Development of a Biofidelic Flexible Pedestrian Legform Impactor (Flex-PLI 2003)

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Japan Automobile Research Institute
Masaaki Tanahashi
Japan Automobile Manufactures Association, Inc
Back Ground
### Distributions of Pedestrian Injuries by Body Region and Country (All Age Groups, AIS 2-6)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Head</strong></td>
<td>32.7%</td>
<td>29.9%</td>
<td>28.9%</td>
<td>39.3%</td>
<td>31.4%</td>
</tr>
<tr>
<td>Face</td>
<td>3.7%</td>
<td>5.2%</td>
<td>2.2%</td>
<td>3.7%</td>
<td>4.2%</td>
</tr>
<tr>
<td>Neck</td>
<td>0.0%</td>
<td>1.7%</td>
<td>4.7%</td>
<td>3.1%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Chest</td>
<td>9.4%</td>
<td>11.7%</td>
<td>8.6%</td>
<td>10.4%</td>
<td>10.3%</td>
</tr>
<tr>
<td>Abdomen</td>
<td>7.7%</td>
<td>3.4%</td>
<td>4.7%</td>
<td>4.9%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Pelvis</td>
<td>5.3%</td>
<td>7.9%</td>
<td>4.4%</td>
<td>4.9%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Arms</td>
<td>7.9%</td>
<td>8.2%</td>
<td>9.2%</td>
<td>8.0%</td>
<td>8.2%</td>
</tr>
<tr>
<td><strong>Lower Limbs</strong></td>
<td><strong>33.3%</strong></td>
<td><strong>31.6%</strong></td>
<td><strong>37.2%</strong></td>
<td><strong>25.8%</strong></td>
<td><strong>32.6%</strong></td>
</tr>
<tr>
<td>Unknown</td>
<td>0.0%</td>
<td>0.4%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.2%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: IHRA/PS WG 2001 report

**Headform Impactor Test**

**Legform Impactor Test**
## Relationship between Pedestrian Lower Limb Injuries and Contact Locations

<table>
<thead>
<tr>
<th>AIS 2-6</th>
<th>Contact Location</th>
<th>Overall</th>
<th>Thigh</th>
<th>Knee</th>
<th>Leg</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA, Japan, Europe, and Australia</td>
<td><strong>Front Bumper</strong></td>
<td>1.6%</td>
<td>2.9%</td>
<td><strong>7.0%</strong></td>
<td><strong>43.5%</strong></td>
<td>2.9%</td>
</tr>
<tr>
<td></td>
<td>Top surface of bonnet/wing</td>
<td>2.1%</td>
<td>0.3%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td>Leading edge of bonnet/ wing</td>
<td>4.7%</td>
<td>3.3%</td>
<td>0.5%</td>
<td>2.4%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Windscreen glass</td>
<td>0.1%</td>
<td></td>
<td>0.1%</td>
<td></td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Windscreen frame/ A pillars</td>
<td>0.5%</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Front Panel</td>
<td>0.9%</td>
<td>0.9%</td>
<td>1.0%</td>
<td>3.2%</td>
<td>0.3%</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>0.6%</td>
<td>0.4%</td>
<td>0.5%</td>
<td>2.6%</td>
<td>1.3%</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-Total</strong></td>
<td>10.5%</td>
<td>8.0%</td>
<td>9.1%</td>
<td>52.0%</td>
<td>5.0%</td>
</tr>
</tbody>
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<th>Knee</th>
<th>Leg</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA, Japan, Europe, and Australia</td>
<td><strong>Front Bumper</strong></td>
<td>0.3%</td>
<td>3.0%</td>
<td>0.7%</td>
<td>4.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td>Top surface of bonnet/wing</td>
<td>0.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leading edge of bonnet/ wing</td>
<td>0.4%</td>
<td>0.7%</td>
<td>0.1%</td>
<td>0.6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windscreen glass</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Windscreen frame/ A pillars</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Front Panel</td>
<td>0.9%</td>
<td>0.5%</td>
<td>0.1%</td>
<td>0.3%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>0.9%</td>
<td>0.5%</td>
<td></td>
<td>1.3%</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Sub-Total</strong></td>
<td>1.9%</td>
<td>4.8%</td>
<td>0.9%</td>
<td>7.0%</td>
<td>0.7%</td>
</tr>
</tbody>
</table>

source: IHRA/PS WG 2001 report
Pedestrian Legform Impactor Test Proposals

- EEVC/WG10(1994), and EEVC/WG17 (1998)

