NHTSA
www.nhtsa.gov

Correlation study -
BioRID Injury Criteria Measures to PMHS Injury

GTR7 Update July 2015

Kevin Moorhouse, Ph.D. – NHTSA/VRTC

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

Jim Stricklin, Transportation Research Center, Inc

Outline

- Review previous BioRID injury criteria correlation results/issues
  - Design and intent of sled test matrix to address issues

- BioRID R&R in production seat sled tests

- New correlation of BioRID injury criteria measures to PMHS injury

- Conclusions / Future options

NHTSA
www.nhtsa.gov

Outline

- Review previous BioRID injury criteria correlation results/issues
  - Design and intent of sled test matrix to address issues

- BioRID R&R in production seat sled tests

- New correlation of BioRID injury criteria measures to PMHS injury

- Conclusions / Future options

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov

Review of Previous Results
PMHS IV-NIC Injury Risk Curve
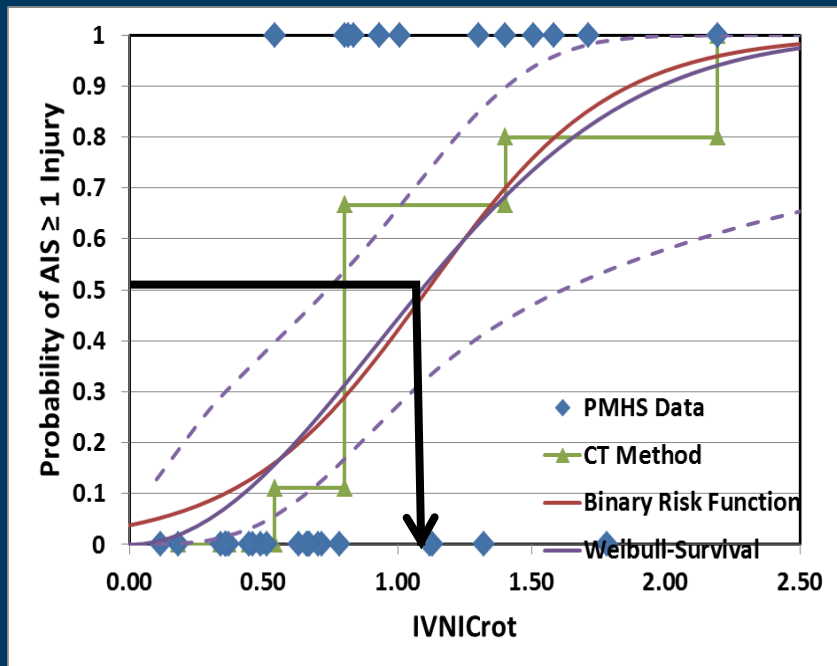
IV-NIC = 1.1
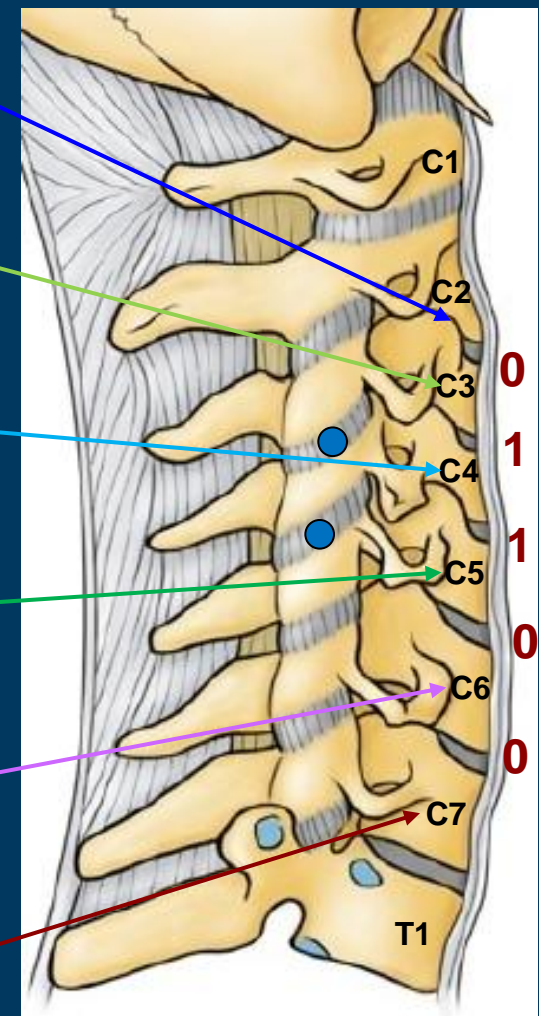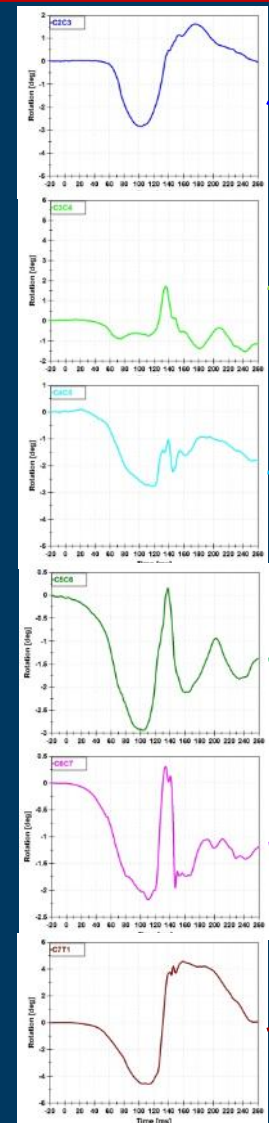
Normalized Intervertebral Rotation	Log-Likelihood P-value	Goodman-Kruskal Gamma	AUROC
IV-NIC	0.001	0.71	0.86

Safer drivers. Safer cars. Safer roads.

