Inova Regional Trauma Center

Inova Fairfax Hospital
Falls Church, VA
Non Ankle Lower extremity Fractures in Frontal Crashes: The Importance of Occupant Height and Vehicle Type
Team Members:

- Samir M. Fakhry, MD, Principal Investigator
- Dorraine D. Watts, PhD, RN, Principal Investigator
- Refaat Hanna, M.D., M.A., Epidemiologist
- James D. Bean, Crash Reconstructionist
- Christine Burke, CIREN Study Coordinator
- Christopher Sherwood, Auto Safety Lab, University of VA
- Capt. Christine Woodard, Fairfax County Fire and Rescue
- Detective J.J. Banachoski, Fairfax County Police CRU
Non-Ankle Lower Extremity Fracture (NALEF)

Lower Extremity Regions under study:
1- Pelvis/Hip
2- Femur
3- Knee/Patella
4- Tibia/Fibula
Research Questions??

• Does the driver’s **height** play a role in NALEF injuries?

• Does the **vehicle type** play a role in the type of NALEF injury?
Selection Criteria

- Age: ≥ 16 Years
- Vehicle Make Year: ≥ 1996
- Role: Belted Drivers Only
- PDOF: 11 – 1 O’clock
- No Ejection
- No Rollover
- No Fire
- AIS ≥ 2
- The Vehicle types included in the study are:
  a) Passenger Cars
  b) SUV/Light Trucks
Sample Size

1- NASS Data
• 613 cases met the selection criteria in NASS data
• 473 cases in passenger cars
• 140 cases in SUV/Light Trucks

2- CIREN Data
• 233 cases met the selection criteria in CIREN data
• 175 cases in passenger cars
• 58 in SUV/Light Trucks
Binary Logistic Regression

Logistic regression is useful for situations in which we want to be able to predict the presence or absence of a characteristic or outcome based on values of a set of predictor variables. It is similar to a linear regression model but is suited to models where the dependent variable is dichotomous. Logistic regression coefficients can be used to estimate odds ratios (OR) for each of the independent variables in the model.
Variables Tested

- Vehicle Type
  *Passenger Cars Vs. SUV/Light Trucks*
- Height
  *3 categories < 65 Inch, 65 to 69 Inch & > 69 Inch*

- Reference Values
  - Vehicle type: Passenger Cars
  - Height: < 65 Inch
Individual Analysis of Different Components of Non Ankle Lower Extremity Fractures
## Pelvic/Hip Fracture
### CIREN Data Analysis

**Passenger Cars**

<table>
<thead>
<tr>
<th>Height Range</th>
<th>Odds Ratio (OR)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 65 Inch : 65-69 Inch</td>
<td>2.06</td>
<td>0.165</td>
</tr>
<tr>
<td>65-69 Inch : &gt; 69 Inch</td>
<td>1.88</td>
<td>0.154</td>
</tr>
</tbody>
</table>

Drivers > 69 inch are less likely to sustain Pelvic/Hip fractures in SUV/Light Trucks than in Passenger Cars

<table>
<thead>
<tr>
<th>SUV/Light Trucks</th>
<th>Odds Ratio (OR)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>65-69 Inch : &gt; 69 Inch</td>
<td>0.714</td>
<td>0.683</td>
</tr>
</tbody>
</table>

Drivers > 69 inch are less likely to sustain Pelvic/Hip fractures in SUV/Light Trucks than in Passenger Cars

\[ OR = 0.385 \quad SUV/Light \text{ Trucks} : \text{Passenger Cars} \quad P = 0.171 \]

*P* value is considered statistically significant if < 0.05
## Pelvic/Hip Fracture
### NASS Data Analysis

<table>
<thead>
<tr>
<th></th>
<th>Passenger Cars</th>
<th>SUV/Light Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver’s height played a significant role in Hip/Pelvic fractures</td>
<td>Driver’s height did not play a significant role in Hip/Pelvic fractures</td>
<td></td>
</tr>
<tr>
<td>( OR = 2.70 ) (&lt; 65 \text{ Inch} : 65 \text{ to} 69 \text{ Inch} )</td>
<td>( OR = 1.37 ) ( 65 \text{ to} 69 : &gt; 69 \text{ Inch} )</td>
<td></td>
</tr>
<tr>
<td>( P = 0.027 )</td>
<td>( P = 0.599 )</td>
<td></td>
</tr>
</tbody>
</table>

