Preliminary PMHS Injury Risk Curves & Potential BioRID Injury Criteria

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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

**Sled Acceleration**

**Sled Velocity**

**PMHS09**
**PMHS10**
**PMHS11**
**PMHS12**
**PMHS13**
**PMHS14**
**PMHS15**

JNCAP

24 km/h

FMVSS 202a

-2.5
0
2.5
5
7.5
10
12.5
15
20
25

Time [ms]

-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Test Matrix Details
Production Seats

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

PMHS13
Toyota Camry
JNCAP

PMHS14
Chevy Cruze
24 kph

PMHS15
Toyota Camry
24kph

78yo
188cm/79kg

86yo
180cm/85kg

71yo
178cm/71kg
PMHS Anthropometry

50th percentile male

- Age
- Weight (kg)
- Height (cm)
- Seated Height (cm)
Head Restraint Forces
Production Seats
Head Restraint Forces
Production Seats
Production Seat Sled Tests
Chevy Cruze - FMVSS 202a

Chevy Cruze FMVSS 202a

Chevy Cruze FMVSS 202a
Production Seat Sled Tests
Toyota Camry - JNCAP
Production Seat Sled Tests
Toyota Camry – 24 km/h
Production Seat Sled Tests
Toyota Camry – JNCAP

Toyota Camry
JNCAP

PMHS13
Production Seat Sled Tests
Chevy Cruze – 24 km/h

Chevy Cruze
24 km/h

PMHS14
Production Seat Sled Tests
Toyota Camry – 24 km/h
Documentation of Injuries
## Documentation of Injuries
### Production Seats

<table>
<thead>
<tr>
<th>Injury Documentation</th>
<th>PMHS09</th>
<th>PMHS10</th>
<th>PMHS11</th>
<th>PMHS12</th>
<th>PMHS13</th>
<th>PMHS14</th>
<th>PMHS15</th>
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<tbody>
<tr>
<td>updated</td>
<td>FMVSS202</td>
<td>JNCAP</td>
<td>JNCAP</td>
<td>24 km/h</td>
<td>JNCAP</td>
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<td>C2/C3</td>
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<tr>
<td>C4/C5</td>
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<tr>
<td>C5/C6</td>
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<td>Subluxation</td>
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</tr>
<tr>
<td>C6/C7</td>
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<td>Subluxation</td>
<td>Subluxation</td>
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</tbody>
</table>
Injury Criteria Analysis
PMHS Injury Analysis

Step 1

Intervertebral kinematics

Linear/angular acceleration, velocity, and displacement

Step 2

Best injury predictors

Kinetics/kinematics

Current/potential injury criteria

Correlation?

Normalization?
PMHS Injury Analysis
Injury Risk Curves – 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

Probability of AIS ≥ 1 Injury

Rotation [deg]

PMHS Data
CT Method
Binary Risk Function
Weibull-Survival
### PMHS Injury Analysis

#### Injury Risk Curves – Intervertebral Kinematics

*Production Seats Only*

<table>
<thead>
<tr>
<th>Intervertebral kinematics</th>
<th>Log-Likelihood P-value</th>
<th>Goodman-Kruskal Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>** Acceleration x**</td>
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<td></td>
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<tr>
<td>(+)</td>
<td>0.026</td>
<td>0.54</td>
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<tr>
<td>(-)</td>
<td>0.531</td>
<td>0.17</td>
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<tr>
<td>Max</td>
<td>0.038</td>
<td>0.54</td>
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<tr>
<td>** Acceleration z**</td>
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<td></td>
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<tr>
<td>(+)</td>
<td>0.016</td>
<td>0.46</td>
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<td>(-)</td>
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<tr>
<td>Max</td>
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<td>** Velocity x**</td>
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<td>(+)</td>
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<td>** Velocity z**</td>
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<td>(+)</td>
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<tr>
<td>(-)</td>
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<td>0.53</td>
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<tr>
<td>Max</td>
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<td>0.56</td>
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<tr>
<td>** Rotation y**</td>
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<tr>
<td>(-)</td>
<td>0.000</td>
<td>0.76</td>
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<tr>
<td>** Facet JT Slide**</td>
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<tr>
<td>(+)</td>
<td>0.058</td>
<td>0.40</td>
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<tr>
<td>** Facet JT Slide Rate**</td>
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<tr>
<td>Max</td>
<td>0.083</td>
<td>0.36</td>
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<tr>
<td>** Facet JT Axial**</td>
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<tr>
<td>Max</td>
<td>0.005</td>
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<td>** Facet JT Axial Rate**</td>
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<tr>
<td>(-)</td>
<td>0.001</td>
<td>0.66</td>
</tr>
</tbody>
</table>

- (+): 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

![Graph showing Intervertebral Rotation vs. Probability of AIS ≥ 1 Injury]

- **Intervertebral Rotation**: 6.4°
- **Log-Likelihood P-value**: 0.000
- **Goodman-Kruskal Gamma**: 0.76
- **AUROC**: 0.85

<table>
<thead>
<tr>
<th>Intervertebral Rotation</th>
<th>Log-Likelihood P-value</th>
<th>Goodman-Kruskal Gamma</th>
<th>AUROC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervertebral Rotation y</td>
<td>0.000</td>
<td>0.76</td>
<td>0.85</td>
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</tbody>
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PMHS Injury Analysis

Step 1: Intervertebral kinematics
Linear/angular acceleration, velocity, and displacement

Normalization?