Review of Previous Results

Correlation of PMHS Injury Criteria Measures to IV-NIC

Left chart: NDCr [deg] vs IV-NICrot, $y = 23.99x + 6.08$, $R^2 = 0.75$

Right chart: NIC [m²/s²] vs IV-NICrot, $y = 29.56x + 7.33$, $R^2 = 0.45$

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov
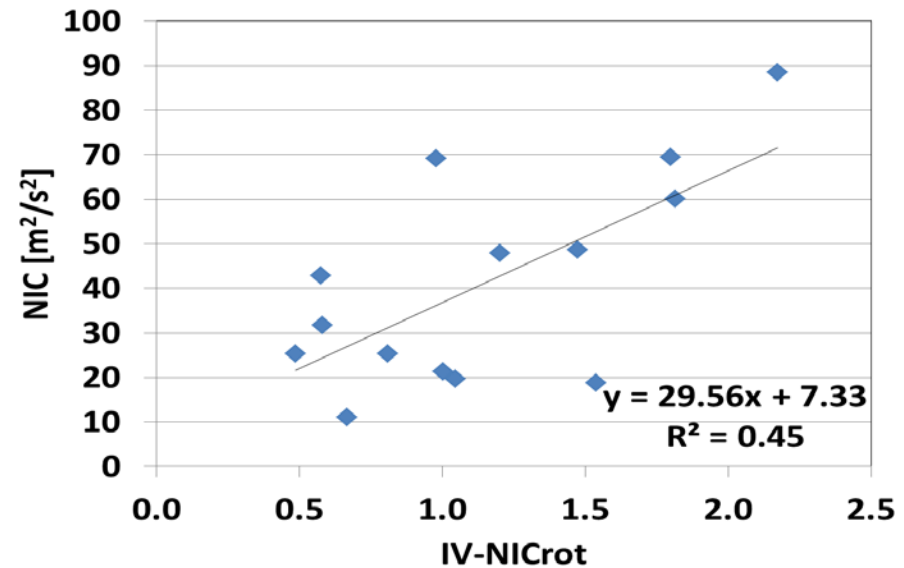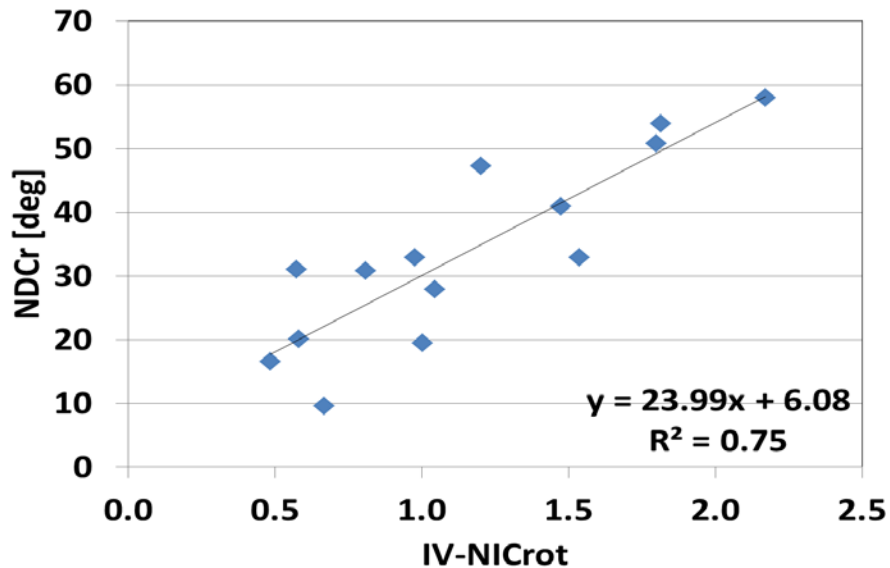
Review of Previous Results
Correlation of PMHS Injury Criteria Measures to IV-NIC
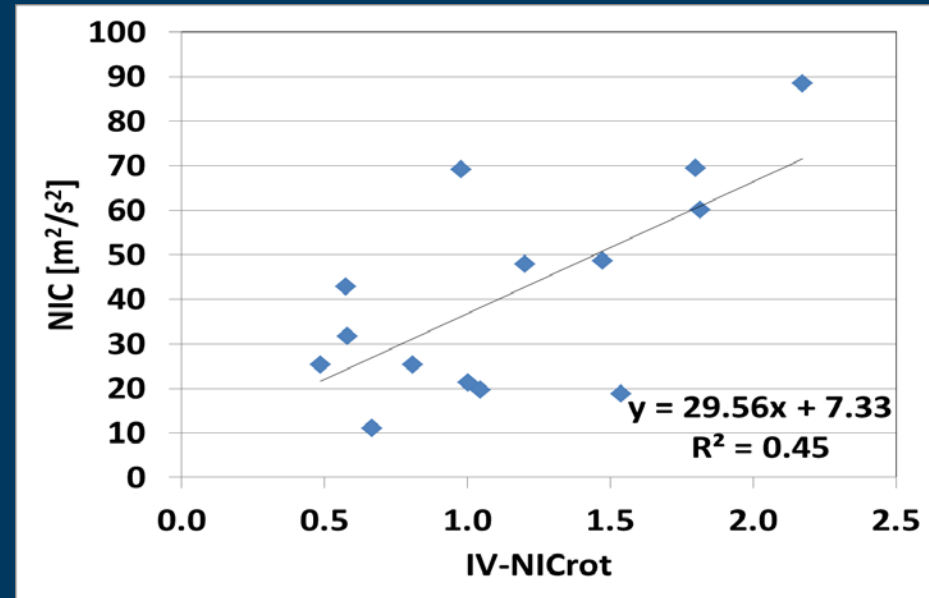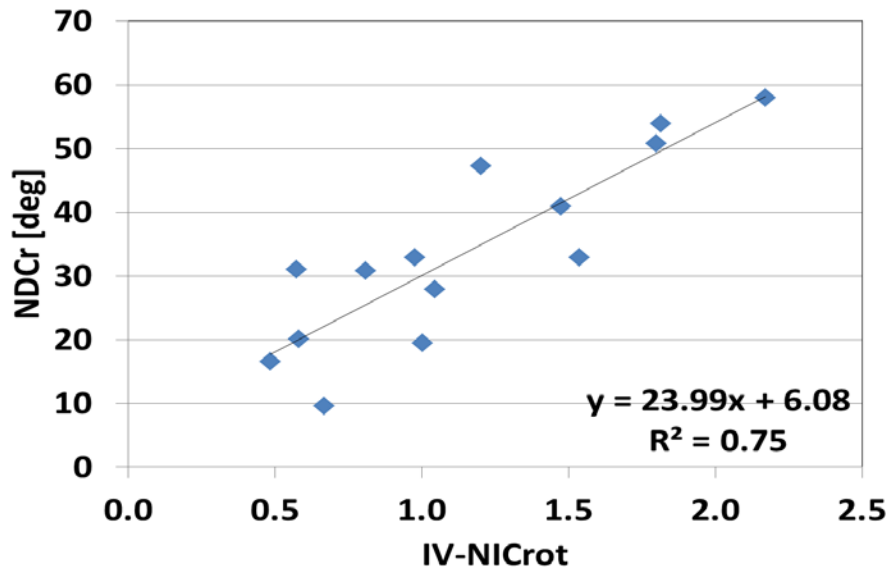
– Make similar correlations using BioRID measures...

Review of Previous Results

Convert PMHS injury measures to BioRID

May 2013 test series

- Initial paired tests using BioRID 8599 (side-by-side with PMHS)
  - No luck with direct correlations

  - Applied scaling technique between PMHS and BioRID for kinematics
    - Could not use scaling for neck loads (issues with PMHS inverse dynamics)
    - Direct correlation is preferred over scaling if possible

  - Concern that BioRID used in testing wasn't latest design level
    - Single BioRID dummy used in all tests over 8 month span

  - Sent BioRID 8599 and 0073 to HIS for calibration/upgrade

NHTSA
www.nhtsa.gov

Review of Previous Results

Convert PMHS injury measures to BioRID

March 2014 test series

- Dummies upgraded to latest build level received

- Conducted sled tests with BioRIDs 8599 and 0073
  - Test Matrix:
    - Two initial tests to evaluate R&R
    - Re-conduct PMHS replicate tests
    - Increased backset tests
    - Small-scale fleet analysis for injury criteria efficacy and seat discrimination
  - Initial two tests showed questionable R&R
  - Dummies sent back to Humanetics for revision and Gen-X testing

Review of Previous Results

Convert PMHS injury measures to BioRID

January 2015 test series

- Dummies deemed to have sufficient R&R in Gen-X tests

- Conducted sled tests with BioRIDs 8599, 0073, 0100
  - Test Matrix:
    - Four initial tests to evaluate R&R
    - Re-conduct PMHS replicate tests
    - Increased backset tests
    - Small-scale fleet analysis for injury criteria efficacy and seat discrimination
  - R&R from first four tests still questionable (but not quantifiable)
  - Poor injury criteria correlations