Drivers > 69 inch are **less likely** to sustain Pelvic/Hip fractures in SUV/Light Trucks than in Passenger Cars

\[ OR = 0.904 \text{ SUV/Light Trucks : Passenger Cars} \ P = 0.827 \]

*\( P \) value is considered statistically significant if \( < 0.05 \)*
## Femur Fracture  
### CIREN Data Analysis

<table>
<thead>
<tr>
<th>Passenger Cars</th>
<th>SUV/Light Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driver’s height played a significant role in Femur fractures</strong></td>
<td>Driver’s height did not play a significant role in Femur fractures</td>
</tr>
</tbody>
</table>
| \( \text{OR} = 2.28 \) 65 to 69 vs. < 65 Inch  
\( P = 0.075 \) | \( \text{OR} = 0.639 \) 65 to 69 vs. > 69 Inch  
\( P = 0.507 \) |
| \( \text{OR} = 2.31 \) < 65 vs. > 69 Inch  
\( P = 0.037 \) |  |

Drivers > 69 inch are **less likely** to sustain Femur fractures in SUV/Light Trucks than in Passenger Cars  
**OR = 0.416** SUV/Light Trucks : Passenger Cars  
\( P = 0.131 \)

\( P \) value is considered statistically significant if < 0.05
# Femur Fracture

## NASS Data Analysis

<table>
<thead>
<tr>
<th>Passenger Cars</th>
<th>SUV/Light Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver’s height played a significant role in Femur fractures</td>
<td>Driver’s height did not play a significant role in Femur fractures</td>
</tr>
</tbody>
</table>

- **Passenger Cars**
  - OR = 2.29 65 Inch : 65 to 69 Inch
  - \( P = 0.075 \)
  - OR = 1.65 65 to 69 Inch : > 69 Inch
  - \( P = 0.154 \)

- **SUV/Light Trucks**
  - OR = 0.436 65 Inch : 65 to 69 Inch
  - \( P = 0.386 \)
  - OR = 0.382 65 to 69 Inch : > 69 Inch
  - \( P = 0.191 \)

Drivers > 69 inch are less likely to sustain Femur fractures in SUV/Light Trucks than in Passenger Cars

\[
\text{OR} = 0.288 \text{ SUV/Light Trucks} : \text{Passenger Cars} \quad P = 0.054
\]

*\( P \) value is considered statistically significant if \( < 0.05 \)
### Knee/Patella

#### CIREN Data Analysis

<table>
<thead>
<tr>
<th></th>
<th>Passenger Cars</th>
<th>SUV/Light Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Taller drivers were less likely to sustain Knee/Patella fractures than shorter drivers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(The results are statistically insignificant)</td>
<td></td>
</tr>
</tbody>
</table>

#### OR and P values

**Passenger Cars**

- **65 to 69: < 65 Inch**:  
  \[ OR = 0.777 \]
  \[ P = 0.674 \]

- **> 69: < 65 Inch**:  
  \[ OR = 0.963 \]
  \[ P = 0.945 \]

**SUV/Light Trucks**

- **65 to 69: < 65 Inch**:  
  \[ OR = 0.818 \]
  \[ P = 0.876 \]

- **> 69: < 65 Inch**:  
  \[ OR = 0.221 \]
  \[ P = 0.081 \]

*P* value is considered statistically significant if *P* < 0.05
Knee/Patella
CIREN Data Analysis

Drivers < 65 inch are more likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars
OR = 1.615 Passenger Cars : SUV/Light Trucks \( P = 0.672 \)

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Drivers 65 to 69 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars
OR = 0.352 SUV/Light Trucks : Passenger Cars \( P = 0.063 \)

-----

Drivers > 69 inch are more likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars
OR = 1.535 Passenger Cars : SUV/Light Trucks \( P = 0.617 \)

\( P \) value is considered statistically significant if \( < 0.05 \)
### Passenger Cars

