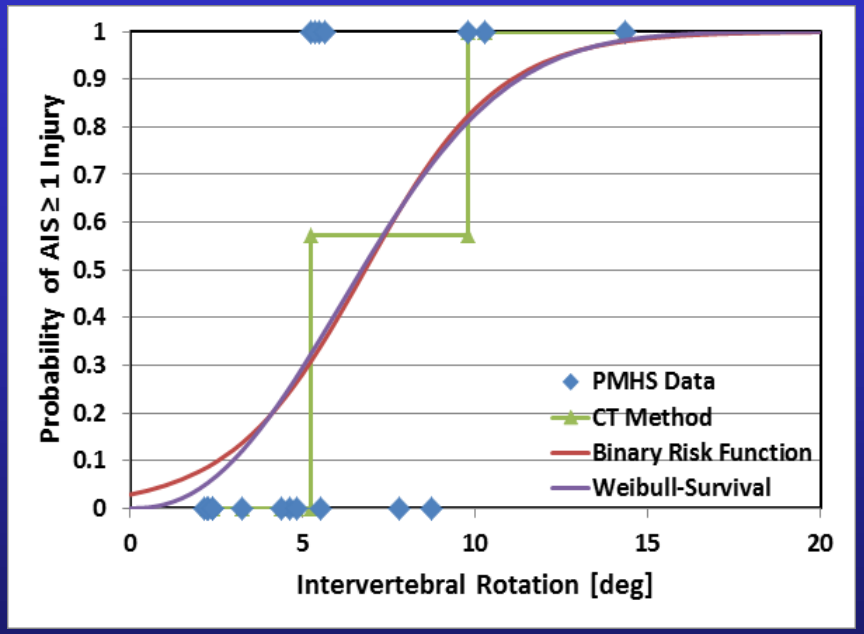
Intervertebral kinematics		Pseudo R^2	Nagelkerke R^2	Log-Likelihood	P-value	Goodman-Kruskal Gamma
Acceleration x	(+)	0.11	0.19	-11.49	0.09	0.42
	(-)	0.01	0.01	-12.88	0.72	-0.01
	Max	0.09	0.15	-11.81	0.13	0.34
Acceleration z	(+)	0.04	0.06	-12.49	0.34	0.18
	(-)	0.11	0.18	-11.55	0.09	0.46
	Max	0.12	0.20	-11.39	0.08	0.49
Velocity x	(+)	0.00	0.00	-12.95	1.00	-0.02
	(-)	0.05	0.09	-12.28	0.25	0.31
	Max	0.07	0.11	-12.10	0.19	0.38
Velocity z	(+)	0.03	0.05	-12.59	0.39	0.38
	(-)	0.01	0.01	-12.85	0.66	0.10
	Max	0.04	0.06	-12.47	0.33	0.32
Angular velocity y	(+)	0.02	0.03	-12.28	0.50	0.11
	(-)	0.17	0.27	-10.41	0.04	0.52
	Max	0.22	0.34	-9.80	0.02	0.55
Rotation y	**Max**	**0.28**	**0.43**	**-8.96**	**0.01**	**0.74**
Facet JT Slide	**(+)**	0.10	0.17	-11.63	0.10	0.49
Facet JT Slide Rate	Max	0.21	0.32	-10.27	0.02	0.51
Facet JT Axial	Max	0.17	0.27	-10.81	0.04	0.56
Facet JT Axial Rate	**(-)**	**0.29**	**0.43**	**-9.20**	**0.01**	**0.67**

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

Peudo R^2 > 0.2, Nagelkerke R^2 > 0.4, P-value < 0.05 , Goodman-Kruskal Gamma > 0.6

Best correlation and prediction

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



Intervertebral kinematics		Pseudo R^2	Nagelkerke R^2	Log-Likelihood	P-value	Goodman-Kruskal Gamma
Intervertebral Rotation y	Max	0.28	0.43	-8.96	0.000	0.74

Pseudo $R^2 > 0.2$, Nagelkerke $R^2 > 0.4$, P-value < 0.05 , Goodman-Kruskal Gamma > 0.6

Best correlation and prediction

PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics
Combined Exp/Prod Seats

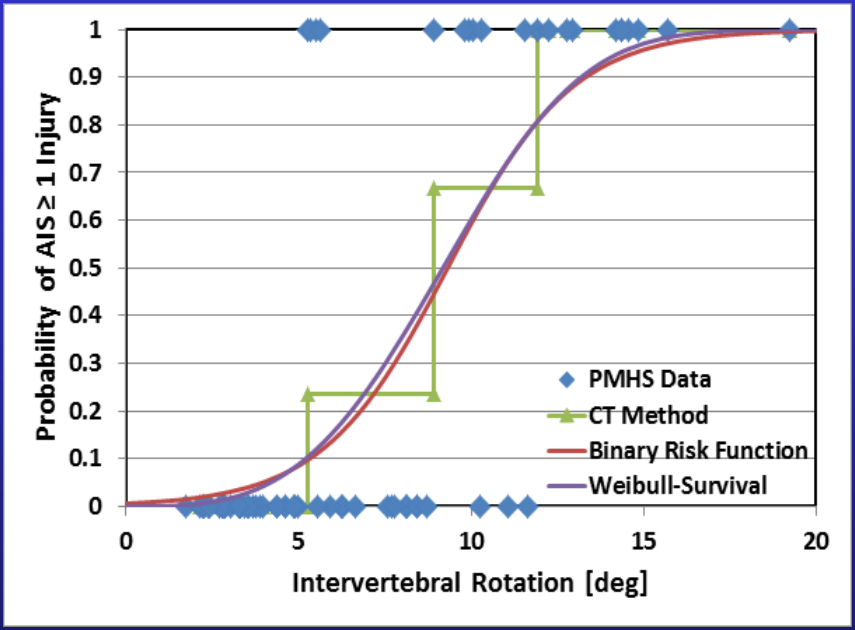
Intervertebral kinematics		Pseudo R^2	Nagelkerke R^2	Log-Likelihood	P-value	Goodman-Kruskal Gamma
Acceleration x	(+)	0.02	0.03	-39.23	0.23	0.27
	(-)	0.04	0.06	-38.55	0.09	0.21
	Max	0.03	0.05	-38.84	0.14	0.29
Acceleration z	(+)	0.08	0.14	-36.63	0.01	0.30
	(-)	0.05	0.08	-38.02	0.05	0.40
	Max	0.06	0.10	-37.58	0.03	0.35
Velocity x	(+)	0.01	0.02	-39.47	0.33	0.22
	(-)	0.03	0.05	-38.66	0.11	0.21
	Max	0.03	0.06	-38.58	0.10	0.22
Velocity z	(+)	0.00	0.01	-39.80	0.58	-0.11
	(-)	0.06	0.10	-37.52	0.03	0.26
	Max	0.02	0.03	-39.30	0.26	0.16
Angular velocity y	(+)	0.10	0.16	-38.25	0.00	0.41
	(-)	0.07	0.11	-39.55	0.02	0.45
	Max	0.12	0.20	-37.14	0.00	0.58
Rotation y	**Max**	**0.47**	**0.62**	**-22.40**	**0.00**	**0.85**
Facet JT Slide	Max	0.23	0.34	-33.04	0.00	0.63
Facet JT Slide Rate	Max	0.09	0.15	-38.74	0.01	0.43
Facet JT Axial	Max	0.03	0.04	-41.65	0.14	0.20
Facet JT Axial Rate	Max	0.01	0.02	-42.31	0.34	0.20

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

Peudo $R^2 > 0.2$, Nagelkerke $R^2 > 0.4$, P-value < 0.05 , Goodman-Kruskal Gamma > 0.6

Best correlation and prediction

PMHS Injury Analysis
Injury Risk Curves – Intervertebral Kinematics
Combined Exp/Prod Seats



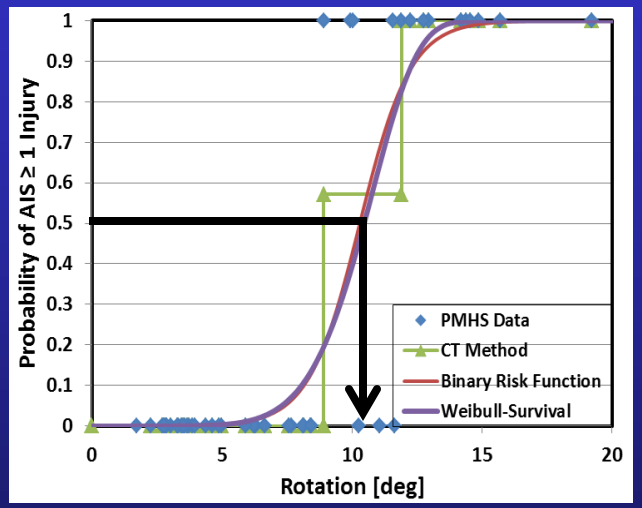
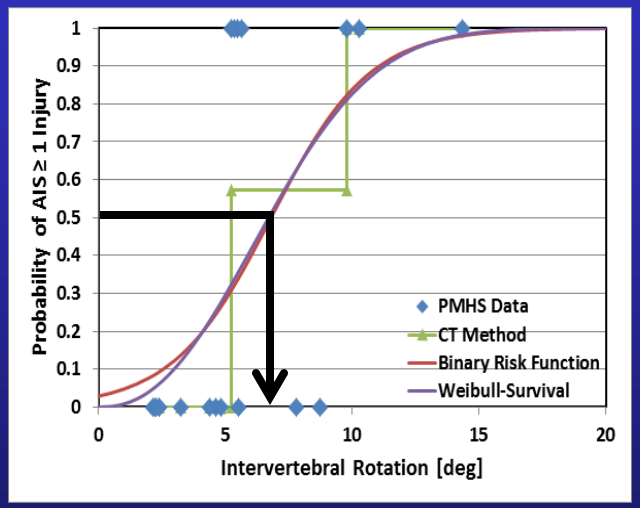
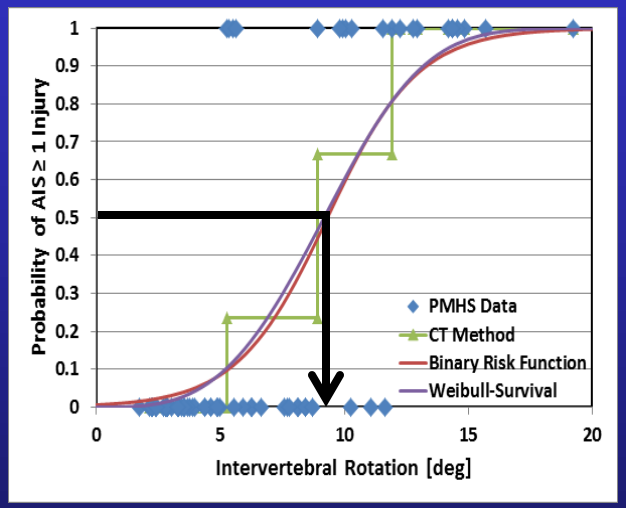
Intervertebral kinematics		Pseudo R^2	Nagelkerke R^2	Log-Likelihood	P-value	Goodman-Kruskal Gamma
Rotation y	Max	0.47	0.62	-22.40	0.00	0.85
(+) : positive peak, (-): negative peak, Max: maximum peak						