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov

Review of Previous Results

Correlation of BioRID Injury Criteria Measures to IV-NIC

Poor (and negative) correlation for BioRID

NHTSA
www.nhtsa.gov
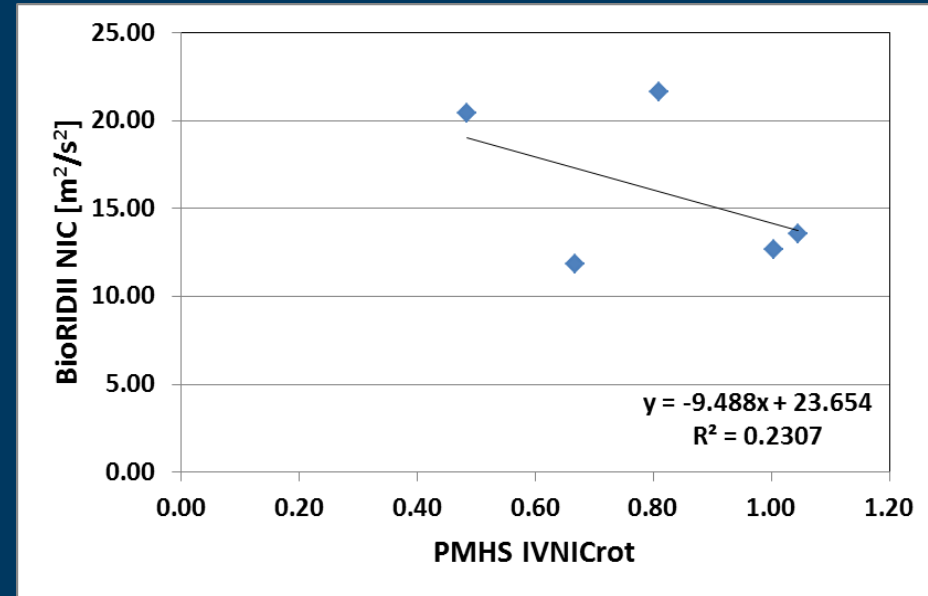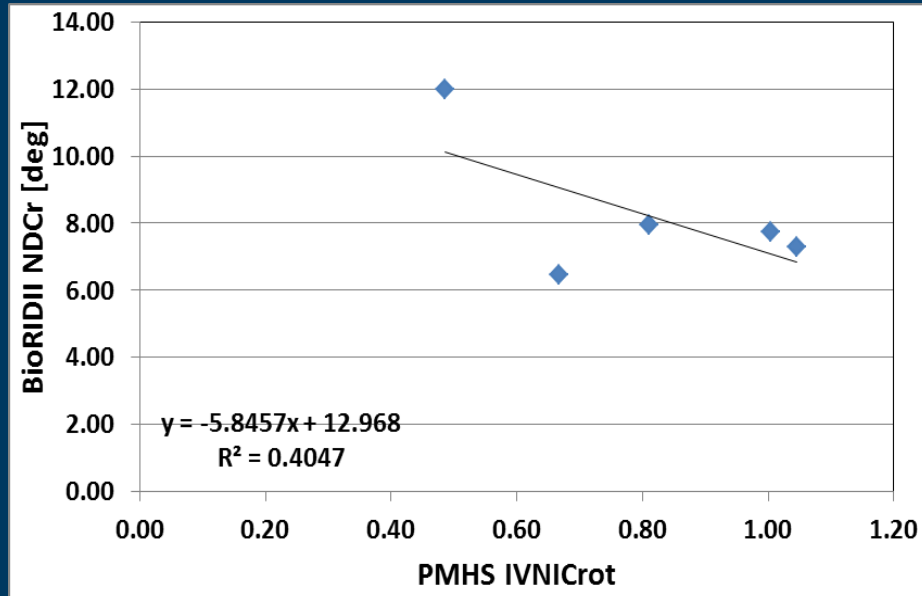
Review of Previous Results
Correlation of BioRID Injury Criteria Measures to IV-NIC

Poor (and negative) correlation for BioRID
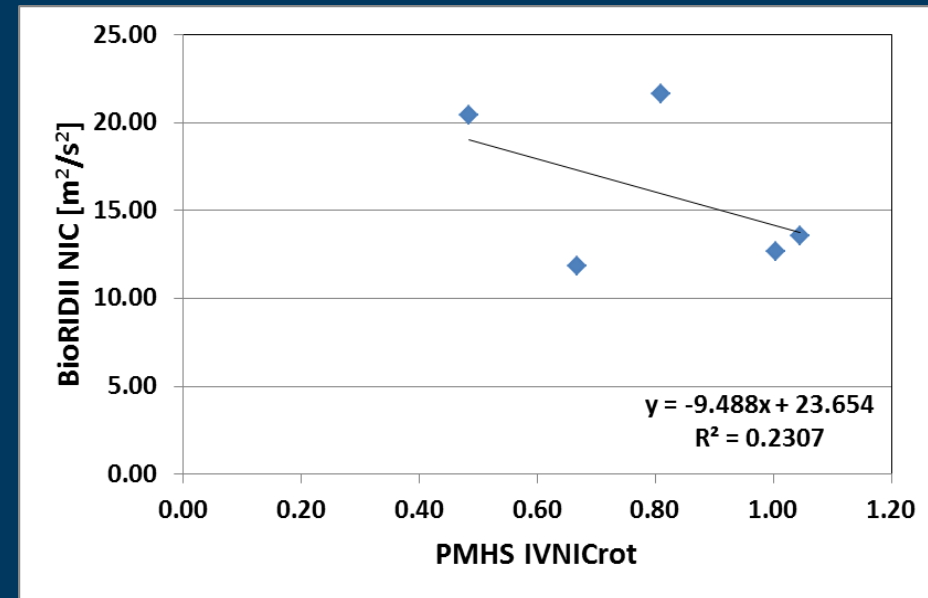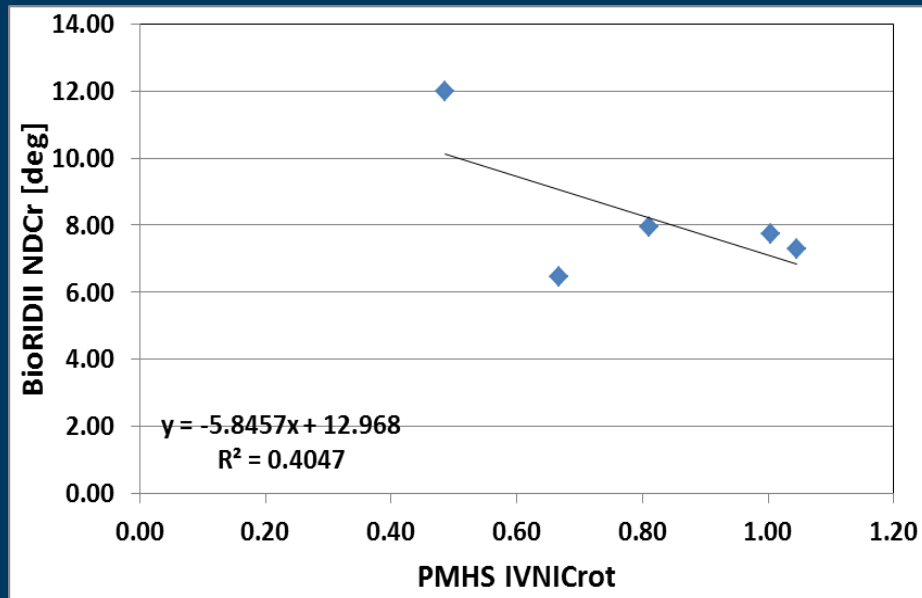
- Poor biofidelity?
- Limited Data?
- Variation due to single data point for each test condition?