Legform to Bumper Test
Proposed Pedestrian Legform Impactor

- EEVC/WG10(1994), and EEVC/WG17 (1998)
  -> TRL Pedestrian Legform Impactor (TRL-PLI)
  -> Only Requirements

My Leg is so RIGID? Damper?
Development of a Biofidelic Pedestrian Legform Impactor

- a) JAMA-JARI PLI 2000
  - Thigh (RIGID)
  - Leg (RIGID)
  - Knee Joint * (ligament restraint system)
  - * utilized Polar pedestrian dummy knee joint

- b) JAMA-JARI PLI 2002 (Flex-PLI 2002)
  - Thigh (FLEXIBLE)
  - Leg (FLEXIBLE)
  - Knee Joint* (ligament restraint system)
  - * compact design

- c) JAMA-JARI PLI 2003 (Flex-PLI 2003)
  - Thigh* (FLEXIBLE)
  - Leg (FLEXIBLE)
  - Knee Joint* (ligament restraint system)
  - * Improved its dynamic response
Flexible Pedestrian Legform Impactor (Flex-PLI 2003)

- Thigh*
  - (Flexible)

- Knee Joint*
  - (ligament restraint system)

* Improved its dynamic response

- Leg
  - (Flexible)

- Thigh/Leg

- Knee Joint
Thigh/Leg Construction

1: Exterior Housing
2: Bone Core
3: Hard Urethane
4: Core Binder
5: Screw

Compressive force → ←
Bone Core Specification

a) Bone Core for Thigh

Impact direction
Bending direction

Material: Glass-Reinforced Plastic (GRP)
Knee Joint Construction

1: Knee spring
2: Knee cable (lateral ligament)
3: Knee cable (cruciate ligament)
4: Femoral condyle
5: Hard Urethane
6: Tibial plateau
7: Tibial condyle
Knee Joint Construction (lateral view)

1: Knee Spring
2: Knee Cable
Flesh Construction

Flesh for Flex-PLI 2003

Neoprene (10mm+5mm)  
20mm  
Rubber 30 (5 mm)

Flesh for Flex-PLI 2002 (TRL-PLI)

Confor Foam™ (25mm)  
31mm  
Neoprene (6mm)
Measurement Instrumentation

**TRL-PLI**
- for Knee ligaments Injury assessment
- Knee Shearing (displacement)
- Knee Bending (angle)
- Leg 0 (acceleration)

**Flex-PLI 2003**
- for Thigh Injury assessment (optional)
- Thigh 4 (strain)
- Thigh 3 (strain)
- Thigh 2 (strain)
- Thigh 1 (strain)
- ACL (elongation)
- PCL (elongation)
- MCL (elongation)
- LCL (elongation)
- Lateral and Medial Condyle (force)

**Impact**

**Leg 0**
- for Leg Injury assessment

**Knee Joint**
- 92 mm
- 172 mm
- 252 mm
- 332 mm
- 413 mm

**Flex-PLI 2003**
- for Knee ligaments Injury assessment
- for Knee Condyle Injury assessment (optional)
- for Leg Injury assessment
Thigh/Leg Measurement (Strain)

Bone Core of Thigh

1: Bone Core
2: Strain Gage

Bone Core of Leg

1: Bone Core
2: Strain Gage

Thigh/Leg Measurement (Strain)
Thigh/Leg Measurement (Acceleration)
Knee Joint Measurement
(Elongation and Compressive Force)

1: Measurement cable (collateral)
2: Measurement cable (cruciate)
3: Potentiometer (cruciate)
4: Potentiometer (collateral)
5: Load transducer (inside of the condyle)
Knee Joint Measurement
(Compressive Force)