Pseudo R^2 > 0.2, Nagelkerke R^2 > 0.4, P-value < 0.05 , Goodman-Kruskal Gamma > 0.6

Best correlation and prediction

PMHS Injury Analysis

Injury Risk Curves – Intervertebral Kinematics Comparison - 50% Chance of AIS 1+

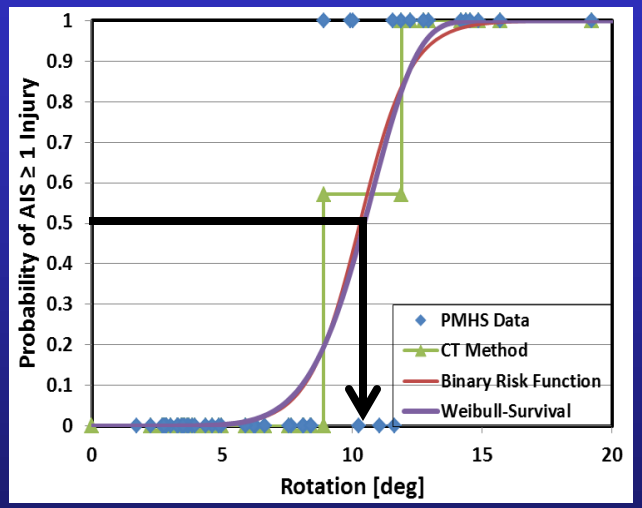
Experimental Seat	Production Seats	Combined Exp/Prod Seats
		
10.5 deg (flexion)	6.7 deg (flexion)	8.8 deg (flexion)

PMHS Injury Analysis

Injury Risk Curves – Intervertebral Kinematics

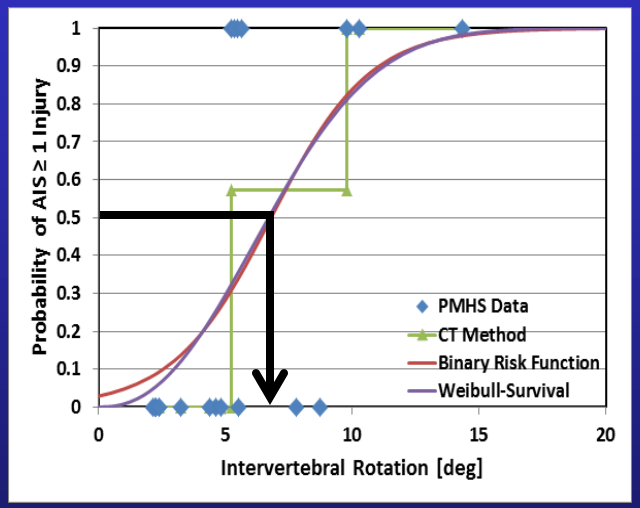
Comparison - 50% Chance of AIS 1+

Experimental Seat



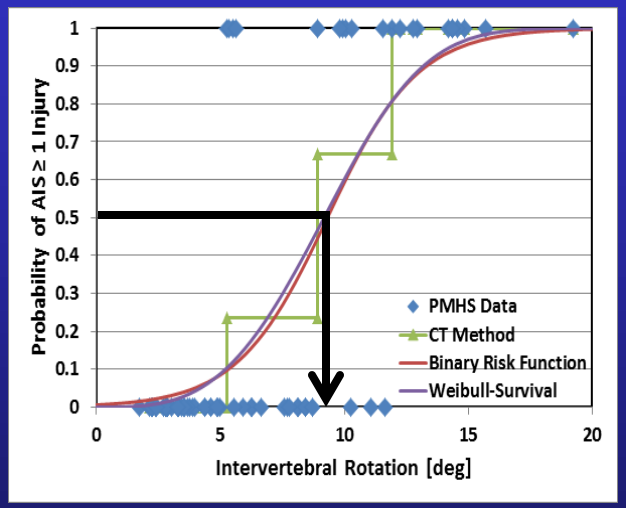
10.5 deg (flexion)

Production Seats

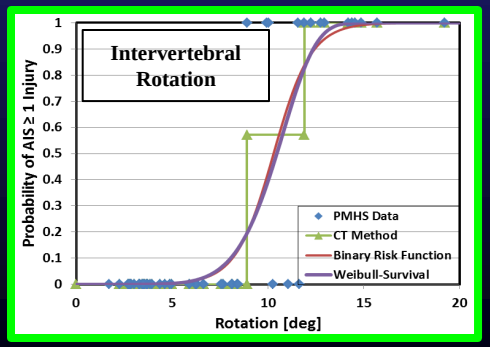


6.7 deg (flexion)

Combined Exp/Prod Seats



8.8 deg (flexion)



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

PMHS Injury Analysis

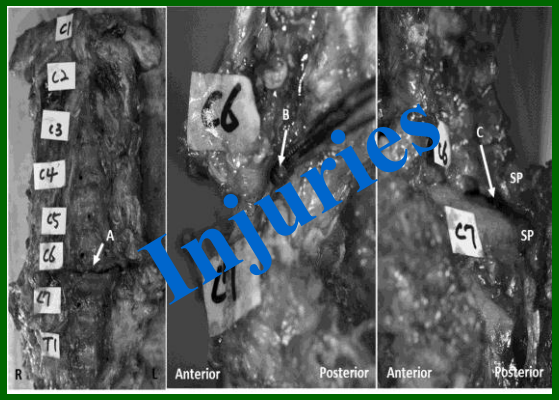
PMHS

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Correlation?



Normalization?

Step 2

Best injury predictors

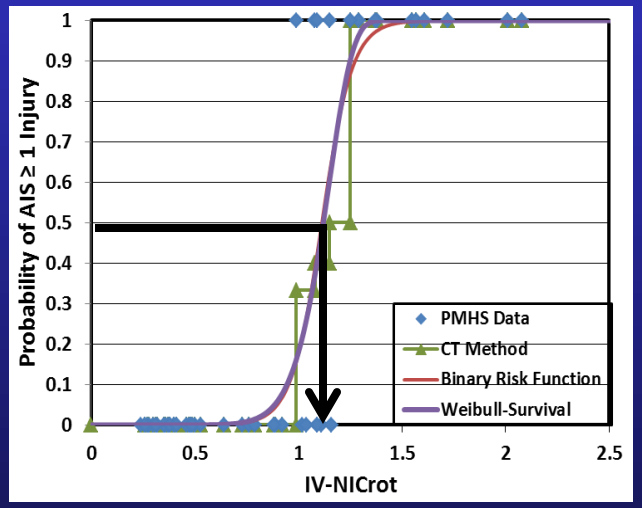
Correlation?

Kinetics/kinematics

Current/potential injury criteria

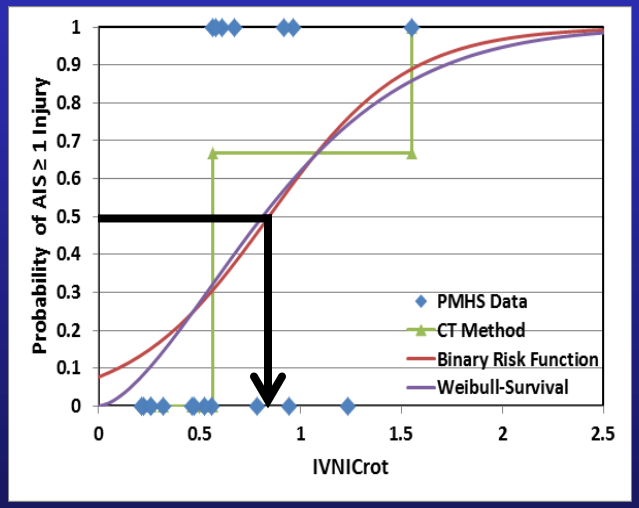
PMHS Injury Analysis
Injury Risk Curves – IV-NICrot
Comparison - 50% Chance of AIS 1+

Experimental Seat



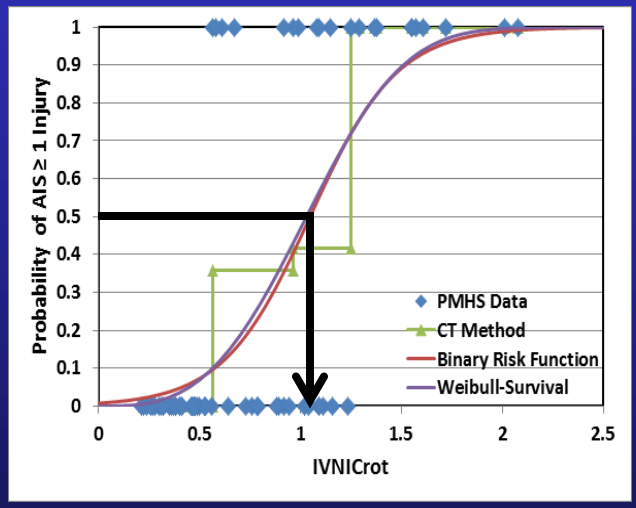
IV-NIC = 1.12

Production Seats



IV-NIC = 0.81

Combined Exp/Prod Seats



IV-NIC = 1.03

PMHS Injury Analysis

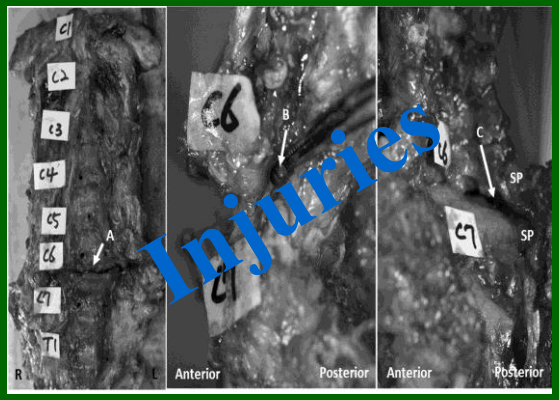
PMHS

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
IV-NIC vs. Current/Potential Injury Criteria

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

$IV-NICrot$ ⟷ **Correlation?**

Yes ↓

Potential PMHS IARVs

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

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

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

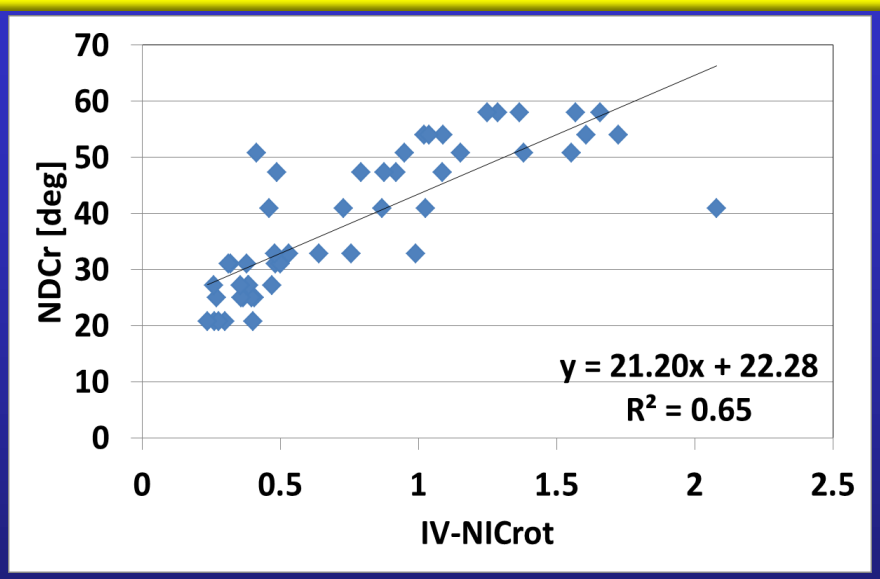
$$LNL-index(t) = \left| \frac{\sqrt{My_{lower}(t)^2 + Mx_{lower}(t)^2}}{C_{moment}} \right| + \left| \frac{\sqrt{Fx_{lower}(t)^2 + Fy_{lower}(t)^2}}{C_{shear}} \right| + \left| \frac{Fz_{lower}(t)}{C_{tension}} \right|$$

