Correlation study - BioRID Injury Criteria Measures to PMHS Injury

GTR7 Update July 2015

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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
Outline

- Review previous BioRID injury criteria correlation results/issues
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- Conclusions / Future options
Review of Previous Results
PMHS IV-NIC Injury Risk Curve

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>IV-NIC</td>
<td>0.001</td>
<td>0.71</td>
<td>0.86</td>
</tr>
</tbody>
</table>
Review of Previous Results

Correlation of PMHS Injury Criteria Measures to IV-NIC

![Graph 1](y = 23.99x + 6.08, R² = 0.75)

![Graph 2](y = 29.56x + 7.33, R² = 0.45)
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
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
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
Review of Previous Results

Correlation of BioRiD Injury Criteria Measures to IV-NIC

Poor (and negative) correlation for BioRiD

\[ y = -5.8457x + 12.968 \]
\[ R^2 = 0.4047 \]

\[ y = -9.488x + 23.654 \]
\[ R^2 = 0.2307 \]
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?
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
Review of Previous Results

Correlation of BioRID Injury Criteria Measures to IV-NIC

Potential Sources of Poor Correlation

– Poor biofidelity in BioRID?
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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)
Review of Previous Results
Correlation of BioRID Injury Criteria Measures to IV-NIC

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)

- Conduct repeat tests to average out variation
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
• 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
J NCAP Pulse
Camry Seats
BioRID Sled Test R&R
JNCAP – Camry Seats - NDCr

JNCAP Pulse - Camry Seat

%CV = 6.7%
BioRID Sled Test R&R
JNCAP – Camry Seats - UNFx

%CV = 11.2%
BioRID Sled Test R&R

JNCAP – Camry Seats - LNFx

%CV = 11.3%
BioRID Sled Test R&R
JNCAP – Camry Seats - NIC

JNCAP Pulse - Camry Seat

%CV = 12.6%
BioRID Sled Test R&R Summary

- 202a pulse
  - Cruze seats
    - NDCr: 6.4%; UNFx = 9.4%; LNFx = 10.6%; NIC = 7.5%
BioRID Sled Test R&R Summary

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

- **J NCAP 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%
- J NCAP 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%
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
# BioRID Injury Criteria Correlations

<table>
<thead>
<tr>
<th>BioRID II</th>
<th>PMHS IV-NICrot</th>
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<tr>
<td></td>
<td>R²</td>
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<td>NIC</td>
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<td>NDCr product (max)</td>
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<td>C2 to T1 rotation</td>
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## Upper Neck

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<thead>
<tr>
<th>BioRID II</th>
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<tbody>
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<td>Fx</td>
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BioRiD Injury Criteria Correlations
NDCr

Single Test

- Graph: Scatter plot with linear trend line
  - Equation: $y = -5.8457x + 12.968$
  - $R^2 = 0.4047$

Multiple tests averaged

- Graph: Scatter plot with linear trend line
  - Equation: $y = -6.30x + 13.90$
  - $R^2 = 0.70$
BioRiD Injury Criteria Correlations
Biofidelity: NDCr

PMHS1 vs. BioRIDII1 (FMVSS202a): NRMSD = 36.44%
PMHS2 vs. BioRIDII2 (JNCAP): NRMSD = 40.10%
PMHS6 vs. BioRIDII6 (24 km/h): NRMSD = 35.60%

Fig. 3. Head rotation relative to T1 rotation (average NRMSD of 37.7 ± 3.2%)
BioRID Injury Criteria Correlations
Biofidelity: Intervertebral Rotations

Cruze (202a)

Cruze (JNCAP)

Cruze (10.5g/24kph)
BioRID Injury Criteria Correlations
Biofidelity: Intervertebral Rotations

Camry (JNCAP)

Camry (10.5g/24kph)
BioRID Injury Criteria Correlations Summary

- **NDCr range:**
  - **BioRID:** 8 to 12 deg
    - 12 deg 202a, 10.5 deg J NCAP, 8.5 deg 10.5g/24kph
  - **PMHS:** 9 to 30 deg
    - 9 deg 202a, 22 deg J NCAP, 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
Review previous BioRID injury criteria correlation results/issues
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BioRID R&R in production seat sled tests

New correlation of BioRID injury criteria measures to PMHS injury

Conclusions / Future options
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
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