Biomechanical Analysis of Brain Injury Lesions from Real World Crashes


CIREN Public Meeting
September 2011
WFU CIREN Brain Project Team

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Brain Injury

• ~1.4 million people sustain a TBI each year
  – TBI from MVCs are a leading cause for hospitalization

• Head injuries second only to thoracic injuries for fatal frontal crashes in NASS-CDS
Anatomy

Meninges

Ventricles
Brain Anatomy – from MR Scans

- Cerebellum
- Ventricles
- White Matter
- Grey Matter
- Brain Stem
- Cerebellum
Brain Anatomy – from Soft Tissue CT Scans

- Grey Matter
- Ventricles
- White Matter
- Brain Stem
- Cerebellum
Biomechanics Paradigm

Outside Vehicle
- Crash Reconstruction
- Crash Characteristics

Inside Vehicle
- Belt Use
- Involved Physical Component
- Airbag Deployment

Outside Occupant
- Scalp Contusion
- Injury Causation Scenario

Internal Injury
- Intracranial Lesion
- Glasgow Coma Scale
- Injury Severity Score
Previous Research on Functional Outcome from Head Trauma

- Trauma to *prefrontal cortex* affects memory concentration, and information processing – associated with patient outcome of *depression and aggression*
- Jorge et al performed a 1 year post trauma neurological assessment in patients with traumatic brain injury
  - Observed trends of depression, anxiety, and aggression
- Trauma to...
  - *corpus callosum* inhibits *attention and memory*
  - *parietal lobes* affects *senses, movement, spatial orientation*
  - *Broca’s area* affects *formation of speech*

Limited research into volumetric analysis of brain injury and functional outcome
Further Studies of Brain Injury

- Blumbergs et al – found axons to be most vulnerable to brain injury esp. corpus callosum and fornices
- Gale et al – Decreasing gray matter concentration in various brain regions associated with lower score of consciousness (glasgow coma scale)
  - Small sample size of 9 subjects
- Wilde et al – Decreased whole brain and total brain gray matter with an increase in total cerebrospinal fluid volume
  - Gray matter loss associated with focal injury
  - White matter loss associated with diffuse and focal injury
- Anderson et al – Decrease in thalamic volume when lesion is present
CIREN Brain Project Goal

• Quantify intracranial injury volume
• Correlate injured volume with crash parameters (mechanical insult)
  – Analyze injury location and expected functional outcome based on structural damage
• Future analyses using biomechanical modeling

This example case was a coup injury with a left-side head strike to the left roof rail in a near side crash with a tree, which was coded as probable and supported by component contact evidence and the side impact PDOF.
Additions to Proposal

• Identify injuries that were not coded and coded injuries that weren’t identified

• Create a CT atlas
  – Standard brain atlas is MR (1 mm isotropic)
  – Problem: Soft Tissue Window CT scans are generally anisotropic with larger slice thickness

• Define common coordinate system between subjects
Methods

1. Download Radiology Report and scans from CIREN database
2. Select Soft Tissue CT of head injury
3. Segment DICOM:
   - Intracranial volume
   - Injured volume
4. Segmentations reviewed by Board Certified Radiologist
5. Segmentations reviewed by Board Certified Neuroradiologist

- Volumetric Analysis
- Spatial Distribution
- Atlas-based registration/segmentation
- Crash Test/SIMon validation
- Brain Rotational Injury Criterion (BRIC)
Contrecoup, Frontal, Driver, Contact at right temporal
Coup, Near side crash, driver, contact at left parietal side of head
Contrecoup, Far side crash, driver, contact at left frontal bone
The CIREN Head-CT DICOM Network