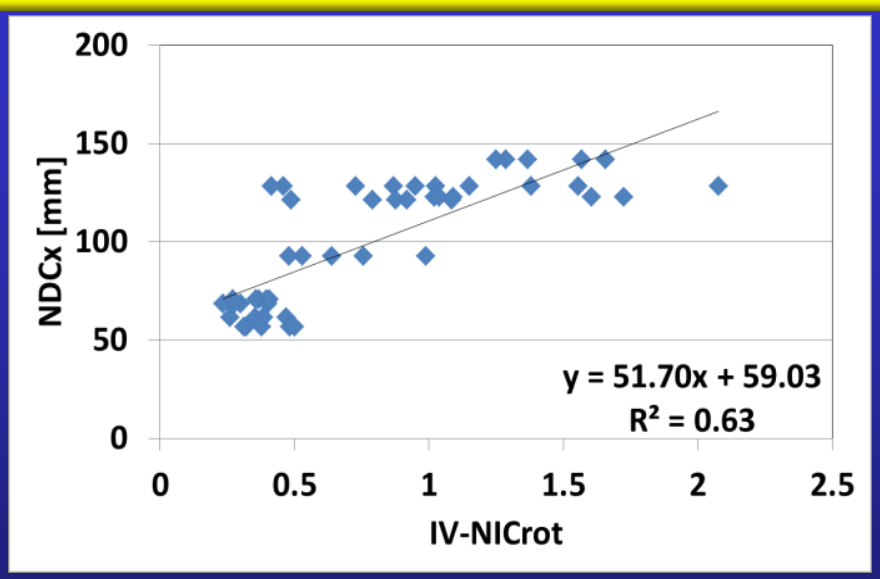
PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Experimental Seat Only

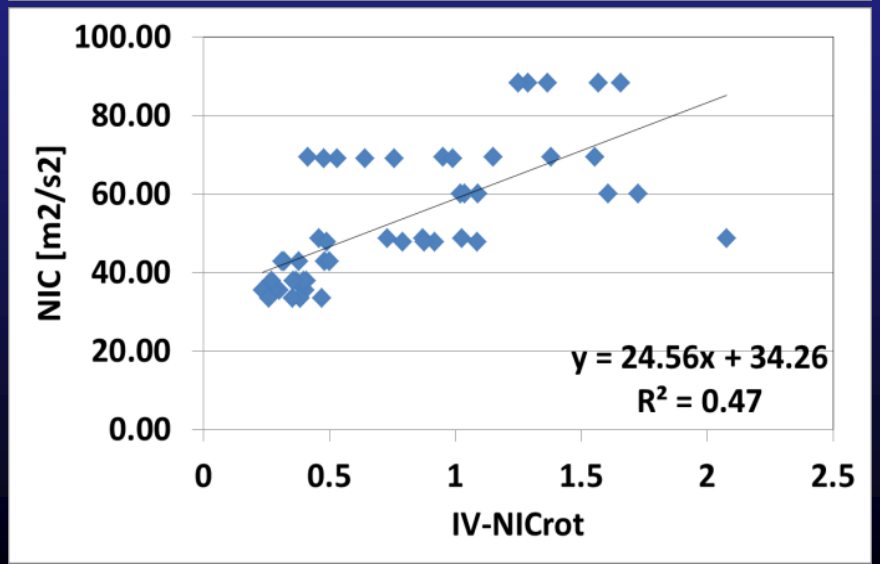
Experimental Seat

	IV-NICrot
	R^2 - value
NDCrot	0.65
NDCx	0.63
NDCz	0.07
NIC	0.47

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Experimental Seat Only







- 50 % chance of AIS 1+ injuries
  - IV-NICrot : 1.12
  - NDCrot : 46 deg (flexion)
  - NDCx: 117 mm
  - NIC: 62 m^2/s^2

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Experimental Seat Only

Experimental Seat

	IV-NICrot
	R^2 - value
NDCrot	0.65
NDCx	0.63
NDCz	0.07
NIC	0.47

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria Correlation Comparison

Experimental Seat

	IV-NICrot
	R^2 - value
NDCrot	0.65
NDCx	0.63
NDCz	0.07
NIC	0.47

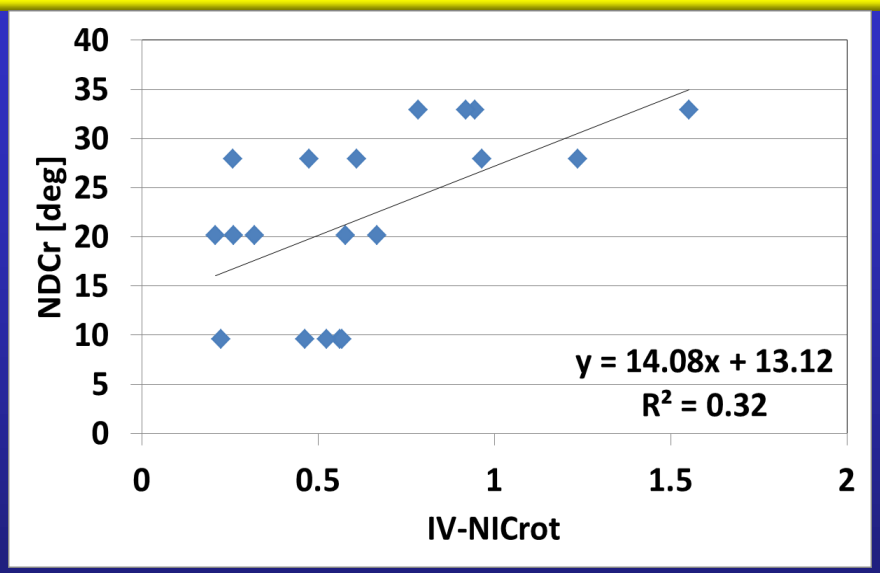
Production Seats

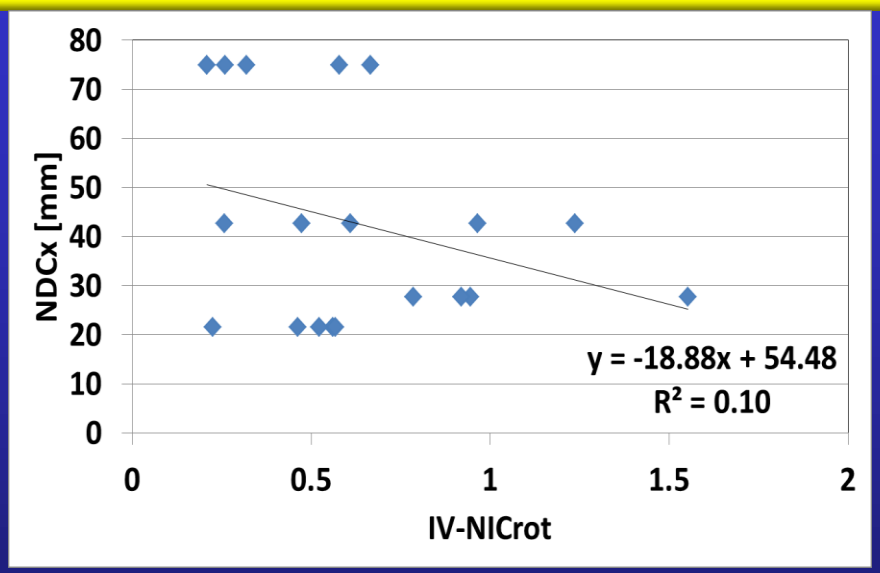
	IV-NICrot
	R^2 - value
NDCrot	0.32
NDCx	0.10
NDCz	0.02
NIC	0.03

