# Biomechanical Analysis of Brain Injury Lesions from Real World Crashes

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CIREN Public Meeting

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Wake Forest School of Medicine

Wake Forest University
School of Medicine
CIREN Center

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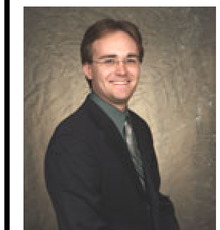

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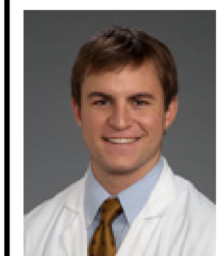
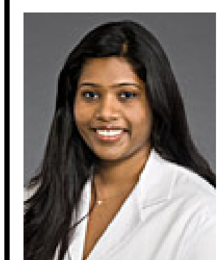
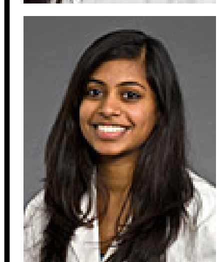


Colston Edgerton



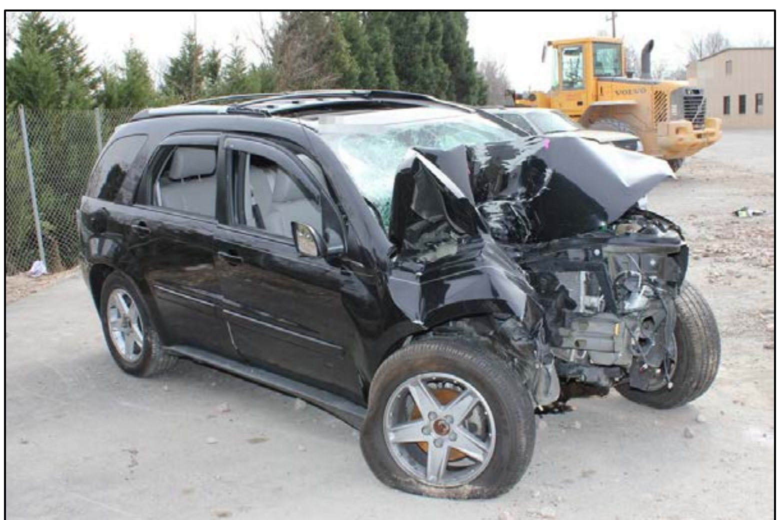
Kavya Reddy

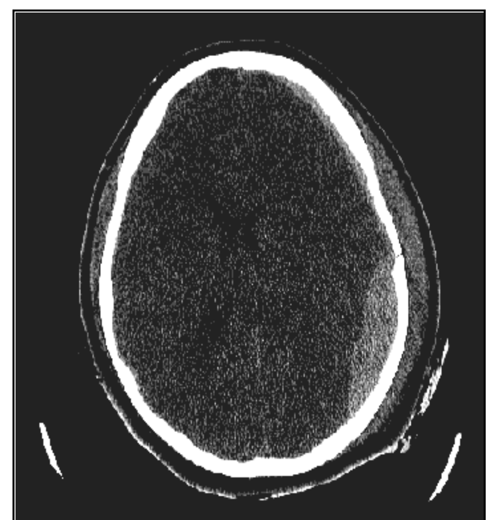


Pavani Thotakura

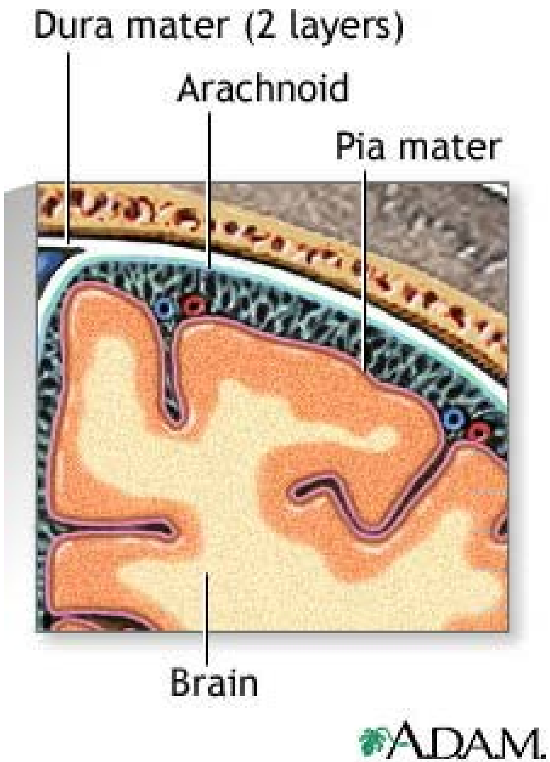
# Brain Injury

- ~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

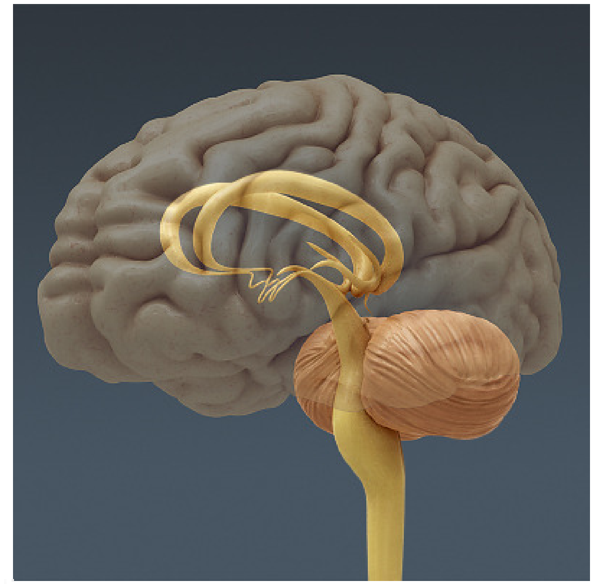




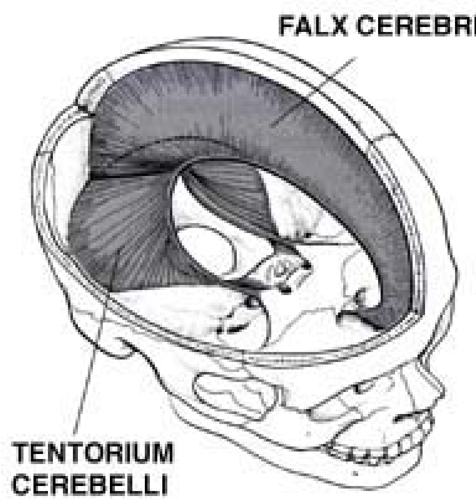
# Anatomy



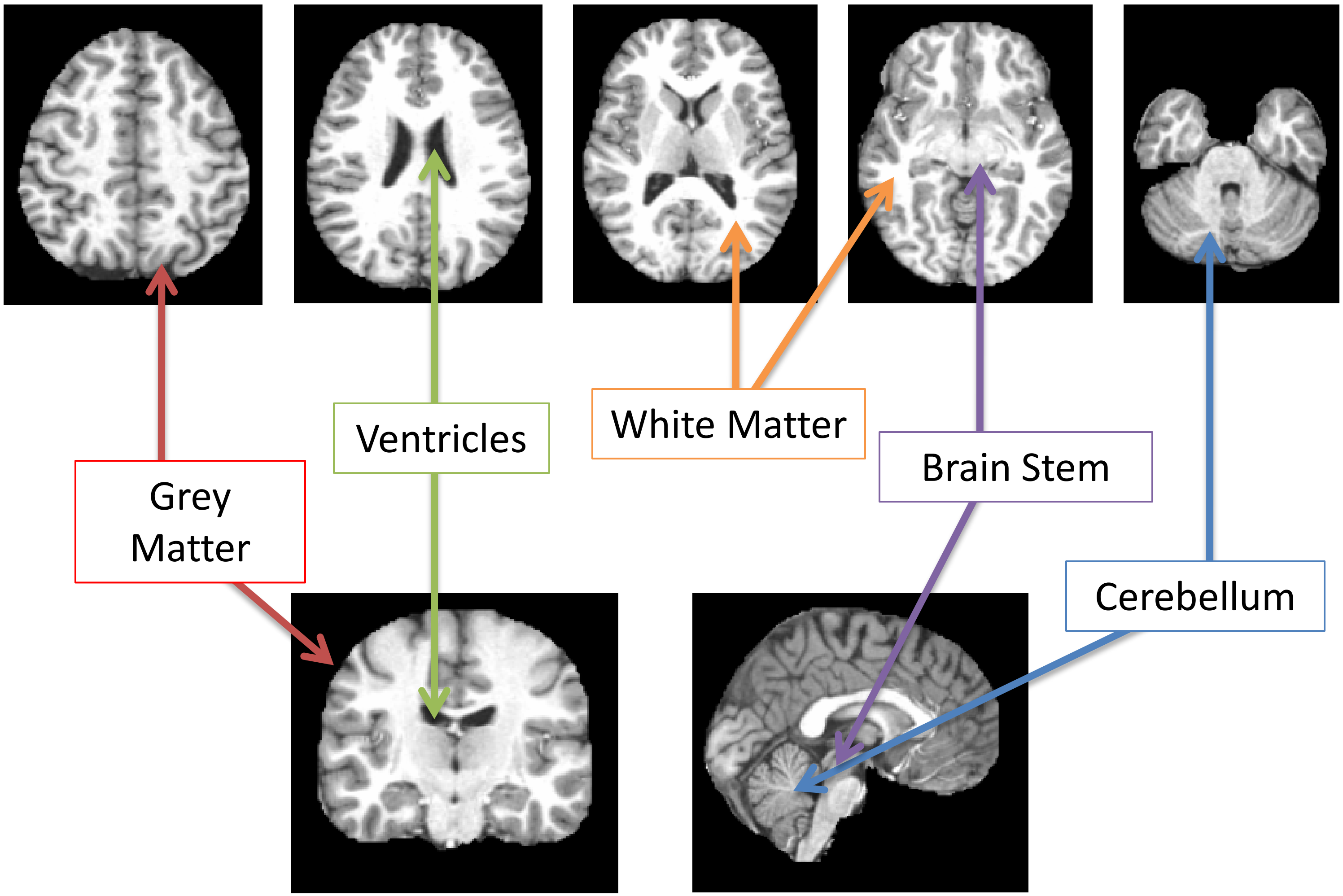

Meninges



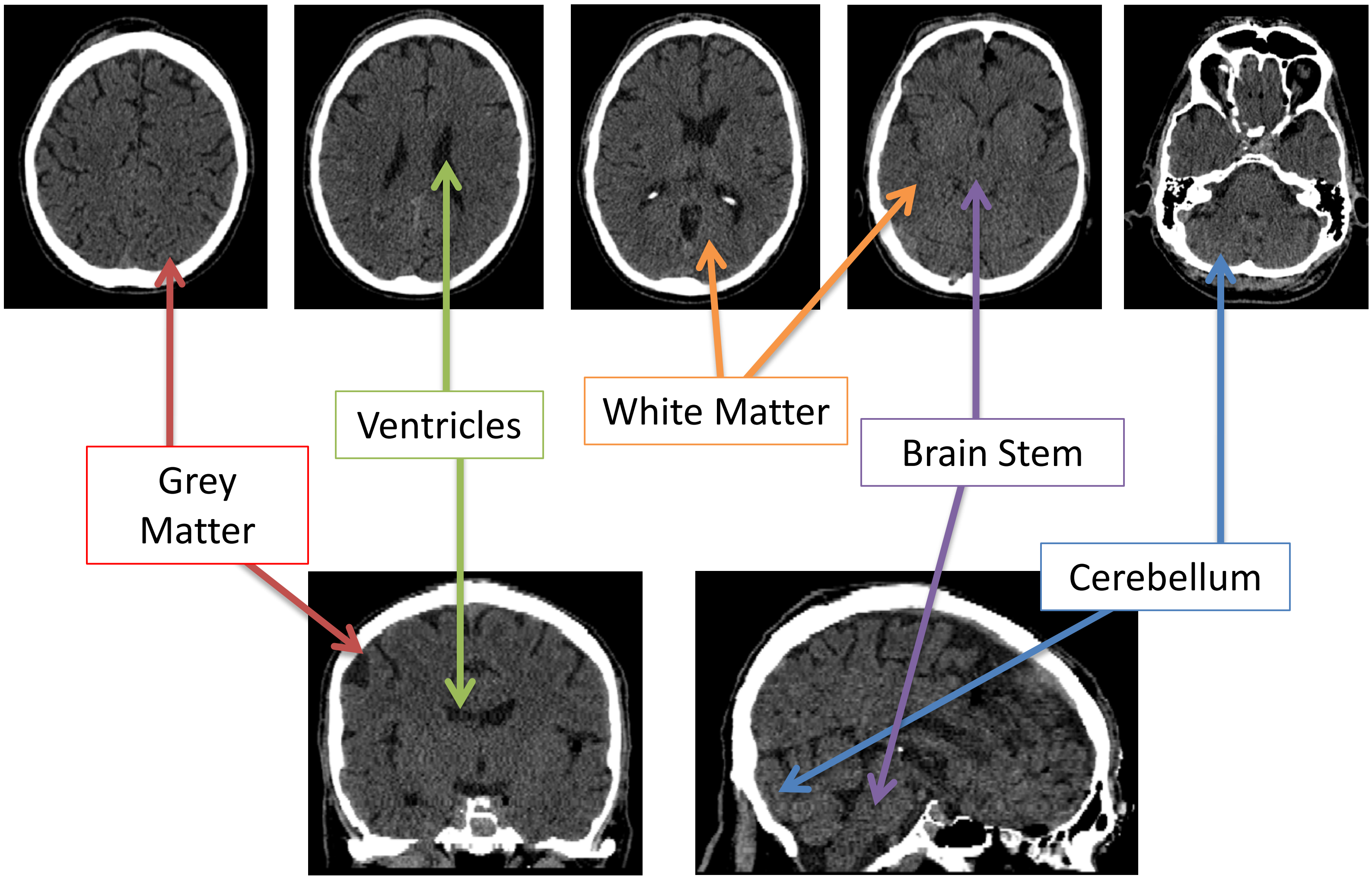
Ventricles



# Brain Anatomy – from MR Scans



# Brain Anatomy – from Soft Tissue CT Scans



# Biomechanics Paradigm

**Outside Vehicle**

Crash Reconstruction

Crash Characteristics

**Inside Vehicle**

Belt Use

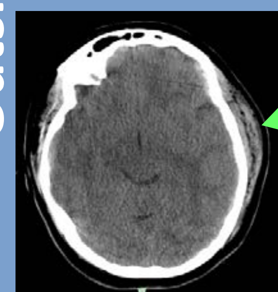
Involved Physical Component

Airbag Deployment

**Outside Occupant**

Scalp Contusion

Injury Causation Scenario

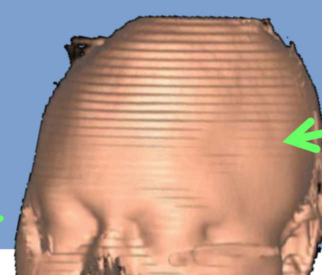


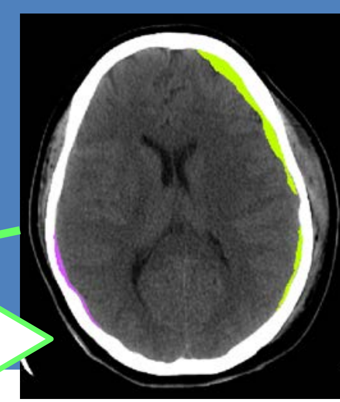
**Internal Injury**

Intracranial Lesion

Glasgow Coma Scale

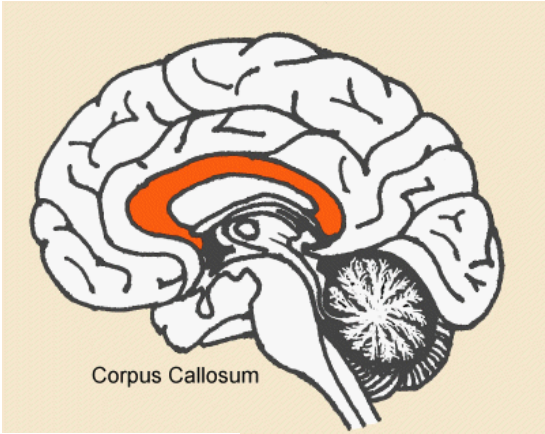
Injury Severity Score



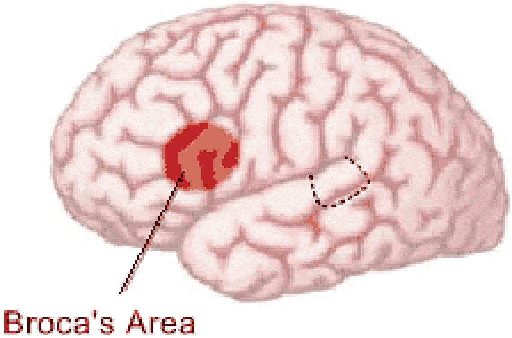


# Previous Research on Functional Outcome from Head Trauma

- 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 speech*

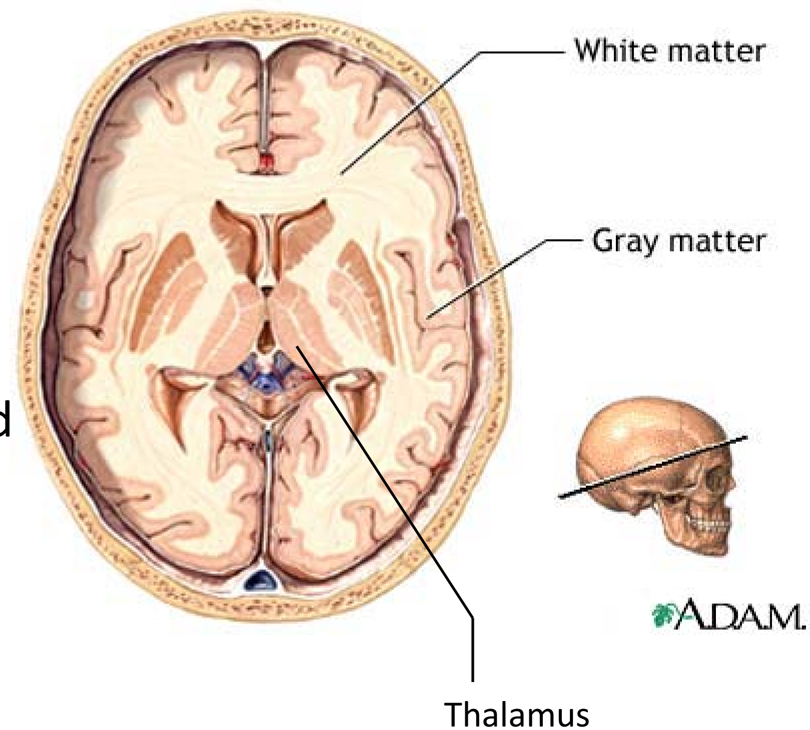



Limited research into volumetric analysis of brain injury and functional outcome



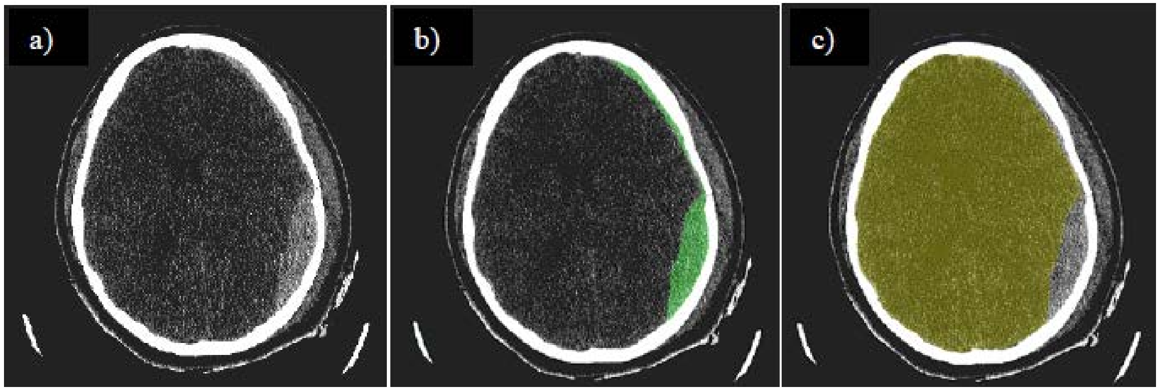
# Further Studies of Brain Injury

- 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

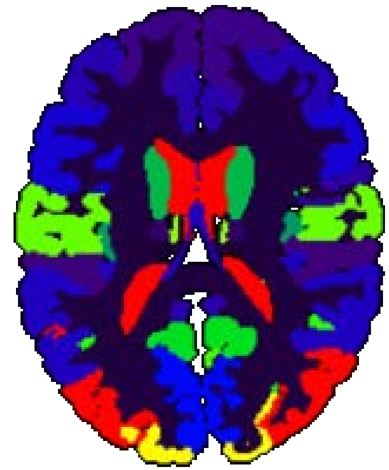
- Quantify intracranial injury volume
- Correlate injured volume with crash parameters (mechanical insult)
  - Analyze injury location and expected functional outcome based on structural damage
- Future analyses using biomechanical modeling



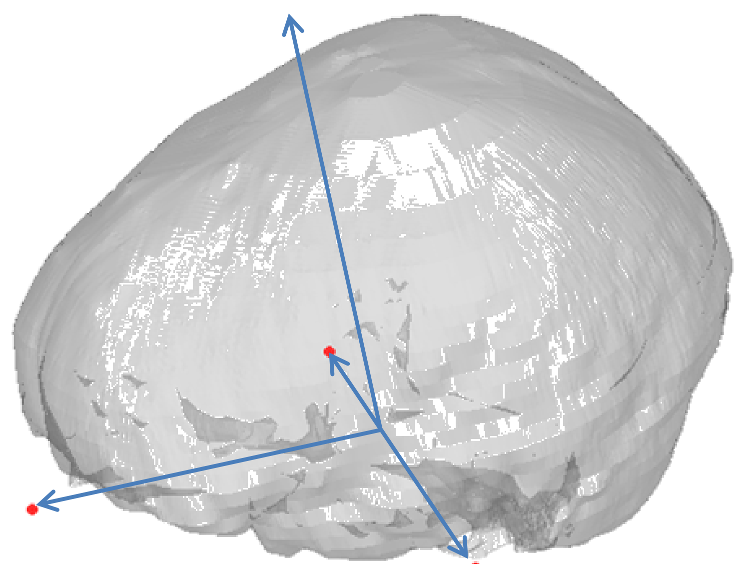

This example case was a coup injury with a left-side head strike to the left roof rail in a near side crash with a tree, which was coded as probable and supported by component contact evidence and the side impact PDOF.