1st DICOM study of intracranial injury to include scans within the CIREN network

Head-CT scans studied from 8/9 previous or current CIREN centers

<table>
<thead>
<tr>
<th>Center</th>
<th>No DICOM Available</th>
<th>DICOM Available</th>
<th>TOTAL</th>
<th>% Total Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltimore</td>
<td>7</td>
<td>46</td>
<td>53</td>
<td>14.11%</td>
</tr>
<tr>
<td>CHOP</td>
<td>0</td>
<td>31</td>
<td>31</td>
<td>9.51%</td>
</tr>
<tr>
<td>Fairfax</td>
<td>3</td>
<td>28</td>
<td>31</td>
<td>8.59%</td>
</tr>
<tr>
<td>MCW</td>
<td>10</td>
<td>45</td>
<td>55</td>
<td>13.80%</td>
</tr>
<tr>
<td>Michigan</td>
<td>2</td>
<td>51</td>
<td>53</td>
<td>15.64%</td>
</tr>
<tr>
<td>San Diego</td>
<td>3</td>
<td>43</td>
<td>46</td>
<td>13.19%</td>
</tr>
<tr>
<td>Seattle</td>
<td>4</td>
<td>45</td>
<td>49</td>
<td>13.80%</td>
</tr>
<tr>
<td>UAB</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>0.00%</td>
</tr>
<tr>
<td>WF</td>
<td>0</td>
<td>37</td>
<td>37</td>
<td>11.35%</td>
</tr>
<tr>
<td>Totals</td>
<td>38</td>
<td>326</td>
<td>364</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Scan Analysis

Total Number Possible Cases 364

Initial DICOM available 296

Total DICOM Available 326

Requested Scans Provided 30

No DICOM available 68

Good Scans 272

Problem Scans 64

Not Available 38

<table>
<thead>
<tr>
<th></th>
<th>Good Resolution</th>
<th>Bad Resolution</th>
<th>Missing Large Portion of Anatomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Tissue CT</td>
<td>267</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Bone Window</td>
<td>5</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>Soft Tissue CT with Contrast</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
DICOM examples – WF CIREN-052

Standard slices – 5 mm thickness, 40 slices

Bone slices – 0.63 mm thickness, 320 slices
Injuries were identified in radiology report and not coded for or injuries were coded but not identified by the neuroradiologist.

<table>
<thead>
<tr>
<th></th>
<th>Injury Identified</th>
<th>Injury Not Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury Coded</td>
<td>537</td>
<td>41</td>
</tr>
<tr>
<td>Injury Not Coded</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

Did not include scans including injuries found after treatment (craniectomy, craniotomy, etc) or from previous injury.
## Top 10 NASS AIS CODES

<table>
<thead>
<tr>
<th>Order</th>
<th>AIS Codes</th>
<th>Injury Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1406843</td>
<td>Subarachnoid hemorrhage</td>
</tr>
<tr>
<td>2</td>
<td>1406784</td>
<td>Intraventricular hemorrhage</td>
</tr>
<tr>
<td>3</td>
<td>1406524</td>
<td>Small subdural hematoma unilateral</td>
</tr>
<tr>
<td>4</td>
<td>1406063</td>
<td>Small unilateral contusion</td>
</tr>
<tr>
<td>5</td>
<td>1406545</td>
<td>Bilateral subdural hematoma</td>
</tr>
<tr>
<td>6</td>
<td>1406465</td>
<td>Bilateral hematoma</td>
</tr>
<tr>
<td>7</td>
<td>1406223</td>
<td>Multiple small contusions</td>
</tr>
<tr>
<td>8</td>
<td>1406285</td>
<td>Diffuse axonal injury</td>
</tr>
<tr>
<td>9</td>
<td>1406623</td>
<td>Mild brain swelling</td>
</tr>
<tr>
<td>10</td>
<td>1406823</td>
<td>Pneumocephalus</td>
</tr>
</tbody>
</table>

The chart shows the percentage of AIS 3+ head injuries in NASS.
<table>
<thead>
<tr>
<th>Number of Good Scans</th>
<th>Number of Coded Intracranial Injuries (excluding Fractures)</th>
<th>Number of Top 10 Intracranial Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>272</td>
<td>475</td>
<td>378</td>
</tr>
</tbody>
</table>