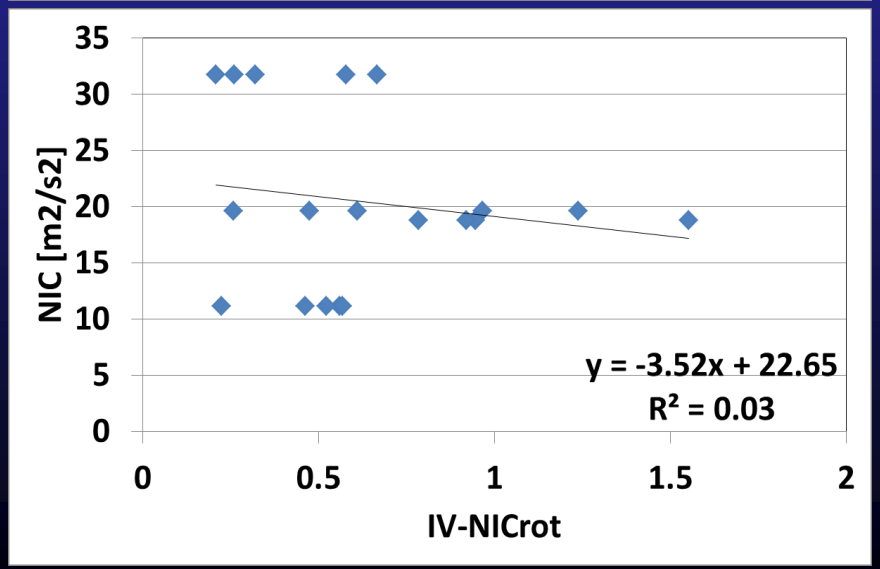
Combined Exp/Prod Seats

	IV-NICrot
	R^2 - value
NDCrot	0.46
NDCx	0.30
NDCz	0.04
NIC	0.26

Injury Analysis
IV-NIC vs. Kinematic Criteria
Production Seats only

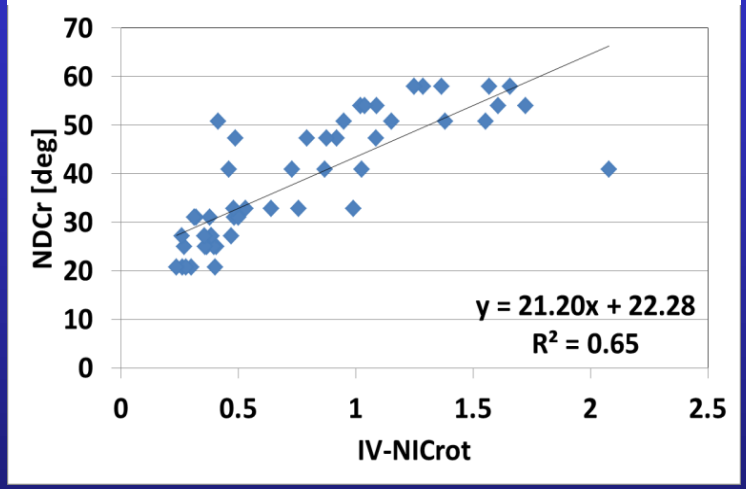




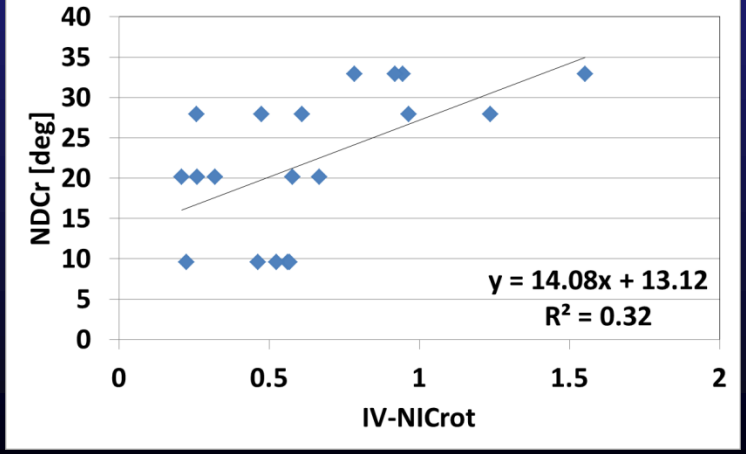


PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Correlation using all data

Experimental Seat (all data)

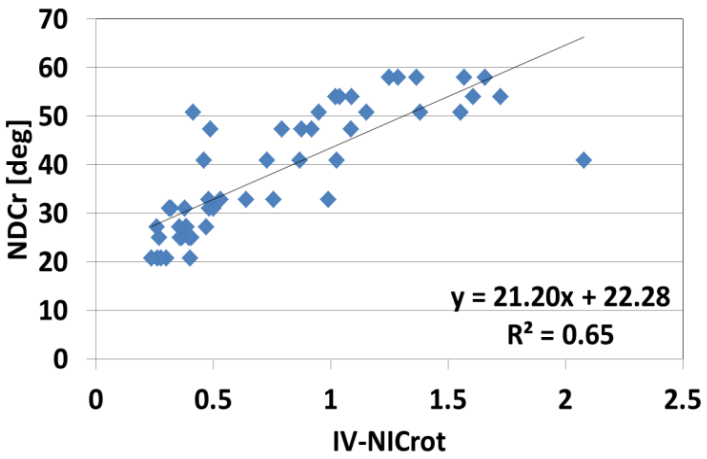


Production Seats (all data)

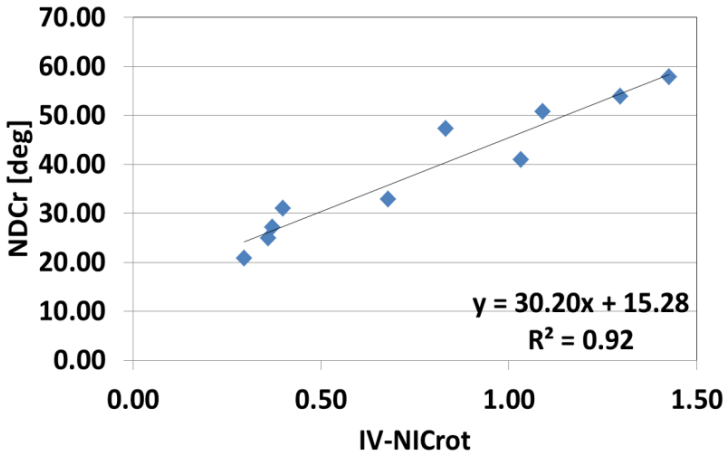


PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Correlation using mean IV-NIC

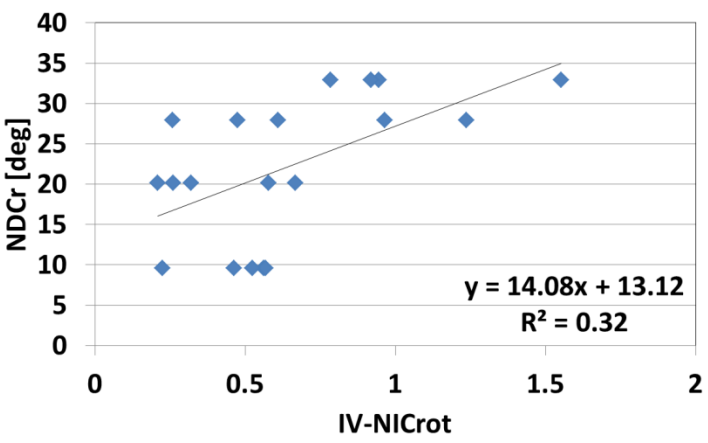
Experimental Seat (all data)



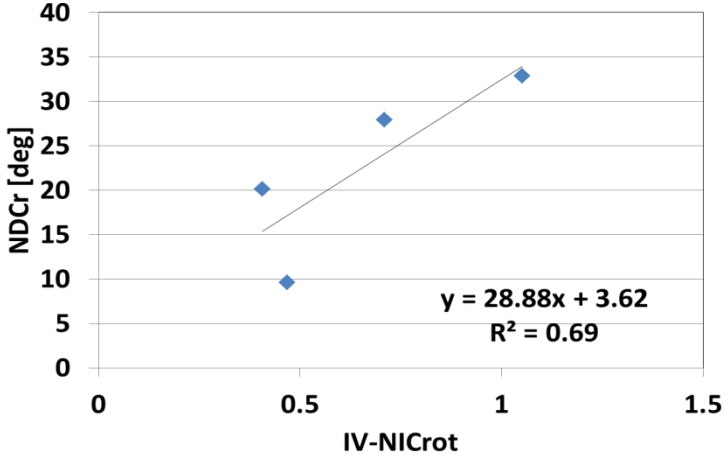
Experimental Seat (mean IV-NIC)



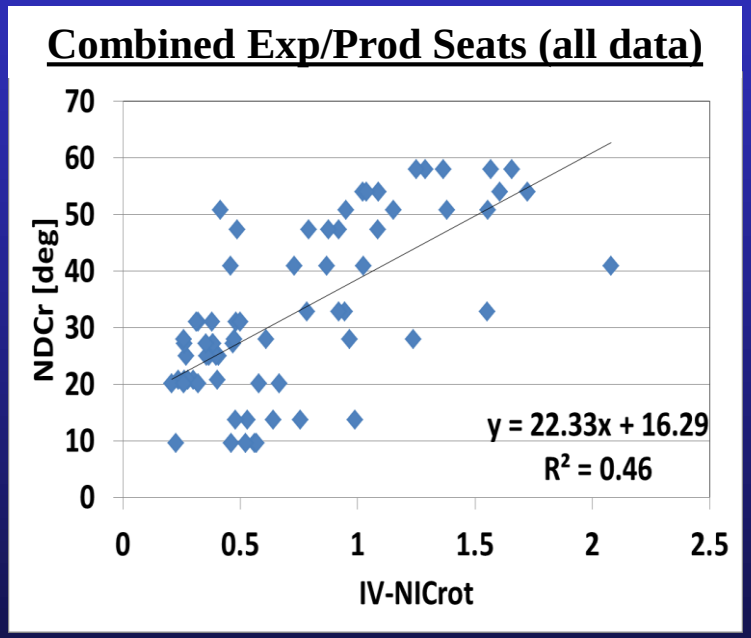
Production Seats (all data)

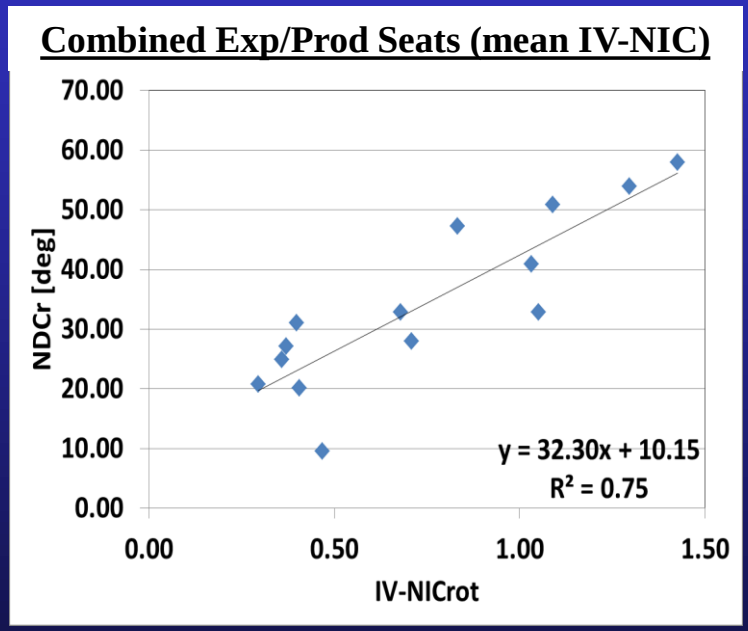


Production Seats (mean IV-NIC)



PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Correlation using mean IV-NIC





PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Correlation using all data

Experimental Seat

	IV-NICrot	
	R^2 (all data)	
NDCrot	0.65	
NDCx	0.63	
NDCz	0.07	
NIC	0.47	

Production Seats

	IV-NICrot	
	R^2 (all data)	
NDCrot	0.32	
NDCx	0.10	
NDCz	0.02	
NIC	0.03	

Combined Exp/Prod Seats

	IV-NICrot	
	R^2 (all data)	
NDCrot	0.46	
NDCx	0.30	
NDCz	0.04	
NIC	0.26	

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Correlation using mean IV-NIC

Experimental Seat

	IV-NICrot	
	R^2 (all data)	R^2 (mean)
NDCrot	0.65	0.92
NDCx	0.63	0.89
NDCz	0.07	0.10
NIC	0.47	0.67