NHTSA
www.nhtsa.gov

Review of Previous Results

Correlation of BioRID Injury Criteria Measures to IV-NIC

Potential Sources of Poor Correlation

- Poor biofidelity in BioRID?
  - Been shown to have adequate biofidelity and better than other RIDs
  - Can't improve without design change

- Limited Data?
  - Only 5 data points for correlation
  - Can't improve without additional PMHS tests

- Variation due to single data point for each test condition
  - Subject-to-subject variation in PMHS response on x-axis
    - Different subject used in each test condition
    - Can't improve without more PMHS tests
    - Didn't have problem using correlation of PMHS measures

Correlation of BioRID Injury Criteria Measures to IV-NIC

Potential Sources of Poor Correlation

- Poor biofidelity in BioRID?
  - Been shown to have adequate biofidelity and better than other RIDs
  - Can't improve without design change

- Limited Data?
  - Only 5 data points
  - Can't improve without more PMHS tests

- Variation due to different test points in each test condition
  - Subject-to-subject variation in PMHS results on x-axis
    - Different subject used in each test condition
    - Can't improve without more PMHS tests
    - Didn't have problem using correlation of PMHS measures

NHTSA
www.nhtsa.gov

Potential Sources of Poor Correlation

– Variation due to single data point for each test condition
- Variation in BioRID response on y-axis
  - BioRID R&R and/or sensitivity to initial positioning

- Test variation due to seats (cushions, HR, etc)

NHTSA
www.nhtsa.gov

Correlation of BioRID Injury Criteria Measures to IV-NIC

<u>Potential Sources of Poor Correlation</u>

- Variation due to single data point for each test condition
  - Variation in BioRID response on y-axis
    - BioRID R&R and/or sensitivity to initial positioning

  - Test variation due to seats (cushions, HR, etc)

- Conduct repeat tests to average out variation

Review of Previous Results
Convert PMHS injury measures to BioRID
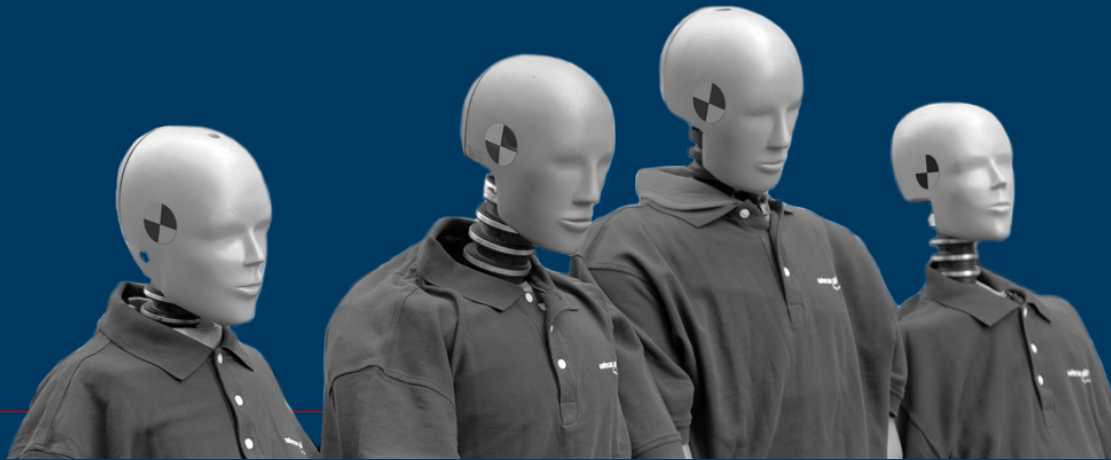
May 2015 test series

- Dummies sent to Humanetics for Gen-X tests to ensure they still perform similarly

- Conducted sled tests with BioRIDs 8599, 0073, and 0100
  - Test Matrix:
    - Re-conduct all 5 PMHS replicate tests 3 more times
    - 0073 in every test for 4-point repeatability
    - All three BioRIDs exposed at least once in each condition for reproducibility
    - Multiple OSCAR measurements to assess repeatability of seat H-point
    - Tight tolerances on final seating position

  - Average BioRID responses to reduce y-axis variation in correlation

NHTSA
www.nhtsa.gov

Outline

- Review previous BioRID injury criteria correlation results/issues
  - Design and intent of sled test matrix to address issues

- | BioRID R&R in production seat sled tests |

- New correlation of BioRID injury criteria measures to PMHS injury
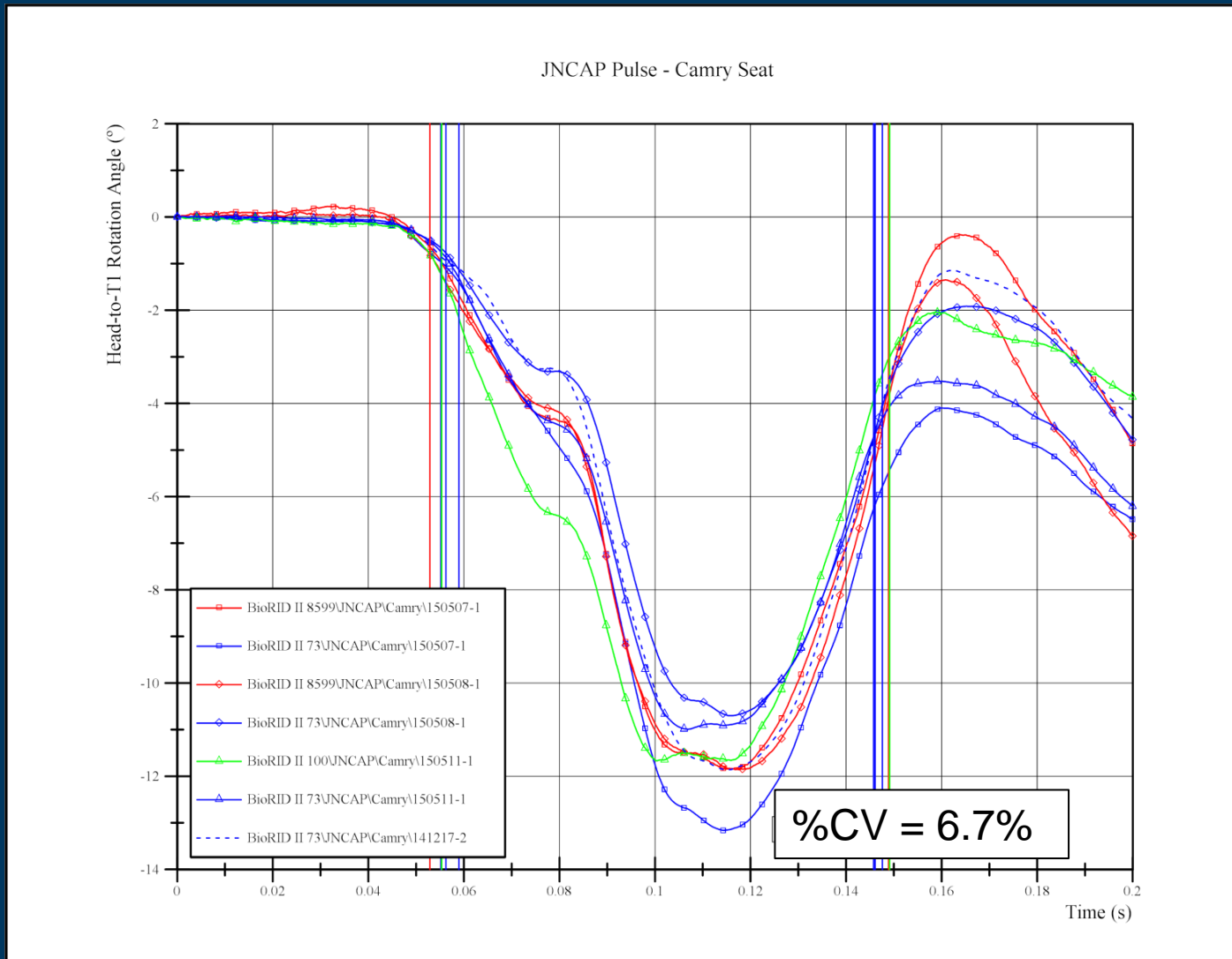
- Conclusions / Future options

NHTSA
www.nhtsa.gov

JNCAP Pulse

Camry Seats

BioRID Sled Test R&R

JNCAP – Camry Seats - NDCr

JNCAP Pulse - Camry Seat

Legend:
- BioRID II 8599\JNCAP\Camry\150507-1
- BioRID II 73\JNCAP\Camry\150507-1
- BioRID II 8599\JNCAP\Camry\150508-1
- BioRID II 73\JNCAP\Camry\150508-1
- BioRID II 100\JNCAP\Camry\150511-1
- BioRID II 73\JNCAP\Camry\150511-1
- BioRID II 73\JNCAP\Camry\141217-2