**Distribution of Top 10 Injury Codes**

- SAH: [Bar Height]
- SDH: [Bar Height]
- Unilateral Contusion: [Bar Height]
- IVH: [Bar Height]
- DAI: [Bar Height]
- Mult Contusion: [Bar Height]
- EDH: [Bar Height]
- Pneumo: [Bar Height]
- BiSDH: [Bar Height]
Vocabulary

• Hematoma- a collection of blood in or around the brain
  – Epidural hematoma- blood between skull and dura (outer layer)
  – Subdural hematoma- blood between dura (outer layer) and arachnoid membrane (middle layer)

• Hemorrhage- bleeding
  – Subarachnoid hemorrhage- bleeding between the brain and the thin tissues that covers the brain

• Contusion- bruise

• Edema- abnormal accumulation of fluid (swelling)
Identifying and Masking Specific Injuries

- Identified injured brain tissue based on Radiology Report description and common injury identifiers
  - Subarachnoid Hemorrhage (SAH)
  - Subdural Hematoma (SDH)
  - Epidural Hematoma (EDH)
  - Cerebral Contusion or Intracerebral Hemorrhage
  - Intraventricular Hemorrhage (IVH)
  - Diffuse Axonal Injury (DAI)
  - Pneumocephalus

- Segmented using a semi-automated method of thresholding and dynamic region growing
Subarachnoid Hemorrhage Background

- The Subarachnoid space exists between the arachnoid mater and the pia mater
- This space contains blood vessels and CSF that flows between the ventricular system and dural venous sinuses in the brain
- Hemorrhage in this space occurs when blood vessels rupture
SAH Background Continued

- Hemorrhage is allowed to enter the sulci of the brain and conform to gyri
- Often there is more a “diffuse” presentation of SAH with less clearly defined borders compared to SDH or EDH
- SAH is seen best when the image contrast is darkened so the lighter SAH stands out better
Subarachnoid Hemorrhage
Subarachnoid Hemorrhage
Subdural Hematoma (SDH)

- Occurs when blood enters the space between the dura mater and arachnoid mater
- Often because of ruptured bridging veins
- Classically defined as being “crescent shaped”
- Unlike Epidural Hematomas, SDH’s can cross suture lines and therefore enter the tentorium cerebelli and falx cerebri (parafalcine)
Subdural Hematoma
Subdural Hematoma
Epidural Hematoma (EDH)

- Often the result of ruptured meningeal arteries, with the middle meningeal artery being a common culprit.
- Described as having a “lentiform” shape or lens shape.
- Do not extend beyond sutures lines and therefore do not enter the falx cerebri or tentorium cerebelli – helpful in distinguishing from Subdural Hematomas.
Epidural Hematoma
Epidural Hematoma
Cerebral Contusion, Intracerebral Hemorrhage

- Blood is extravasated into the brain parenchyma
- Visualized by area of hyperattenuation – areas that look more white
- Often surrounded by hypoattenuation indicative of edema
Unilateral Contusion
Multiple Contusions
Multiple Contusions
Intraventricular Hemorrhage

- Occurs when blood collects in the ventricular system of the brain
- Because of supine position in scanner, blood might be described as being “pooled” or “layered” in the occipital horns of the lateral ventricles
- Hyperattenuations can be seen in ventricles that are not blood, but rather calcified choroid plexus
Intraventricular Hemorrhage
Intraventricular Hemorrhage
Intraventricular Hemorrhage
Diffuse Axonal Injury (DAI)

• Myelinated axons make up the white matter of the brain - these are often seen at the gray/white junction where brain tissue of different densities is sheared apart.

• DAI’s often result from “shearing forces” that happen during rapid linear acceleration or deceleration. DAI can also result from rotational forces.