# Additions to Proposal

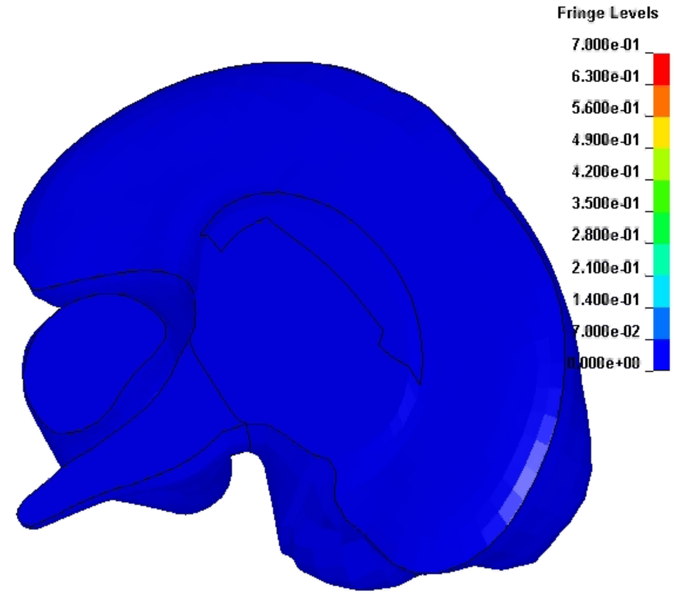
- Identify injuries that were not coded and coded injuries that weren't identified
- Create a CT atlas
  - Standard brain atlas is MR (1 mm isotropic)
  - Problem: Soft Tissue Window CT scans are generally anisotropic with larger slice thickness
- Define common coordinate system between subjects



ICBM Atlas



# Methods




Download Radiology Report and scans from CIREN database

Select Soft Tissue CT of head injury

Segment DICOM:

Intracranial volume

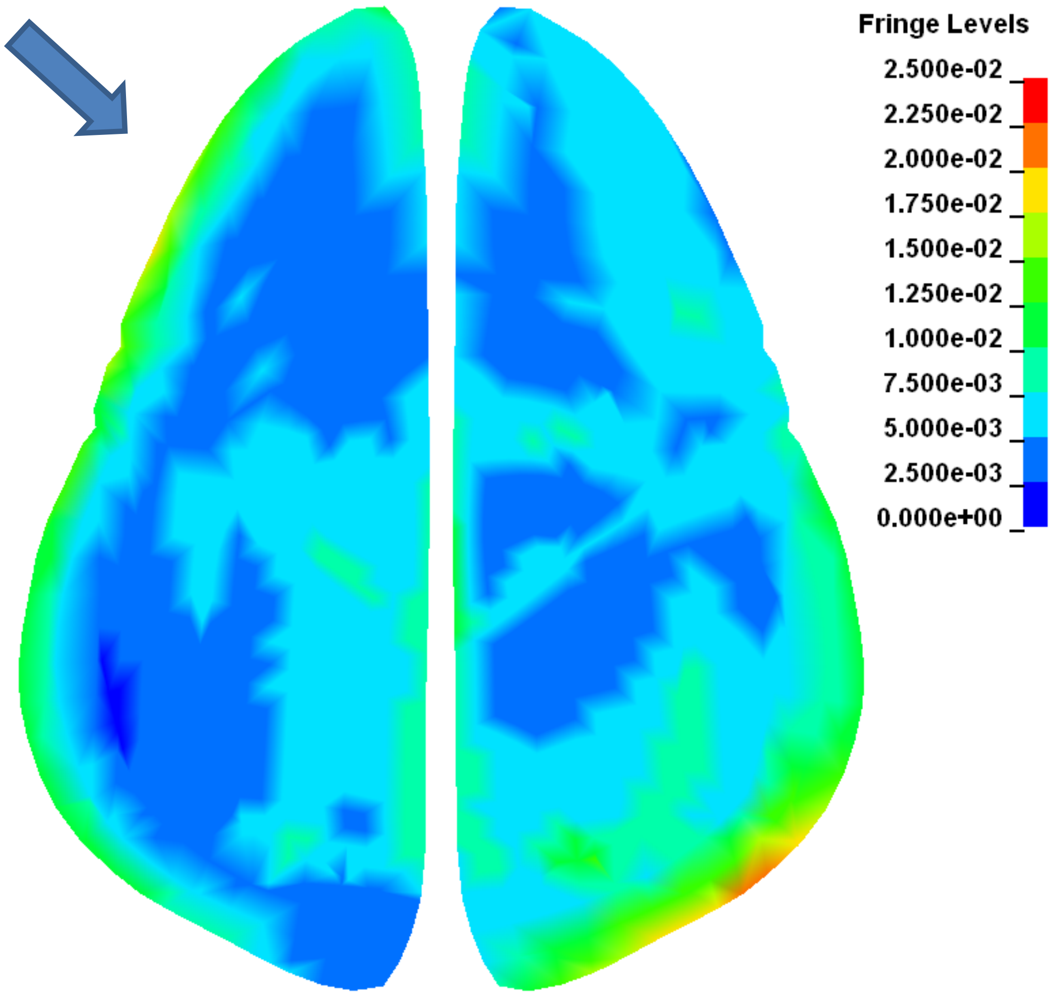
Injured volume

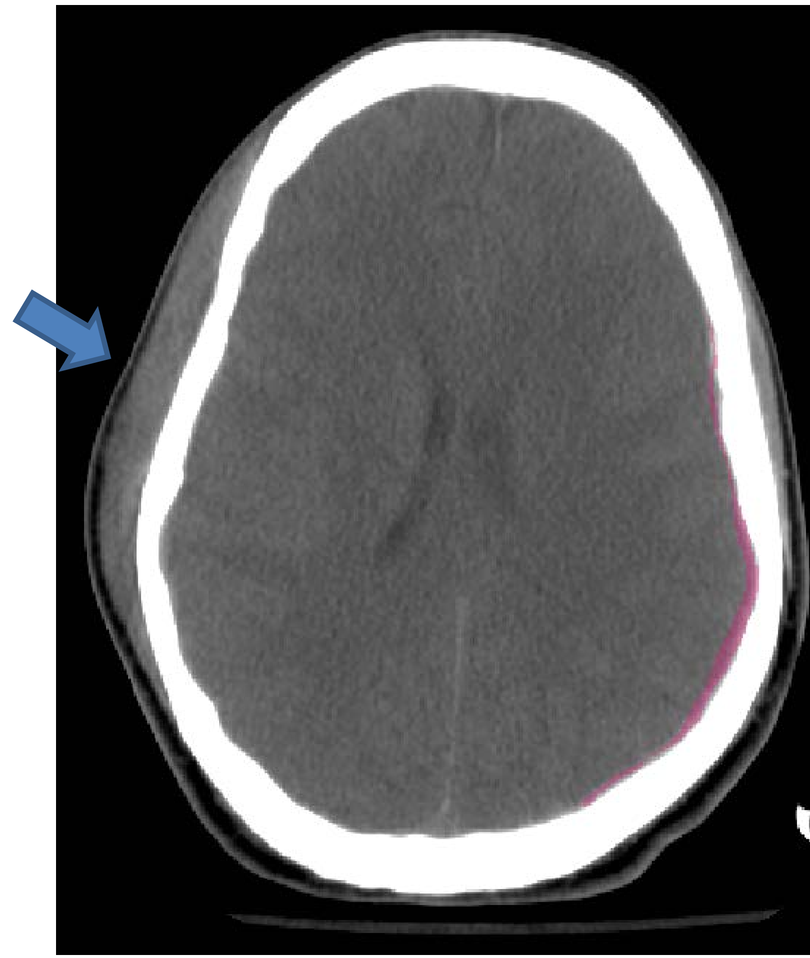
Segmentations reviewed by Board Certified Radiologist

Segmentations reviewed by Board Certified Neuroradiologist

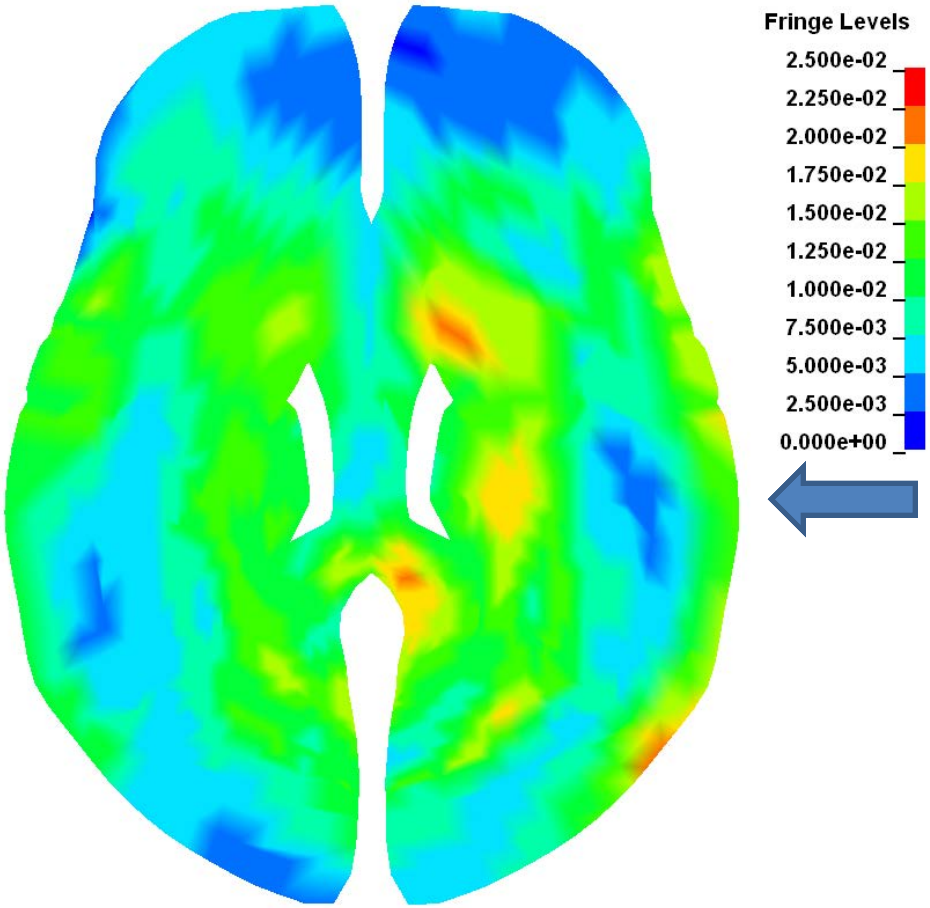
- **Volumetric Analysis**
- **Spatial Distribution**
- **Atlas-based registration/segmentation**
- **Crash Test/SIMon validation**
- **Brain Rotational Injury Criterion (BRIC)**

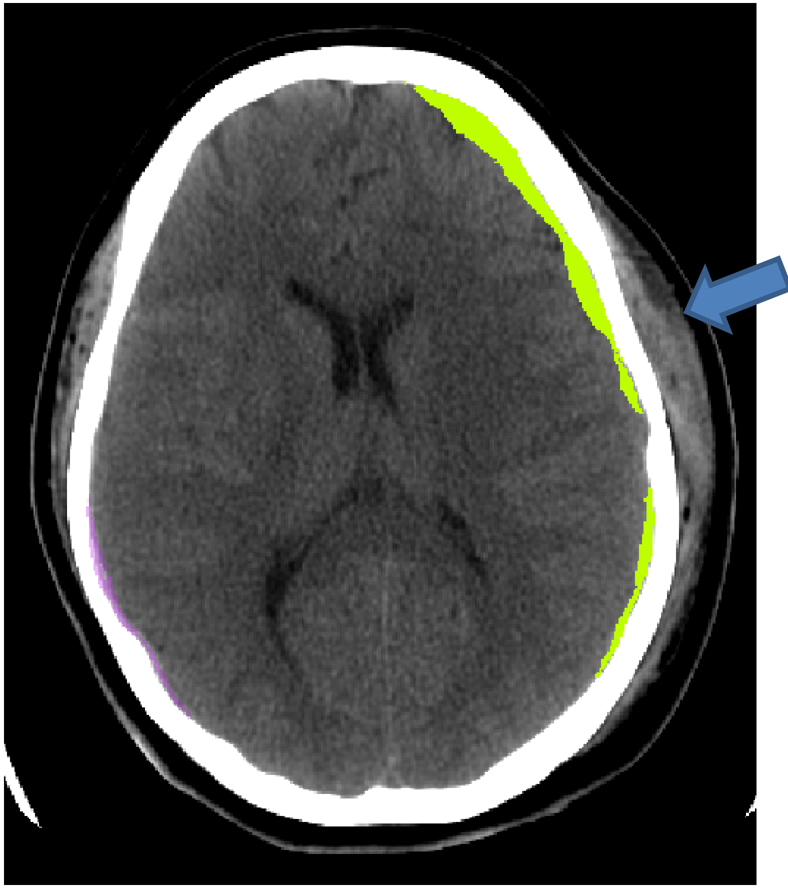
# Contrecoup, Frontal, Driver, Contact at right temporal



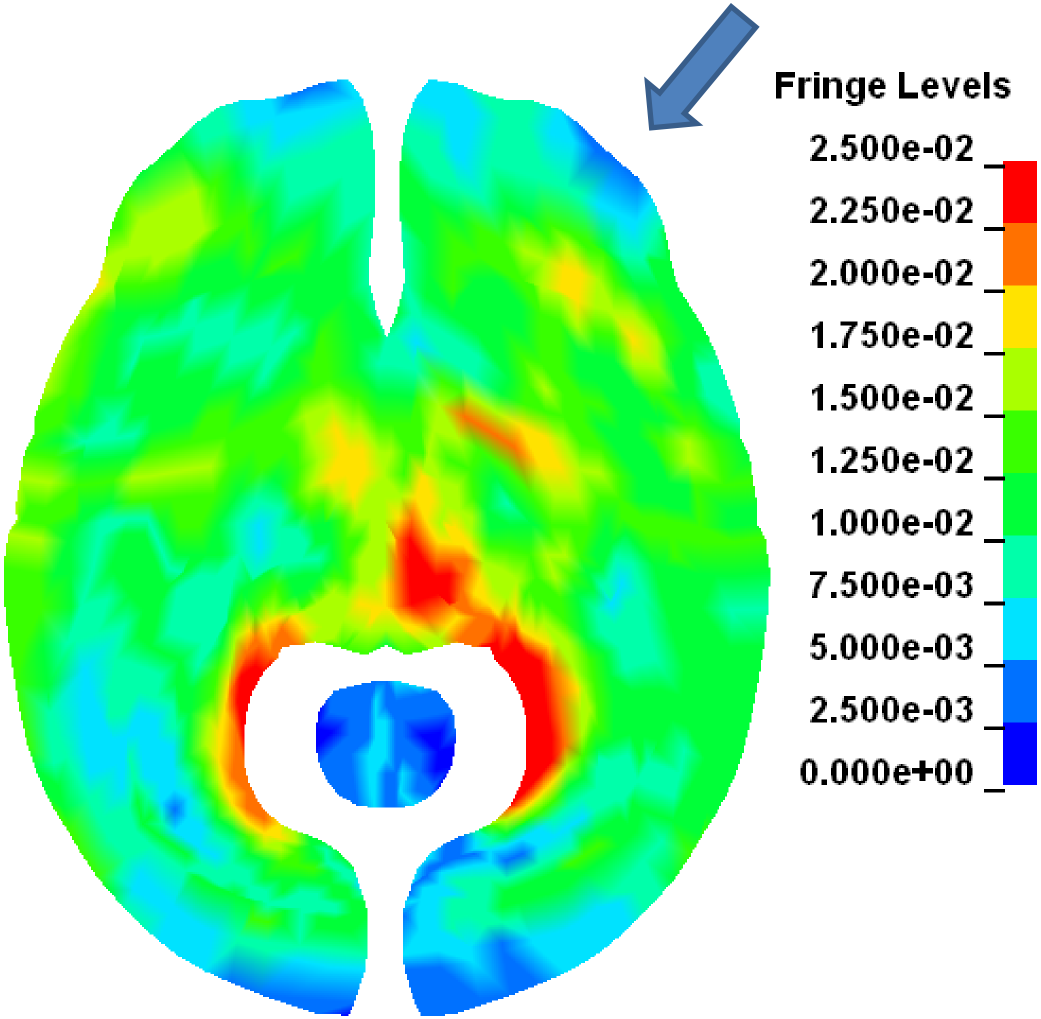



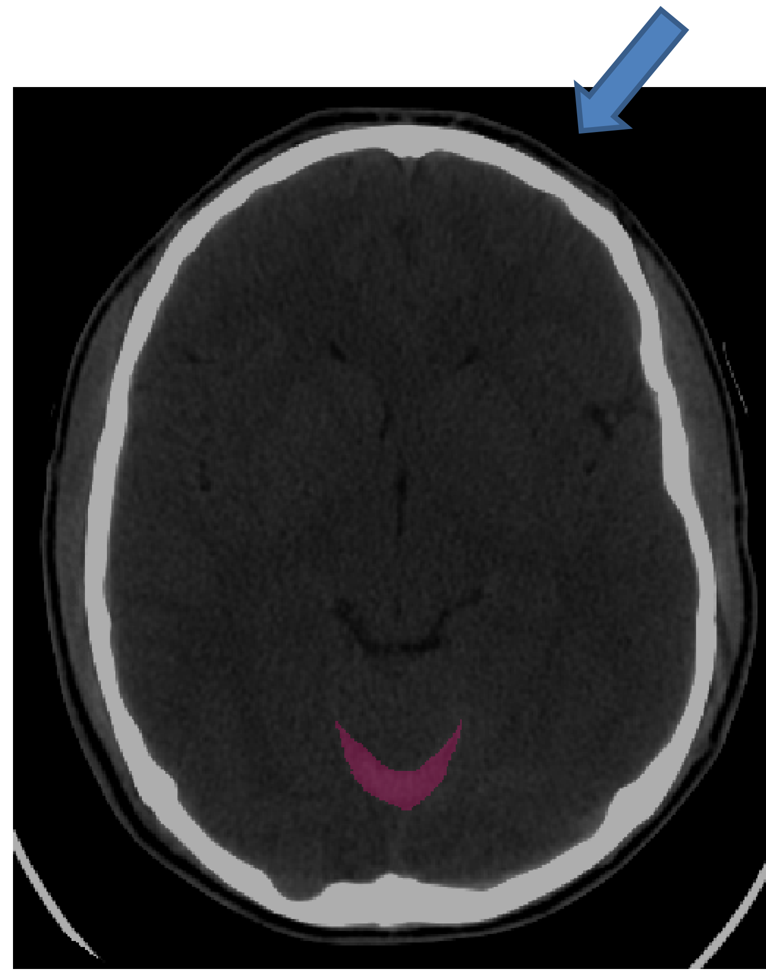
# Coup, Near side crash, driver, contact at left parietal side of head



# Contrecoup, Far side crash, driver, contact at left frontal bone



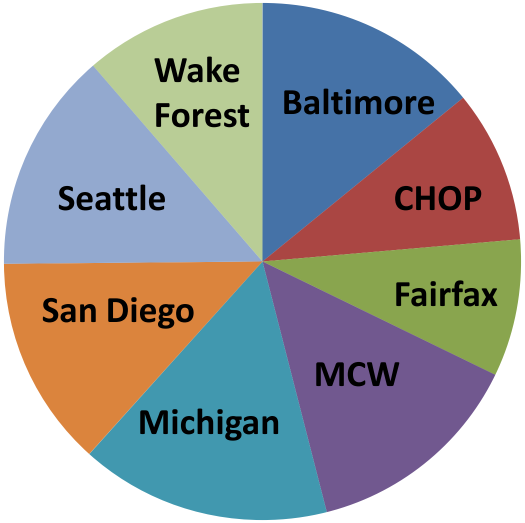



# The CIREN Head-CT DICOM Network

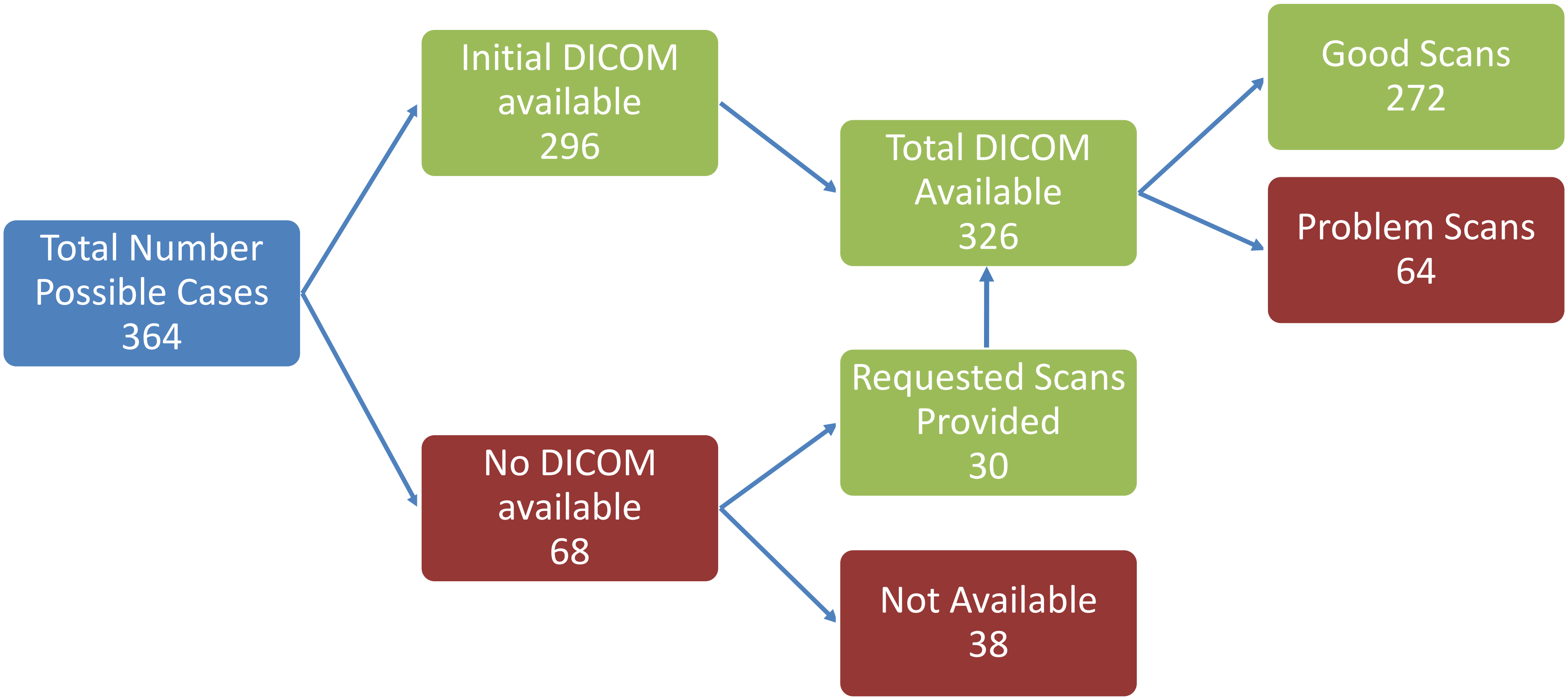
**1st DICOM study of intracranial injury to include scans within the CIREN network**

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

| Center | No DICOM Available | DICOM Available | TOTAL | % Total Study |
|---|---|---|---|---|
| Baltimore | 7 | 46 | 53 | 14.11% |
| CHOP | 0 | 31 | 31 | 9.51% |
| Fairfax | 3 | 28 | 31 | 8.59% |
| MCW | 10 | 45 | 55 | 13.80% |
| Michigan | 2 | 51 | 53 | 15.64% |
| San Diego | 3 | 43 | 46 | 13.19% |
| Seattle | 4 | 45 | 49 | 13.80% |
| UAB | 9 | 0 | 9 | 0.00% |
| WF | 0 | 37 | 37 | 11.35% |
| Totals | 38 | 326 | 364 | 100.00% |



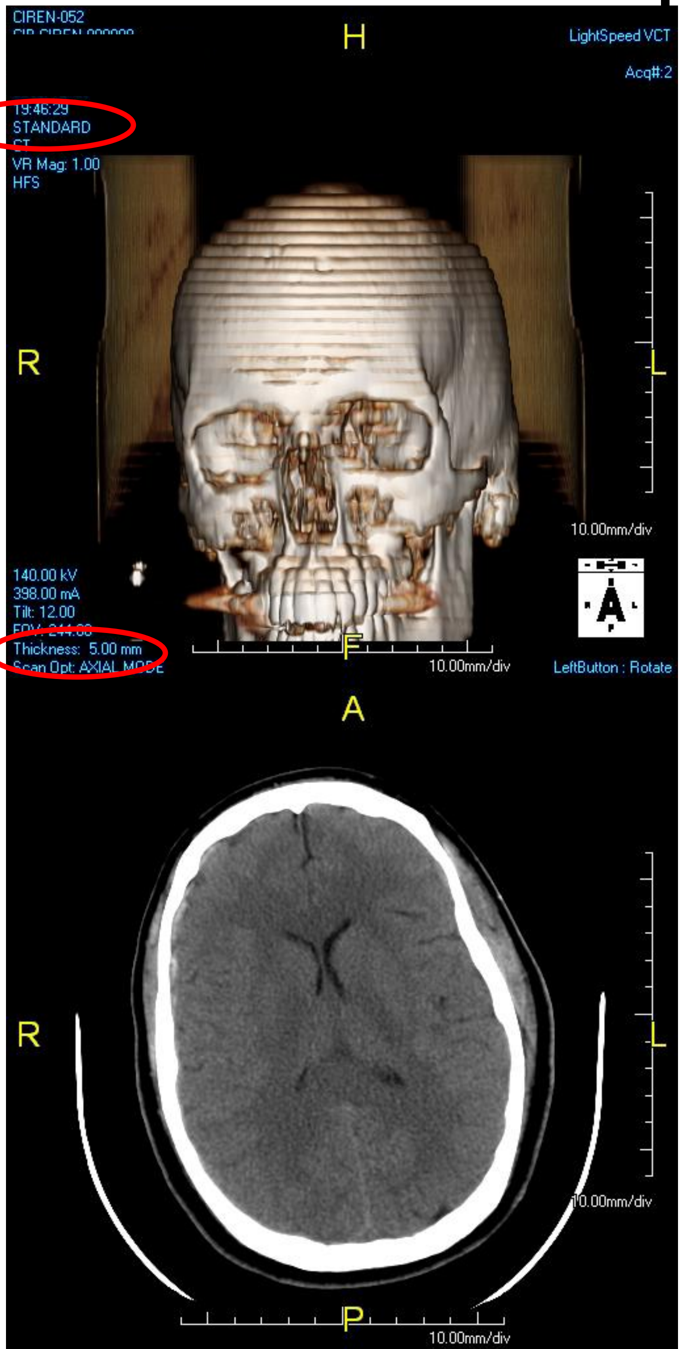
# Scan Analysis



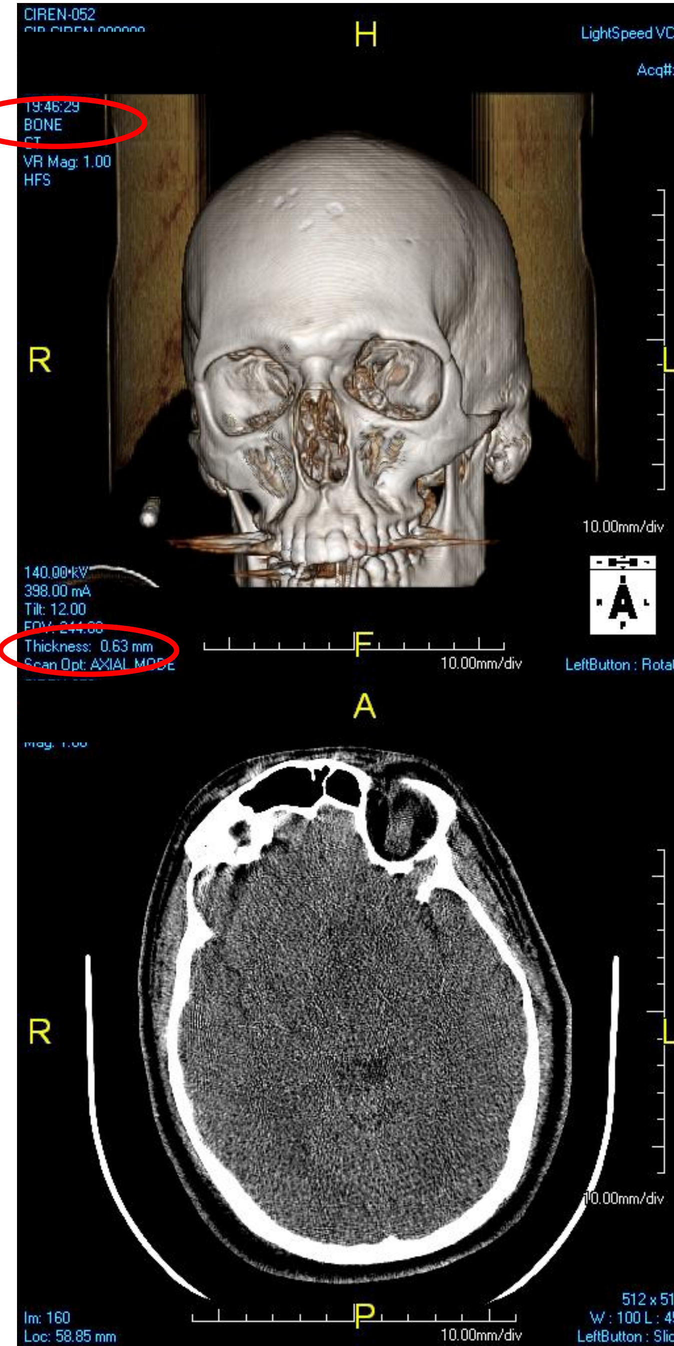

| | Good Resolution | Bad Resolution | Missing Large Portion of Anatomy |
|---|---|---|---|
| **Soft Tissue CT** | 267 | 15 | 4 |
| **Bone Window** | 5 | 29 | 12 |
| **Soft Tissue CT with Contrast** | 0 | 2 | 0 |