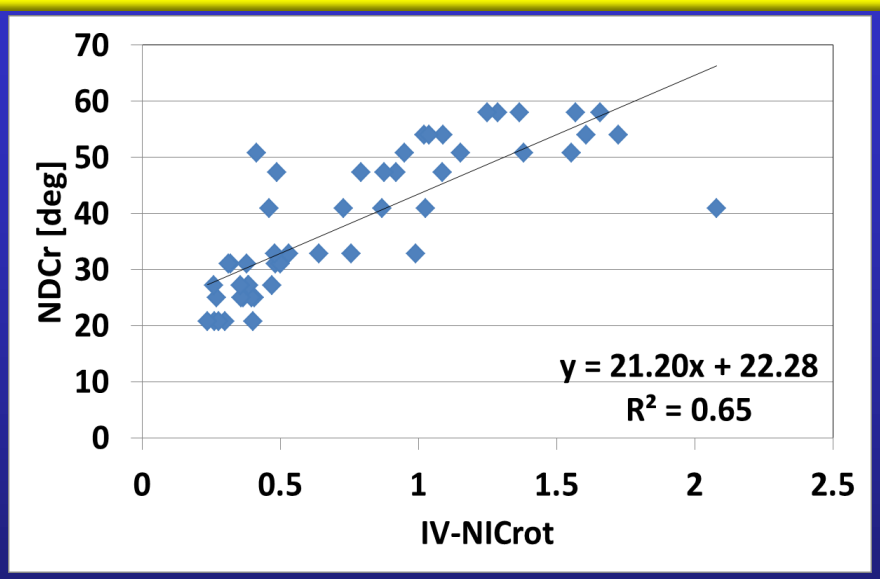
Production Seats

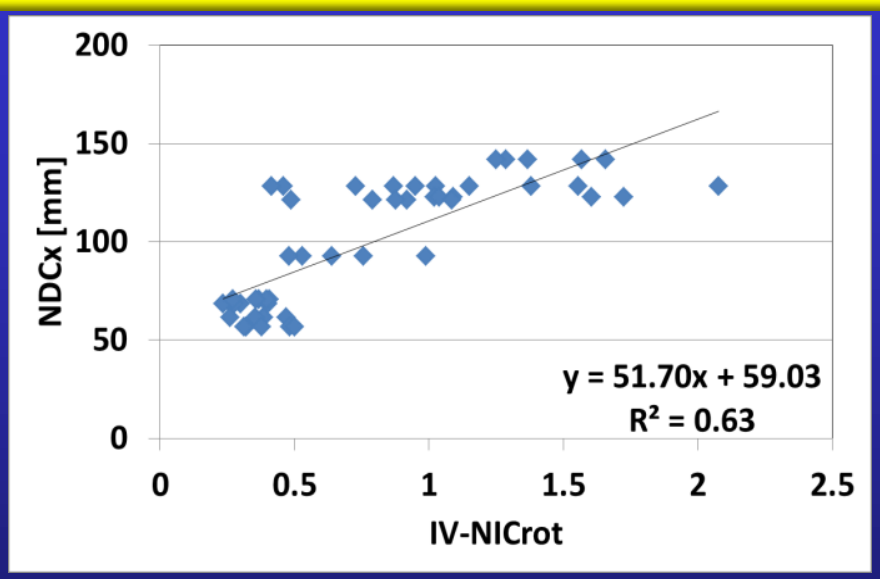
	IV-NICrot	
	R^2 (all data)	R^2 (mean)
NDCrot	0.32	0.69
NDCx	0.10	-0.23
NDCz	0.02	-0.09
NIC	0.03	-0.06

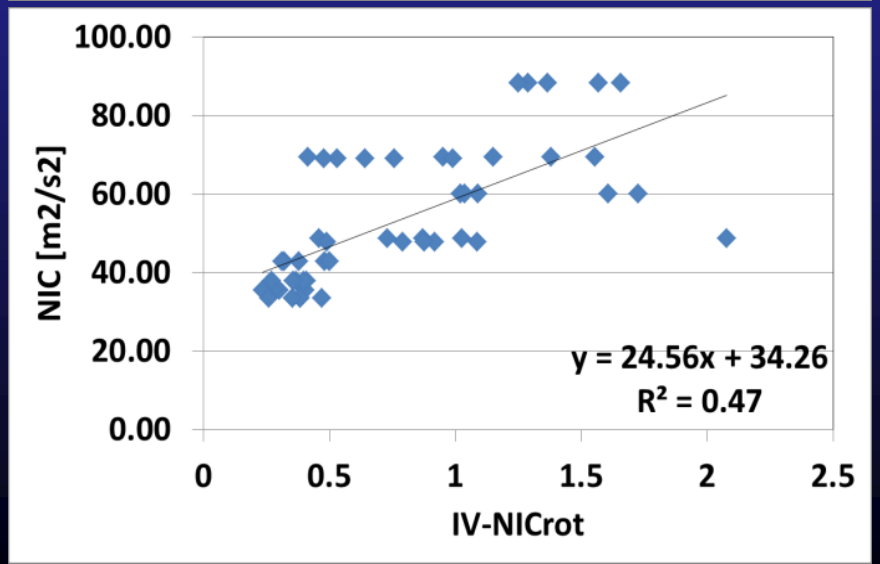
Combined Exp/Prod Seats

	IV-NICrot	
	R^2 (all data)	R^2 (mean)
NDCrot	0.46	0.75
NDCx	0.30	0.41
NDCz	0.04	0.06
NIC	0.26	0.36

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Experimental Seat Only (Correlation with all data)

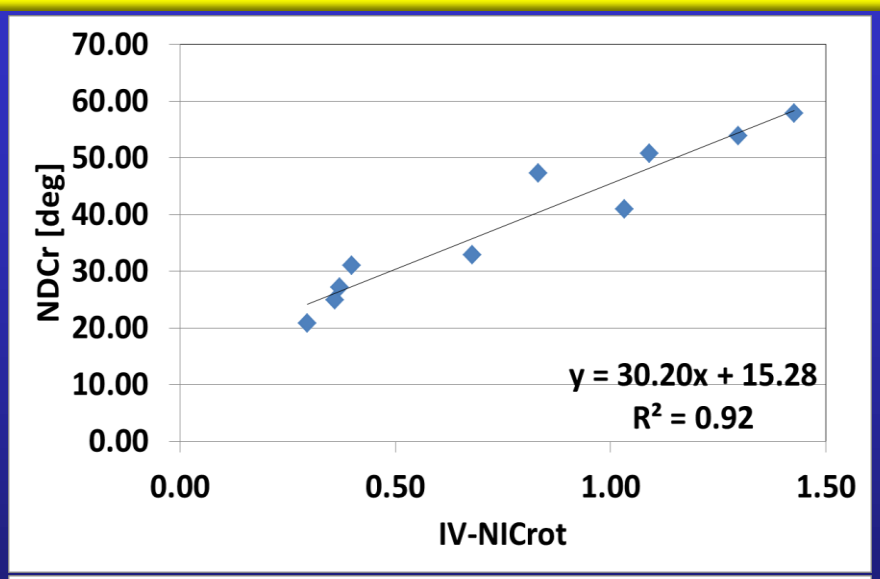


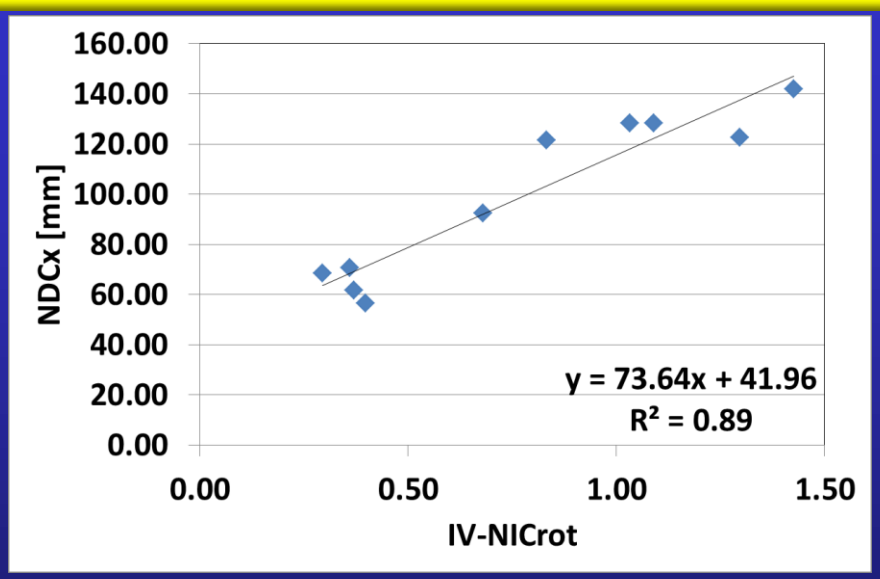


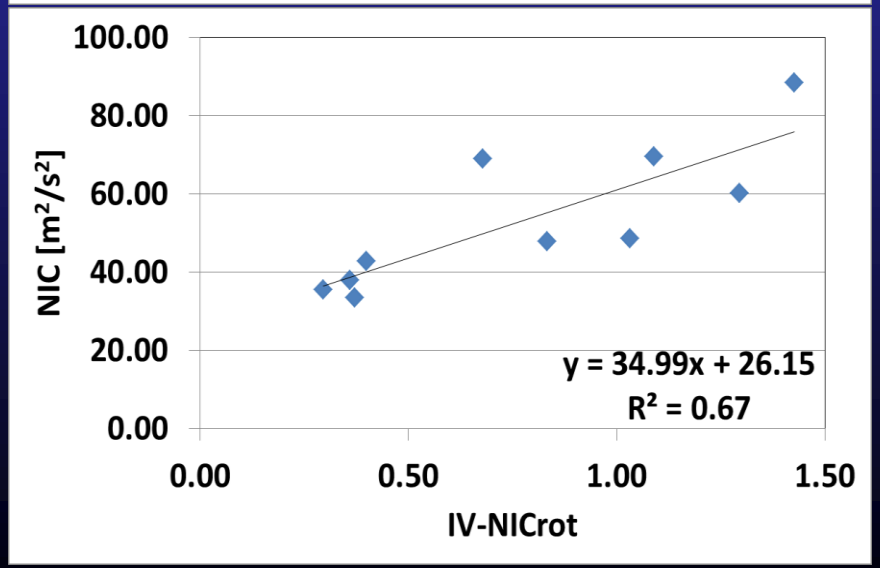


- 50 % chance of AIS 1+ injuries
  - IV-NICrot : 1.12
  - NDCrot : 46 deg (flexion)
  - NDCx: 117 mm
  - NIC: 62 m^2/s^2

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Experimental Seat Only (Correlation using mean IV-NIC)







- 50 % chance of AIS 1+ injuries
  - IV-NICrot : 1.12
  - NDCrot : 49 deg (flexion)
  - NDCx: 124 mm
  - NIC: 65 m^2/s^2

PMHS Injury Analysis
IV-NIC vs. Kinematic Criteria
Comparison - 50% Chance of AIS 1+

Experimental Seat

	IV-NICrot	
	R^2 (all data)	R^2 (mean)
NDCrot	0.65	0.92
NDCx	0.63	0.89
NDCz	0.07	0.10
NIC	0.47	0.67

Production Seats

	IV-NICrot	
	R^2 (all data)	R^2 (mean)
NDCrot	0.32	0.69
NDCx	0.10	-0.23
NDCz	0.02	-0.09
NIC	0.03	-0.06

Combined Exp/Prod Seats

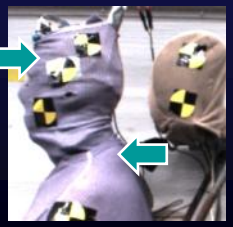
	IV-NICrot	
	R^2 (all data)	R^2 (mean)
NDCrot	0.46	0.75
NDCx	0.30	0.41
NDCz	0.04	0.06
NIC	0.26	0.36

NDCrot = 49 deg (flexion) → NDCrot = 43 deg (flexion)

PMHS Injury Analysis
IV-NICrot vs. Kinetic criteria
Experimental Seat (Entire time history)