• Because of the type of force responsible, there is less often “focal” injury, but can be seen in a more diffuse pattern.
Diffuse Axonal Injury
Pneumocephalus

• As the name implies, this is when air exists within the cranium
• Can be extradural, subdural, subarachnoid, intracerebral, and intraventricular
Pneumocephalus
Segment Intracranial Volume

- Thresholding techniques used to identify the bone and soft tissue
- Region growing separated the soft tissue: brain and skin masks
- A boolean operation was used to isolate the intracranial volume
Calculate Injured Volume

- Pneumocephalus
- Subdural Hematoma
- Multiple Contusions

\[
\text{Intracranial Volume} = \text{Number of Injured Pixels} \times \text{Voxel Size} \\
\% \text{ Injured Volume} = \frac{\text{Intracranial Volume}}{\text{Intracranial Volume}} \times 100
\]
Brain
Subdural Hematoma
Contusion
Results
Study Group

• 137 Female
  (2 pregnant – 1st trimester, 2nd trimester)
• 135 Male

254 Non-Fatal
18 Fatal
General Injury Totals

- SAH
- SDH
- Contusion
- IVH
- DAI
- Intracerebral Hematoma
- Multiple contusions
- EDH
- Pneumocephalus
- Other injuries
- Vault Fracture
- Base fracture
Subdural Hematoma Statistical Analysis

Multivariate Analysis
One-way ANOVA

Dependent Variables
Injury Data
% Subdural Volume

Independent Variables
Crash Characteristics
Delta V/ Barrier Estimate Speed
Maximum Crush

Contact Information
Airbag Use
Involved Physical Component
Injury Location

Occupant Data
Age
Subdural Hematoma Statistical Analysis

Multivariate Analysis

Dependent Variables
- Injury Data
- % Subdural Volume

Independent Variables
- Crash Characteristics
  - Delta V/ Barrier Estimate Speed
  - Maximum Crush
- Contact Information
  - Airbag Use
  - Involved Physical Component
  - Injury Location
- Occupant Data
  - Age
## % Subdural Volume – Crash Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>By Variable</th>
<th>Correlation</th>
<th>p-value</th>
<th>n</th>
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<tbody>
<tr>
<td>Far</td>
<td>% SDH</td>
<td>Maximum Crush</td>
<td>+</td>
<td>**0.0216</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DeltaV/BES</td>
<td>+</td>
<td>0.1177</td>
</tr>
<tr>
<td>Frontal</td>
<td>% SDH</td>
<td>Maximum Crush</td>
<td>+</td>
<td>0.5999</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DeltaV/BES</td>
<td>+</td>
<td>0.6032</td>
</tr>
<tr>
<td>Near</td>
<td>% SDH</td>
<td>Maximum Crush</td>
<td>+</td>
<td>0.1136</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DeltaV/BES</td>
<td>+</td>
<td>*0.0867</td>
</tr>
<tr>
<td>All Crash Type Combined</td>
<td>% SDH</td>
<td>Maximum Crush</td>
<td>+</td>
<td>*0.1612</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DeltaV/BES</td>
<td>+</td>
<td>0.1066</td>
</tr>
</tbody>
</table>
% Subdural Hematoma Volume increases with:

- Delta V/barrier estimate speed in Near Side Crashes (*p=0.0867)
- Maximum crush in Far Side Crashes (p=0.00216)
- Maximum crush when looking at all crash modes (p=0.0612)
Subdural Hematoma Statistical Analysis

One-way ANOVA

Dependent Variables

- Injury Data
  - % Subdural Volume

Independent Variables

- Crash Characteristics
  - Delta V/Barrier Estimate Speed
  - Maximum Crush

- Contact Information
  - Airbag Use
  - Involved Physical Component
  - Injury Location

- Occupant Data
  - Age
Certain and Probable IPC Distribution – Subdural Hematoma
IPC Weighting