# DICOM examples – WF CIREN-052

Standard slices – 5 mm thickness, 40 slices




Bone slices – 0.63 mm thickness, 320 slices



# Neuroradiology Review

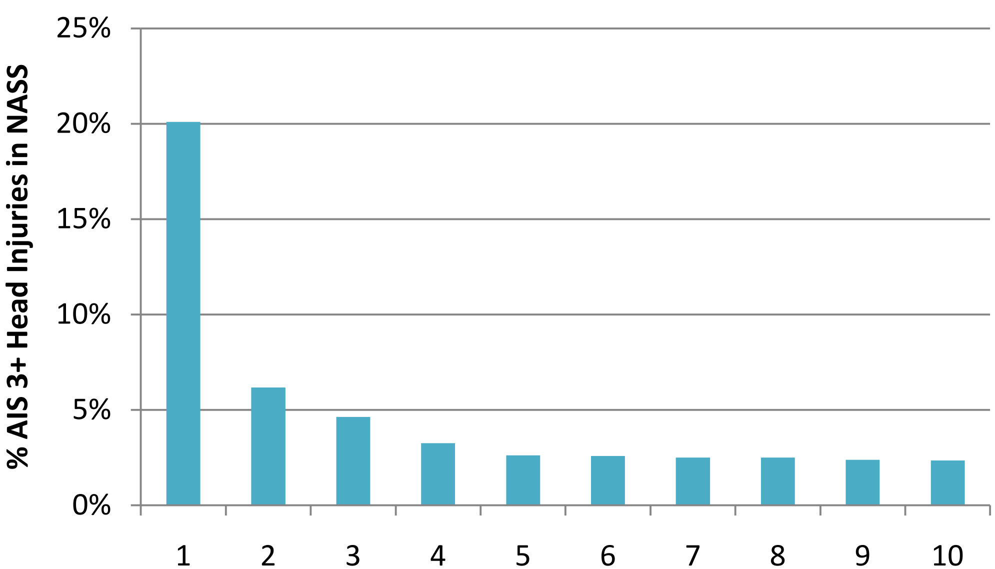
Injuries were identified in radiology report and not coded for or injuries were coded but not identified by the neuroradiologist

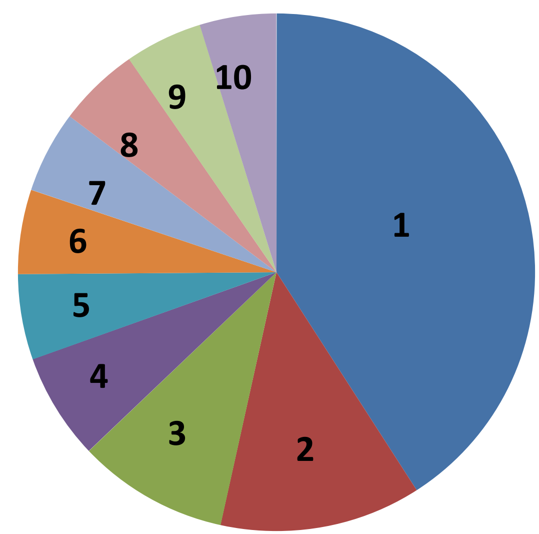
| | Injury Identified | Injury *Not* Identified |
|---|---|---|
| Injury Coded | 537 | 41 |
| Injury *Not* Coded | 46 | |

Did not include scans including injuries found after treatment (craniectomy, craniotomy, etc) or from previous injury

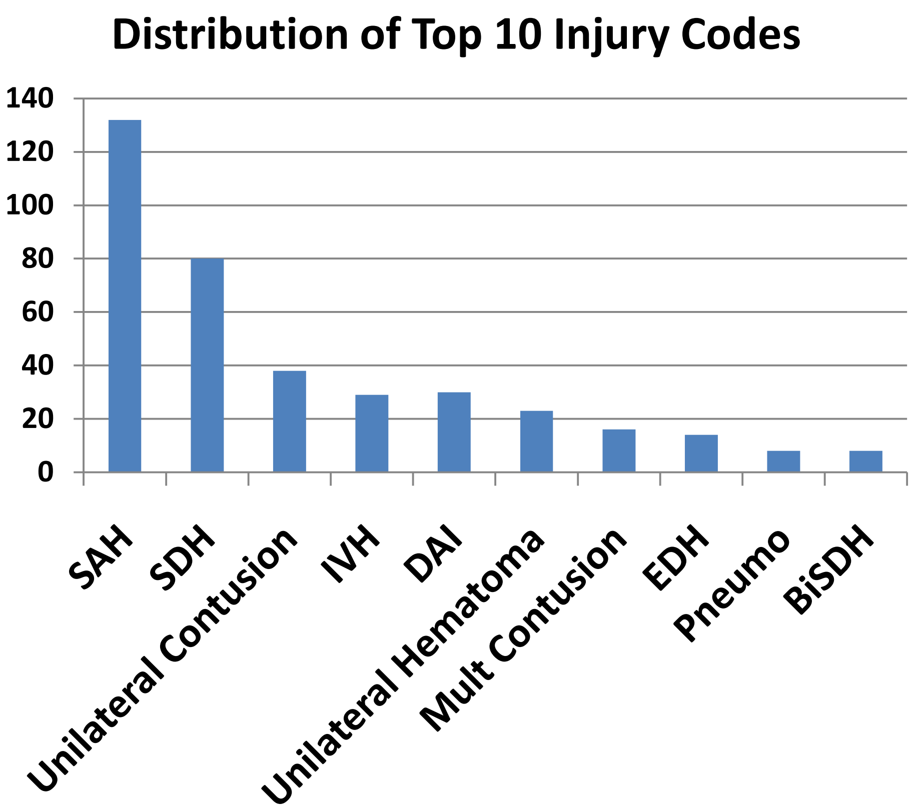
# Top 10 NASS AIS CODES

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



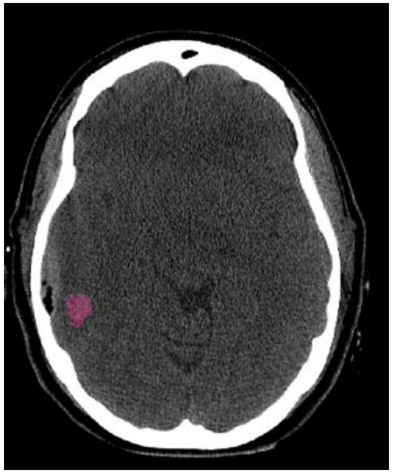



| Number of Good Scans | Number of Coded Intracranial Injuries (excluding Fractures) | Number of Top 10 Intracranial Injuries |
|---|---|---|
| 272 | 475 | 378 |

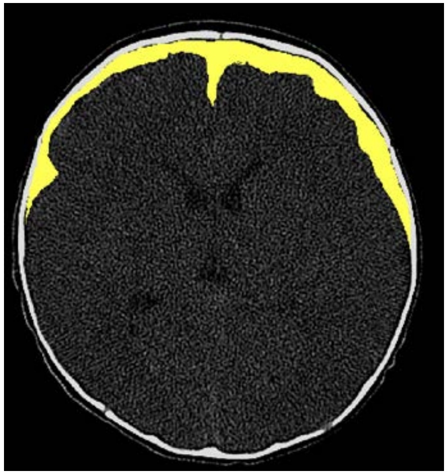



# Vocabulary

Unilateral



Bilateral



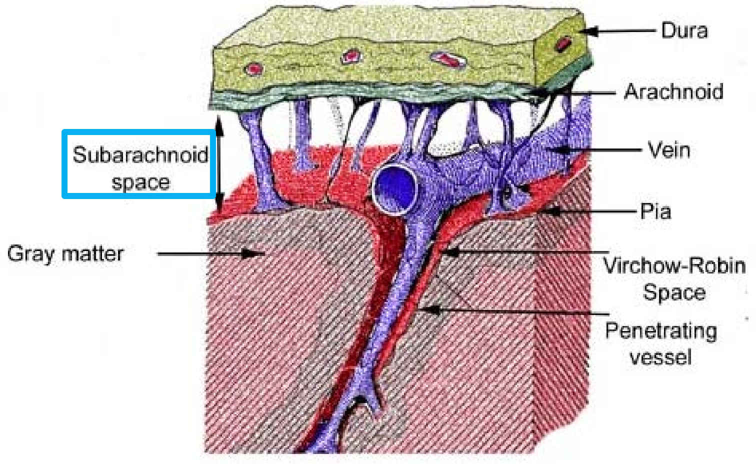
- Hematoma- a collection of blood in or around the brain
  - Epidural hematoma- blood between skull and dura (outer layer)
  - Subdural hematoma- blood between dura (outer layer) and arachnoid membrane (middle layer)
- Hemorrhage- bleeding
  - Subarachnoid hemorrhage- bleeding between the brain and the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

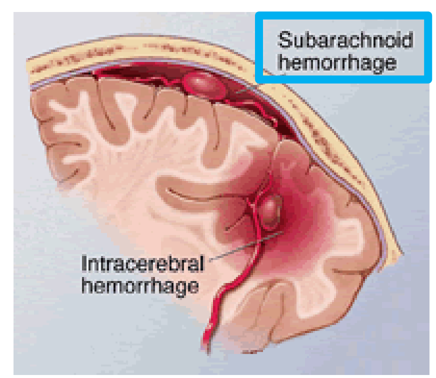
# Subarachnoid Hemorrhage Background

- 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



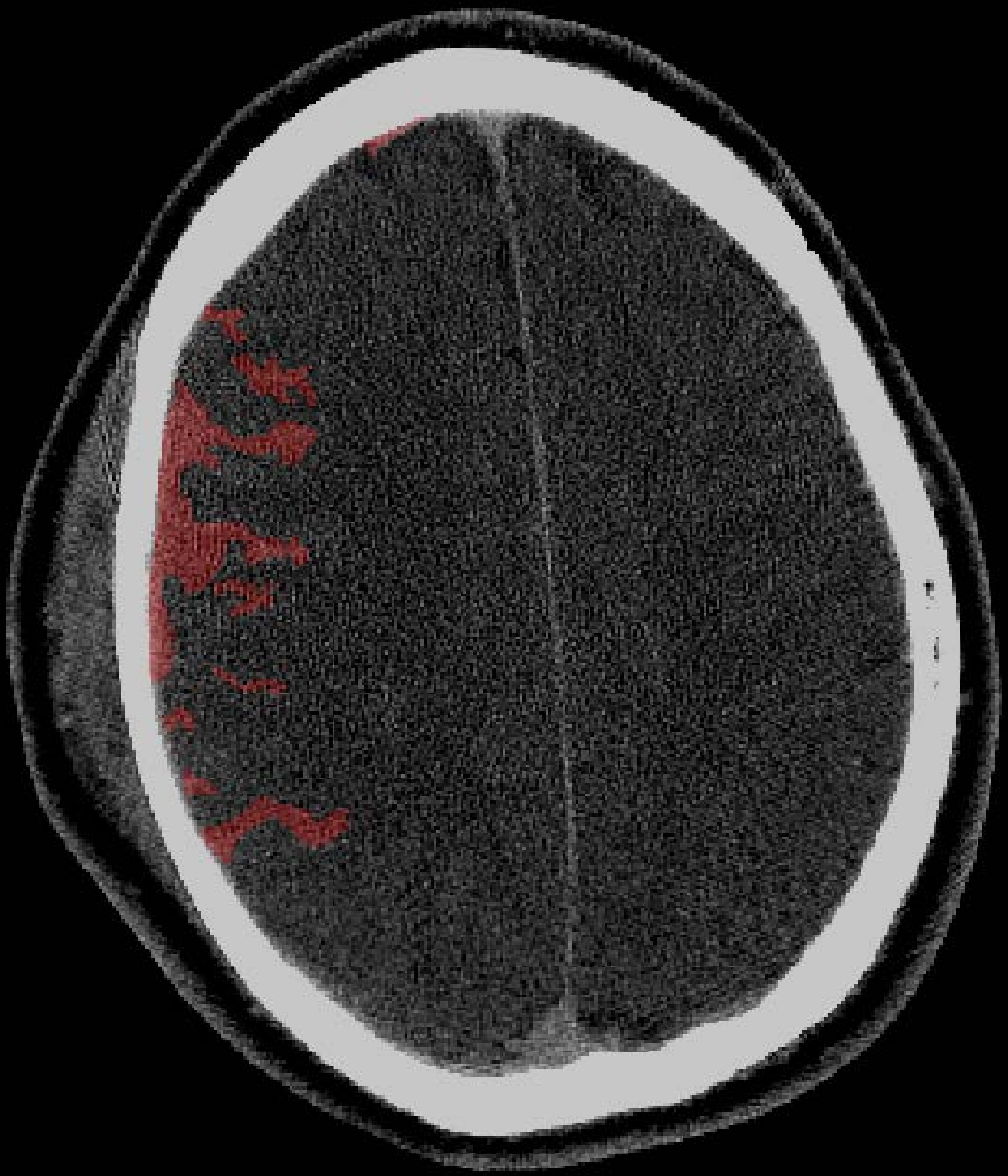
# SAH Background Continued

- 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



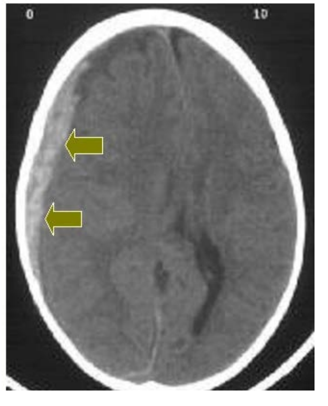
Subarachnoid Hemorrhage

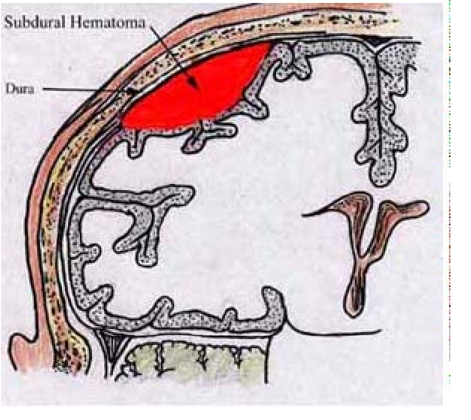
Subarachnoid Hemorrhage



# Subdural Hematoma (SDH)

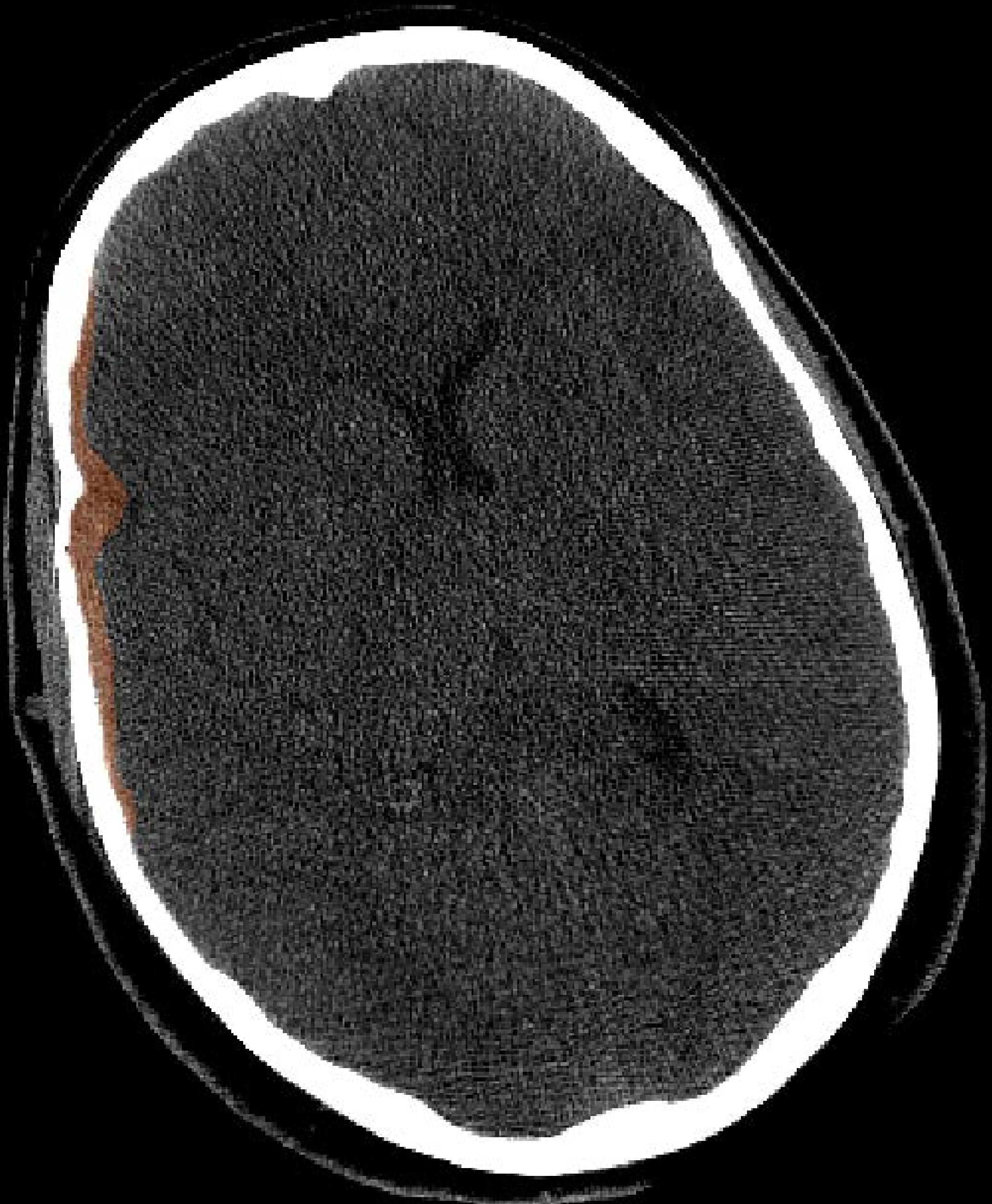
- Occurs when blood enters the space between the dura mater and arachnoid mater
- Often because of ruptured bridging veins
- Classically defined as being “crescent shaped”
- Unlike Epidural Hematomas, SDH’s can cross suture lines and therefore enter the tentorium cerebelli and falx cerebri (parafalcine)





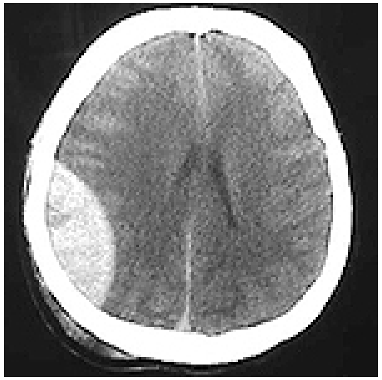
Subdural Hematoma

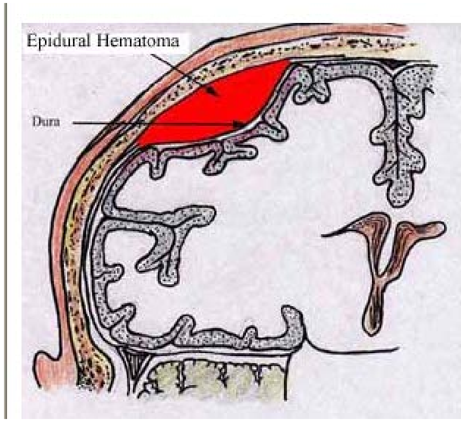
Subdural
Hematoma



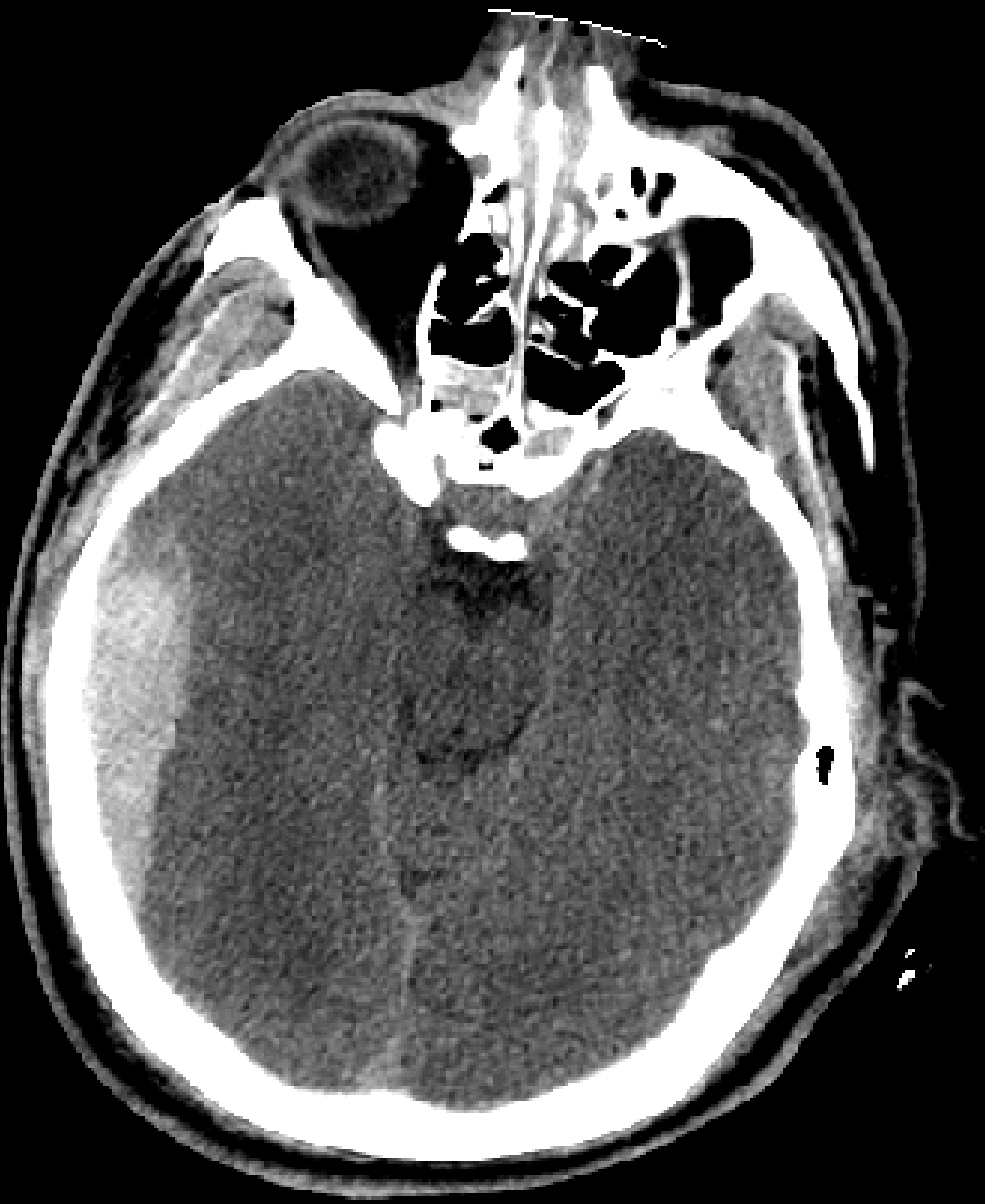
# Epidural Hematoma (EDH)