1: Load transducer for lateral condyle
2: Load transducer for medial condyle
Biofidelity Evaluation for Flex-PLI 2003

Thigh*
(Flexible)

Knee Joint*
(ligament restraint system)

Leg
(Flexible)

* Improved its dynamic response

Dynamic Bending Test

Ram (Mass: 67.8kg, Initial impact speed: 1.0 m/s)

Thigh
Loading face (R=25mm)
Support end (R=75mm)
Support length (L=360mm)
Load cell

Ram (Mass: 74.5kg, Initial impact speed: 1.4m/s)

Rubber
Loading length (L=360mm)
Loading face (R=7mm)
Support end (R=75mm)
Knee Joint
Load cell
Support length (L=550mm)

Ram (Mass: 67.8kg, Initial impact speed: 1.0m/s)

Leg
Loading face (R=25mm)
Support end (R=75mm)
Support length (L=320mm)
Load cell
Biofidelity Evaluation for Thigh of Flex-PLI 2003

PMHS (Femur)  Flex-PLI 2003 (Thigh)

Ram (Mass: 67.8kg, Initial impact speed: 1.0 m/s)

Support length (L=360mm)

Loading face (R=25mm)

Support end (R=75mm)

Kerrigan et al. 2003
Dynamic Response
for Thigh of Flex-PLI 2003
Result of Biofidelity Evaluation for Thigh of Flex-PLI 2003

PMHS, Femur (Kerrigan et al. 2003)

112L, Male (55)

120R, Female (59)

127L, Female (54)

Flex-PLI 2003, Thigh

Force (kN) vs. Deflection (mm)
Biofidelity Evaluation for Leg of Flex-PLI 2003

PMHS (Leg)

Kerrigan et al. 2003

Flex-PLI 2003 (Leg)

Ram (Mass: 67.8kg, Initial impact speed: 1.0m/s)

Loading face (R=25mm)

Support end (R=75mm)

Load cell

Support length (L=320mm)
Dynamic Response for Leg of Flex-PLI 2003
Results of Biofidelity Evaluation for Leg of Flex-PLI 2003

PMHS, Leg
Kerrigan et al. 2003
(Average +/- 1SD)

Flex-PLI 2003, Leg

fibula fracture effect

Force (kN)

Deflection (mm)
Biofidelity Evaluation for Knee Joint of Flex-PLI 2003

PMHS (Knee Joint)

Kerrigan et al. 2003

Flex-PLI 2003 (Knee Joint)

Ram (Mass: 74.5kg, Initial impact speed: 1.4m/s)

Support end (R=75mm)

Loading face (R=7mm)

Loading length (L=360mm)

Support length (L=550mm)

Knee Joint

Load cell

Rubber
Dynamic Response for Knee Joint of Flex-PLI 2003
Results of Biofidelity Evaluation for Knee Joint of Flex-PLI 2003

Knee angle (deg.)

0 2 4 6 8 10 12 14 16

0 2 4 6 8 10 12 14 16

Moment (Nm)

* Bhalla et al. 2003
** Kerrigan et al. 2003

Inertia Effect

TRL-PLI*

135L, Male(68)**

167L, Male(66)**

124R, Female(58)**

Flex-PLI 2003

PMHS** (Initial Injury)
Conclusions

• JAMA-JARI developed a biofidelic PLI (Flex-PLI 2003)
• Flex-PLI 2003 response is compared with PMHS component tests (Thigh, Leg, Knee Joint). Therefore, the Flex-PLI 2003 has a high possibility to reproduce more proper response in a car-pedestrian impact than that of other PLI.
• Flex-PLI 2003 installs sensors in wide range. Therefore, the Flex-PLI 2003 has a high possibility to conduct more detailed and proper lower limb injury assessment than that of other PLI.
Future work

• PMHS component test data for Thigh, Leg, Knee Joint is limited. Therefore, additional PMHS test results are needed for more certain validation.
• The Flex-PLI 2003 is validated in component test, however, assembly level (Thigh-Knee Joint-Leg) validation is also needed.
• Flex-PLI 2003 does not have fibula construction. Therefore, the effect should be considered for the leg injury assessment.
Thank you for your attention!