Taller drivers were less likely to sustain Knee/Patella fractures than shorter drivers

(The results are statistically insignificant)

\[ OR = 0.993 \times \frac{69}{< 65 \text{ Inch}} \]

\[ P = 0.983 \]

Drivers 65 to 69 inch were more likely to sustain Knee/Patella fractures than those < 65 inch

\[ OR = 2.33 \times \frac{65 \text{ to } 69 \text{ Inch}}{< 65 \text{ Inch}} \]

\[ P = 0.236 \]

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### SUV/Light Trucks

Taller drivers were more likely to sustain Knee/Patella fractures than shorter drivers

\[ OR = 2.33 \times \frac{< 65 \text{ Inch}}{65 \text{ to } 69 \text{ Inch}} \]

\[ P = 0.443 \]

\[ OR = 2.05 \times \frac{> 69 \text{ Inch}}{< 65 \text{ Inch}} \]

\[ P = 0.316 \]

\( P \) value is considered statistically significant if \( < 0.05 \)
Knee/Patella
NASS Data Analysis

Drivers < 65 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars
OR = 0.529 Passenger Cars : SUV/Light Trucks  \( P = 0.552 \)

Drivers 65 to 69 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars
OR = 0.374 SUV/Light Trucks : Passenger Cars \( P = 0.119 \)

Drivers > 69 inch are less likely to sustain Knee/Patella fractures in SUV/Light Trucks than in Passenger Cars
OR = 775 Passenger Cars : SUV/Light Trucks \( P = 0.597 \)

\( P \) value is considered statistically significant if \( < 0.05 \)
<table>
<thead>
<tr>
<th>Passenger Cars</th>
<th>SUV/Light Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taller drivers were <strong>less likely</strong> to sustain Tibia/Fibula fractures than shorter drivers</td>
<td>Drivers 65 to 69 inch were <strong>less likely</strong> to sustain Tibia/Fibula fractures than shorter drivers</td>
</tr>
<tr>
<td>( OR = 0.528 ) 65 to 69 : &lt; 65 Inch [ P = 0.148 ]</td>
<td>( OR = 0.618 ) 65 to 69 : &lt; 65 Inch [ P = 0.540 ]</td>
</tr>
<tr>
<td>( OR = 0.607 ) &gt; 69 : &lt; 65 Inch Inch [ P = 0.210 ]</td>
<td>There was <strong>no relationship</strong> between Tibia/Fibula fracture and height &gt; 69 inch</td>
</tr>
<tr>
<td>( OR = 1.000 ) , [ P = 1.00 ]</td>
<td></td>
</tr>
</tbody>
</table>

\( P \) value is considered statistically significant if \( < 0.05 \)
Tibia/Fibula
CIREN Data Analysis

Drivers < 65 inch are more likely to sustain Tibia/Fibula fractures in Passenger Cars than SUV/Light Trucks
\[ \text{OR} = 0.947 \text{ SUV/Light Trucks : Passenger Cars} \quad P = 0.939 \]

Drivers 65 to 69 inch are more likely to sustain Tibia/Fibula fractures in Passenger Cars than SUV/Light Trucks
\[ \text{OR} = 0.673 \text{ SUV/Light Trucks : Passenger Cars} \quad P = 0.433 \]

Drivers > 69 inch are more likely to sustain Tibia/Fibula fractures in SUV/Light Trucks than in Passenger Cars
\[ \text{OR} = 1.109 \text{ Passenger Cars : SUV/Light Trucks} \quad P = 0.852 \]

\( P \) value is considered statistically significant if \( < 0.05 \)
Passenger Cars

Taller drivers were less likely to sustain Tibia/Fibula fractures than shorter drivers

OR = 0.569 65 to 69 : < 65 Inch
P = 0.099

OR = 0.456 > 69 : < 65 Inch
P = 0.013

SUV/Light Trucks

Drivers 65 to 69 inch were less likely to sustain Tibia/Fibula fractures than shorter drivers

OR = 0.571 65 to 69 : < 65 Inch
P = 0.539

Drivers > 69 inch were more likely to sustain Tibia/Fibula fracture than drivers < 65 inch