- 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





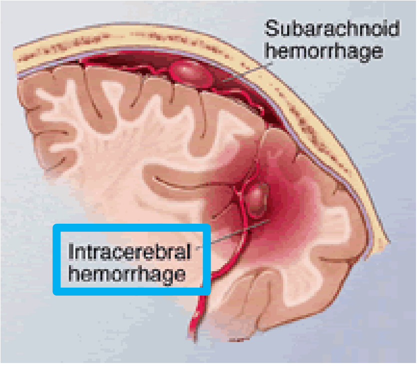
Epidural
Hematoma

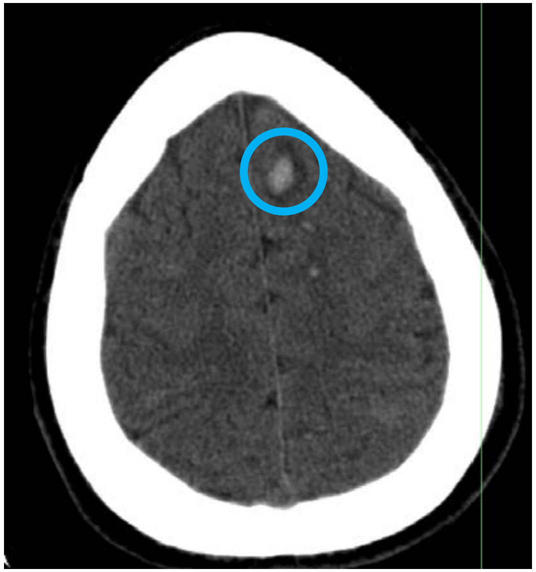


Epidural
Hematoma

# 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

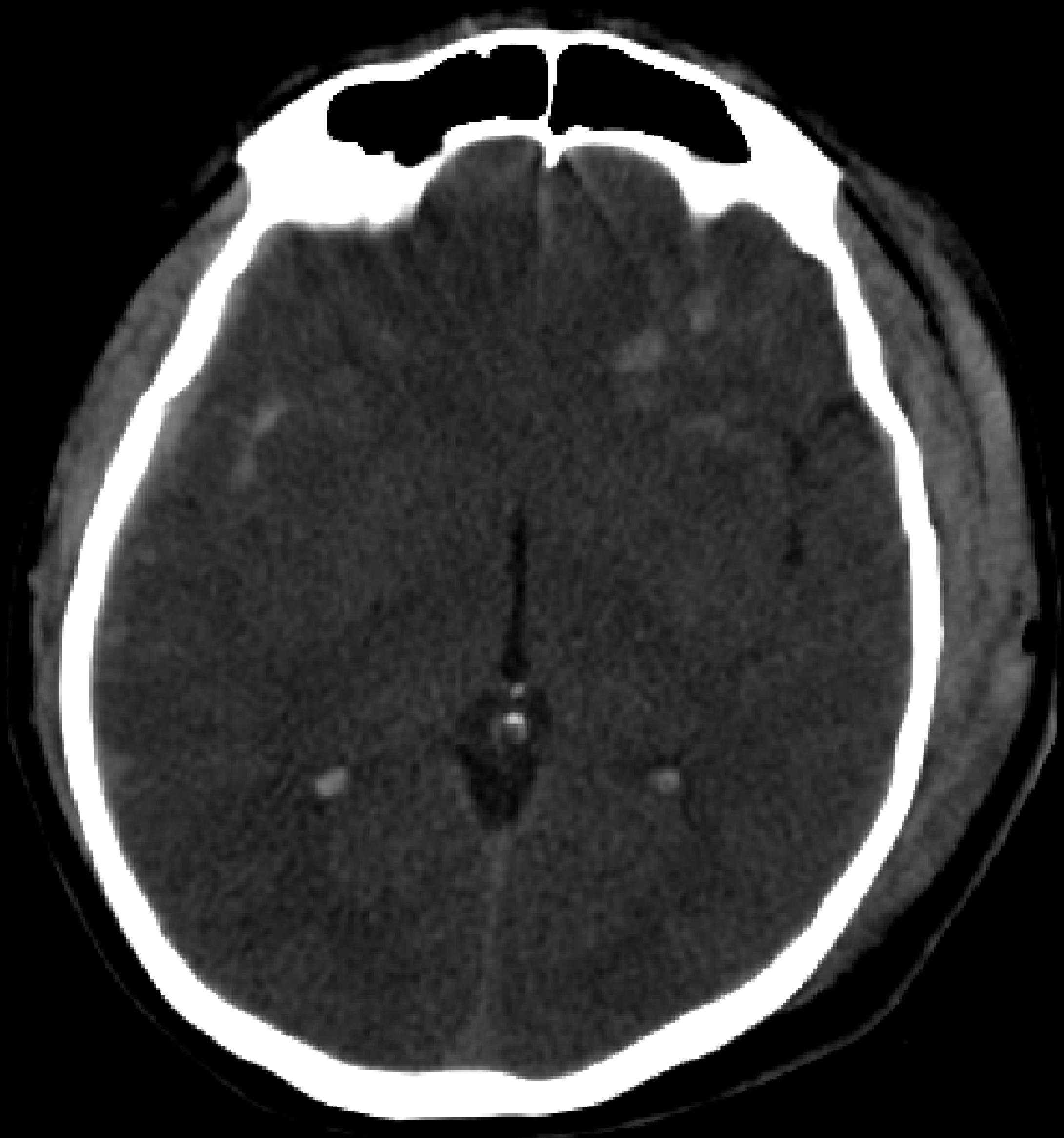


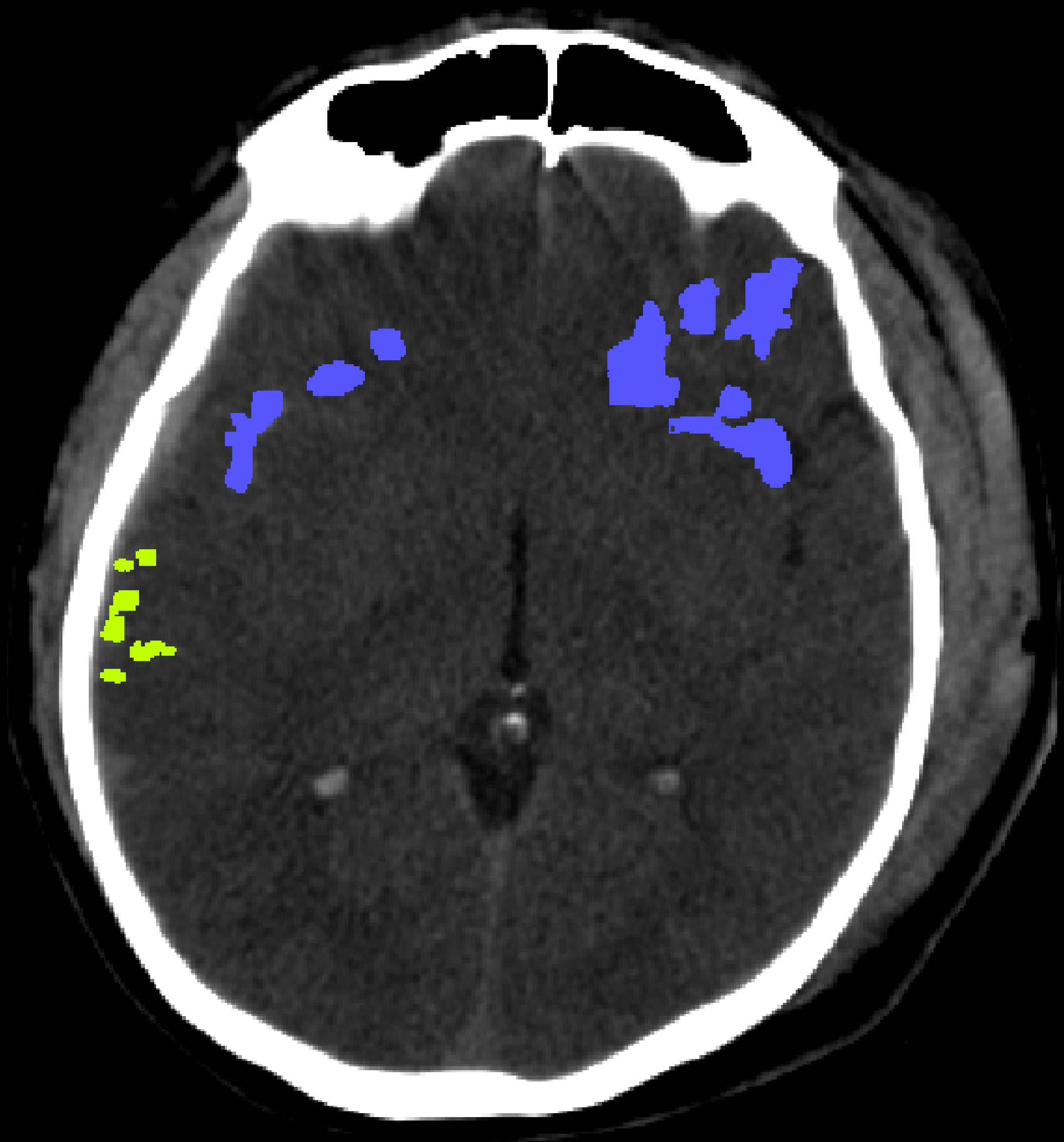
Unilateral
Contusion

Unilateral Contusion

Multiple Contusions

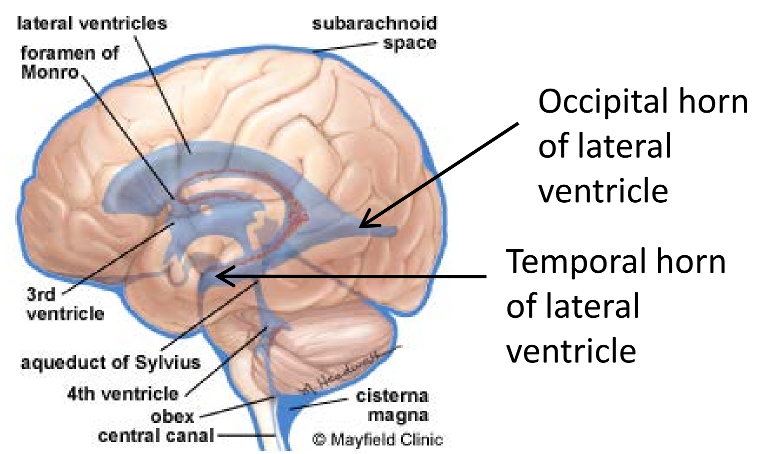


Multiple Contusions



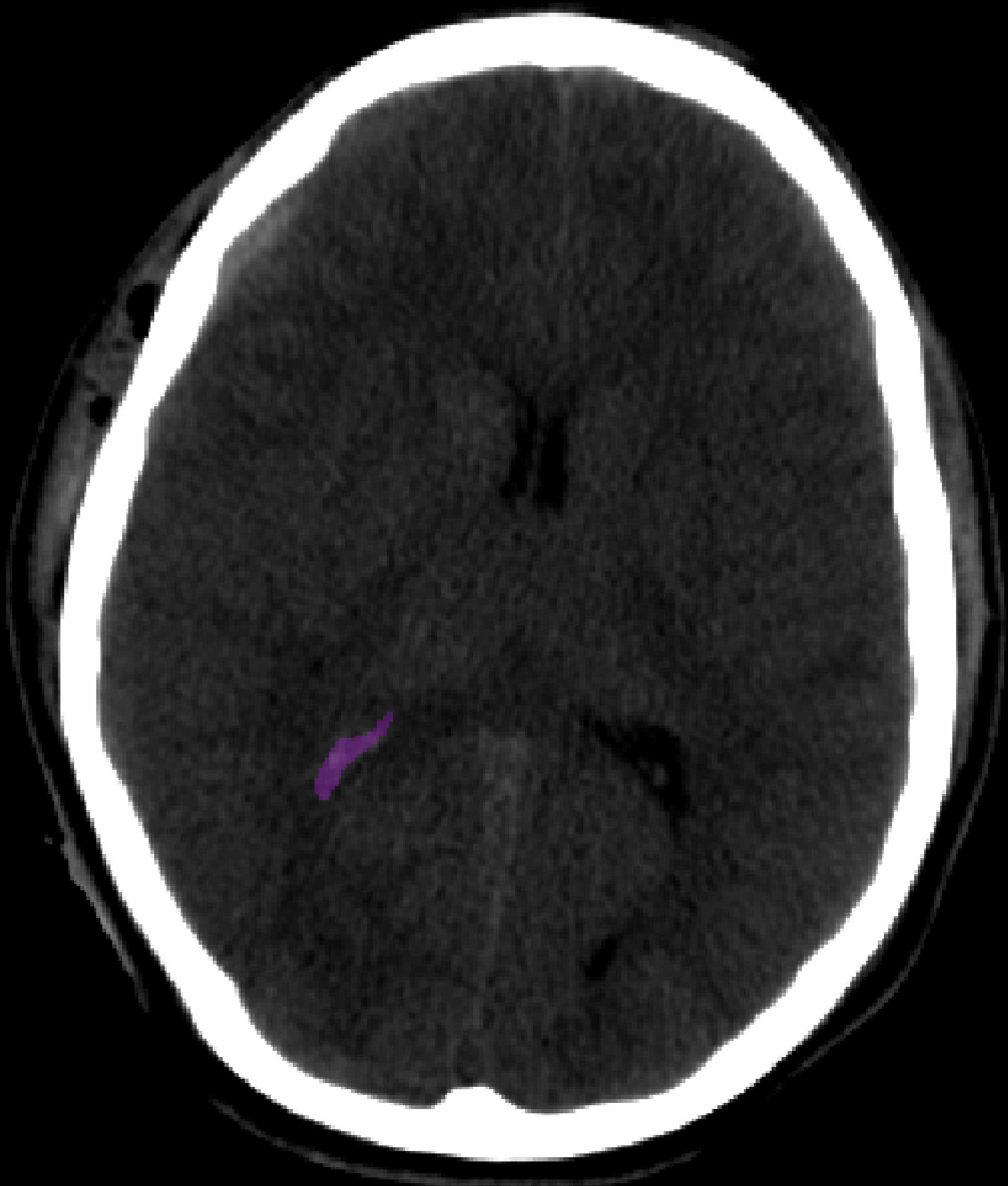
# Intraventricular Hemorrhage

- 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



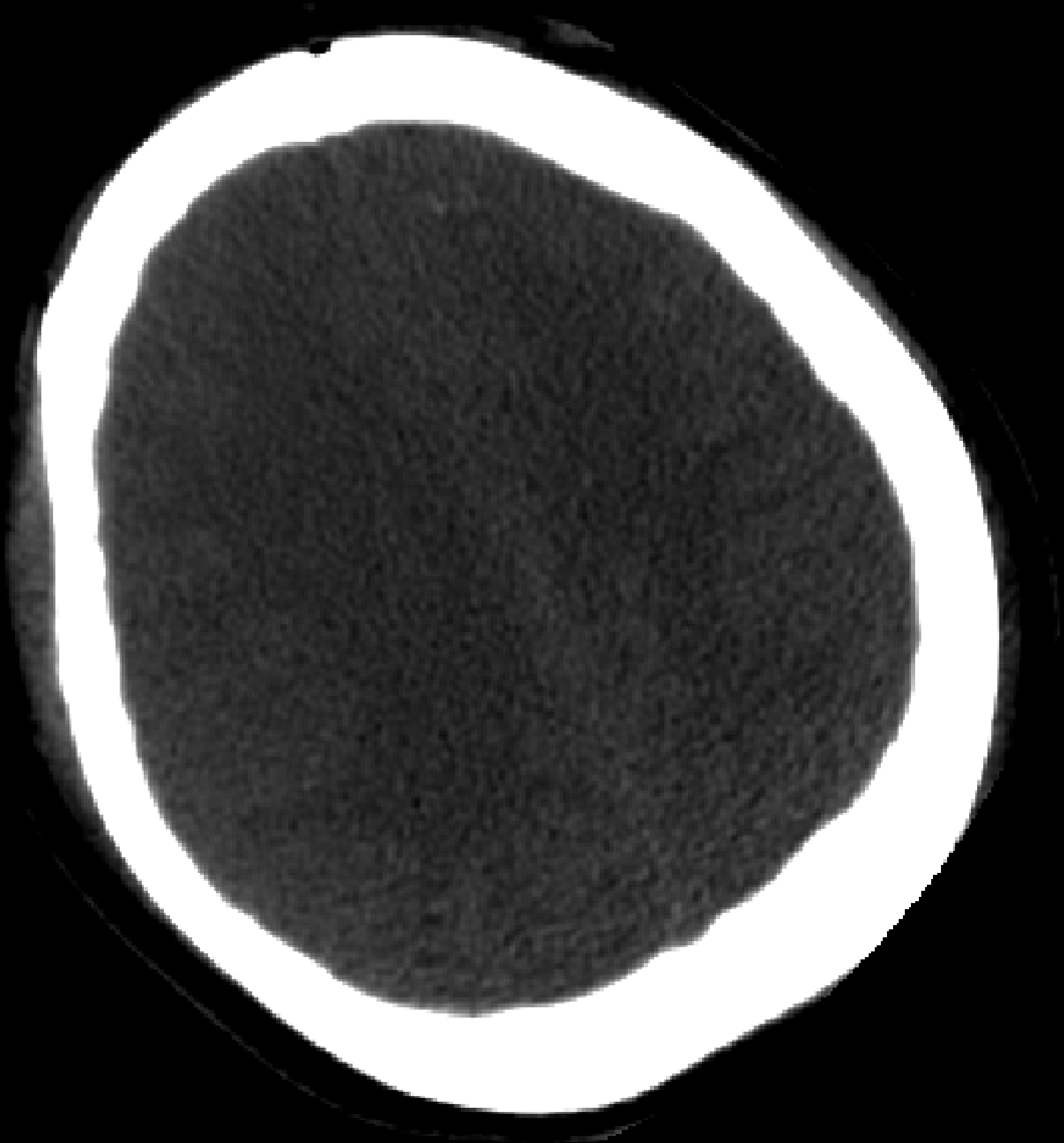
Intraventricular
Hemorrhage

Intraventricular Hemorrhage

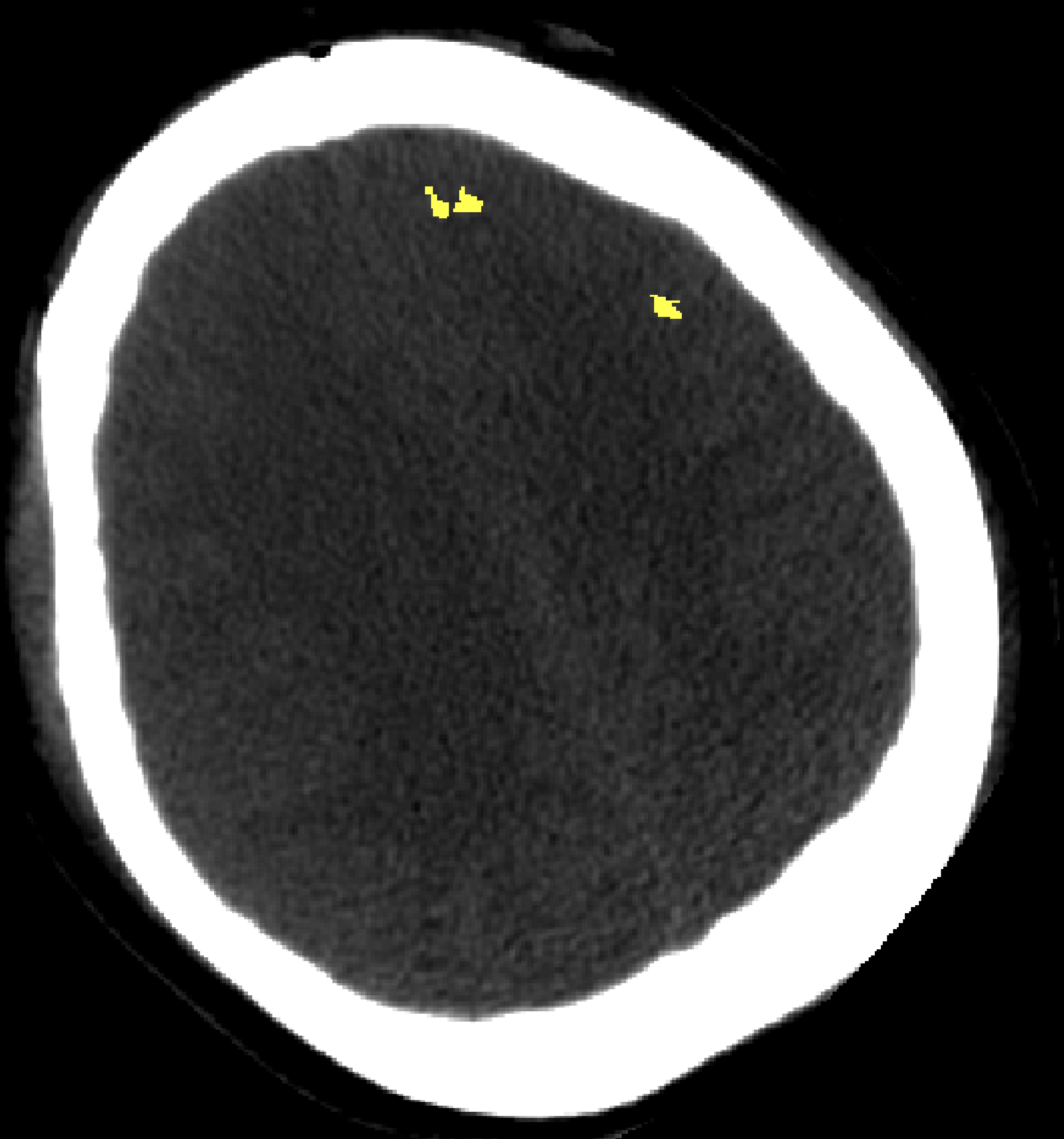
# Diffuse Axonal Injury (DAI)

- 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

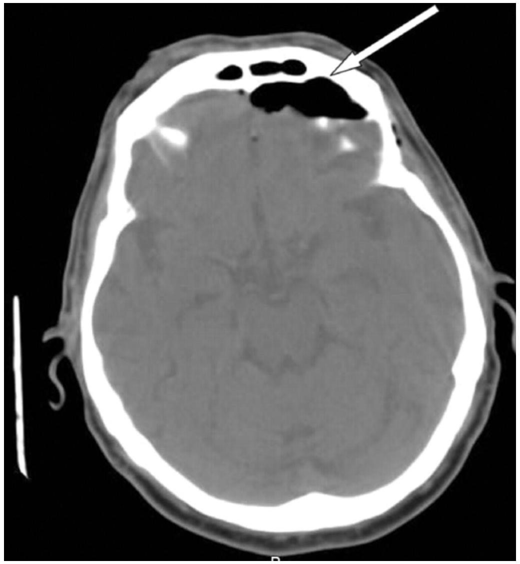


Diffuse Axonal Injury

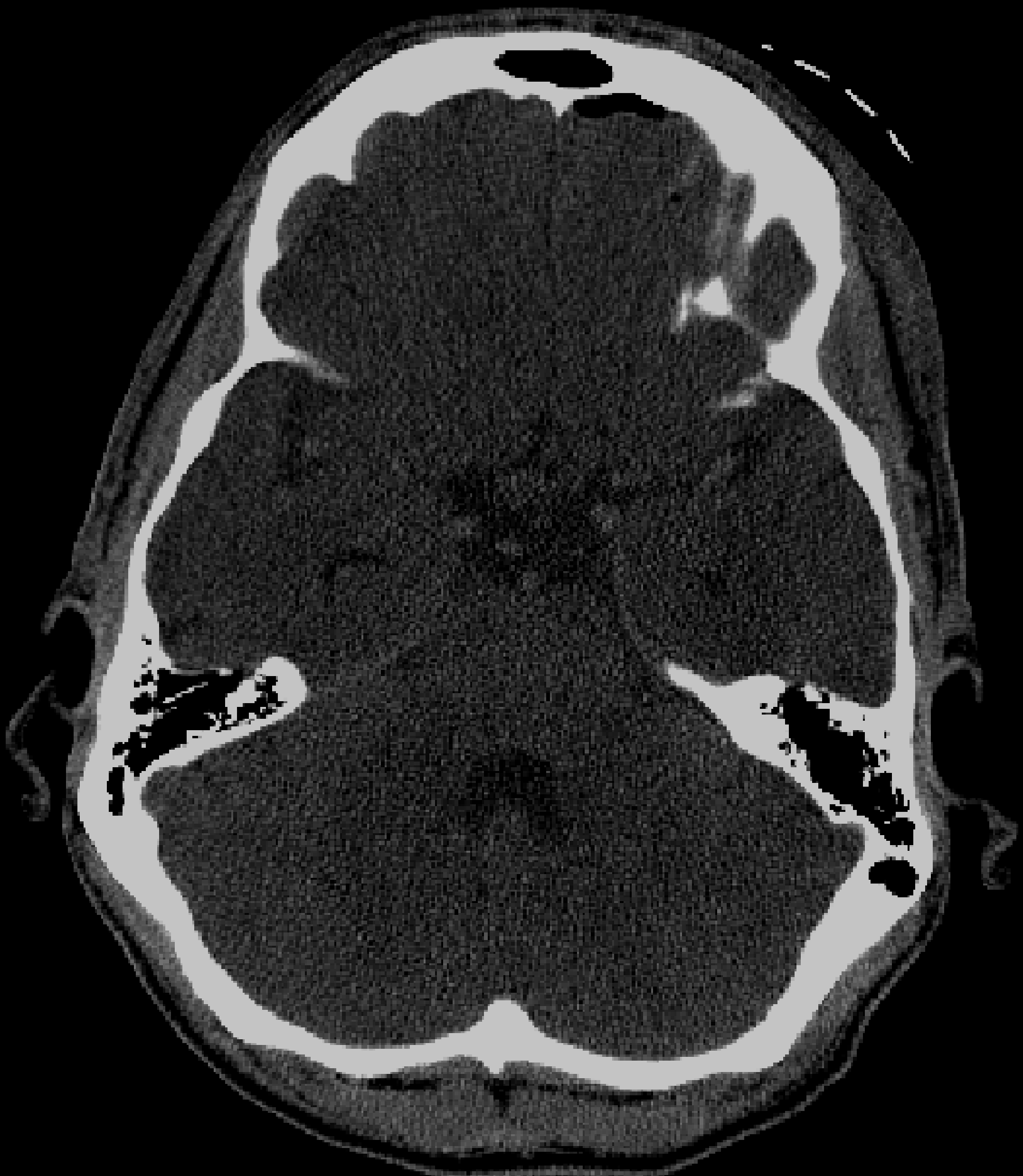


# Pneumocephalus

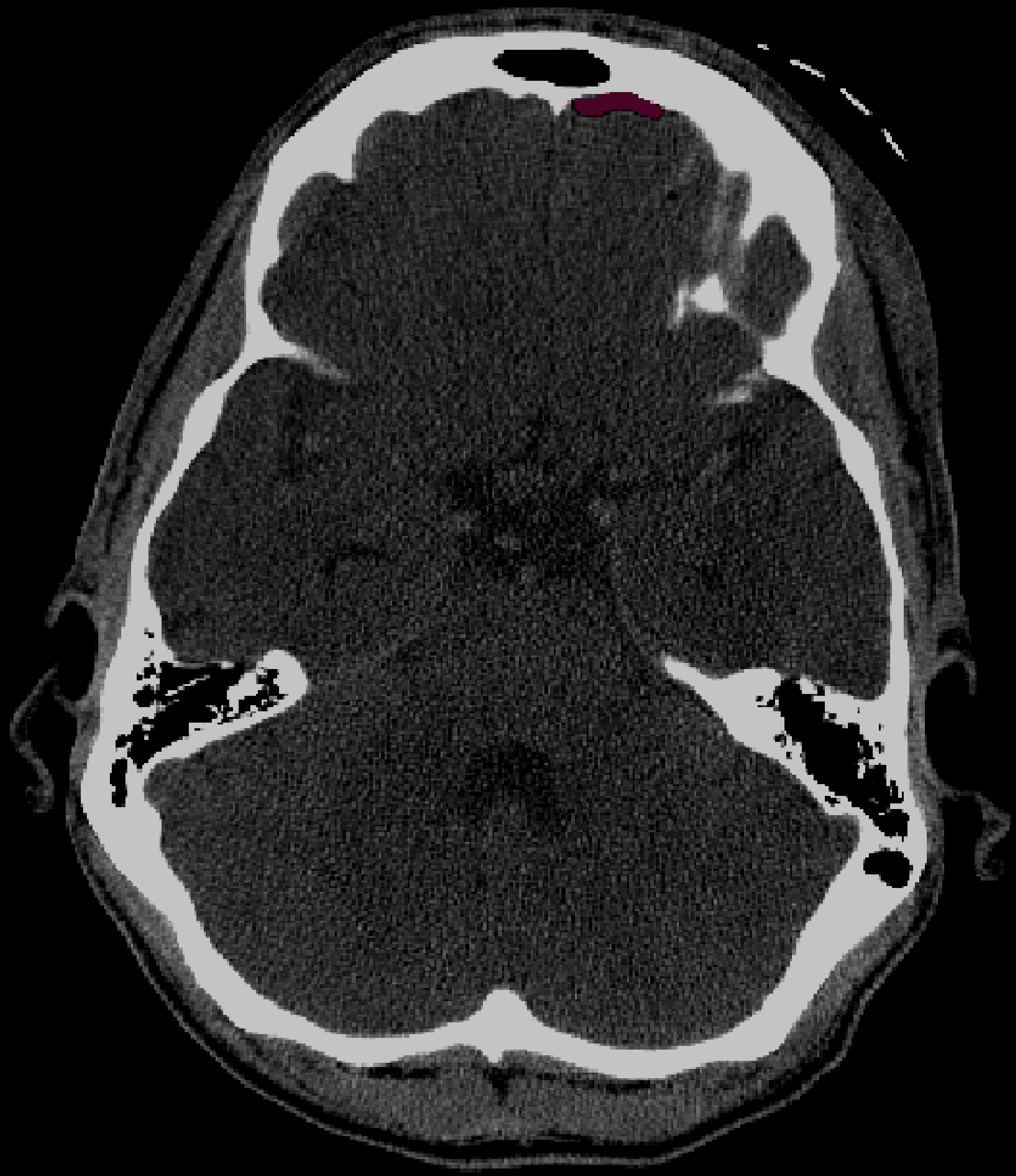
- As the name implies, this is when air exists within the cranium
- Can be extradural, subdural, subarachnoid, intracerebral, and intraventricular