%CV = 6.7%

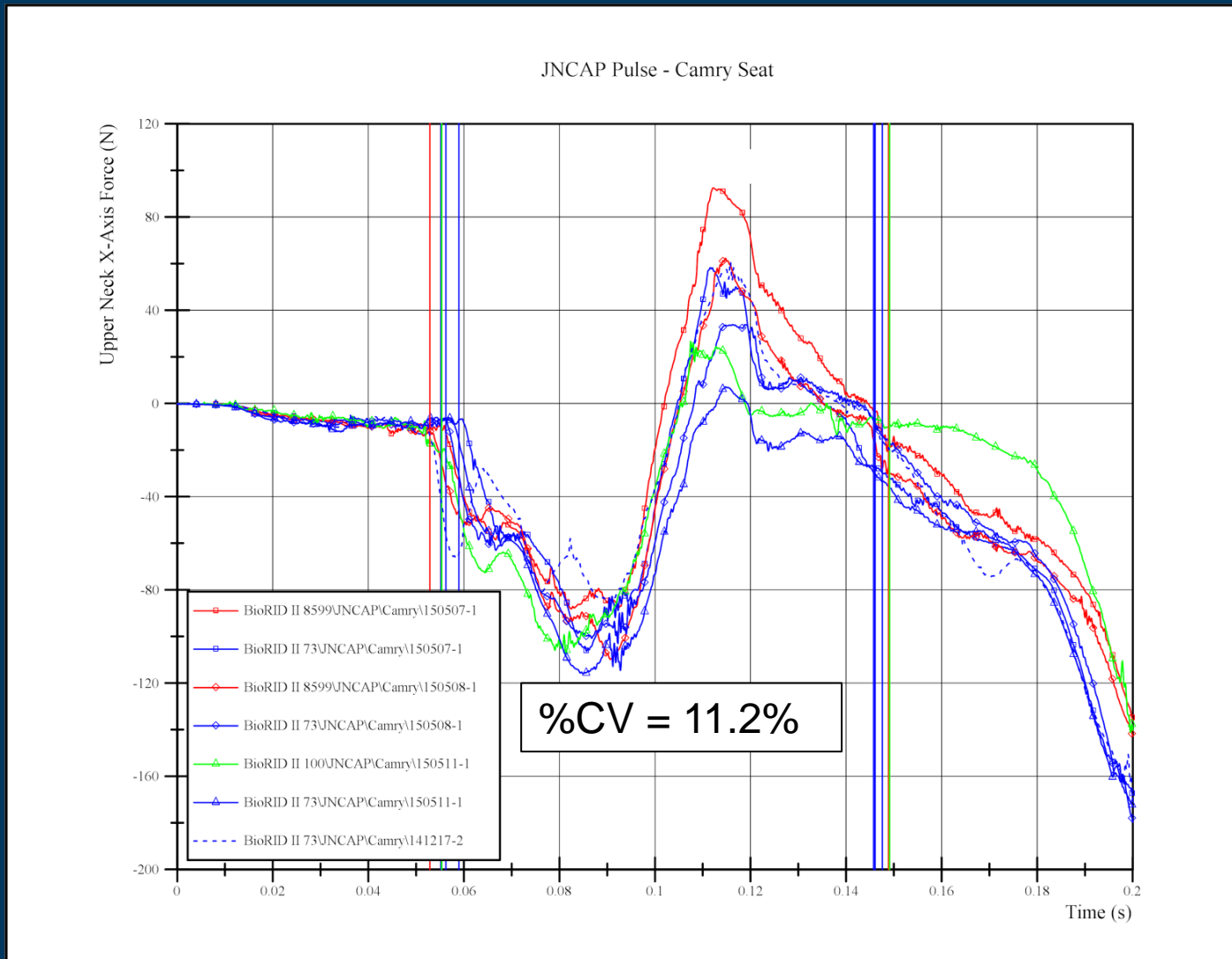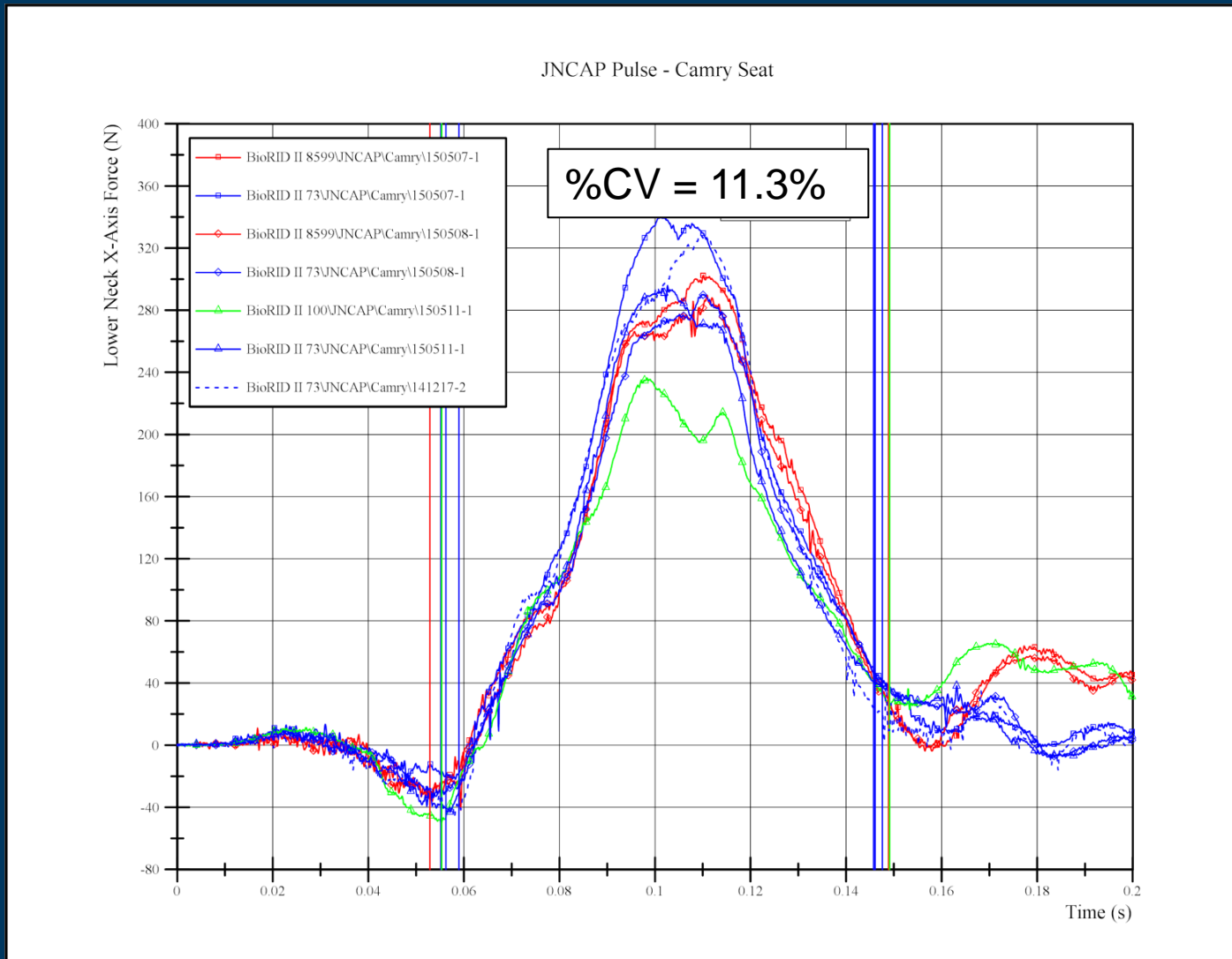*Safer drivers. Safer cars. Safer roads.*