OR = 1.071 65 to 69 : < 65 Inch
P = 0.930

P value is considered statistically significant if < 0.05
Tibia/Fibula
NASS Data Analysis

Drivers < 65 inch are more likely to sustain Tibia/Fibula fractures in Passenger Cars than SUV/Light Trucks
OR = 0.435 SUV/Light Trucks : Passenger Cars  \( P = 0.286 \)

Drivers 65 to 69 inch are more likely to sustain Tibia/Fibula fractures in Passenger Cars than in SUV/Light Trucks
OR = 0.186 SUV/Light Trucks : Passenger Cars  \( P = 0.007 \)

Drivers > 69 inch are more likely to sustain Tibia/Fibula fractures in Passenger Cars than in SUV/Light Trucks
OR = 0.438 SUV/Light Trucks : Passenger Cars  \( P = 0.157 \)

\( P \) value is considered statistically significant if < 0.05
### Attributable Source of NALEF Injuries
#### Belted Drivers
#### CIREN Data Analysis

<table>
<thead>
<tr>
<th>Source of Injury</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee bolster</td>
<td>40</td>
</tr>
<tr>
<td>Floor (Including Toe Pan)</td>
<td>24</td>
</tr>
<tr>
<td>Left instrumental panel and below</td>
<td>13</td>
</tr>
<tr>
<td>Left side interior surface, excluding hardware or armrest</td>
<td>9</td>
</tr>
<tr>
<td>Foot Control including parking brake</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
## Attributable Source of NALEF Injuries

**Belted Drivers In Passenger Cars**

### CIREN Data Analysis

<table>
<thead>
<tr>
<th>NALEF</th>
<th>Floor (Including Toe Pan)</th>
<th>Foot Control including parking brake</th>
<th>Knee bolster</th>
<th>Left instrumental panel and below</th>
<th>Left side interior surface, excluding hardware or armrest</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur Fracture</td>
<td>Count</td>
<td>0</td>
<td>0</td>
<td>37</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>0</td>
<td>0</td>
<td>63</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>0</td>
<td>0</td>
<td>36</td>
<td>41</td>
<td>14</td>
</tr>
<tr>
<td>Knee/Patella</td>
<td>Count</td>
<td>0</td>
<td>1</td>
<td>17</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>0</td>
<td>3</td>
<td>57</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>0</td>
<td>8</td>
<td>17</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>Pelvis/Hip</td>
<td>Count</td>
<td>5</td>
<td>0</td>
<td>28</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>7</td>
<td>0</td>
<td>39</td>
<td>6</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>7</td>
<td>0</td>
<td>27</td>
<td>12</td>
<td>72</td>
</tr>
<tr>
<td>Tibia/Fibula</td>
<td>Count</td>
<td>63</td>
<td>11</td>
<td>20</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>57</td>
<td>10</td>
<td>18</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>93</td>
<td>92</td>
<td>20</td>
<td>24</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>68</td>
<td>12</td>
<td>102</td>
<td>34</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>25</td>
<td>4</td>
<td>38</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
### Attributable Source of NALEF Injuries

**Belted Drivers In SUV/Light Trucks**

**CIREN Data Analysis**

<table>
<thead>
<tr>
<th>NALEF</th>
<th>Floor (Including Toe Pan)</th>
<th>Foot Control including parking brake</th>
<th>Knee bolster</th>
<th>Left instrumental panel and below</th>
<th>Left side interior surface, excluding hardware or armrest</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur Fracture</td>
<td>Count</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>0</td>
<td>0</td>
<td>72</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>Knee/Patella</td>
<td>Count</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>0</td>
<td>0</td>
<td>70</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Pelvis/Hip</td>
<td>Count</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>0</td>
<td>0</td>
<td>85</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>0</td>
<td>0</td>
<td>31</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Tibia/Fibula</td>
<td>Count</td>
<td>16</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>57</td>
<td>11</td>
<td>4</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>100</td>
<td>100</td>
<td>3</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>Count</td>
<td>16</td>
<td>3</td>
<td>35</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>% within NALEF</td>
<td>22</td>
<td>4</td>
<td>48</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>% within Injury Source</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Biomechanics