Pneumocephalus

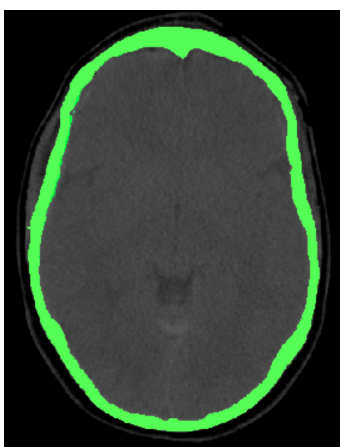


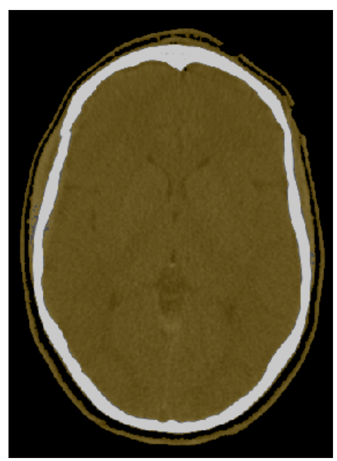
Pneumocephalus

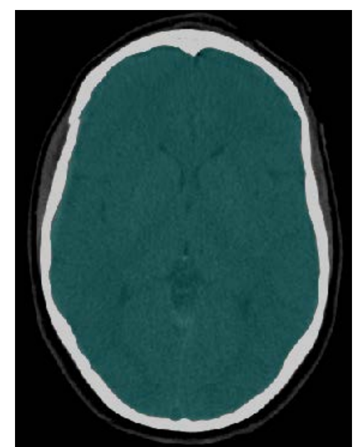


# Segment Intracranial Volume

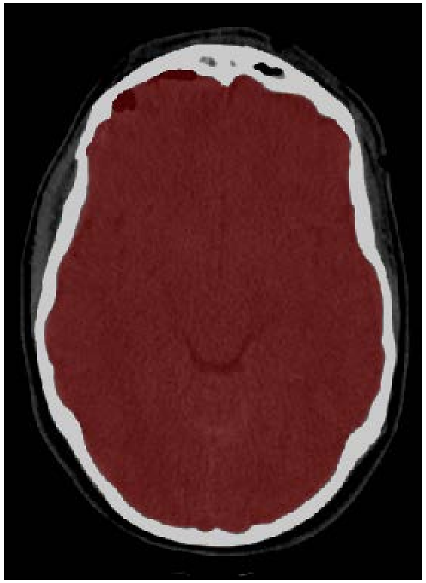
- Thresholding techniques used to identify the bone and soft tissue
- Region growing separated the soft tissue: brain and skin masks
- A boolean operation was used to isolate the intracranial volume

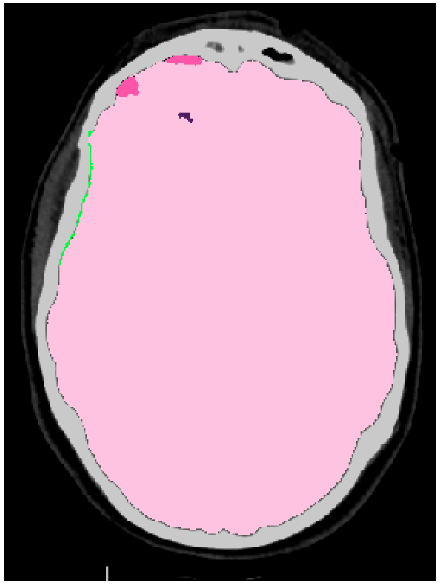






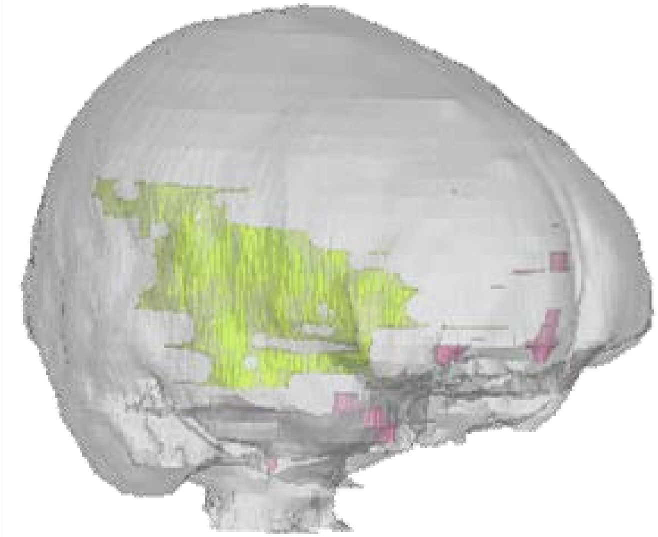
# Calculate Injured Volume



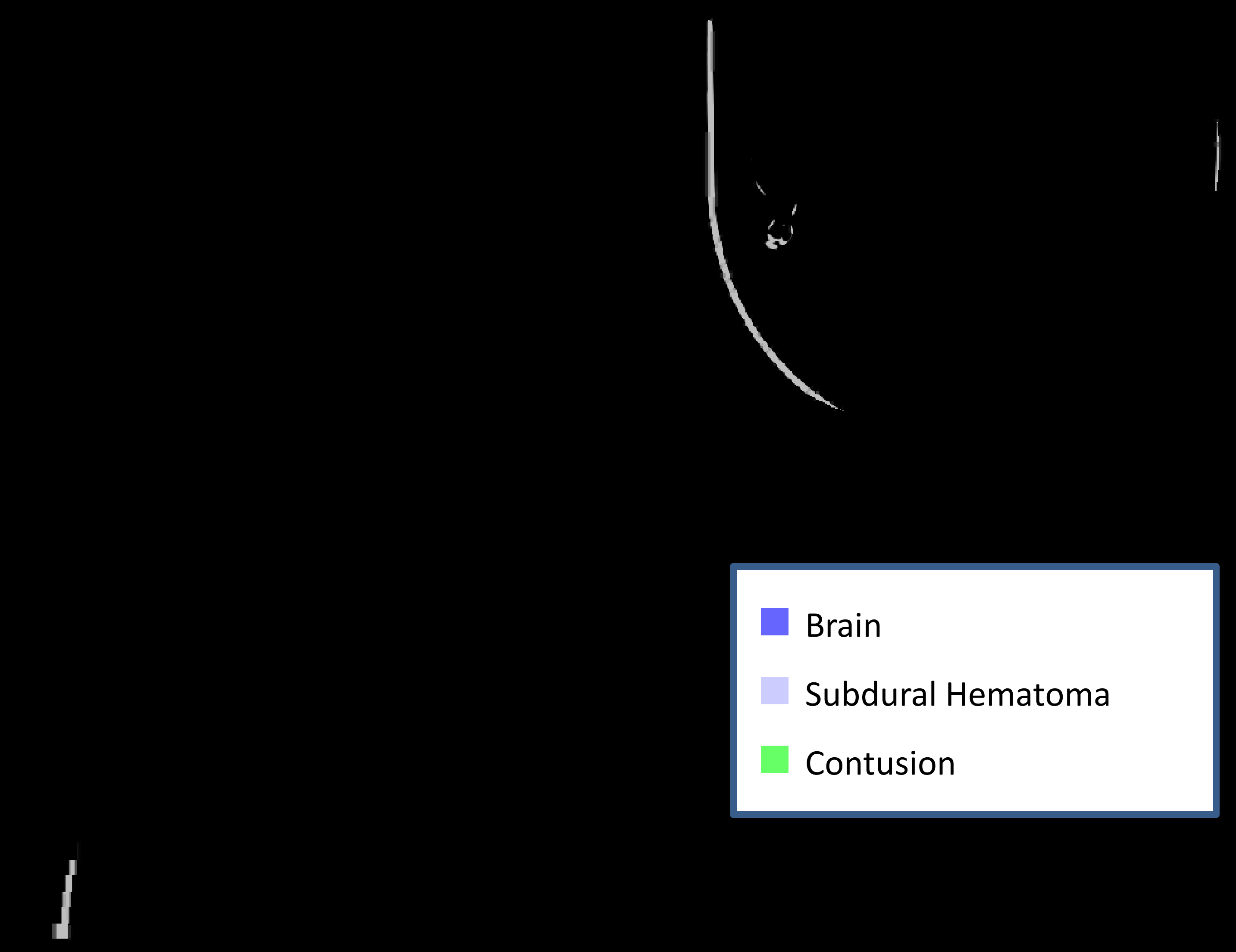


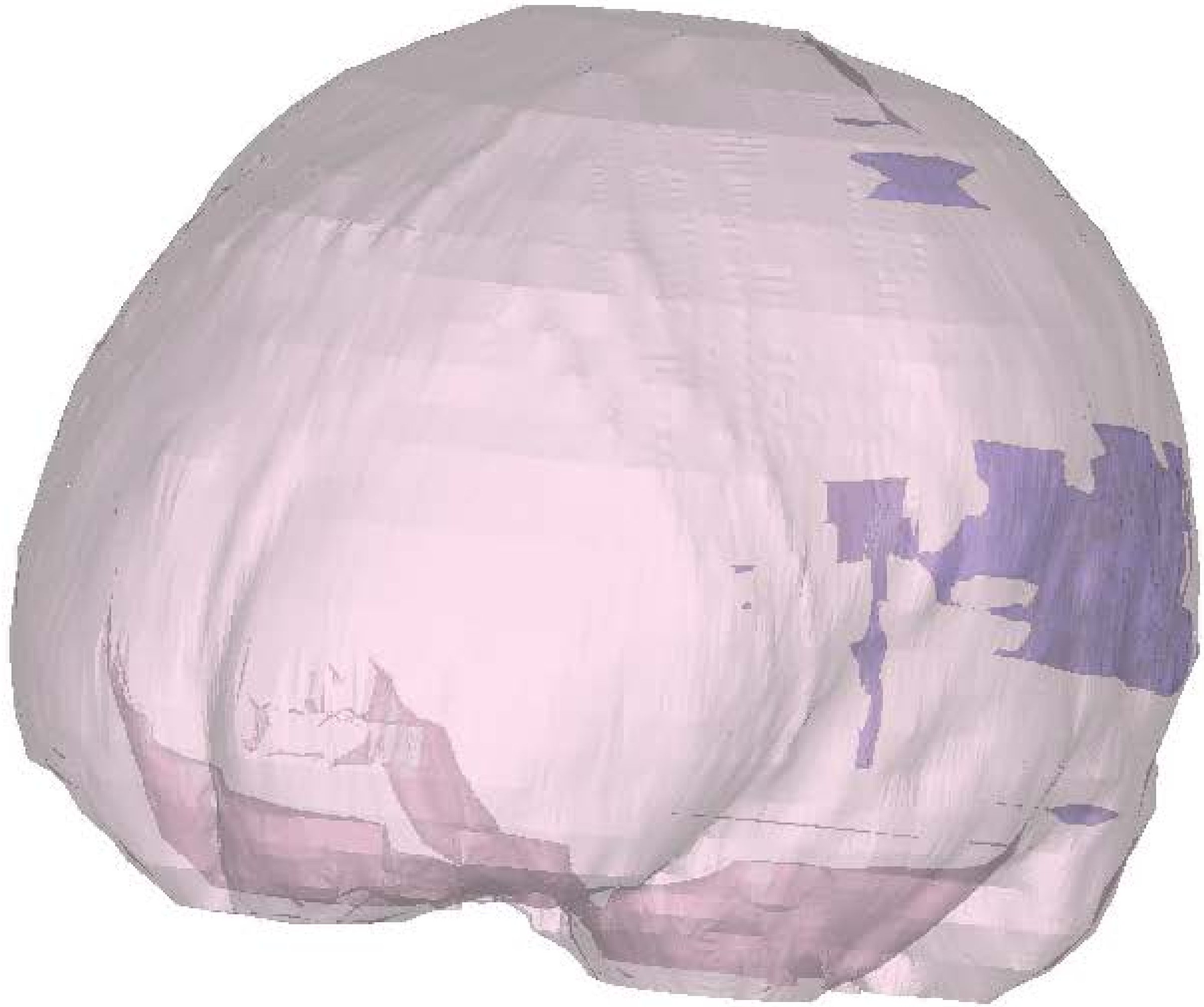
- Pneumocephalus
- Subdural Hematoma
- Multiple Contusions

Intracranial Volume



$$\frac{\text{Number of Injured Pixels * Voxel Size}}{\text{Intracranial Volume}} = \text{\% Injured Volume}$$

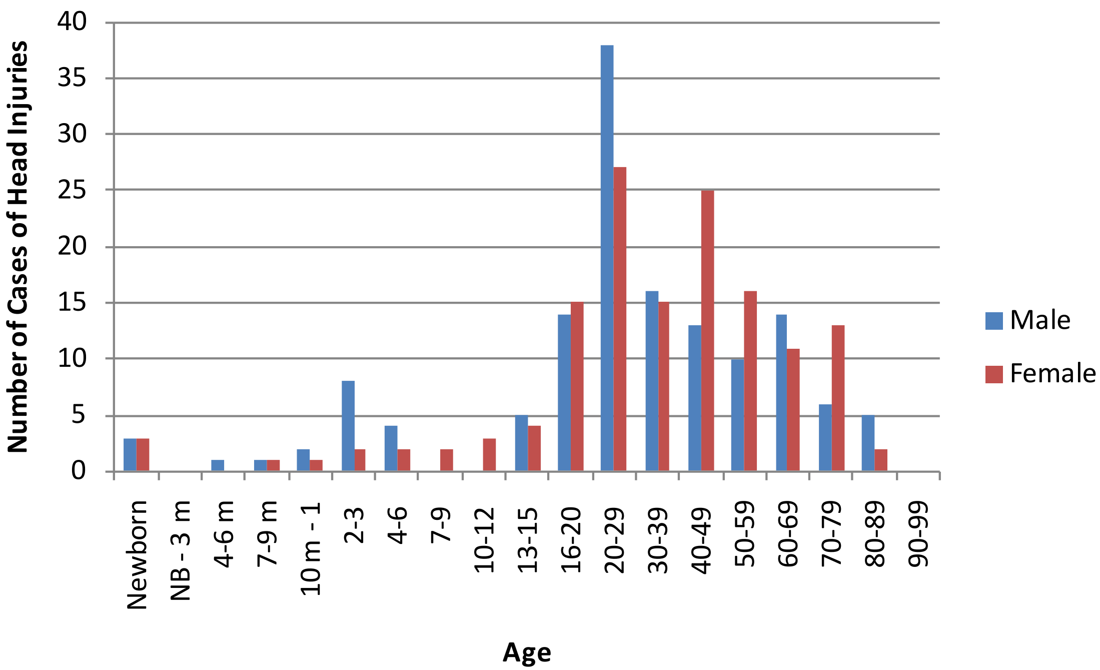

Brain
Subdural Hematoma
Contusion



# Results

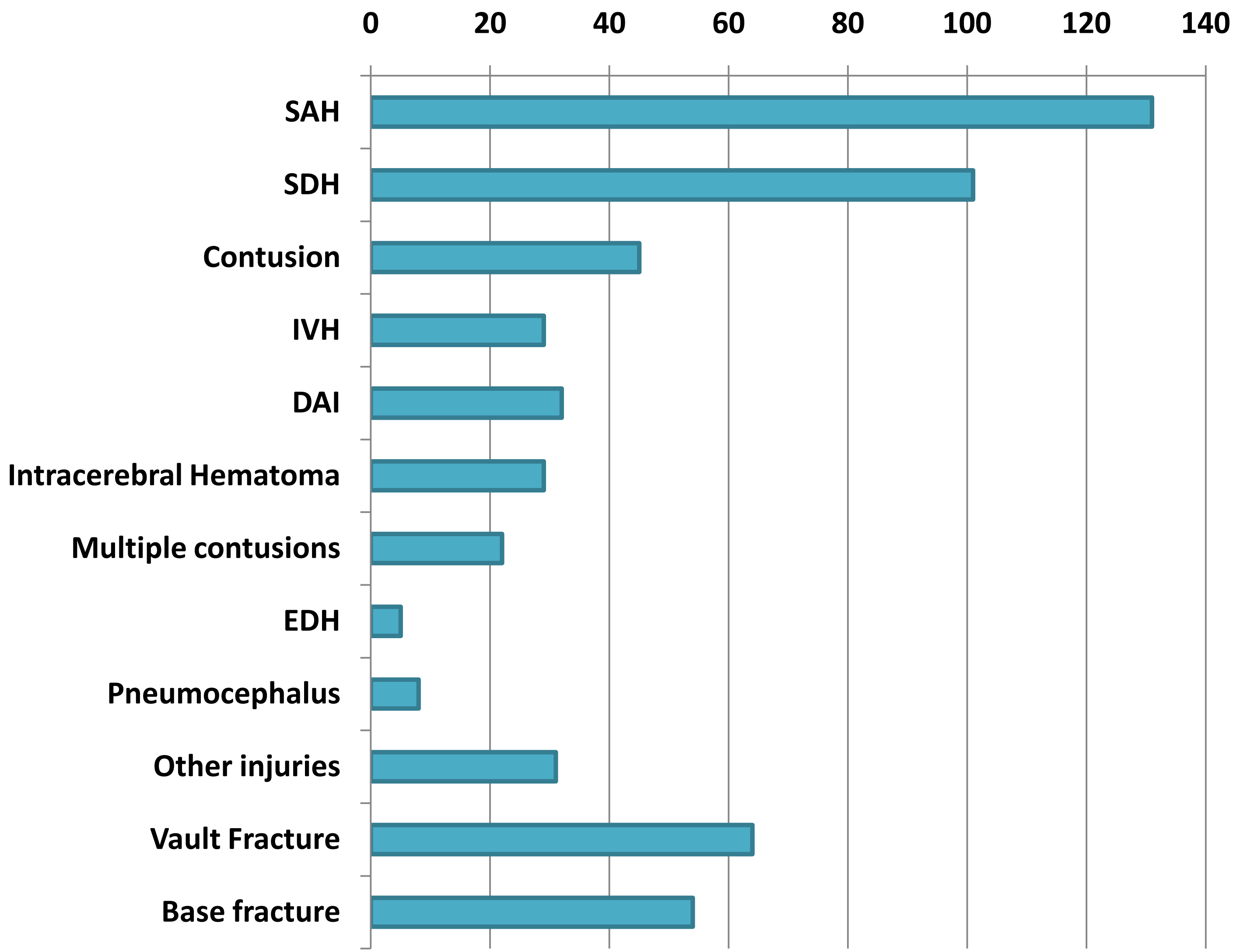
# Study Group

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




**254 Non-Fatal**
**18 Fatal**

# General Injury Totals



# 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 |

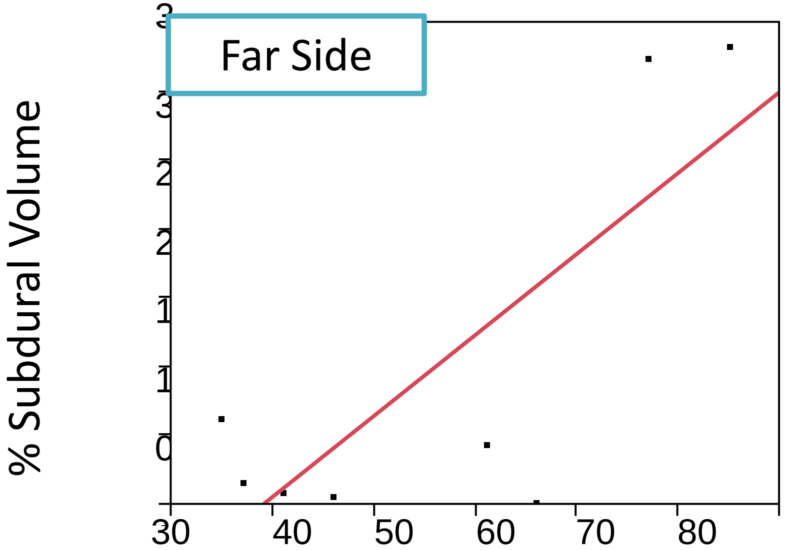
| Contact Information |
|---|
| Airbag Use |
| Involved Physical Component |
| Injury Location |

| Occupant Data |
|---|
| Age |

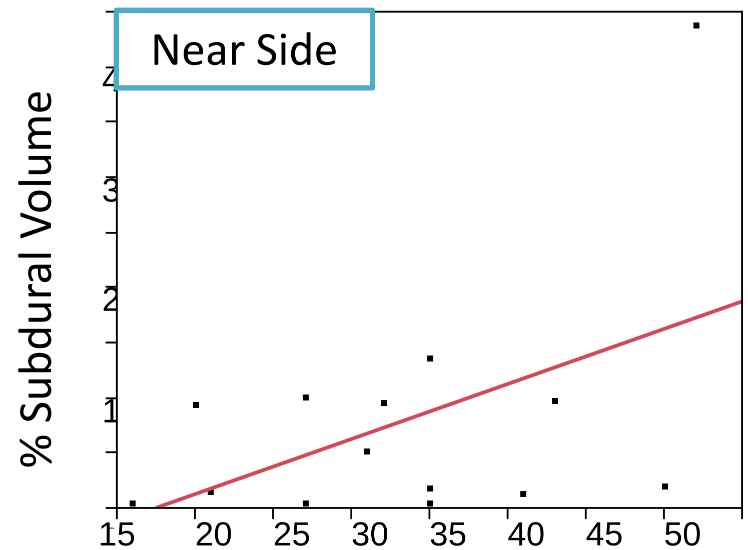
# % Subdural Volume – Crash Characteristics

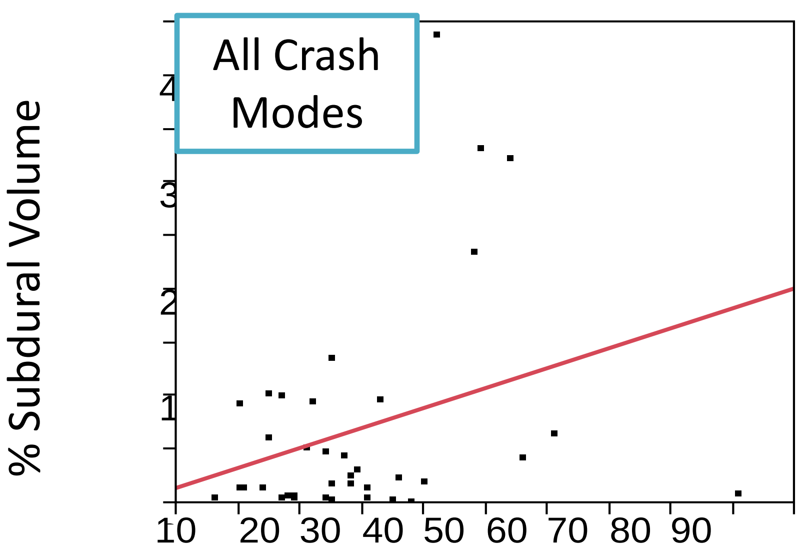
| | Variable | By Variable | Correlation | p-value | n |
|---|---|---|---|---|---|
| Far | % SDH | Maximum Crush | + | **0.0216 | 8 |
| | | DeltaV/BES | + | 0.1177 | 8 |
| Frontal | % SDH | Maximum Crush | + | 0.5999 | 12 |
| | | DeltaV/BES | + | 0.6032 | 15 |
| Near | % SDH | Maximum Crush | + | 0.1136 | 17 |
| | | DeltaV/BES | + | *0.0867 | 17 |
| All Crash Type Combined | % SDH | Maximum Crush | + | *0.1612 | 32 |
| | | DeltaV/BES | + | 0.1066 | 36 |