Step 2: Best injury predictors

Correlation?

Kinetics/kinematics
Current/potential injury criteria

Correlation?
PMHS Injury Analysis
Injury Risk Curves – IV-NIC\textsubscript{rot}
Production Seats Only

6.4 deg rotation

\[ IV - NIC_i = \frac{\Theta_{\text{trauma},i}}{\Theta_{\text{physiological},i}} \]

IV-NIC = 1.1

<table>
<thead>
<tr>
<th>Normalized Intervertebral Rotation</th>
<th>Log-Likelihood P-value</th>
<th>Goodman-Kruskal Gamma</th>
<th>AUROC</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVNIC\textsubscript{rot}</td>
<td>0.001</td>
<td>0.71</td>
<td>0.86</td>
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</tbody>
</table>
PMHS Injury Analysis

**Step 1**
- Intervertebral kinematics
  - Linear/angular acceleration, velocity, and displacement

**Step 2**
- Best injury predictors

**Injuries**
- Correlation?

**Kinetics/kinematics**
- Current/potential injury criteria

**Normalization?**
**PMHS Injury Analysis**

**IV-NIC vs. Current/Potential Injury Criteria**

- Correlation between IV-NIC rotation and existing injury criteria

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

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

- Potential PMHS/BioRID Injury Criteria

\[ LNL - index(t) = \sqrt{M_{y_{lower}}(t)^2 + M_{x_{lower}}(t)^2} \cdot C_{moment} + \sqrt{F_{x_{lower}}(t)^2 + F_{y_{lower}}(t)^2} \cdot C_{shear} + \frac{F_z_{lower}(t)}{C_{tension}} \]

NDC, Nij
Head-to-T1 Rotation
Upper/Lower Fx, Fz, My
Other physical parameters
## PMHS Injury Analysis
### IV-NIC vs. Kinematic Criteria

<table>
<thead>
<tr>
<th></th>
<th>IV-NICrot</th>
</tr>
</thead>
<tbody>
<tr>
<td>R² - value</td>
<td></td>
</tr>
<tr>
<td>NDCrot</td>
<td>0.75</td>
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<tr>
<td>NDCx</td>
<td>0.48</td>
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<tr>
<td>NDCz</td>
<td>0.14</td>
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<tr>
<td>NIC</td>
<td>0.45</td>
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</tbody>
</table>
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 m²/s²
Potential BioRID Injury Criteria
Step 3

Potential BioRID Injury Criteria

PMHS

Best injury predictors

BioRIDII

Current/potential injury criteria

Intervertebral kinematics

Injury risk curves

Injury risk curves
Potential BioRID Injury Criteria
Intervertebral Rotations
Potential BioRID Injury Criteria

Scale to BioRIDII

Average (Max(BioRIDII measure))
Average(Max(PMHS measure))
Potential BioRID Injury Criteria
Intervertebral Rotations
Production Seats Only

Intervertebral Rotation
Log-Likelihood P-value
Goodman-Kruskal Gamma
AUROC

<table>
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<th>Goodman-Kruskal Gamma</th>
<th>AUROC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervertebral Rotation y</td>
<td>0.000</td>
<td>0.76</td>
<td>0.88</td>
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Potential BioRID Injury Criteria
Intervertebral Rotations
Production Seats Only

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Potential BioRID Injury Criteria
Intervertebral Rotations
Production Seats Only

BioRIDII/PMHS Injury Risk Curve for Intervertebral Rotation

BioRIDII

3.7 deg

PMHS

6.4 deg
### Correlations with IV-NICrot

<table>
<thead>
<tr>
<th></th>
<th>R² - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDCrot</td>
<td>32.5 deg</td>
</tr>
<tr>
<td>NDCx</td>
<td>75.1 mm</td>
</tr>
<tr>
<td>NIC</td>
<td>39.6 m²/s²</td>
</tr>
</tbody>
</table>

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)

Scaling

Average(Max(BioRIDII NDCrot))
Average(Max(PMHS NDCrot))
Potential BioRID Injury Criteria
Global Measures (NDCx)
Production Seats Only

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

50% chance of AIS 1+ injuries for PMHS
NDCx = 75.1 mm

Scaling
Average (Max(BioRIDII NDCx))
Average(Max(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 m²/s²

50% chance of AIS 1+ injuries for BioRIDII
NIC = 29.7 m²/s²

PMHS

BioRIDII

Scaling
Average(Max(BioRIDII NIC))
Average(Max(PMHS NIC))
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, LNMMy

- **Common ground:**
  - NIC
  - USA: Still investigating UNFx, UNMy, LNFx, LNMMy, Nkm
    - Inverse Dynamics an issue after HR contact
      - Use direct correlation of BioRID measures??
  - Japan: Still investigating NDCrot, NDCx
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??