			IV-NICrot
			R^2 - value
Upper Neck	Fx	+	0.05
		-	0.00
	Fz	+	0.47
		-	0.25
	My	+	0.69
		-	0.05
Lower Neck	Fx	+	0.04
		-	0.12
	Fz	+	0.48
		-	0.00
	My	+	0.4
		-	0.34

	IV-NICrot
	R^2 - value
Nte	0.07
Ntf	0.64
Nce	0.00
Ncf	-0.13
Nae	0.11
Naf	0.46
Npe	-0.03
Npf	-0.29
LNL	0.13

+Fx 

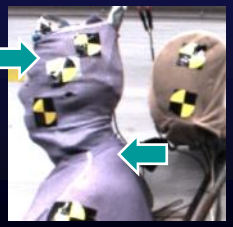
+Fz 

+My 

PMHS Injury Analysis
IV-NICrot vs. Kinetic criteria
Experimental Seat (Prior to HR contact)

			IV-NICrot
			R^2 - value
Upper Neck	Fx	+	0.81
		-	0.17
	Fz	+	0.50
		-	0.69
	My	+	0.75
		-	0.56
Lower Neck	Fx	+	0.01
		-	0.73
	Fz	+	0.64
		-	0.58
	My	+	0.61
		-	0.50

	IV-NICrot
	R^2 - value
Nte	0.72
Ntf	0.67
Nce	0.67
Ncf	0.13
Nae	0.03
Naf	0.91
Npe	0.6
Npf	-0.35
LNL	0.74

+Fx 

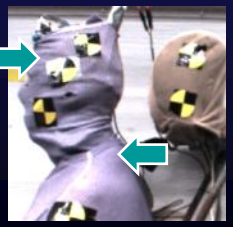
+Fz 

+My 

PMHS Injury Analysis
IV-NICrot vs. Kinetic criteria
Production Seats

			IV-NICrot
			R^2 - value
Upper Neck	Fx	+	0.71
		-	0.44
	Fz	+	0.00
		-	0.37
	My	+	0.03
		-	0.44
Lower Neck	Fx	+	0.01
		-	0.41
	Fz	+	0.02
		-	0.01
	My	+	0.56
		-	0.16

	IV-NICrot
	R^2 - value
Nte	-0.99
Ntf	0.91
Nce	0.44
Ncf	0.01
Nae	0.998
Naf	0.58
Npe	-0.58
Npf	-0.89
LNL	-0.31

+Fx 

+Fz 

+My 

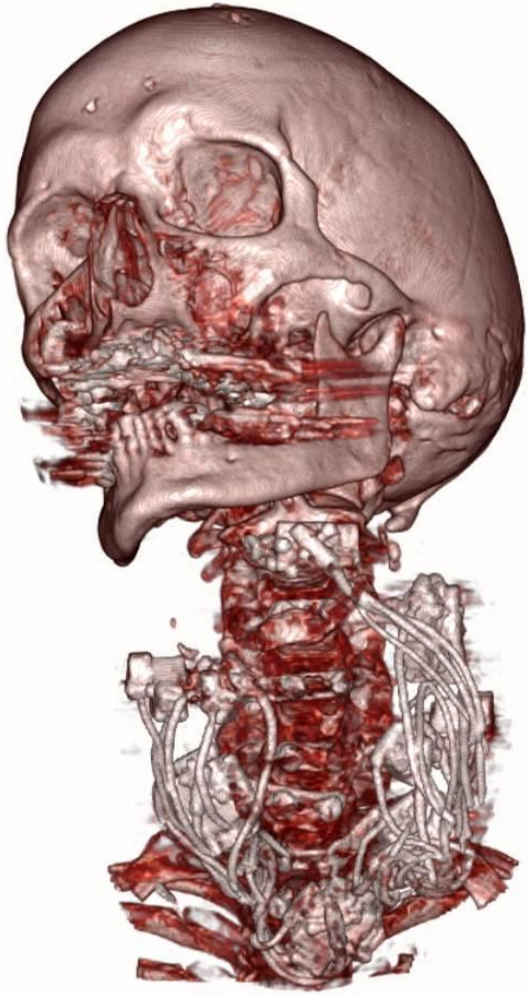
Potential BioRID Injury Criteria

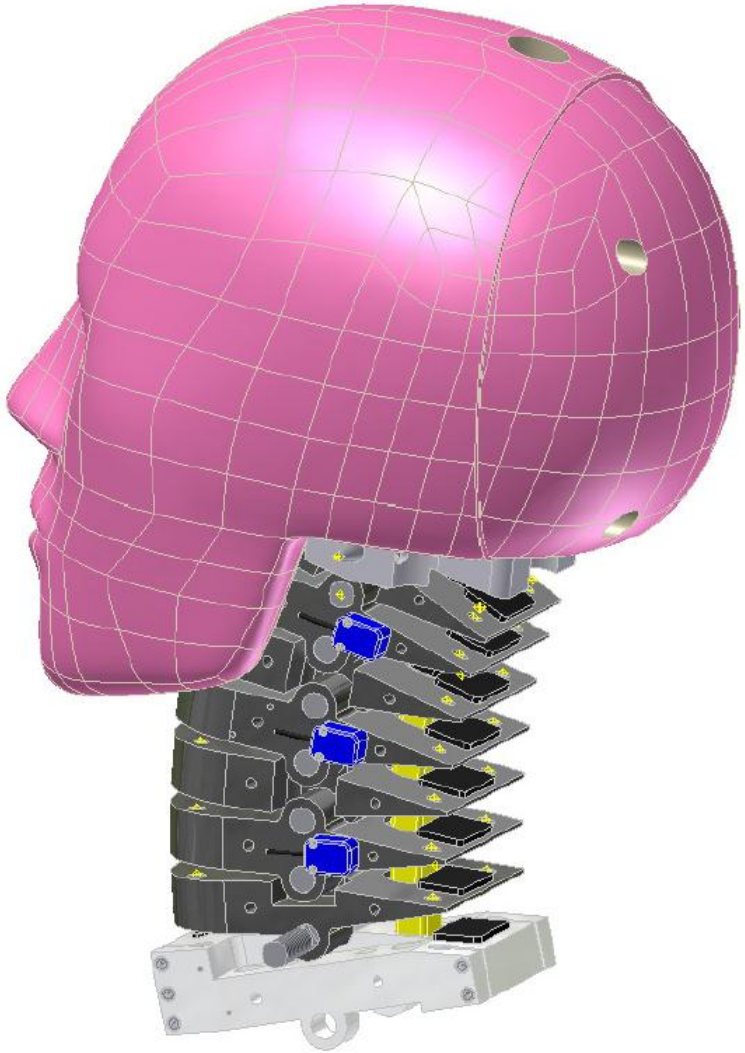
Potential BioRID Injury Criteria

Step 3

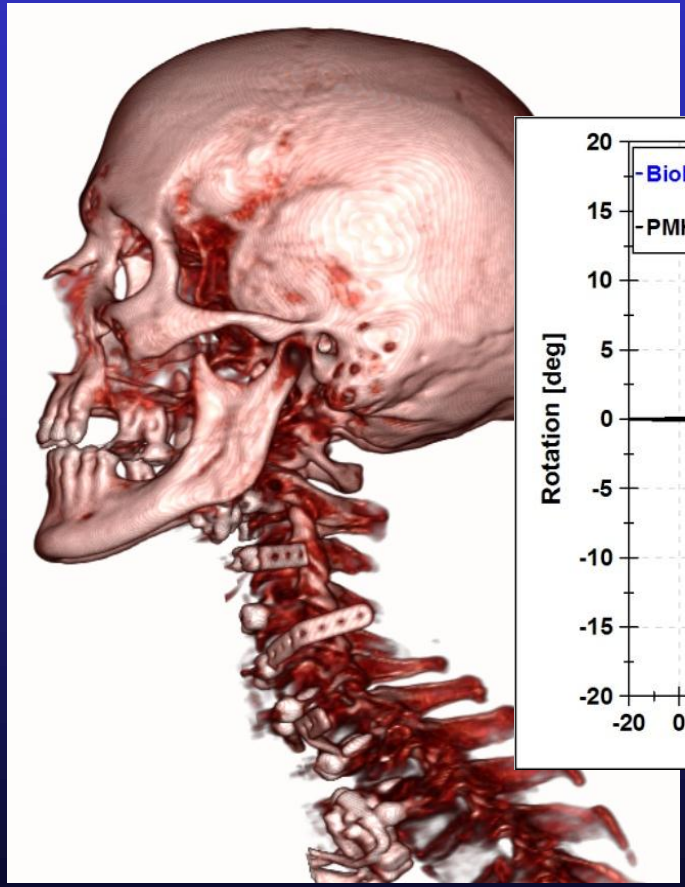
PMHS		BioRIDII
Best injury predictors	linear regression	Current/potential injury criteria
Best injury predictors	linear regression	Intervertebral kinematics
Injury risk curves	Scaled Risk curves	Injury risk curves

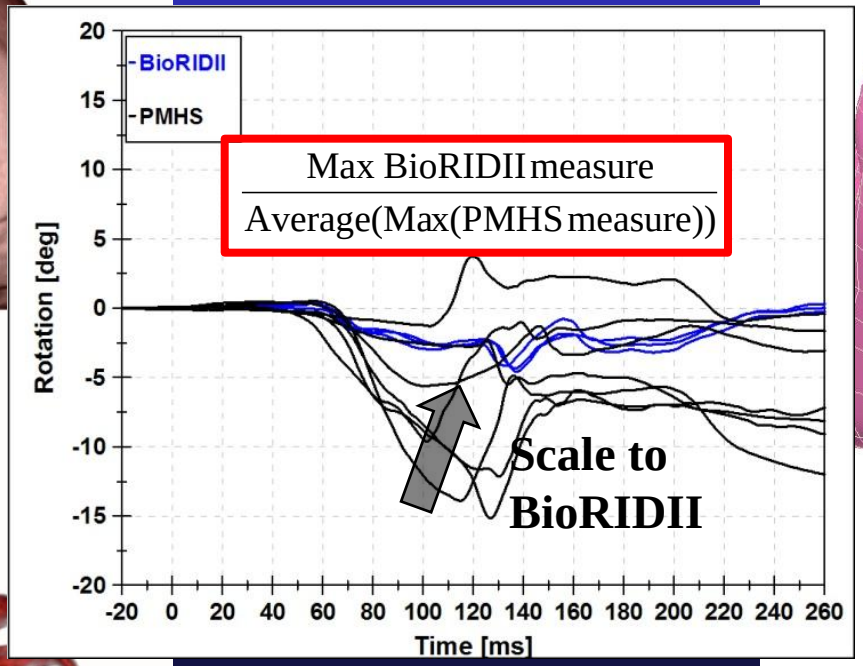
Potential BioRID Injury Criteria
Intervertebral Rotations