Maximum Crush




Delta V/BES




**% 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

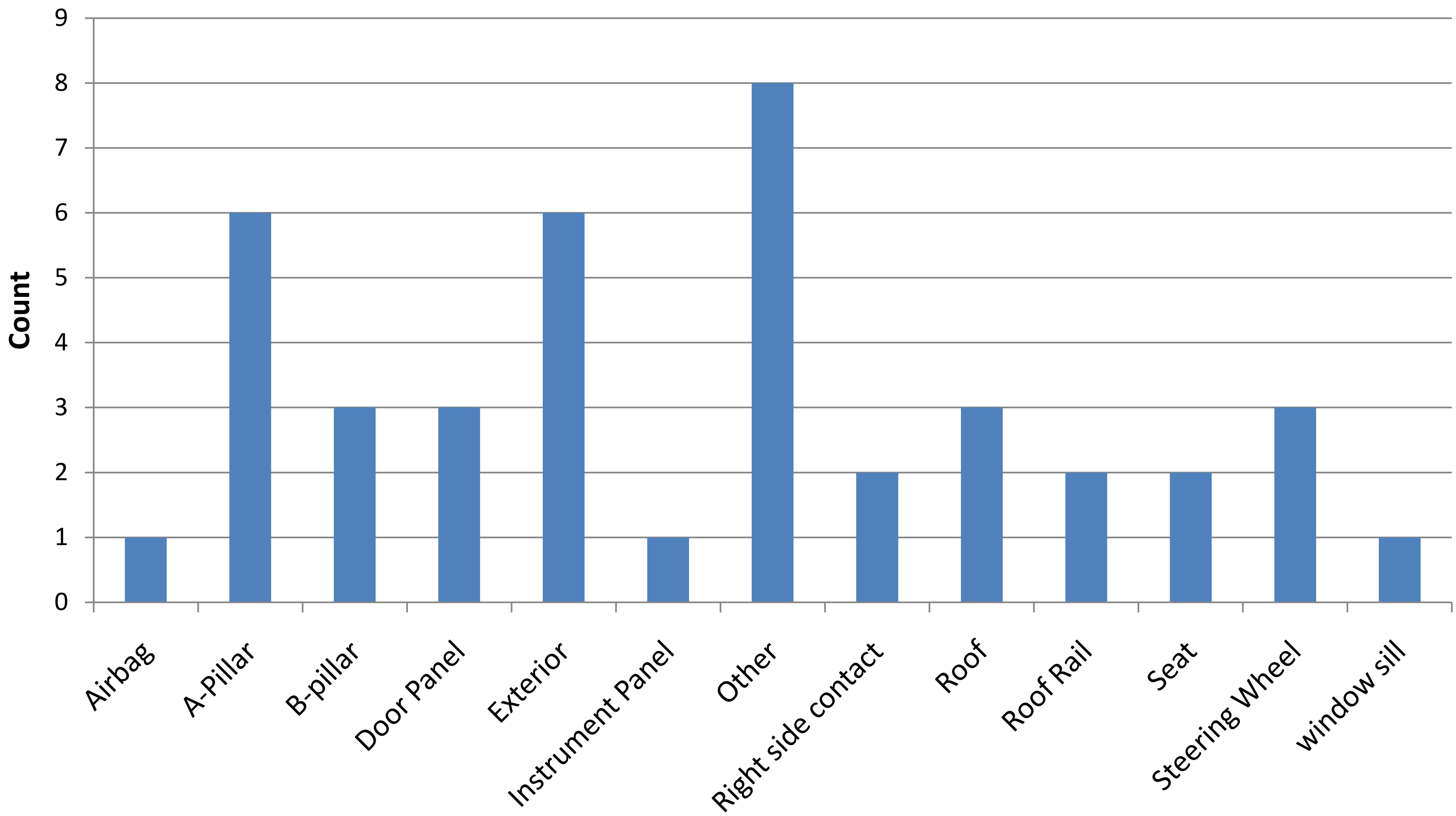
Involved Physical Component

Injury Location

**Occupant Data**

Age

# Certain and Probable IPC Distribution – Subdural Hematoma

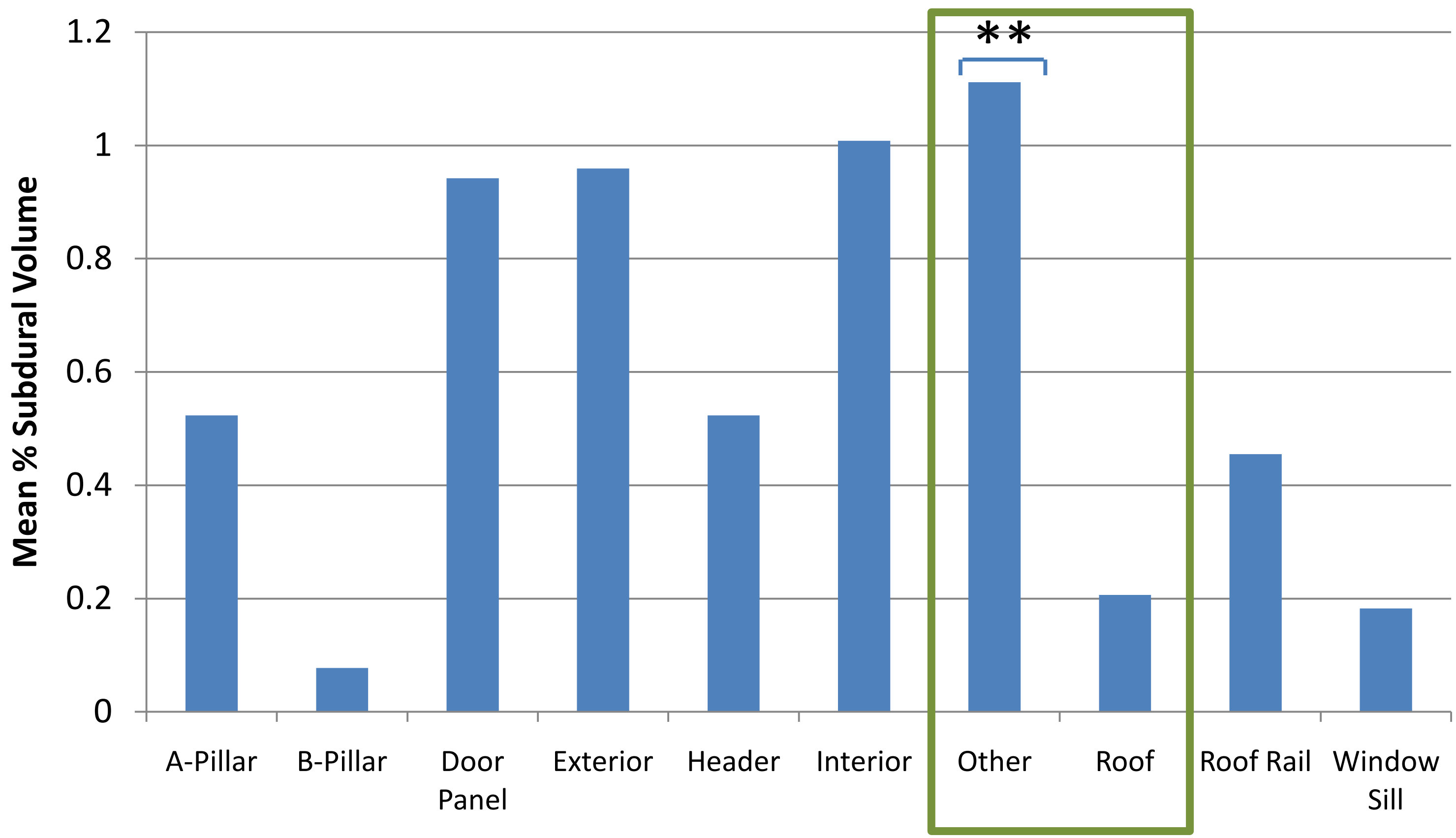


# IPC Weighting

- 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

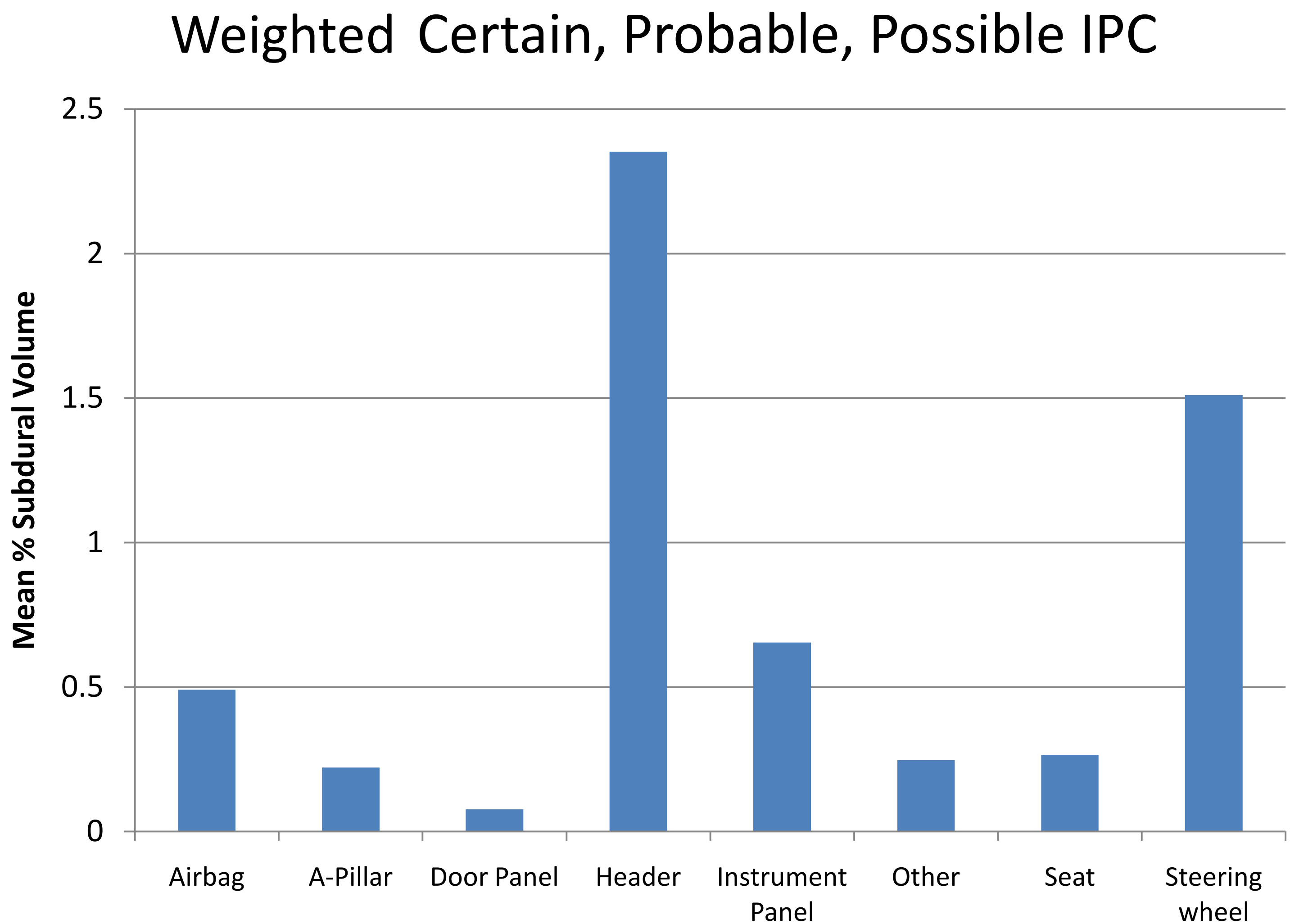
# % Subdural Volume – IPC Near Side Crash

## Certain, Probable, Possible IPC




Small sample size for other contacts

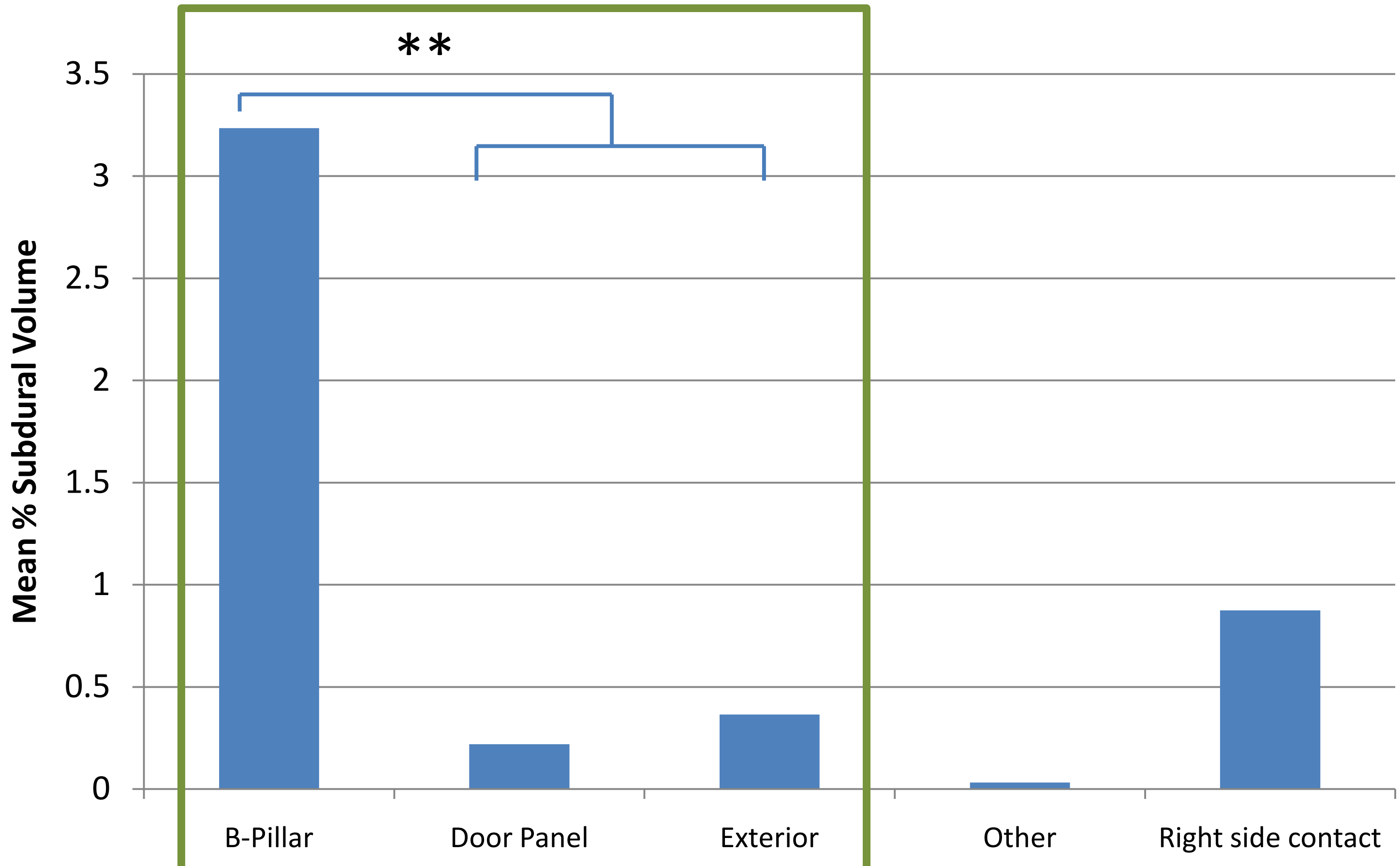
# % Subdural Volume – IPC Frontal Crash




Sample size for each contact too small for statistical significance

# % Subdural Volume – IPC Far Side Crash

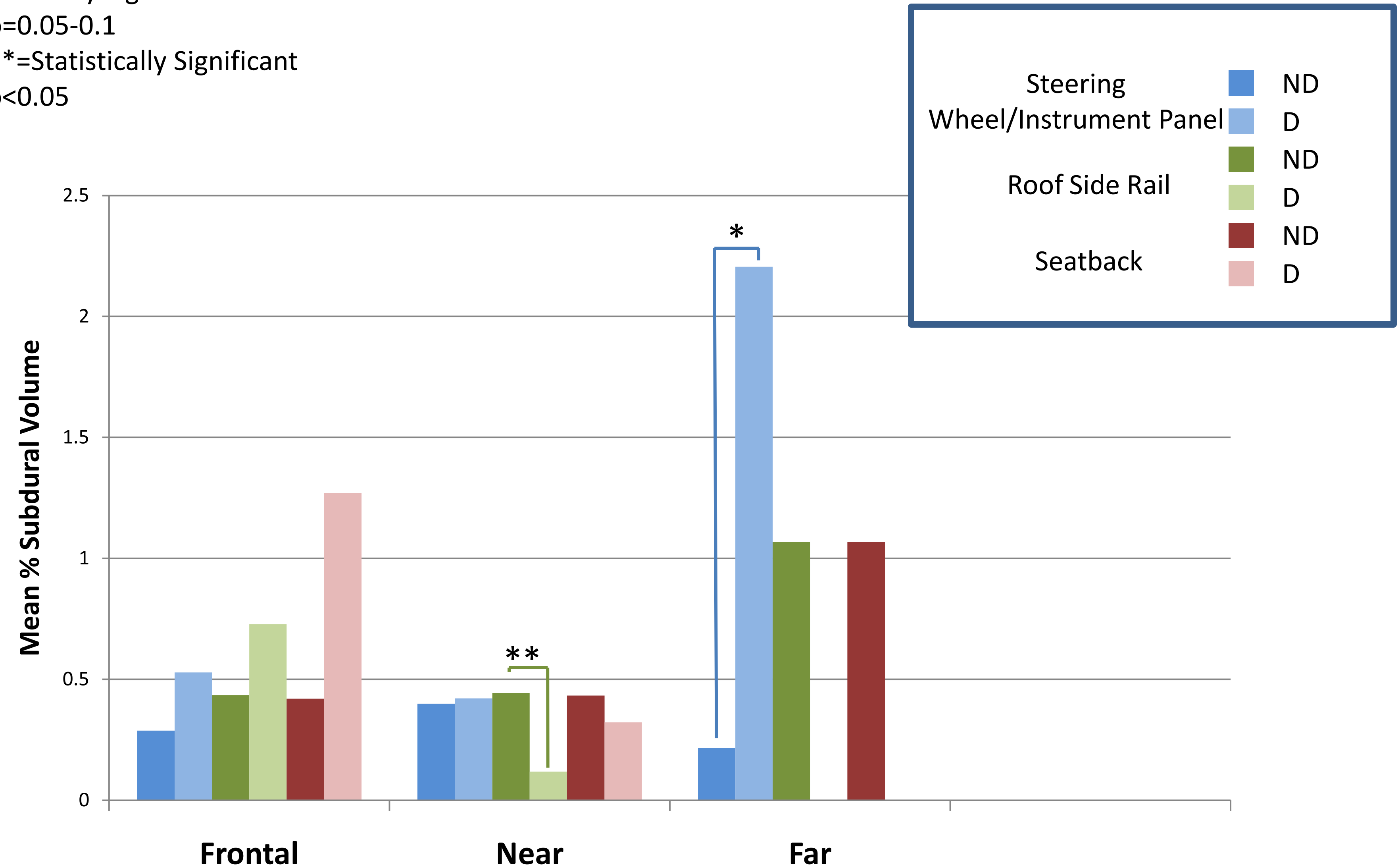
## Weighted Certain, Probable, Possible IPC




Small sample size for other and right side contact

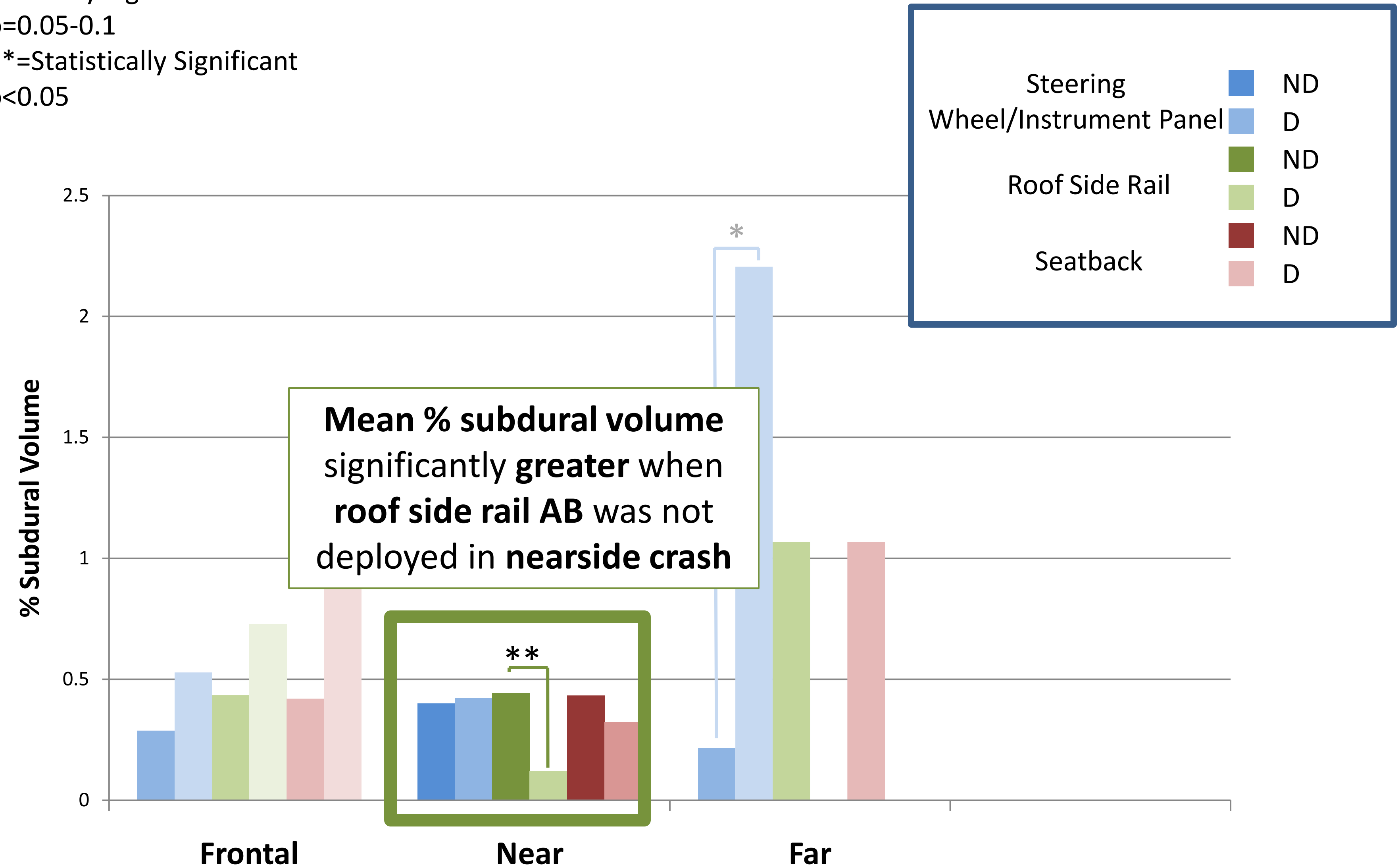
Deploy = D
Not Deployed/ Not available = ND
*= Mildly Significant p=0.05-0.1
**=Statistically Significant p<0.05

# Subdural Hematoma: Airbag Use

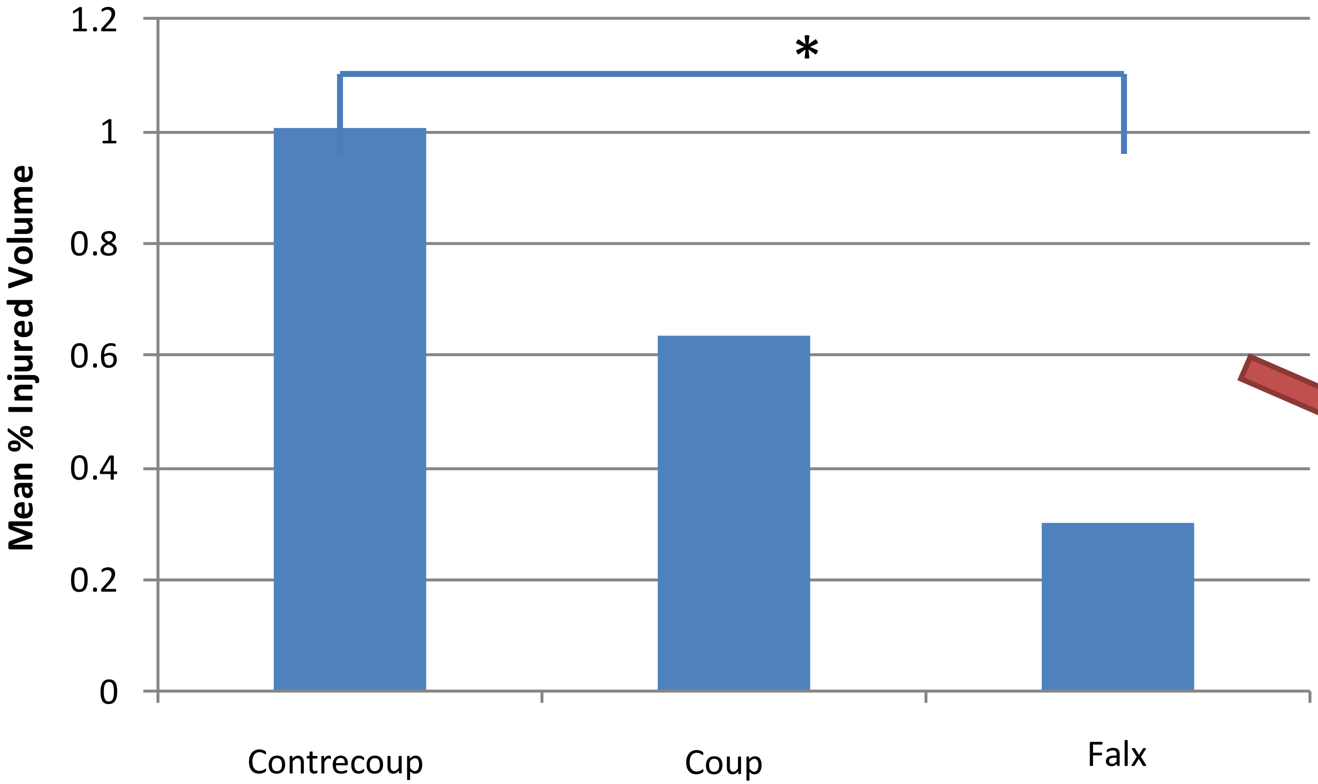


# Subdural Hematoma: Airbag Use

Deploy = D
Not Deployed/ Not available = ND
*= Mildly Significant p=0.05-0.1
**=Statistically Significant p<0.05