Role of Knee Bolster In Non-Ankle Lower Extremity Injuries

Honda Inova Fairfax Hospital CIREN Center
Knee Bolster

- Control Occupant Kinematics in Frontal Crash
- Distribute Lower Extremity Contact Loads
- Absorb Occupant Energy through a Body Region Capable of Accepting Restraining Forces

Culver, 1979
Lower Extremity Injury Research

- Bolster stiffness
- Knee flexion angle
- Gender
- Belt use
- Pre-impact bracing
- Intrusion
Risk of Lower Limb Injury

- Geometry
  - Occupant (Lower Extremity)
  - Vehicle (Knee Bolster, Seat)

Passenger Car → SUV – Light Trucks

5th Female
50th Male
95th Male
THIGH-KNEE LOADING

1. Loading axial to the thigh: potential injury to the knee-thigh-hip complex

   Inertial motion causes contact with instrument panel/knee bolster

2. Loading axial to the leg: potential injury to the knee-leg-ankle complex

   Entrapment between IP and floor pan

3. Loading axial to the entire lower extremity: potential injury to all structures

   Floor pan intrusion
Seating Position

- University of Michigan Transportation Research Institute (UMTRI) (1996-2001)
  - Anthropometric measurements of drivers
  - Dummy Positioning Model (vehicle parameters)
    - 5th Female – 4’ 11” (59”, 151 cm)
    - 50th Male – 5’ 9” (69”, 175 cm)
    - 95th Male – 6’ 2” (74”, 187 cm)

- Insurance Institute for Highway Safety (IIHS) Tests
  - Nissan Titan
  - Nissan Maxima
Lower Extremity Position – Nissan Maxima

- Femur Angle
- Seat Position / H-Point

Legend:
- 5th Female
- 50th Male
- 95th Male
- Bolster
Lower Extremity Position – Nissan Titan

- 5th Female
- 50th Male
- 95th Male
- Bolster
Estimating kinematics

- Estimate lower extremity positions at time of contact with bolster (Culver & Viano, 1979)
  - Stationary ankle position
  - H-Point moved horizontally until contact with bolster
Knee contact
Low on Bolster

Bolsters very similar

5th Female

Maxima Bolster

Titan Bolster

Maxima Seating Position

Titan Seating Position
Knee contact
Knee more flexed in Pass Car

50th Male

Maxima Bolster

Titan Bolster

Maxima Seating Position

Titan Seating Position
Tibia contact
Femur more horizontal in SUV

95th Male

Titan Bolster

Maxima Bolster

Titan Seating Position

Maxima Seating Position
Tibia/Fibula fractures more likely in passenger cars
Possible reasons for increased Tib/Fib injury risk in Passenger Cars

- Knee flexion angle, bolster resistive force
- Increased distance from bolster (also increased knee/patella risk)
Femur and Pelvis/Hip risk increases for taller occupants (Pass Cars)

Tibia/Fib risk decreases for taller occupants (Pass Cars)
Possible reason for decreased Tib/Fib injury risk for taller occupants

Bolster contact below knee

Tibia fractures due to compression more than bending

5th Female

95th Male
Summary

• Preliminary analysis of lower extremity kinematics
  – Occupant Height
    • Initial distance to bolster
    • Anatomic location of bolster contact
  – Vehicle Type
    • Initial distance to bolster
    • Femur angle
    • Knee flexion angle
• May explain some differences in injury patterns
CONCLUSIONS

• The interactions between Driver Height and Vehicle Type play a significant role in the incidence of NALEF injuries

• Eighty-two percent of NALEF injuries are attributable to the Knee Bolster and adjacent areas (Left Instrument Panel, Toe Pan, Foot Control Including Parking Brake)

• Data from CIREN are consistent with data from NASS in most of the analyses presented
RECOMMENDATIONS

• Analyses of the bio-mechanics of car crashes may be of great value in pre-hospital screening for NALEF injuries

• These observations should be considered by health care providers at the crash scene to better manage injured drivers during extrication

• Educational efforts based on these findings may be an effective tool for injury prevention

• The relationship of NALEF injuries and vehicle design require further investigation