• Scoring system created to consider all IPC’s without preference to injuries coded multiple times
  – 1 certain or 1 probable: 1
  – 2 probables: 0.5 each
  – 2 possibles: 0.5 each
  – 1 probable, 1 possible: 0.66 vs 0.33
  – 1 possible, 1 unknown: 0.66 vs 0.33
% Subdural Volume – IPC
Near Side Crash
Certain, Probable, Possible IPC

Small sample size for other contacts
% Subdural Volume – IPC
Frontal Crash

Weighted Certain, Probable, Possible IPC

Sample size for each contact too small for statistical significance
% Subdural Volume – IPC
Far Side Crash

Weighted Certain, Probable, Possible IPC

Small sample size for other and right side contact
Subdural Hematoma: Airbag Use

Deploy = D
Not Deployed/Not available = ND
*= Mildly Significant
p=0.05-0.1
**=Statistically Significant
p<0.05
Subdural Hematoma: Airbag Use

Mean % subdural volume significantly greater when roof side rail AB was not deployed in nearside crash.

Deploy = D
Not Deployed/ Not available = ND
*= Mildly Significant
p=0.05-0.1
**=Statistically Significant
p<0.05
Mean total % injured volume is greater in contrecoup injuries compared to subdural injuries within the falx.
Intracranial Injury Location by Crash Type

- Coup
- Contrecoup
- Falx

% of Total within Crash Type

- Frontal
- Near
- Far
Subdural Hematoma Statistical Analysis

Bivariate Analysis

**Independent Variables**

<table>
<thead>
<tr>
<th>Crash Characteristics</th>
</tr>
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<tbody>
<tr>
<td>Delta V/ Barrier Estimate Speed</td>
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<tr>
<td>Maximum Crush</td>
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</table>

<table>
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<tr>
<th>Contact Information</th>
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<tbody>
<tr>
<td>Airbag Use</td>
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<tr>
<td>Involved Physical Component</td>
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<td>Injury Location</td>
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<table>
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<tr>
<th>Occupant Data</th>
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<tbody>
<tr>
<td>Age</td>
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**Dependent Variables**

<table>
<thead>
<tr>
<th>Injury Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Subdural Volume</td>
</tr>
</tbody>
</table>
Total % injured volume increases with age in those with Subdural Injuries in Near Side Crashes (*p=0.0025)

% Subdural volume increases with age in Near Side Crashes (*p=0.0259)
## Subdural Hematoma Statistical Analysis

### Bivariate Analysis

<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>Independent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neurological Assessment</strong></td>
<td><strong>Crash Characteristics</strong></td>
</tr>
<tr>
<td>Glasgow Coma Scale</td>
<td>Delta V/ Barrier Estimate Speed</td>
</tr>
<tr>
<td></td>
<td>Maximum Crush</td>
</tr>
</tbody>
</table>
Glasgow Coma Scale

GCS score at crash site decreases with increasing C max in Near Side Crashes (*p=0.0274)

GCS – measurement of conscious state of person

Verbal
Motor
Eye
CT Atlas
CT Brain Atlas

- Create CT brain atlas from normal subjects in ICBM space
- Atlas-based segmentation used to identify injured structure and predicted functional outcome
Skull Stripping CT Scan

This is necessary to ease normalization to CT atlas for atlas-based segmentation
Skull Strip CT Scan

- Apply brain label map as a mask
- Set all pixels outside the mask (i.e. not matching the label value) to zero
- Result is skull-stripped CT scan for image registration
Spatial Distribution
Common Coordinate System

- Common brain coordinate system established from bony landmarks on the skull
  - Nasion
  - Right & Left External Auditory Meatus (EAM)
- Translate brain origin to global origin
- Rotate to global axes
- Rotate nasion along positive x-axis
Transform to Global Coordinate System
Transform to Global Coordinate System

• Convert to azimuth and elevation for analysis
Example: SPAK – “Spherical Package”

- Analyzing and plotting spherical localization data
- Kent Distribution
  - G: mean directional distribution
  - Kappa: degree of concentration
  - Beta: ovalness parameter
- k/beta describes if the data is unimodal or bimodal
- This measures azimuth and elevation
  - Plan to examine azimuth, elevation, and depth within the brain
Spatial Distribution
Injury Metrics: CSDM