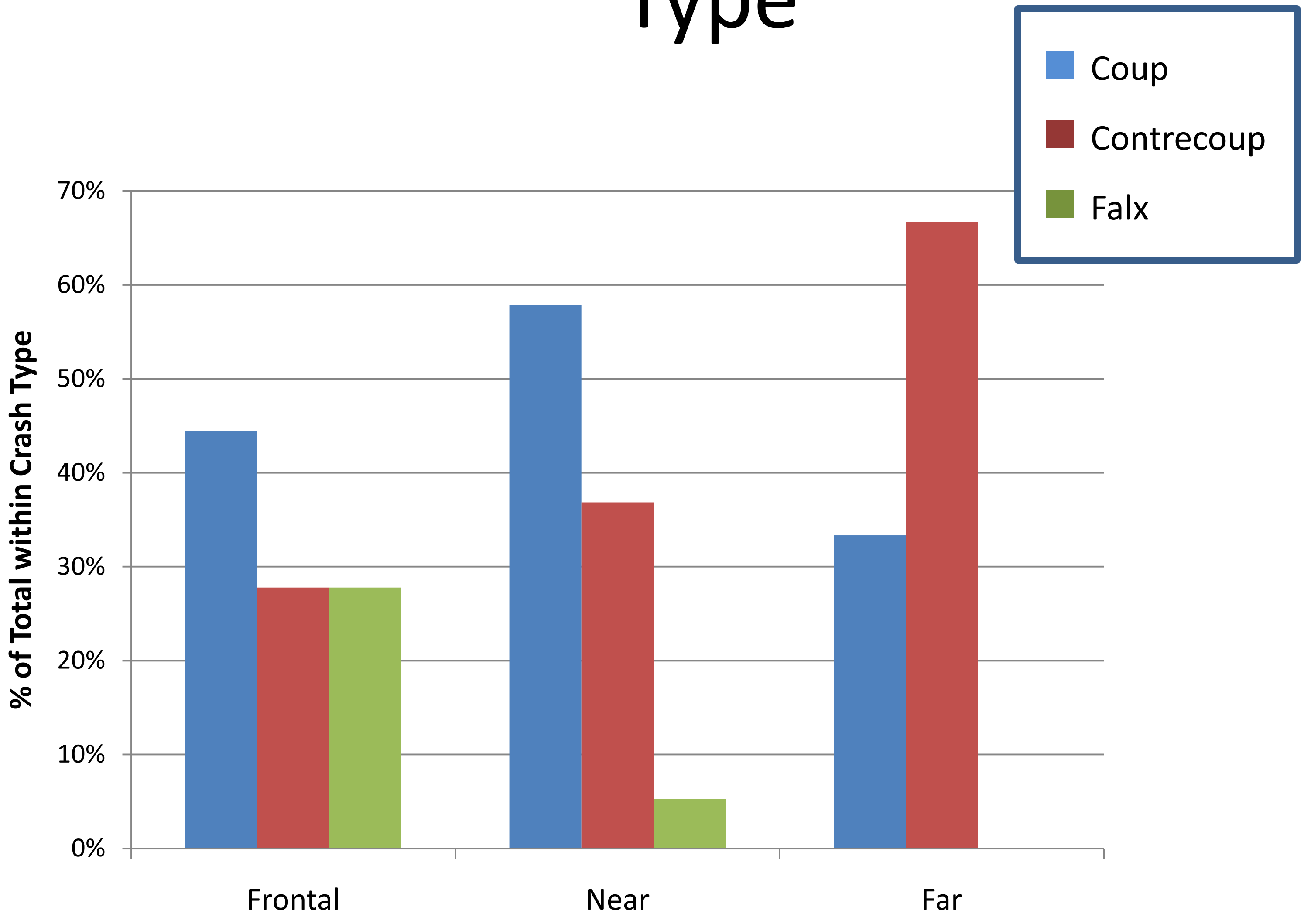
# Subdural Volume Location by % Injured Volume




Contrecoup

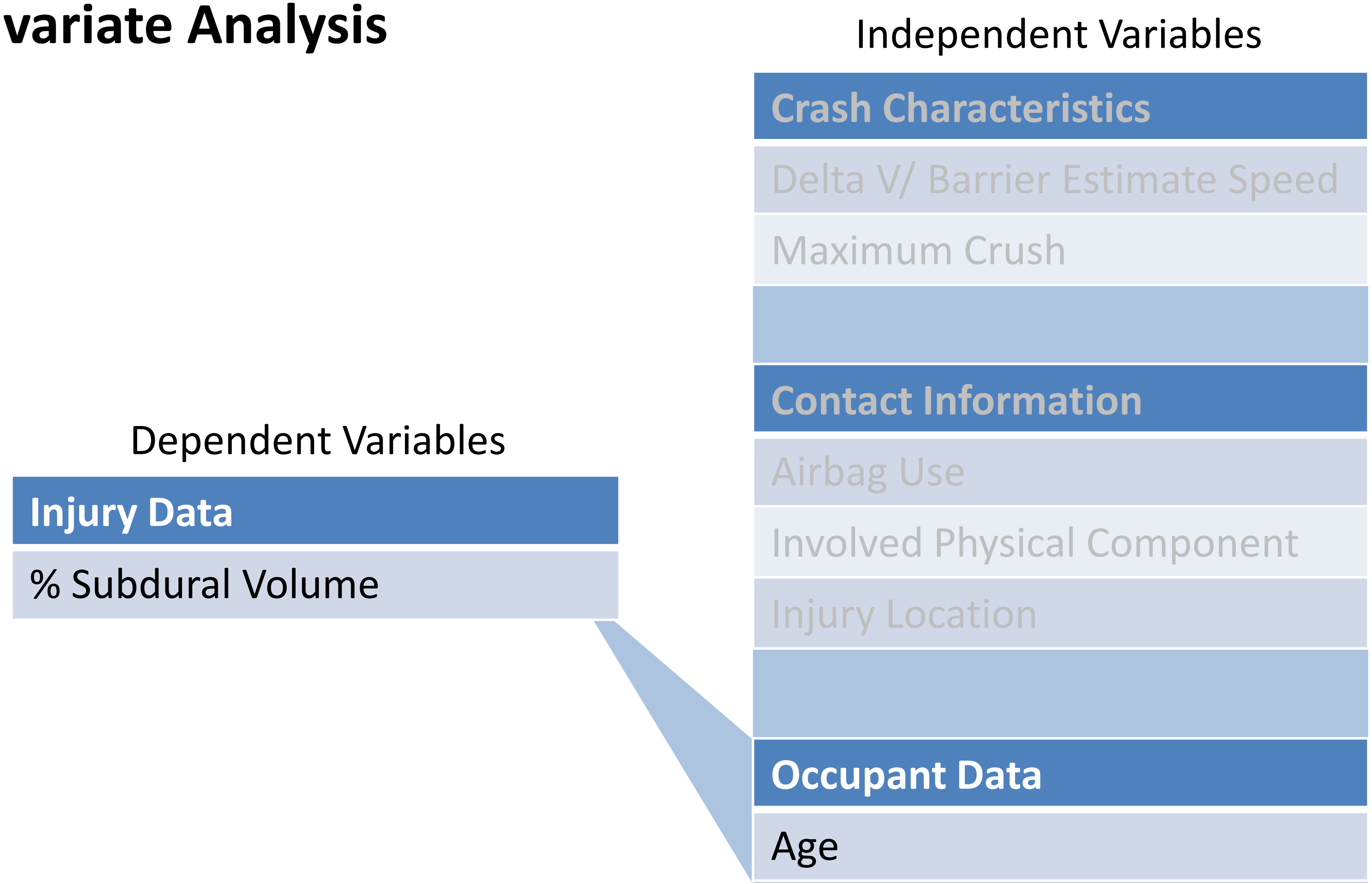
Mean total % injured volume is greater in contrecoup injuries compared to subdural injuries within the falx

# Intracranial Injury Location by Crash Type

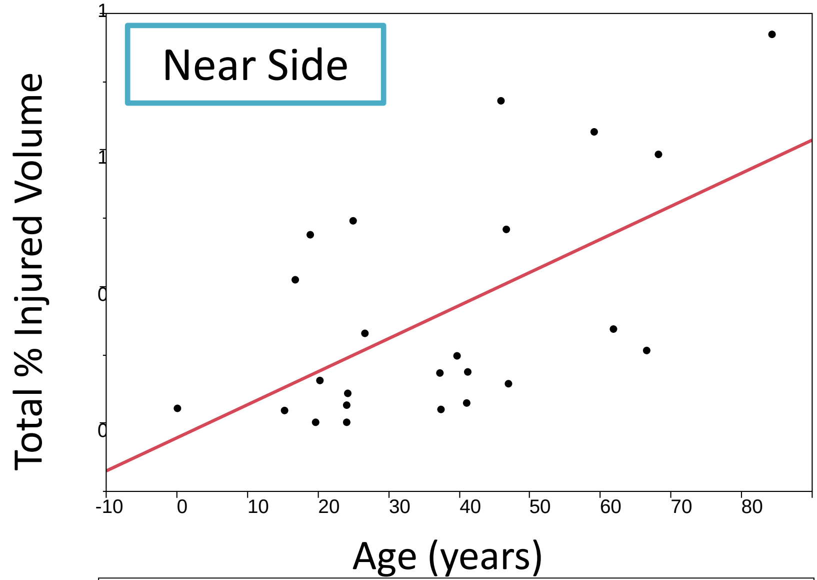


# Subdural Hematoma Statistical Analysis

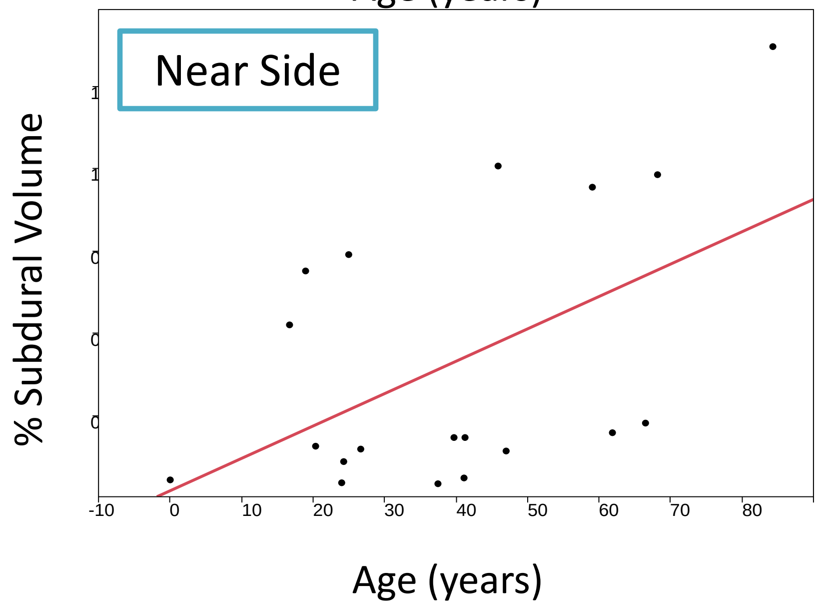
**Bivariate Analysis**



# % Injured Volume – Age




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**

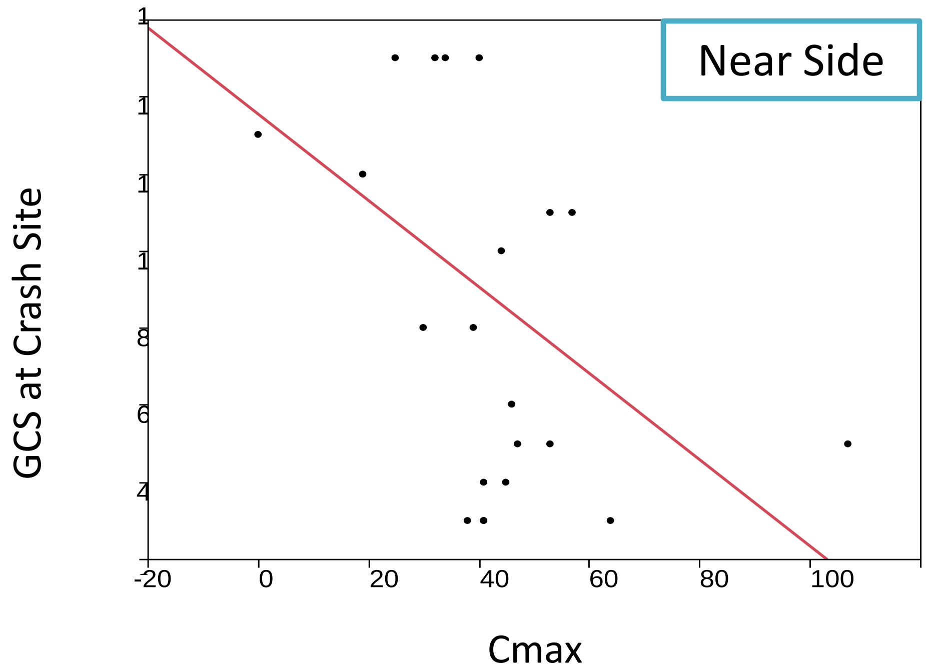
Dependent Variables

| Neurological Assessment |
| --- |
| Glasgow Coma Scale |

Independent Variables

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

# 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

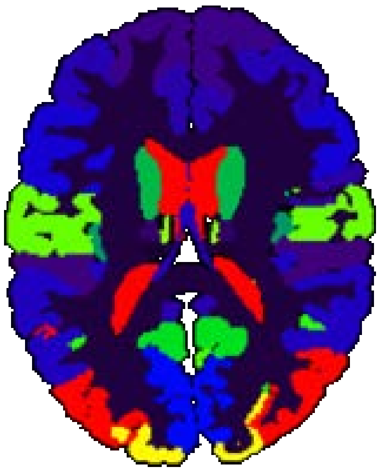
Verbal

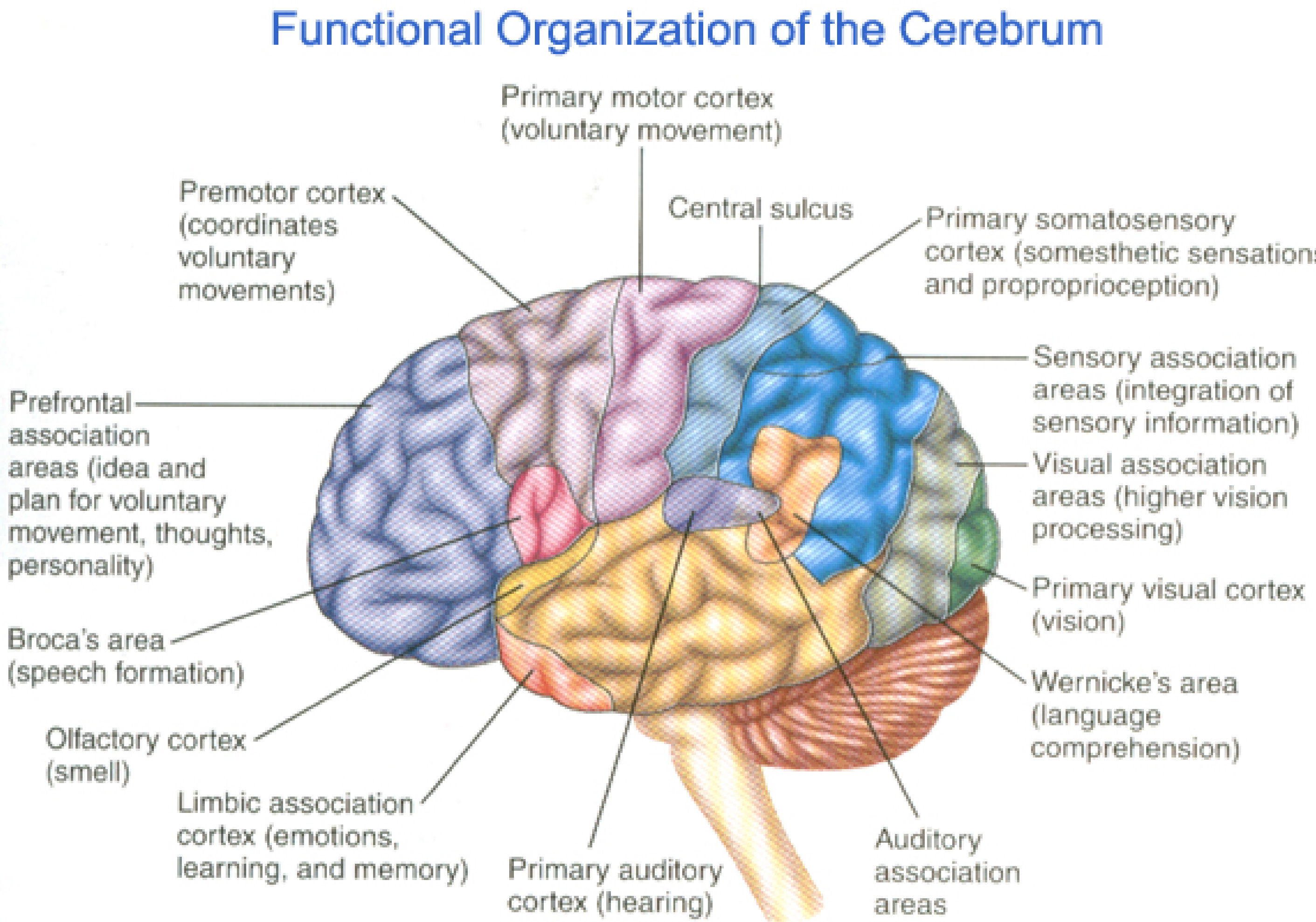
Motor

Eye

# CT Atlas

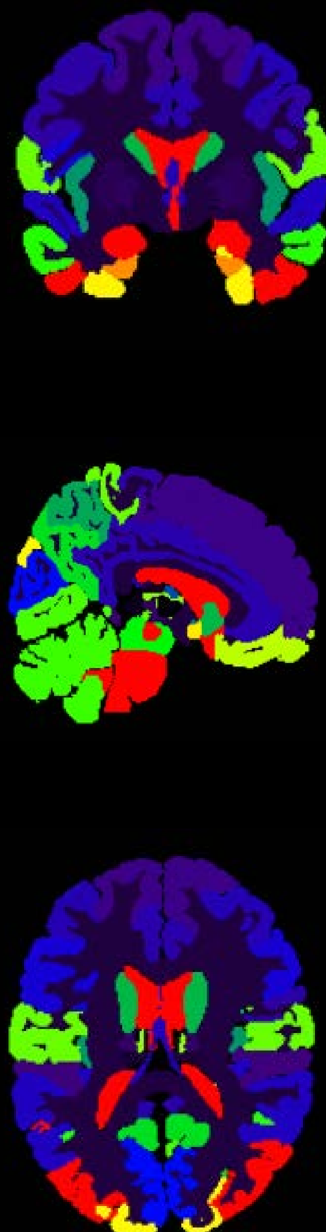
# CT Brain Atlas



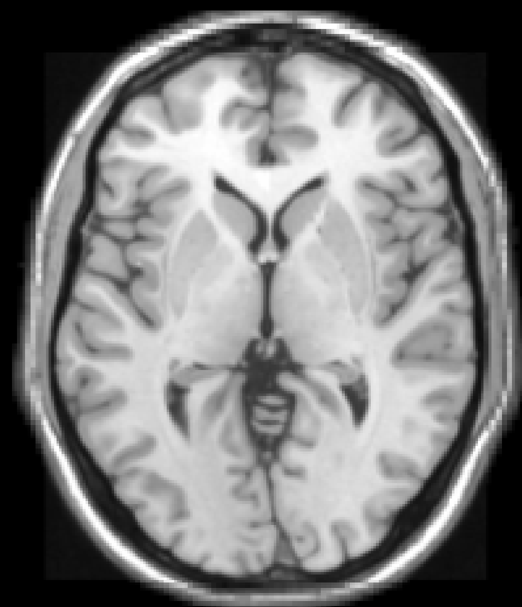



- Create CT brain atlas from normal subjects in ICBM space
- Atlas-based segmentation used to identify injured structure and predicted functional outcome