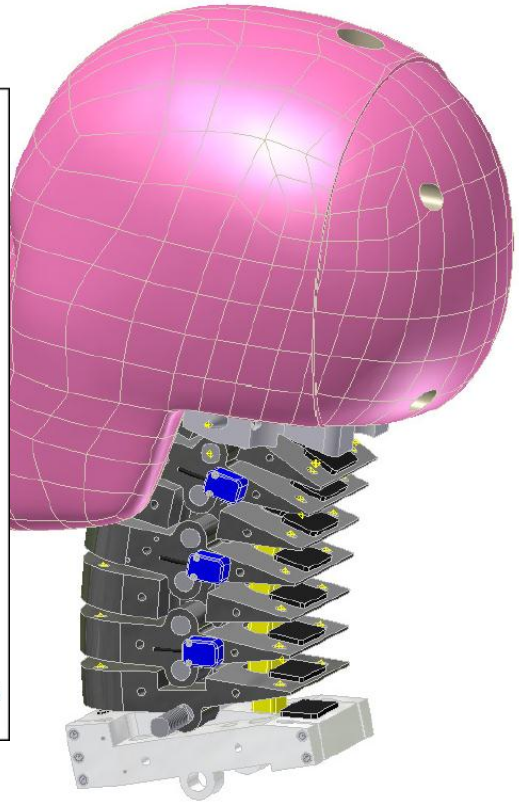




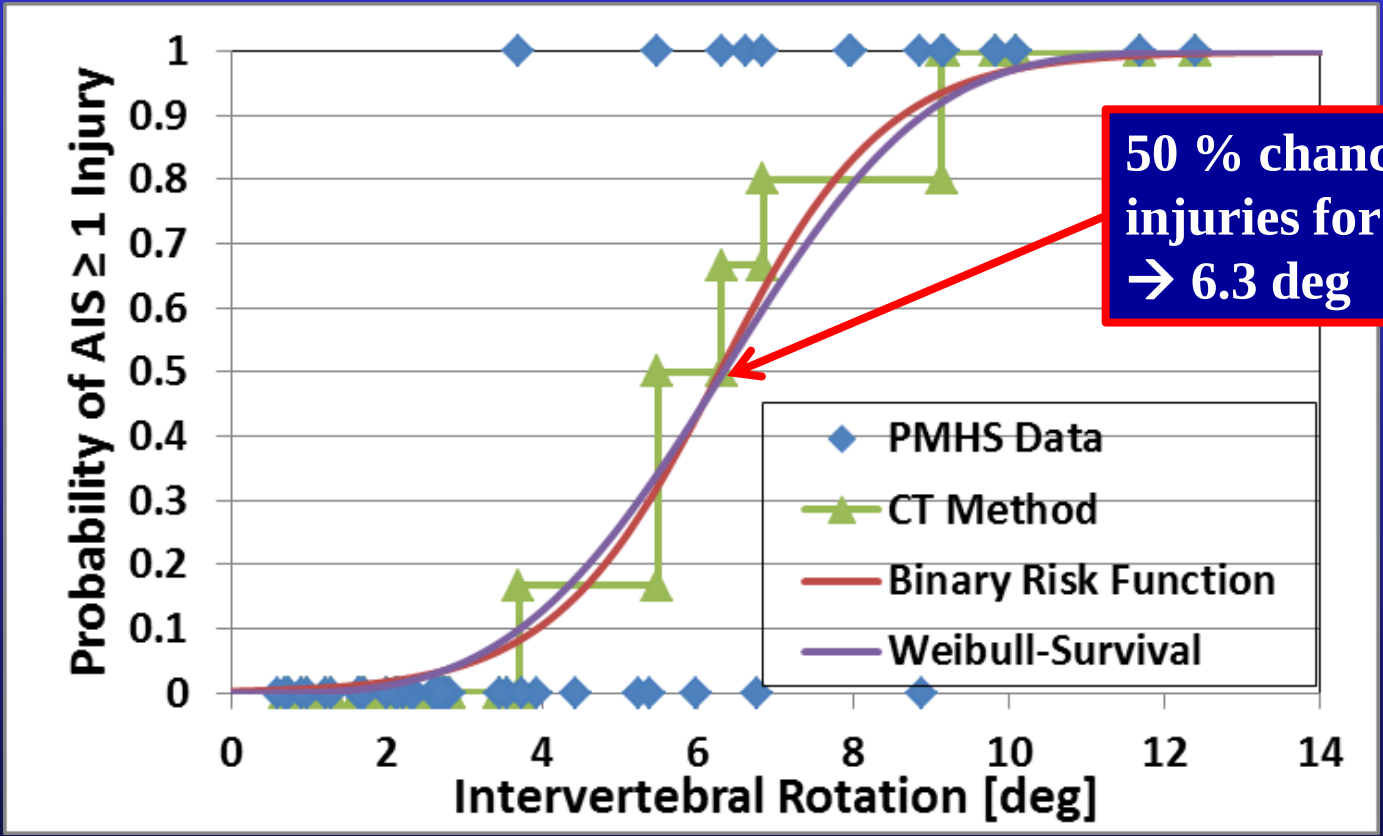
Potential BioRID Injury Criteria







Potential BioRID Injury Criteria
Intervertebral Rotations
Experimental Seat

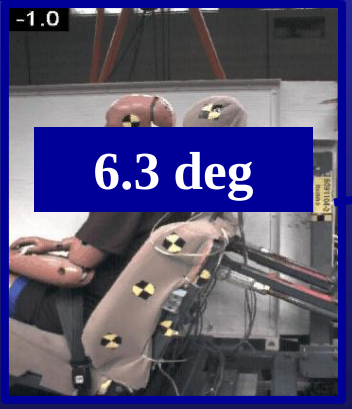


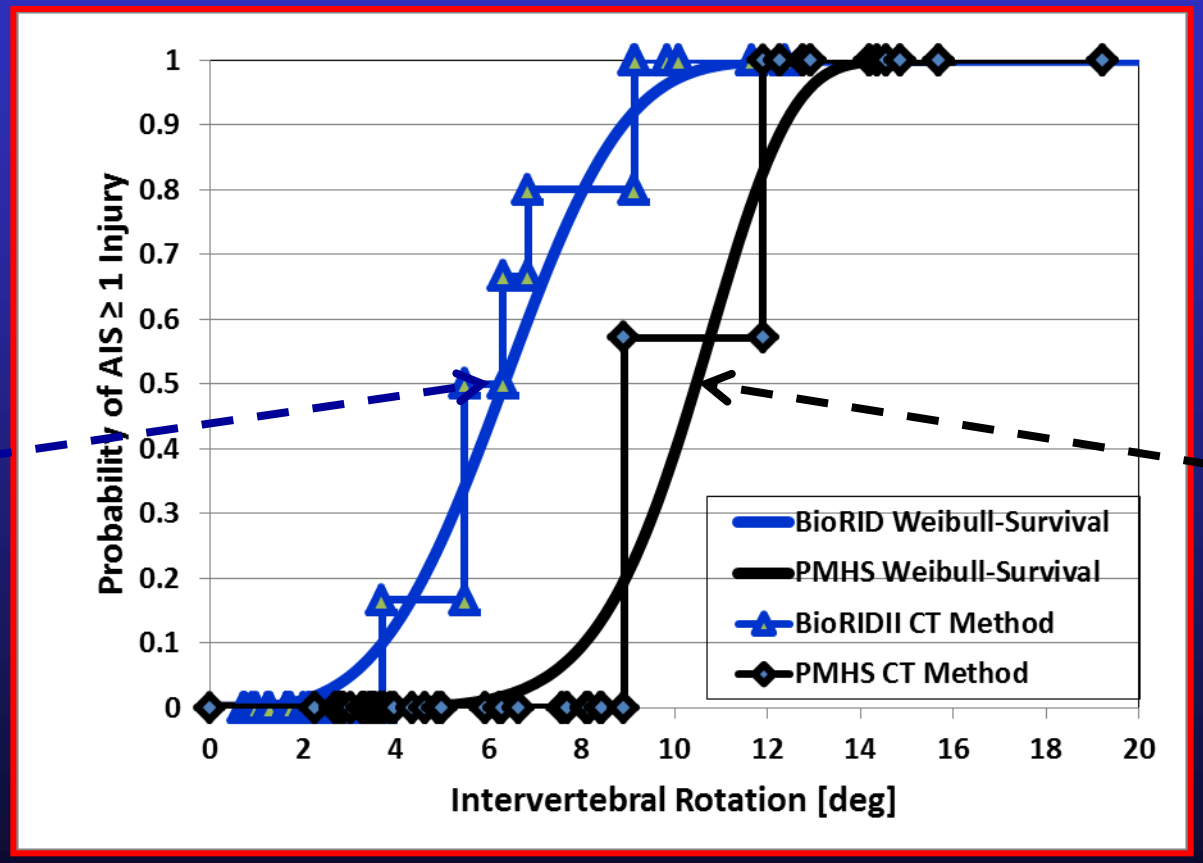
Intervertebral kinematics		Pseudo R^2	Nagelkerke R^2	Log-Likelihood	P-value	Goodman-Kruskal Gamma
Intervertebral rotation	Max	0.61	0.74	-11.687	0.000	0.93

Potential BioRID Injury Criteria
Intervertebral Rotations
Experimental Seat

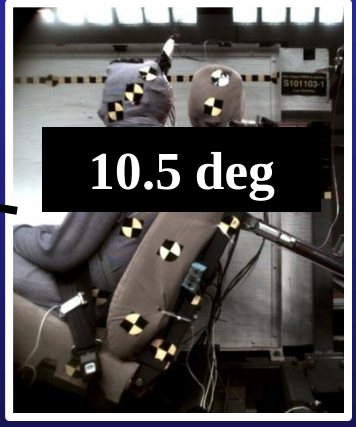
BioRIDII/PMHS Injury Risk Curve for Intervertebral Rotation