- Cumulative Strain Damage Measure, CSDM
- Based on hypothesis that DAI is associated with cumulative volume of brain tissue experiencing tensile strains over a critical level
- Maxwell axotomy study

Takhounts et al, 2003 & 2011
BRIC (brain rotational injury criterion)
BRIC

• BRIC = brain rotational injury criterion (kinematic brain injury criteria)
• Developed from translational and rotational data obtained from college football players
• Linear relationship between CSDM and BRIC
• BRIC = 1 when CSDM = 0.425, 30% prob of DAI/AIS 4+ using AIS 2005

Taknounts et al. 2011
Future Work - Validation

• This data includes real world impact conditions that can be applied to SIMon for development and validation of BRIC
• Utilize this data to compare injury location and impact location to the applied linear and rotational acceleration and resulting anatomical locations of strain

Input Condition from patient data  
Response of the model
Future work - Comparisons

- For cases scoring well in similarity scoring with crash tests (NHTSA and IIHS), head contacts can be investigated between CIREN occupants and ATDs
  - May provide important information about translational vs rotational mechanisms for specific brain injuries based upon PDOF and IPC
- Work has begun – collected comparison crash test for each CIREN occupant with a subdural injury
Conclusions

• This is the first study that has analyzed real-world brain injuries, volumes, and known impacts
• CIREN DICOM acquisition is complete
• All injuries, brains, skulls have been segmented
• Neuroradiologist is finishing up injury review
• Spatial distribution has been coded
• Skull stripping has been completed on all cases
Conclusions Continued

• Subdural hematoma is positively correlated with many crash characteristics in various crash modes

• % Subdural Volume increases with:
  – Delta V/barrier estimate speed in near side crashes
  – Maximum crush in far side crashes
Conclusions Continued

• Subdural analysis shows that.....
  – Mean % subdural volume is greater in farside crashes when contact is made with the b-pillar
  – Mean % subdural volume is greater in frontal crashes when contact is made with the header
  – Mean total % injured volume are greater in coup and contrecoup injuries compared to subdural injuries within the falx
  – % Subdural volume increases with age in Near Side Crashes
  – The most common location for subdural in frontal crashes is in the falx, in near side crashes is contrecoup, and in far side crashes is coup
Limitations

• Scan quality – in-plane resolution, scan artifact
• Scan resolution – often 0.488 x 0.488 x 5 mm
  – Total injured volume may be missed within 5 mm slice thickness
• Limited by what is available in the database
• Currently looking at % injury within intracranial volume
  – Utilizing atlas-based segmentation will allow volumes to be analyzed per region or structure within the brain
THANK YOU!
National Highway Traffic Safety Administration
CIREN Partner Centers
WFU-VT CIB Summer Interns:
Rachel, Andrew, Colston, Kavya, Pavani, Jaclyn

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Scan Date

Mean    13.179688
Std Dev  9.5543306
Std Err Mean  0.5971457
Upper 95% Mean  14.355653
Lower 95% Mean  12.003722

Days post crash
% Subdural Hematoma Volume Distribution by Case
Far Side Crash

Subdural Injury Volume

- B-pillar
- Door Panel
- Exterior
- Other
- Right side contact
Near Side Crash

![Graph showing subdural injury volume across different parts of a vehicle.](image-url)
Contrecoup, Frontal, Driver, Contact at right temporal
Coup – Right Front Passenger
Max isolated velocity - X

Off-axis pulses magnitudes are less than 30% of the primary pulse
Contrecoup – Frontal, Driver
Max isolated velocity- Z

Off-axis pulses magnitudes are less than 30% of the primary pulse
Frontal contrecoup – Frontal, Driver
<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Car</td>
<td>128</td>
</tr>
<tr>
<td>Truck</td>
<td>20</td>
</tr>
<tr>
<td>Van</td>
<td>10</td>
</tr>
<tr>
<td>SUV</td>
<td>31</td>
</tr>
</tbody>
</table>

### Crash Type

- **Frontal**: Number of cases of head injuries for frontal crashes.
- **Narrow Offset Frontal**: Number of cases of head injuries for narrow offset frontal crashes.
- **Rollover**: Number of cases of head injuries for rollover crashes.
- **Rear**: Number of cases of head injuries for rear crashes.
- **Under**: Number of cases of head injuries for under crashes.