NHTSA
www.nhtsa.gov

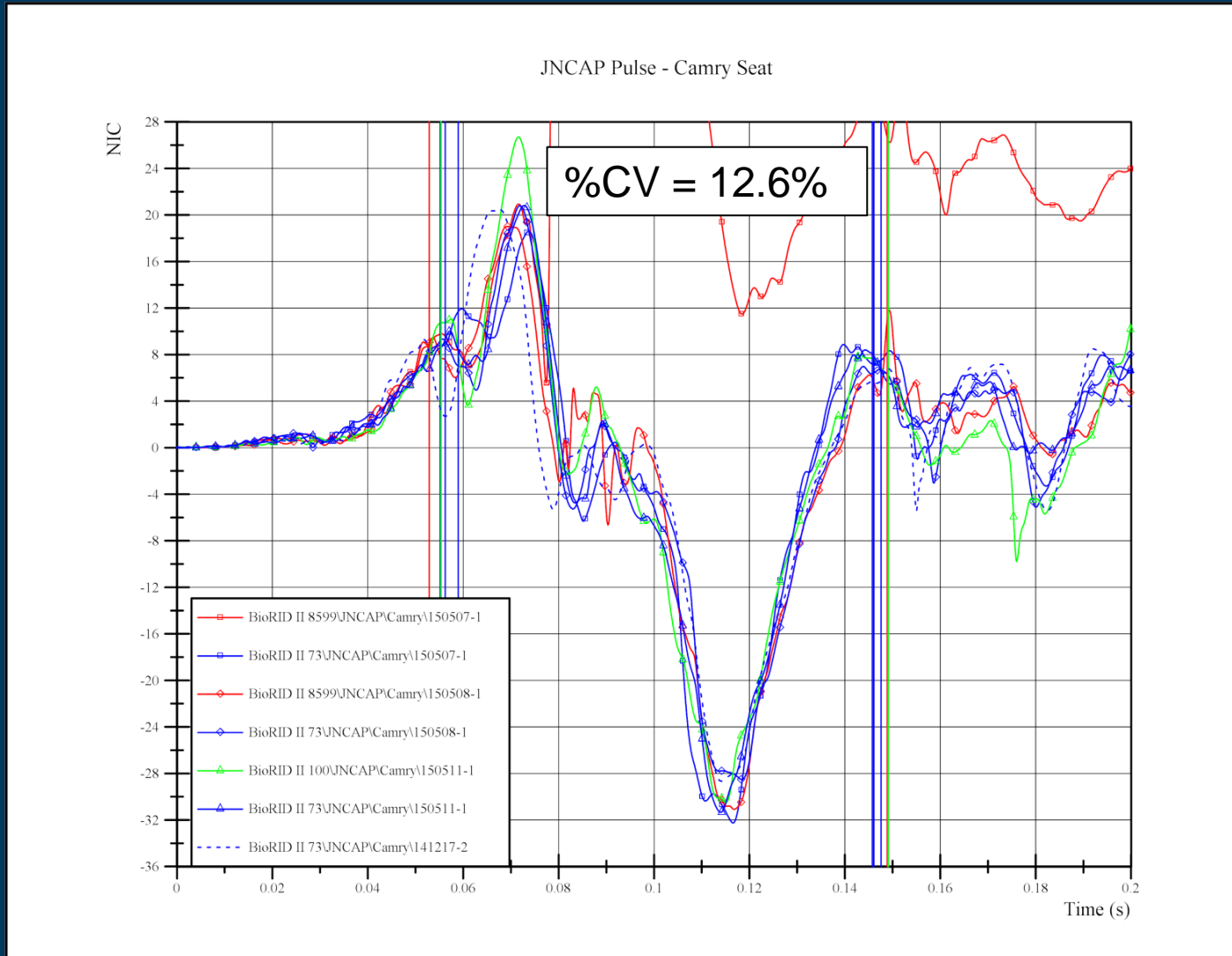# BioRID Sled Test R&R

JNCAP – Camry Seats - UNFx

BioRID Sled Test R&R

JNCAP – Camry Seats - LNFx

BioRID Sled Test R&R

JNCAP – Camry Seats - NIC

BioRID Sled Test R&R Summary

- 202a pulse
  - Cruze seats
    - NDCr: 6.4%; UNFx = 9.4%; LNFx = 10.6%; NIC = 7.5%

NHTSA
www.nhtsa.gov

BioRID Sled Test R&R Summary

- 202a pulse
  - Cruze seats
    - NDCr: 6.4%; UNFx = 9.4%; LNFx = 10.6%; NIC = 7.5%

- JNCAP pulse
  - Cruze seats
    - NDCr: 14.2%; UNFx = 8.0%; LNFx = 9.0%; NIC = 8.1%
  - Camry seats
    - NDCr: 6.7%; UNFx = 11.2%; LNFx = 11.3%; NIC = 12.6%

BioRID Sled Test R&R Summary

- 202a pulse
  - Cruze seats
    - NDCr: 6.4%; UNFx = 9.4%; LNFx = 10.6%; NIC = 7.5%

- JNCAP pulse
  - Cruze seats
    - NDCr: 14.2%; UNFx = 8.0%; LNFx = 9.0%; NIC = 8.1%
  - Camry seats
    - NDCr: 6.7%; UNFx = 11.2%; LNFx = 11.3%; NIC = 12.6%

- 10.5g/24kph pulse
  - Cruze seats
    - NDCr: 13.0%; UNFx = 7.7%; LNFx = 14.4%; NIC = 16.0%
  - Camry seats
    - NDCr: 22.9%; UNFx = 11.9%; LNFx = 17.8%; NIC = 16.8%

NHTSA
www.nhtsa.gov

Outline

- Review previous BioRID injury criteria correlation results/issues
  - Design and intent of sled test matrix to address issues

- BioRID R&R in production seat sled tests

- New correlation of BioRID injury criteria measures to PMHS injury

- Conclusions / Future options

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov

BioRID Injury Criteria Correlations

BioRID II	PMHS IV-NICrot	
	R^2	P - value
NIC	0.09	0.62
Nte	0.06	0.68
Ntf	0.05	0.71
Nce	0.08	0.64
Ncf	0.11	0.59
Nij	0.04	0.75
Nae	0.00	0.97
Naf	0.32	0.32
Npe	0.08	0.64
Npf	0.11	0.58
Nkm	0.29	0.35
NDCx	0.11	0.58
NDCx rate	0.04	0.74
NDCx product (max-max)	0.07	0.68
NDCx product (max)	0.11	0.59
NDCz	0.36	0.29
NDCz rate	0.02	0.81
NDCz product (max-max)	0.55	0.15
NDCz product (max)	0.02	0.81
NDCr	0.70	0.08
NDCr rate	0.72	0.07
NDCr product (max-max)	0.71	0.08
NDCr product (max)	0.83	0.03
C2 to T1 rotation	0.13	0.54

Nij
Nkm
NDC

BioRID II			PMHS IV-NICrot	
			R^2	P - value
Upper Neck	Fx	+	0.05	0.71
		-	0.41	0.24
	Fz	+	0.17	0.49
		-	NA	NA
	My	+	0.60	0.12
		-	0.01	0.87
Lower Neck	Fx	+	0.00	0.93
		-	NA	NA
	Fz	+	0.19	0.46
		-	0.40	0.25
	My	+	NA	NA
		-	0.04	0.76