BioRIDII





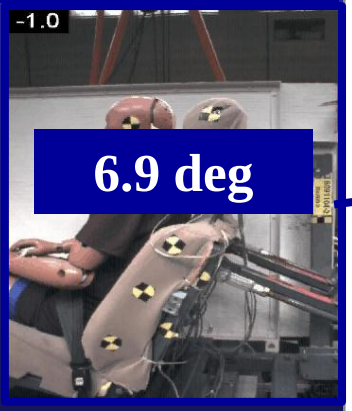
PMHS

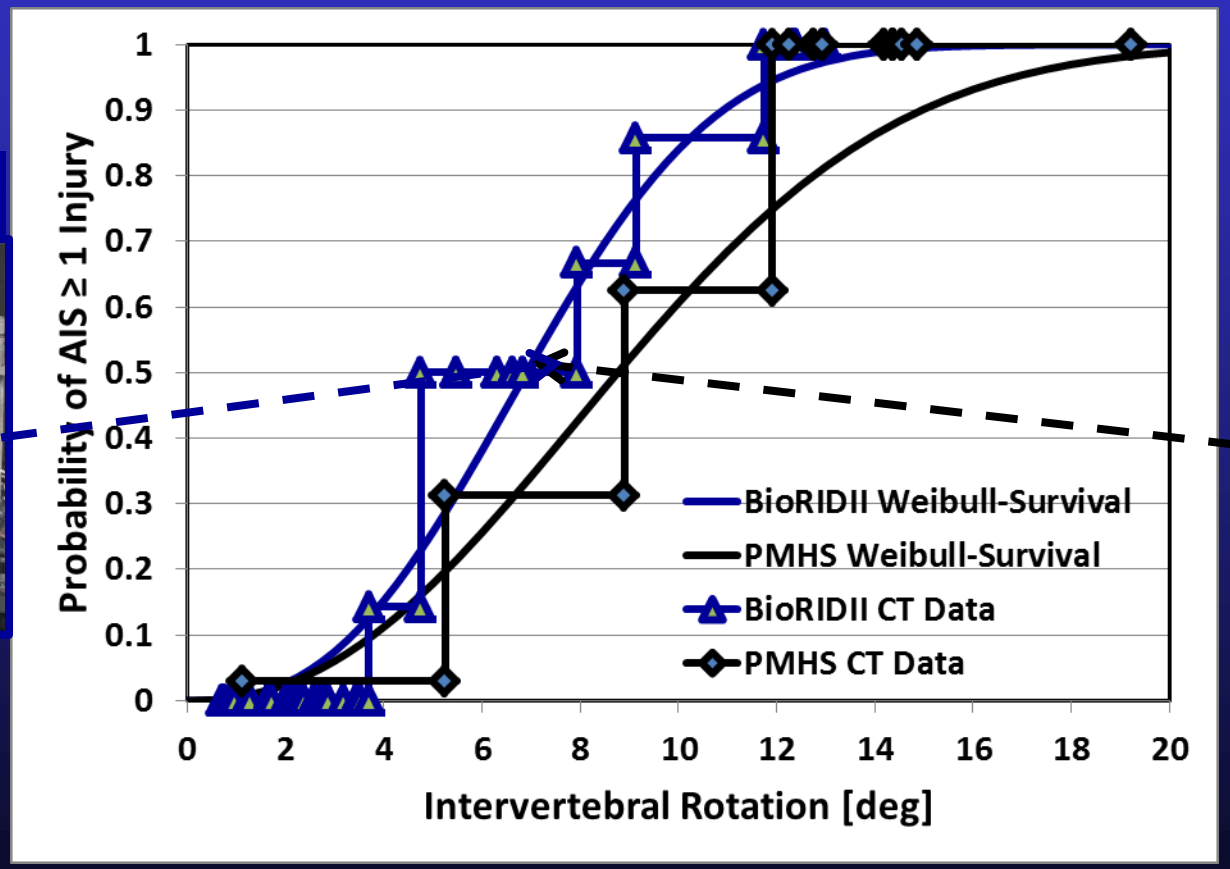


Potential BioRID Injury Criteria
Global Measures
Combined Exp/Prod Seats

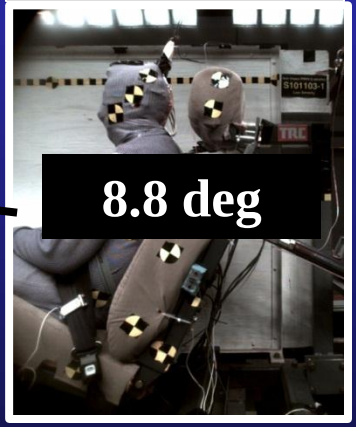
BioRIDII/PMHS Injury Risk Curve for Intervertebral Rotation

BioRIDII



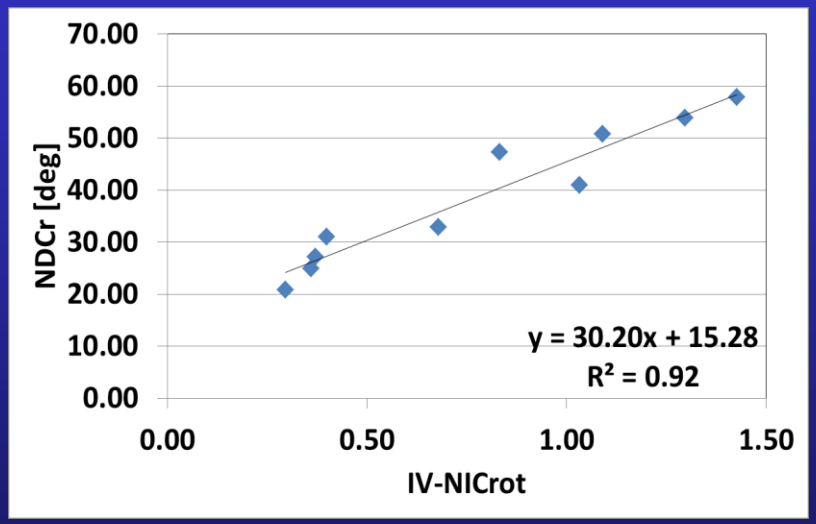


PMHS



Potential BioRID Injury Criteria
Global Measures
Experimental Seat

PMHS Regression model



50 % chance of AIS 1+ injuries for PMHS

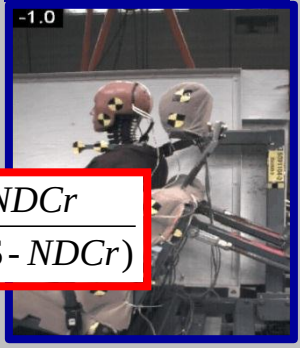
NDCrot = 49 deg (flexion)

50 % chance of AIS 1+ injuries for BioRIDII

NDCrot : 13 deg (flexion)

PMHS

BioRIDII

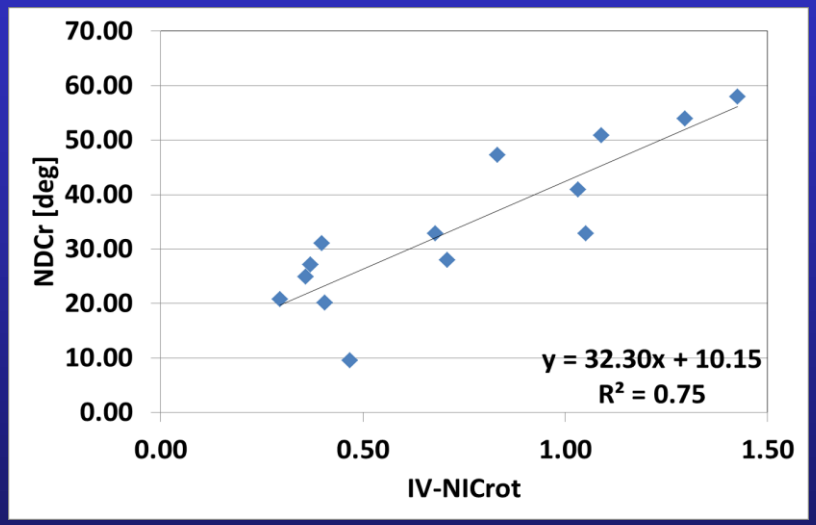


Scaling

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

Potential BioRID Injury Criteria
Global Measures
Combined Exp/Prod Seats

PMHS Regression model



50 % chance of AIS 1+ injuries for PMHS

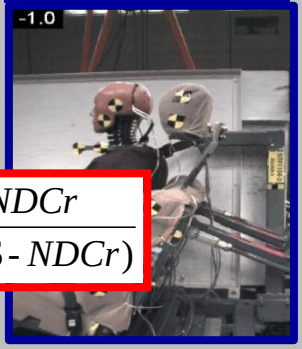
NDCrot = 43 deg (flexion)

50 % chance of AIS 1+ injuries for BioRIDII

NDCrot : 13 deg (flexion)

PMHS

BioRIDII



Scaling

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

Summary

- **Best PMHS injury predictor**
  - IV-NICrot
    - 50% chance of AIS 1+ injury = 1.12

Summary

- **Best PMHS injury predictor**
  - IV-NICrot
    - 50% chance of AIS 1+ injury = ~~1.12~~ → 1.03

Summary

- **Best PMHS injury predictor**
  - IV-NICrot
    - 50% chance of AIS 1+ injury = ~~1.12~~ → 1.03
- **Most promising BioRID injury criteria**
  - IV Rotation, NDCrot
    - 50% chance of AIS 1+ injury:
      - IV Rotation = 10.5 deg PMHS, 6.3 deg BioRID
      - NDCrot = 49 deg flexion PMHS, 13 deg flexion BioRID

Summary

- **Best PMHS injury predictor**
  - IV-NICrot
    - 50% chance of AIS 1+ injury = ~~1.12~~ → 1.03
- **Most promising BioRID injury criteria**
  - IV Rotation, NDCrot
    - 50% chance of AIS 1+ injury:
      - ~~IV Rotation = 10.5 deg PMHS, 6.3 deg BioRID~~

        IV Rotation = 8.8 deg PMHS, 6.9 deg BioRID
      - ~~NDCrot = 49 deg flexion PMHS, 13 deg flexion BioRID~~

        NDCrot = 43 deg flexion PMHS, 13 deg flexion BioRID

Next 4 tests

- **Strengthen production seat IRCs with more data**
  - Determine if NIC and NDCx should be considered
  - Better correlation for kinetic measures
- **Conduct two repeat tests with no rebound allowed**
  - Resolve possible censoring issue due to large rebound
  - Are injuries and measurements consistent?
- **Conduct two more tests at bookend severities**

USA & Japan Collaboration

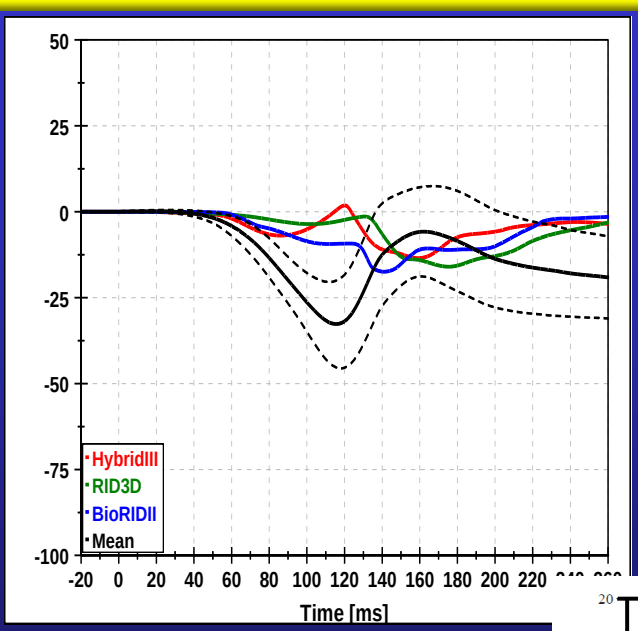
- **Best injury predictor**
  - USA → IV-NICrot
  - Japan → Strain & Strain Rate
- **Common ground:**
  - Found good correlation between the two

USA & Japan Collaboration

- **Potential "global" injury criteria**
  - USA: IV-NICrot → NDCrot, NDCx, NIC
  - Japan: IV-NICrot → NIC, UNFx, UNMy, LNFx, LNMy
- **Common ground:**
  - NIC
  - USA: UNFx, UNMy, LNFx, LNMy, Nkm
    - Mild correlations
    - Inverse Dynamics still an issue after HR contact
      - Use direct correlation of BioRID measures??
  - Japan: NDCrot? NDCx?

Questions??

Questions??



1) Countermeasure for flexion in rear impact??

2) Biofidelity and R&R of flexion bumpers?