#### Right Front Passenger
- Right Front Passenger

#### Driver
- Driver

<table>
<thead>
<tr>
<th>Crash Scenario</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Far Side</td>
<td>35</td>
</tr>
<tr>
<td>Near Side</td>
<td>97</td>
</tr>
</tbody>
</table>
# Preliminary Research: Top 10 Major Intracranial Injuries in CIREN

Top AIS 3+ brain injuries within the intracranial volume for 2005+ cases

<table>
<thead>
<tr>
<th>Order</th>
<th>AIS Codes</th>
<th>Number of Occurrences</th>
<th>Injury Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1406843</td>
<td>190</td>
<td>*cerebrum, supratentorial, anterior cranial fossa, or middle cranial fossa subarachnoid hemorrhage</td>
</tr>
<tr>
<td>2</td>
<td>1406524</td>
<td>95</td>
<td>*cerebrum small subdural hematoma unilateral</td>
</tr>
<tr>
<td>3</td>
<td>1406063</td>
<td>49</td>
<td>*cerebrum small unilateral contusion</td>
</tr>
<tr>
<td>4</td>
<td>1406784</td>
<td>41</td>
<td>*cerebrum, supratentorial, anterior cranial fossa, or middle cranial fossa intraventricular hemorrhage or intracerebral hematoma in ventricular system</td>
</tr>
<tr>
<td>5</td>
<td>1406285</td>
<td>33</td>
<td>*cerebrum diffuse axonal injury</td>
</tr>
<tr>
<td>6</td>
<td>1406404</td>
<td>28</td>
<td>cerebrum small hematoma unilateral</td>
</tr>
<tr>
<td>7</td>
<td>1406223</td>
<td>19</td>
<td>*cerebrum multiple small contusions</td>
</tr>
<tr>
<td>8</td>
<td>1406324</td>
<td>14</td>
<td>cerebrum small epidural hematoma</td>
</tr>
<tr>
<td>9</td>
<td>1406823</td>
<td>14</td>
<td>*cerebrum, supratentorial, anterior cranial fossa, or middle cranial fossa pneumocephalus</td>
</tr>
<tr>
<td>10</td>
<td>1406545</td>
<td>9</td>
<td>*cerebrum bilateral subdural hematoma</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>492</td>
<td></td>
</tr>
</tbody>
</table>

* Indicates AIS codes found on both CIREN and NASS-CDS top 10 lists
Preliminary Research: Top 10 Major Intracranial Injuries in NASS-CDS