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov

BioRID Injury Criteria Correlations
NDCr

Single Test
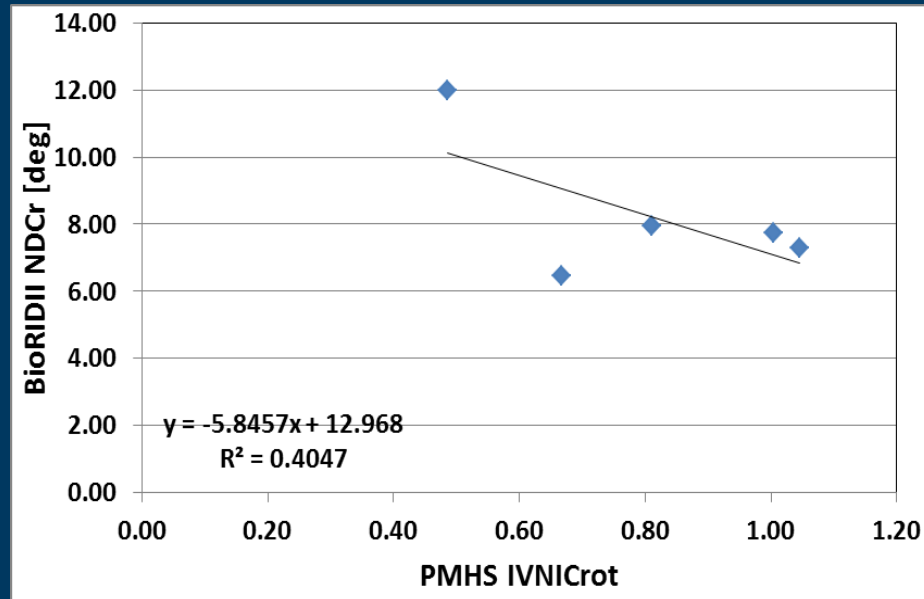
Multiple tests averaged

NHTSA
www.nhtsa.gov
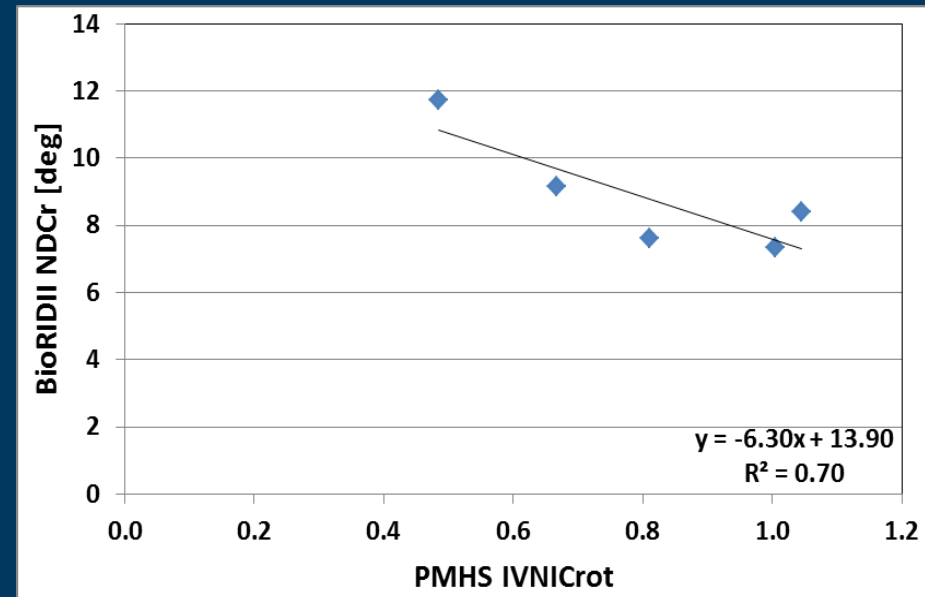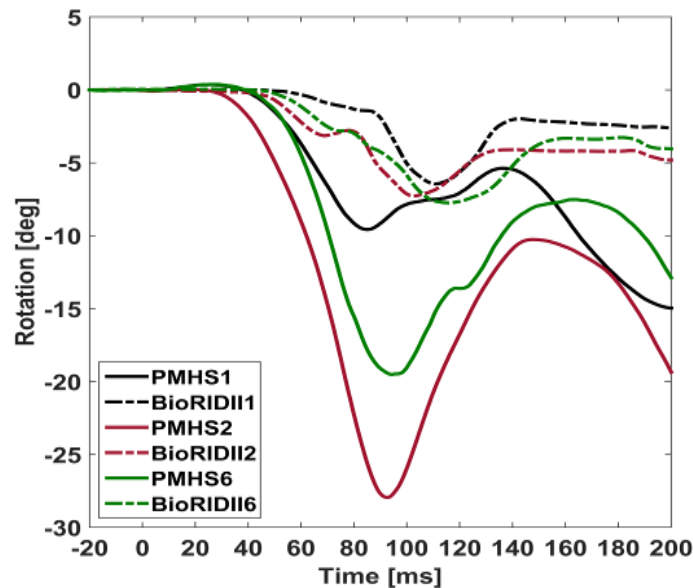
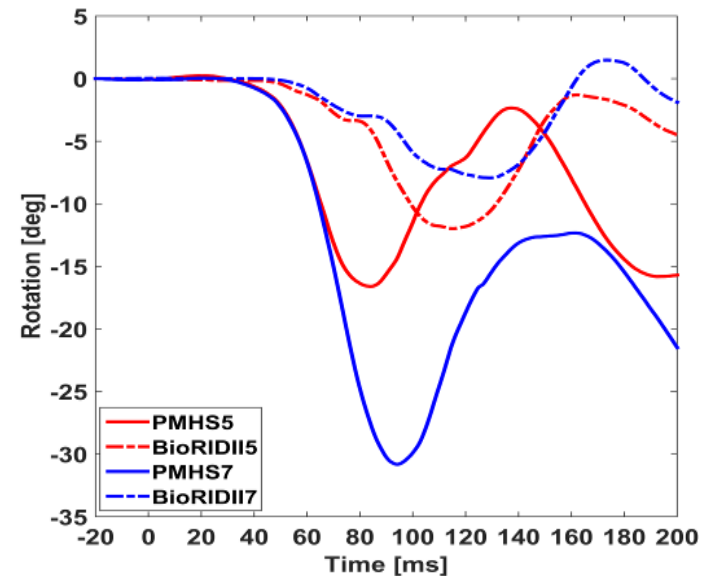# BioRID Injury Criteria Correlations
Biofidelity: NDCr

Cruze

PMHS1 vs. BioRIDII1 (FMVSS202a): NRMSD = 36.44%

PMHS2 vs. BioRIDII2 (JNCAP): NRMSD = 40.10%

PMHS6 vs. BioRIDII6 (24 km/h): NRMSD = 35.60%

Camry

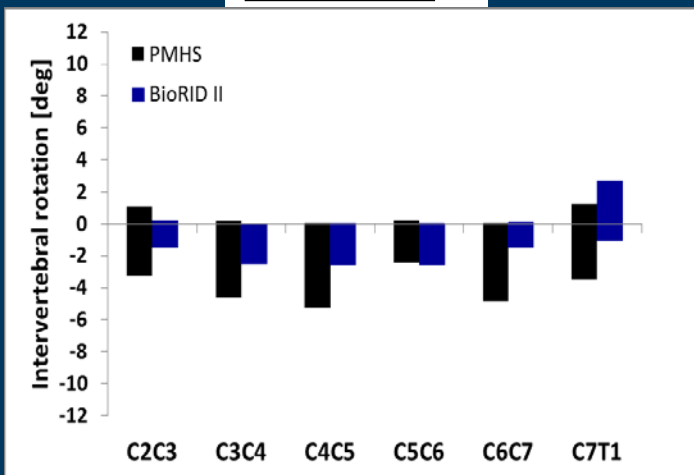PMHS5 vs. BioRIDII5 (JNCAP): NRMSD = 34.50%