Top AIS 3+ brain injuries within the intracranial volume for 2000-2009 cases

<table>
<thead>
<tr>
<th>Order</th>
<th>AIS Codes</th>
<th>Raw N</th>
<th>Weighted N</th>
<th>Injury Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1406843</td>
<td>2986</td>
<td>149117</td>
<td>*cerebrum, supratentorial, anterior cranial fossa, or middle cranial fossa subarachnoid hemorrhage</td>
</tr>
<tr>
<td>2</td>
<td>1406784</td>
<td>682</td>
<td>45870</td>
<td>*cerebrum, supratentorial, anterior cranial fossa, or middle cranial fossa intraventricular hemorrhage or intracerebral hematoma in ventricular system</td>
</tr>
<tr>
<td>3</td>
<td>1406524</td>
<td>611</td>
<td>34412</td>
<td>*cerebrum small subdural hematoma unilateral</td>
</tr>
<tr>
<td>4</td>
<td>1406063</td>
<td>328</td>
<td>24239</td>
<td>*cerebrum small unilateral contusion</td>
</tr>
<tr>
<td>5</td>
<td>1406545</td>
<td>358</td>
<td>19461</td>
<td>*cerebrum bilateral subdural hematoma</td>
</tr>
<tr>
<td>6</td>
<td>1406465</td>
<td>207</td>
<td>19240</td>
<td>cerebrum bilateral hematoma</td>
</tr>
<tr>
<td>7</td>
<td>1406223</td>
<td>257</td>
<td>18637</td>
<td>*cerebrum multiple small contusions</td>
</tr>
<tr>
<td>8</td>
<td>1406285</td>
<td>364</td>
<td>18544</td>
<td>*cerebrum diffuse axonal injury</td>
</tr>
<tr>
<td>9</td>
<td>1406623</td>
<td>278</td>
<td>17678</td>
<td>cerebrum, supratentorial, anterior cranial fossa, or middle cranial fossa mild brain swelling (compressed ventricle(s) w/o compressed brain stem cisterns)</td>
</tr>
<tr>
<td>10</td>
<td>1406823</td>
<td>346</td>
<td>17485</td>
<td>*cerebrum, supratentorial, anterior cranial fossa, or middle cranial fossa pneumocephalus</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>6417</strong></td>
<td><strong>364683</strong></td>
<td></td>
</tr>
</tbody>
</table>

* Indicates AIS codes found on both CIREN and NASS-CDS top 10 lists
Using SQL: cases that had radiology linked to specific head injuries since 2005

Using SQL: cases that didn’t have DICOMs linked to specific head injuries

Requested applicable DICOMs from CIREN case centers

Checked each DICOM for correct images for the injury

Segmented injury and total brain

Received DICOMs

Manually downloaded each DICOM for each case from the DB

Correct DICOM

Incorrect DICOM
369 cases with skull fx or brain inj

Took Jan 2011 case list and joined with injuries file

146 cases without DICOMS for each skull fx/brain inj

Took Jan 2011 cases and injuries and joined with March 2011 SQL cases with DICOM file, then removed rows with DICOMS, leaving rows without DICOMS

Note: There were some cases that had DICOMS linked to some head inj and not for other inj – those cases will show up in the DICOM and non-DICOM lists. This also includes “new” cases that may not be completed in the database yet.
Head Injury Case Selection

Took March 2011 SQL case list and down-selected based on CPT codes for radiology corresponding to Head CT & MRI

Down-selected based on AIS codes (1998 & 2005) for skull or brain injuries

Created code to tally each type of injury separately and output totals

1225 cases, March 2011, SQL Query
CIREN cases with DICOMS linked to injuries

396 cases with Head CT (393) or MRI (4) (one case has both Head CT and MR)

244 cases with Skull fx or Brain Inj (1 case with only MR)

Brain Only = 158 (1 case with only MR)
Skull Only = 30
Brain & Skull = 56

Legend
= down-select
= categories

Note: These are estimates of cases with DICOMS uploaded and does not include cases that may have to be excluded for poor image quality. This will also be reduced if we focus on a particular crash type or head injury contact or if the head injury is so small that it can not be accurately segmented.
All injuries since crash date 2005
16661 rows

All Injuries
(5.11.11 sql)
41152 rows

CIREN without DICOMS

All injuries since crash date 2005
16661 rows

Spec brain and skull injuries since crash date 2005
646 rows

Combined: Spec brain and skull injuries w & w/o rad
since crash date 2005
987 rows

Rows with brain/skull inj since 2005 w/o rad
164 rows – which is 88 cases

Head Injuries with rad
(5.11.11 sql)
1330 rows

Spec brain and skull injuries with rad
(5.11.11 sql)
823 rows

All Injuries with rad
(5.11.11 sql)
8624 rows