PMHS7 vs. BioRIDII7 (24 km/h): NRMSD = 42.01%

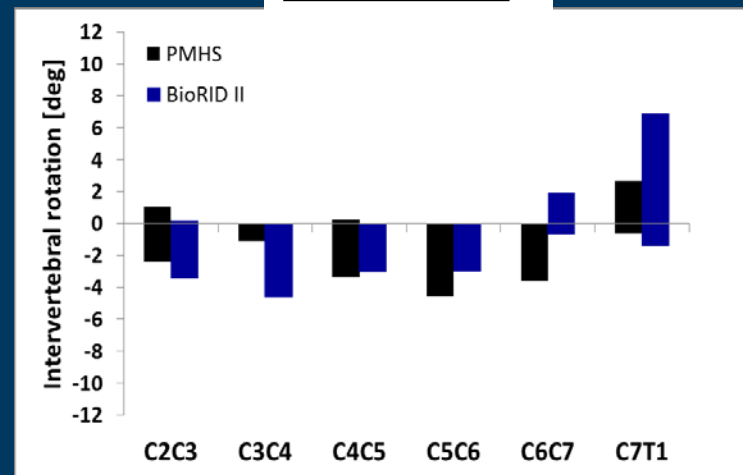Fig. 3. Head rotation relative to T1 rotation (average NRMSD of 37.7 ± 3.2%)

NHTSA
www.nhtsa.gov

BioRID Injury Criteria Correlations
Biofidelity: Intervertebral Rotations

Cruze (202a)

Cruze (JNCAP)

Cruze (10.5g/24kph)

NHTSA
www.nhtsa.gov
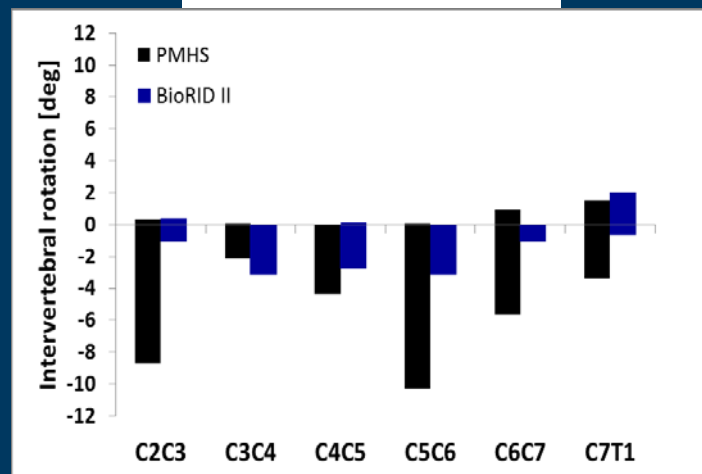
BioRID Injury Criteria Correlations
Biofidelity: Intervertebral Rotations

Camry (JNCAP)

Camry (10.5g/24kph)

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov
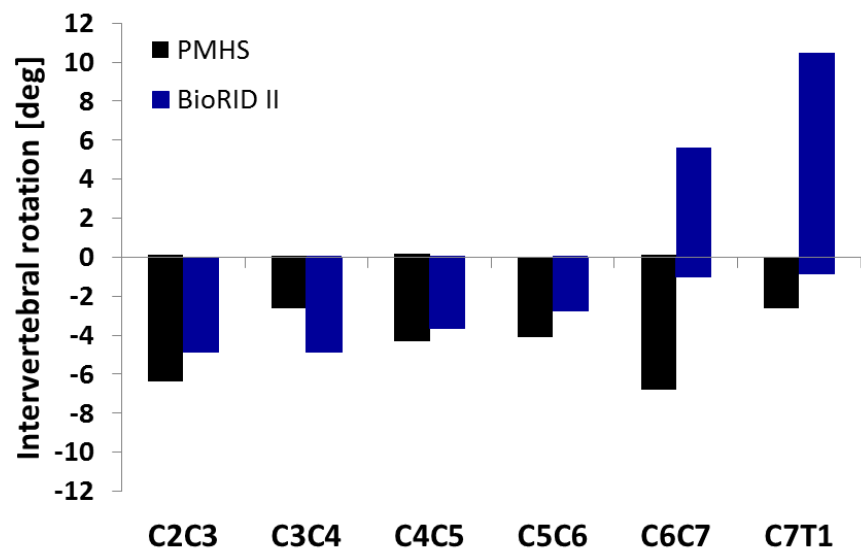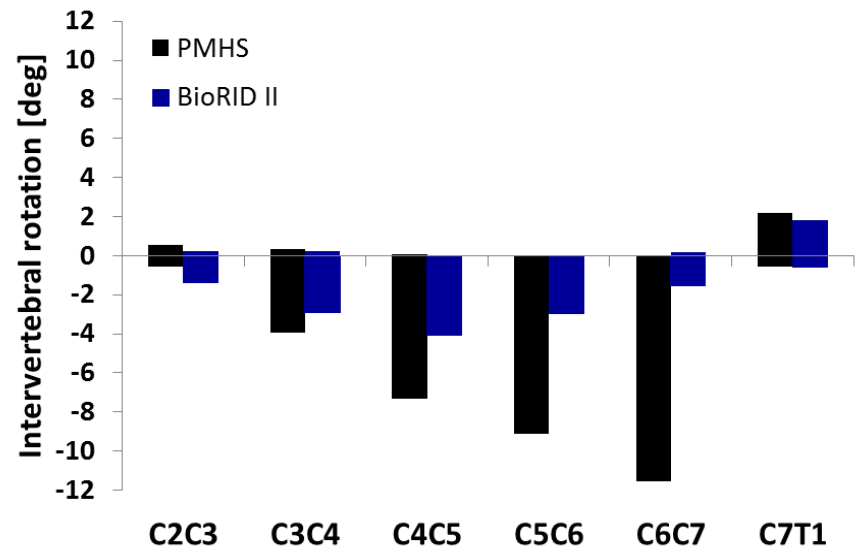
BioRID Injury Criteria Correlations Summary

- NDCr range:
  - BioRID: 8 to 12 deg
    - 12 deg 202a, 10.5 deg JNCAP, 8.5 deg 10.5g/24kph
  - PMHS: 9 to 30 deg
    - 9 deg 202a, 22 deg JNCAP, 24.5 deg 10.5/24kph

- Intervertebral Rotation range:
  - BioRID: 1.1 deg to 4.9 deg
  - PMHS: 1.0 deg to 12.0 deg

NHTSA
www.nhtsa.gov

Outline

- Review previous BioRID injury criteria correlation results/issues
  - Design and intent of sled test matrix to address issues

- BioRID R&R in production seat sled tests

- New correlation of BioRID injury criteria measures to PMHS injury

- Conclusions / Future options

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov

Conclusions

- BioRID seems adequately repeatable and reproducible based on Gen-X tests and production seat sled tests

- BioRID appears to exhibit poor biofidelity in flexion
  - Unable to correlate BioRID measures to PMHS flexion injuries
    - BioRID designed and tuned to match extension kinematics
      - Small 4.5 deg ROM in flexion
    - Does not mean BioRID is not a suitable tool for advancing safety in rear impact
      - Use of seat criteria (e.g., ENCAP/JNCAP/IIHS) may be capable of reducing whiplash injuries even though the criteria may not be directly linked to the injury mechanism
    - Results might be different if extension kinematics and extension injuries occurred

Safer drivers. Safer cars. Safer roads.

NHTSA
www.nhtsa.gov

Potential Future Work

- Develop injury criteria directly linked to the injury mechanism:

  - Options for flexion injuries:
    - Expand range of motion of BioRID cervical vertebrae in flexion
    - Short-term: Re-conduct the BioRID sled test series with new design
    - Longer-term: strengthen correlations by conducting more PMHS tests

  - Options for extension injuries:
    - Conduct increased backset tests (modified production seats) using PMHS
      - Induces extension kinematics and injuries necessary to develop IV-NIC injury risk curves for extension
      - Conduct paired BioRID and Hybrid III tests.
      - Would expect better BioRID correlation to injury due to better biofidelity in extension

NHTSA
www.nhtsa.gov