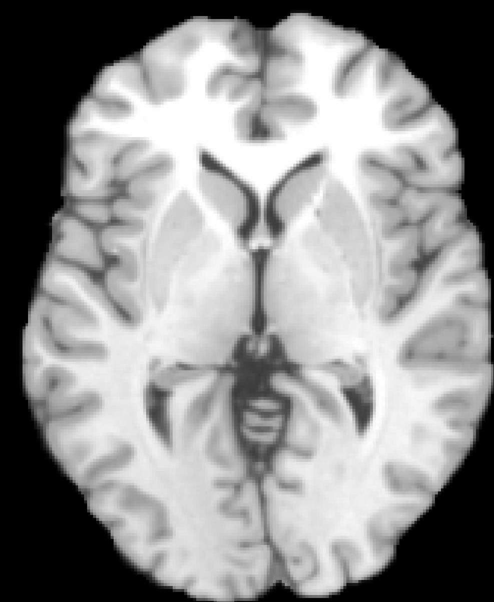
## ICBM Labels



# ICBM Template



**With Skull**



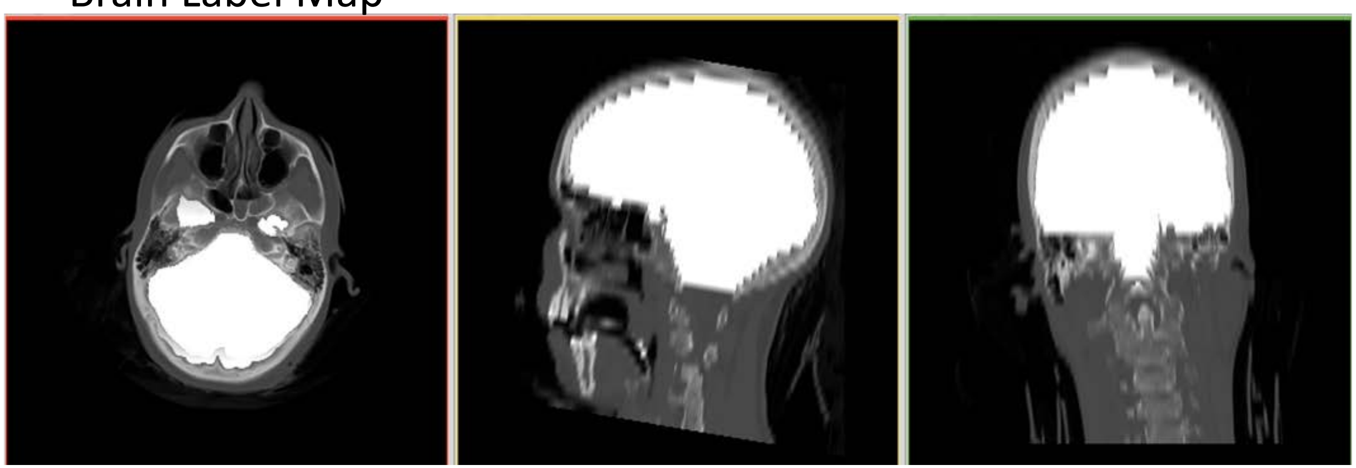
**Skull Stripped**

# Skull Stripping CT Scan

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

Raw DICOM

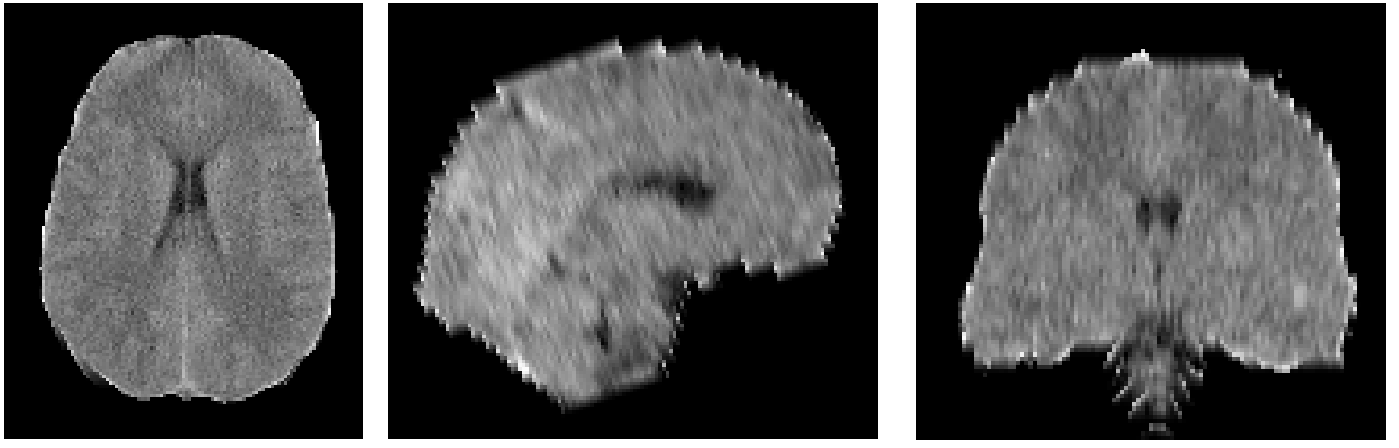
Brain Label Map



# 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

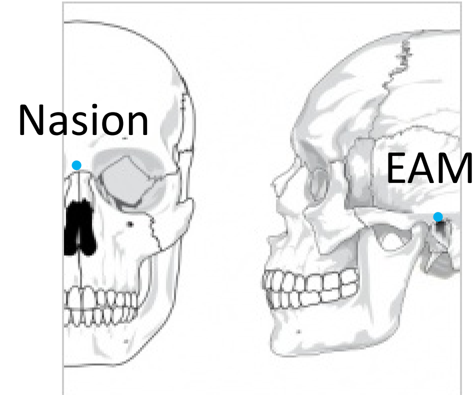
Skull Stripped CT Scan

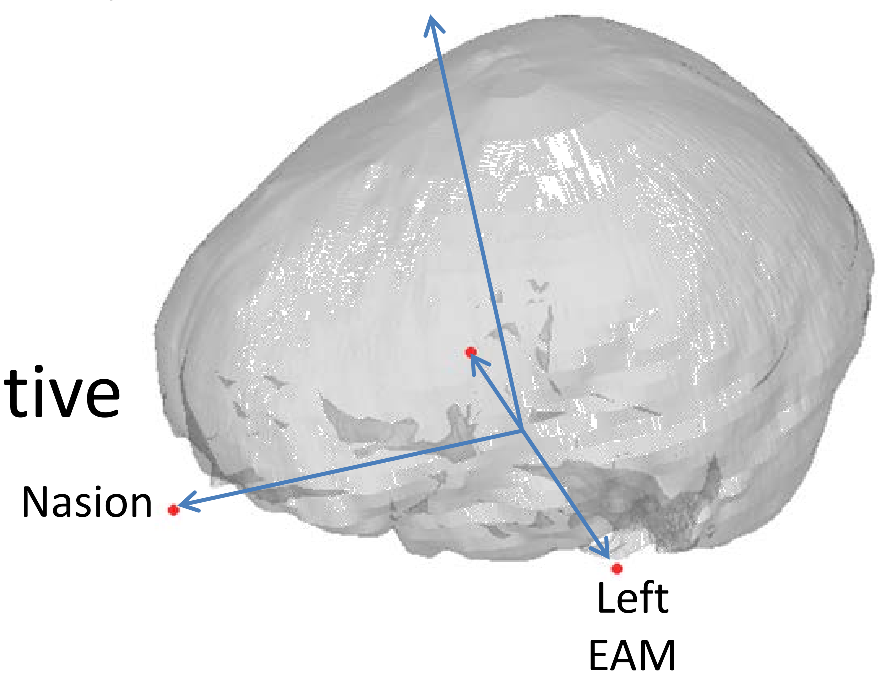


# Spatial Distribution

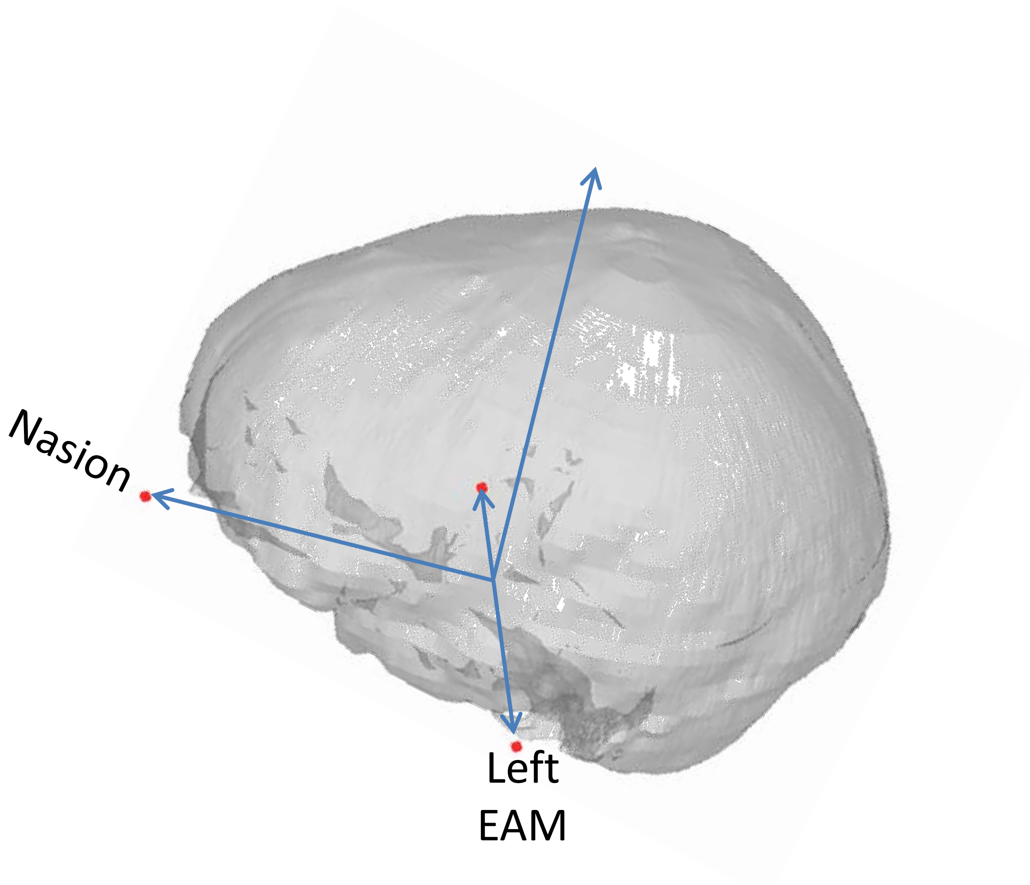
# Common Coordinate System

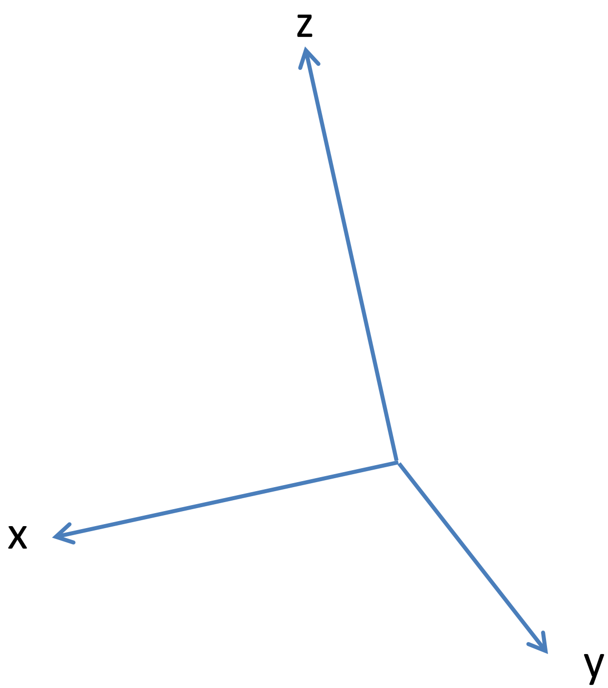
- Common brain coordinate system established from bony landmarks on the skull
  - Nasion
  - Right & Left External Auditory Meatus (EAM)
- Translate brain origin to global origin
- Rotate to global axes
- Rotate nasion along positive x-axis



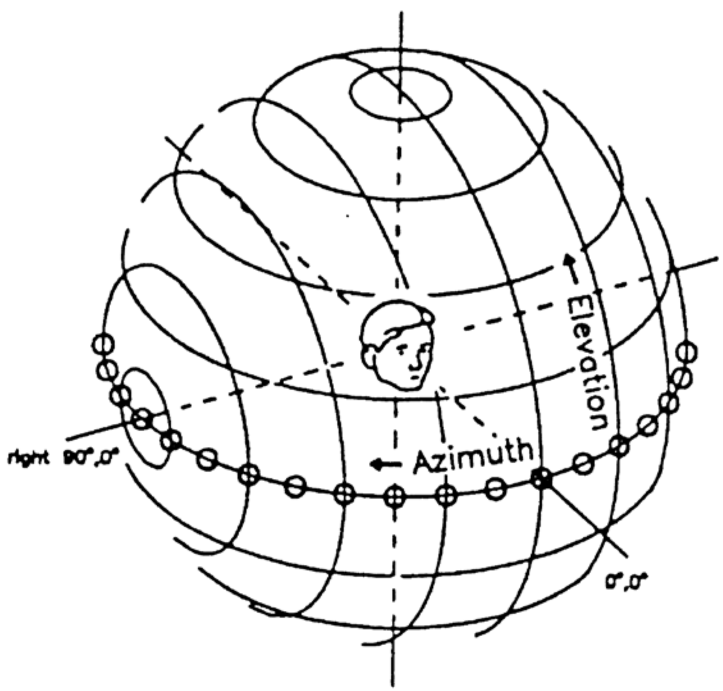
# Transform to Global Coordinate System



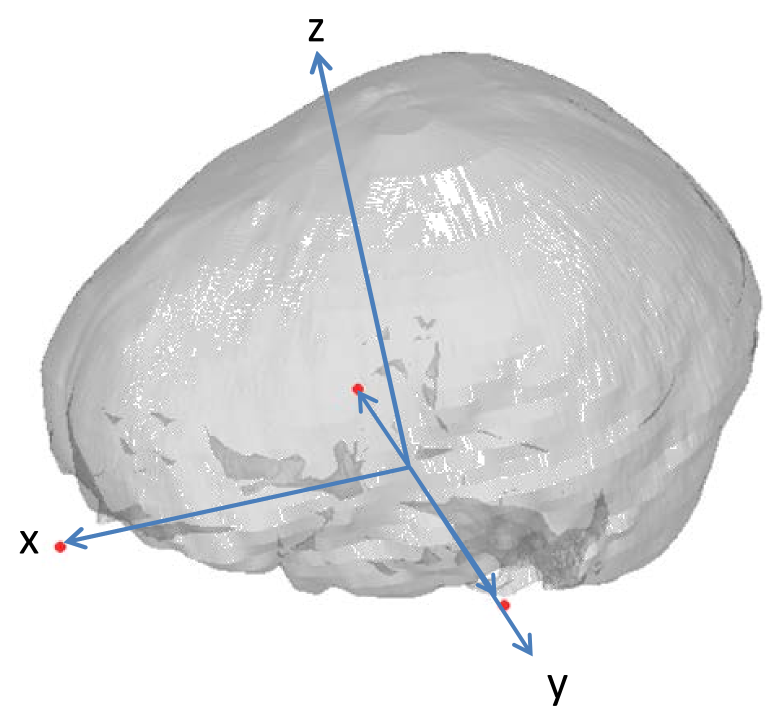



# Transform to Global Coordinate System

- Convert to azimuth and elevation for analysis

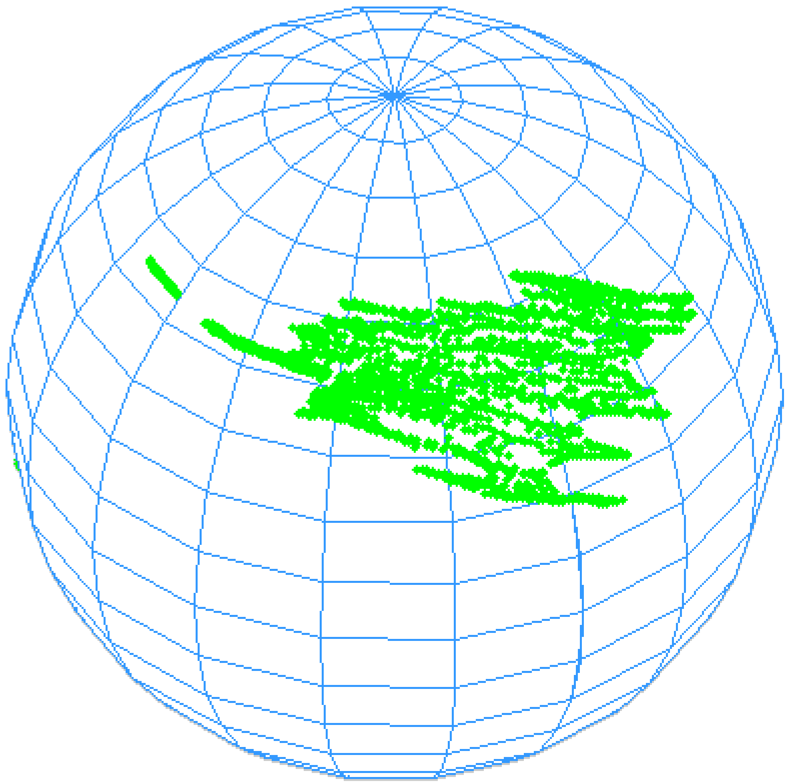



Leong et al – Methods for Spherical Data Analysis and Visualization

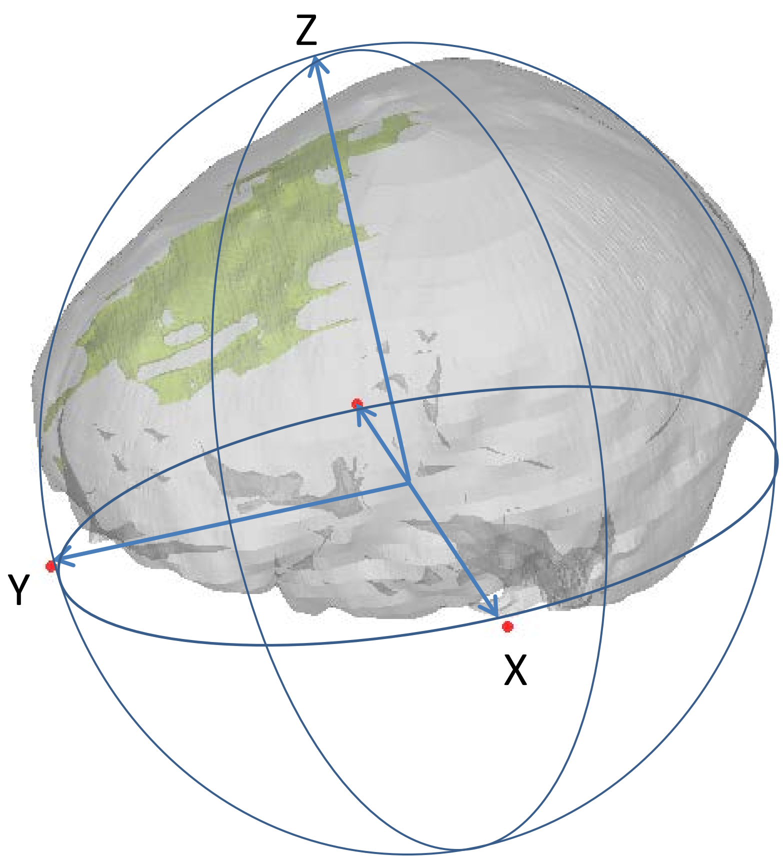


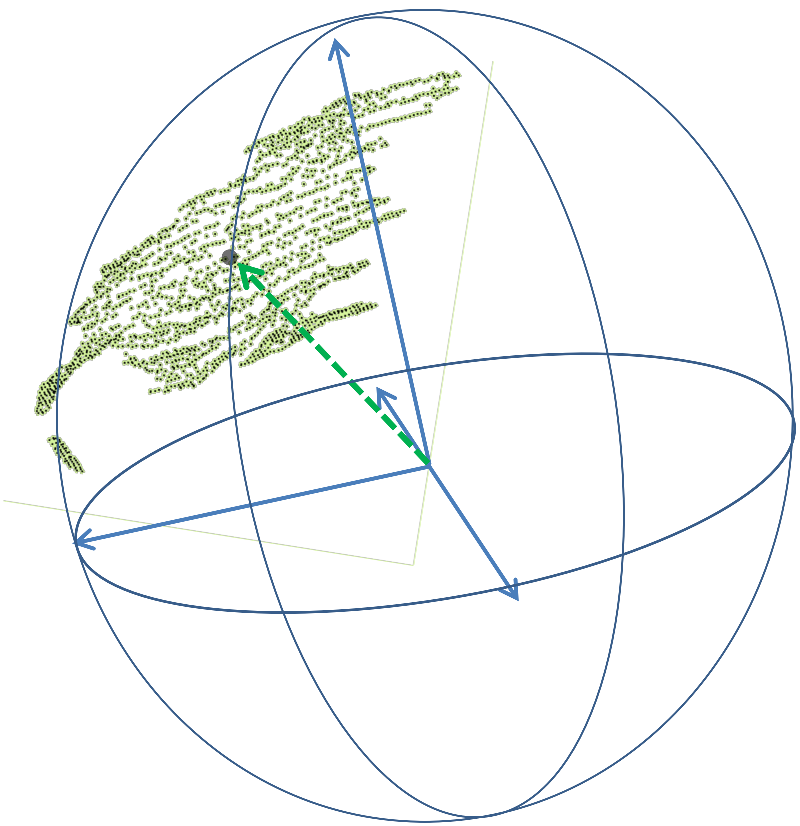
# Example: SPAK – "Spherical Package"

- 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



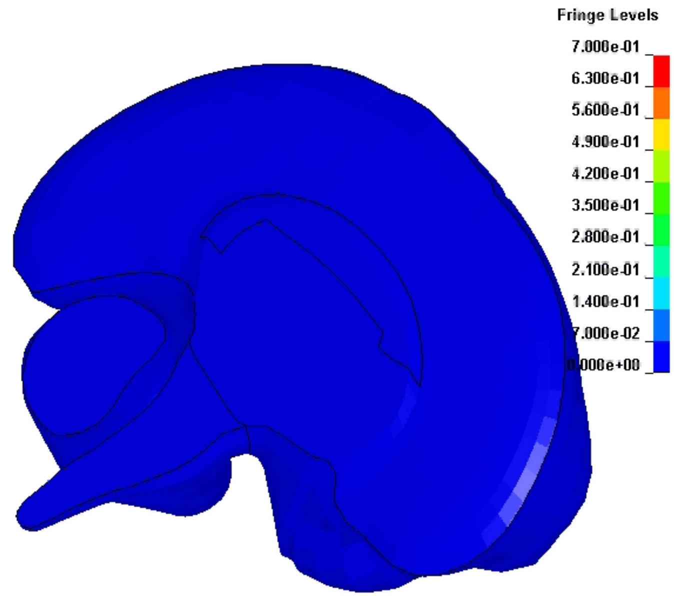
# Spatial Distribution

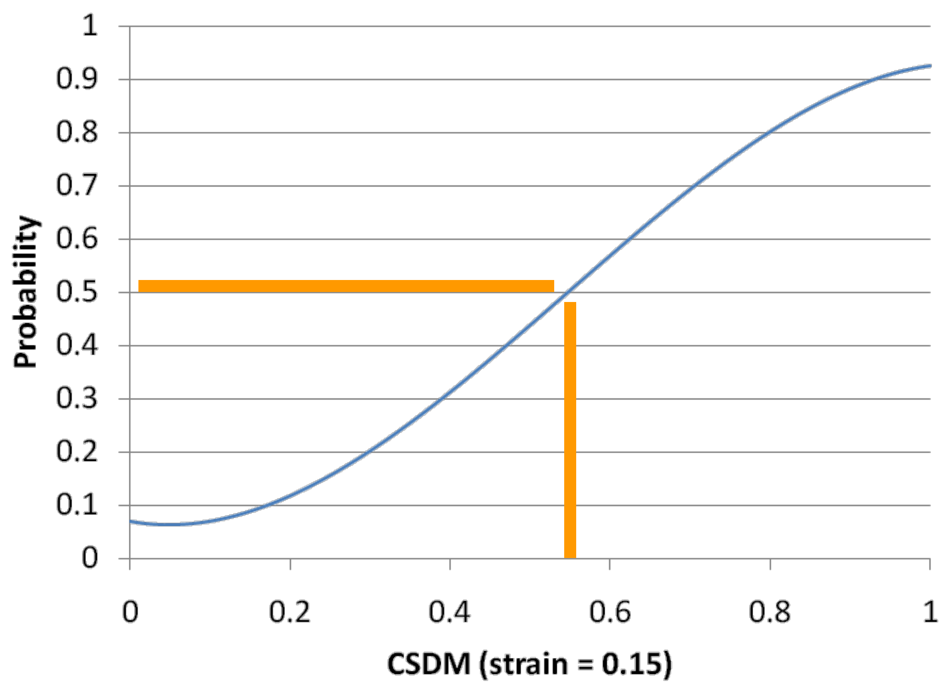


# Injury Metrics: CSDM

- 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

Takhounts 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

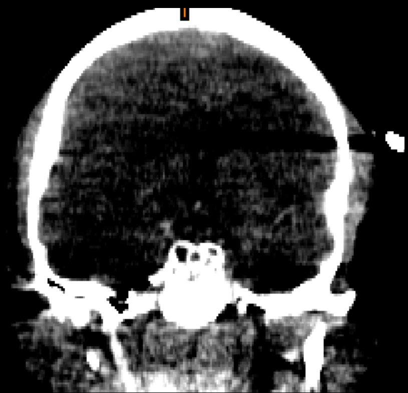
- Subdural hematoma is positively correlated with many crash characteristics in various crash modes
- % Subdural Volume increases with:
  - Delta V/barrier estimate speed in near side crashes
  - Maximum crush in far side crashes

# 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



# Acknowledgments

## THANK YOU!

National Highway Traffic Safety Administration

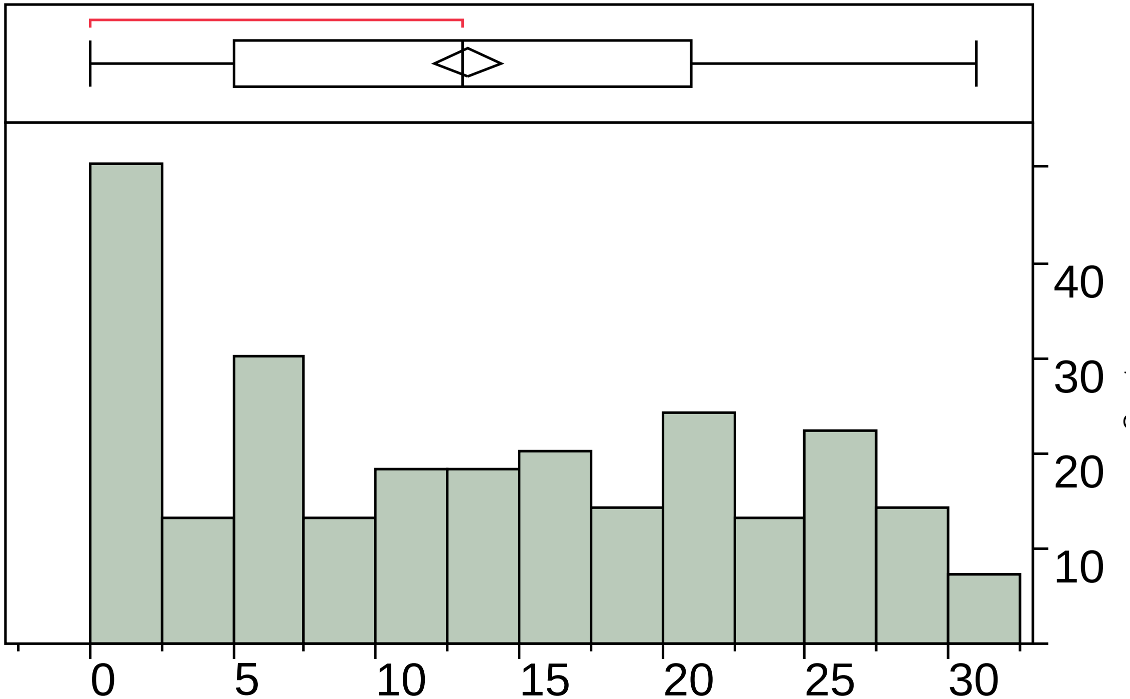
CIREN Partner Centers

WFU-VT CIB Summer Interns:

Rachel, Andrew, Colston, Kavya, Pavani, Jaclyn

Work was performed for the Crash Injury Research and Engineering Network (CIREN) Project at Wake Forest University School of Medicine in cooperation with the United States Department of Transportation/National Highway Traffic Safety Administration (USDOT/NHTSA). Funding has been provided by the National Highway Traffic Safety Administration under Cooperative Agreement Number DTNH22-10-H-00294. Views expressed are those of the authors and do not represent the views of any of the sponsors or NHTSA.

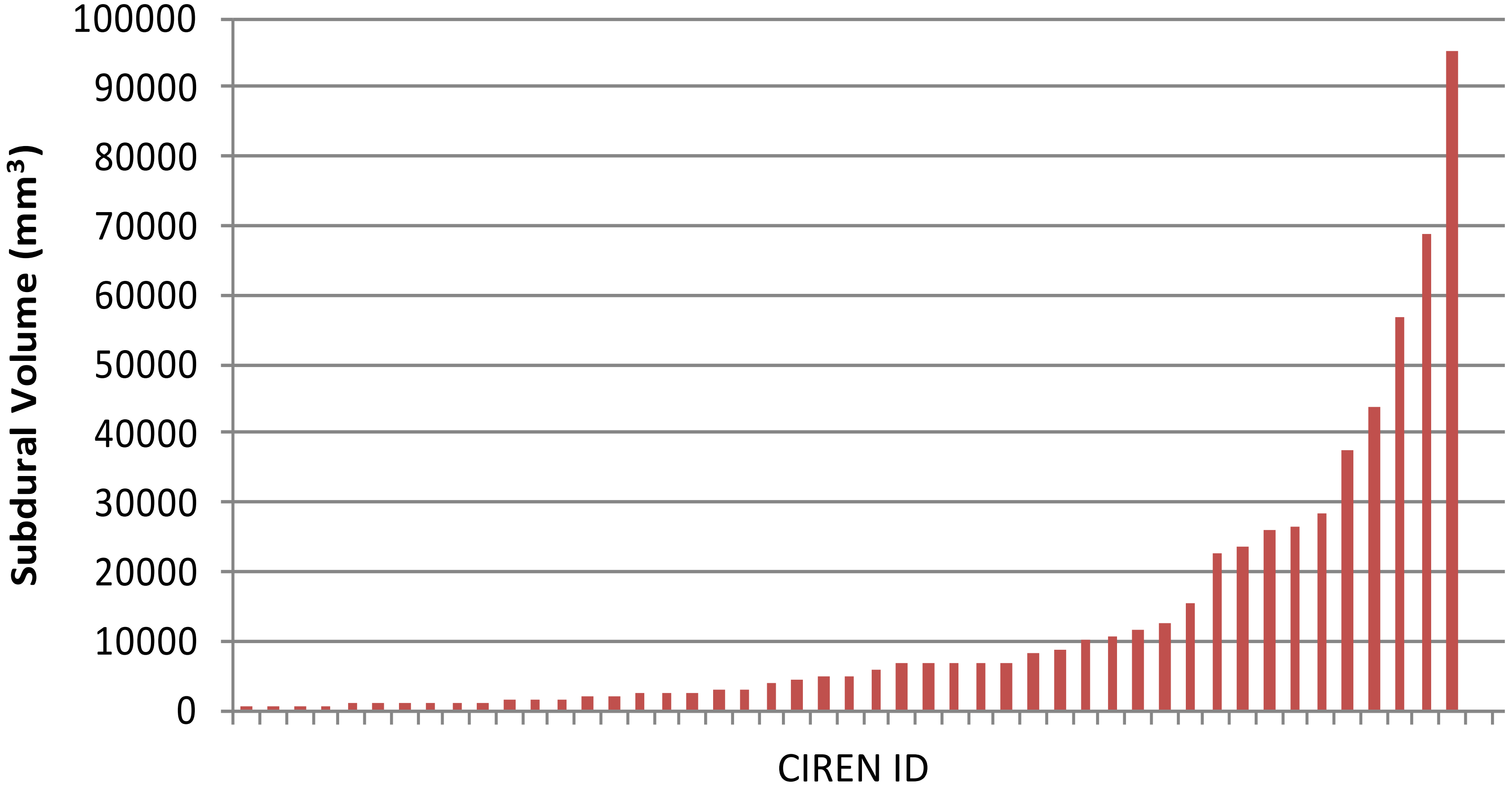
# Scan Date



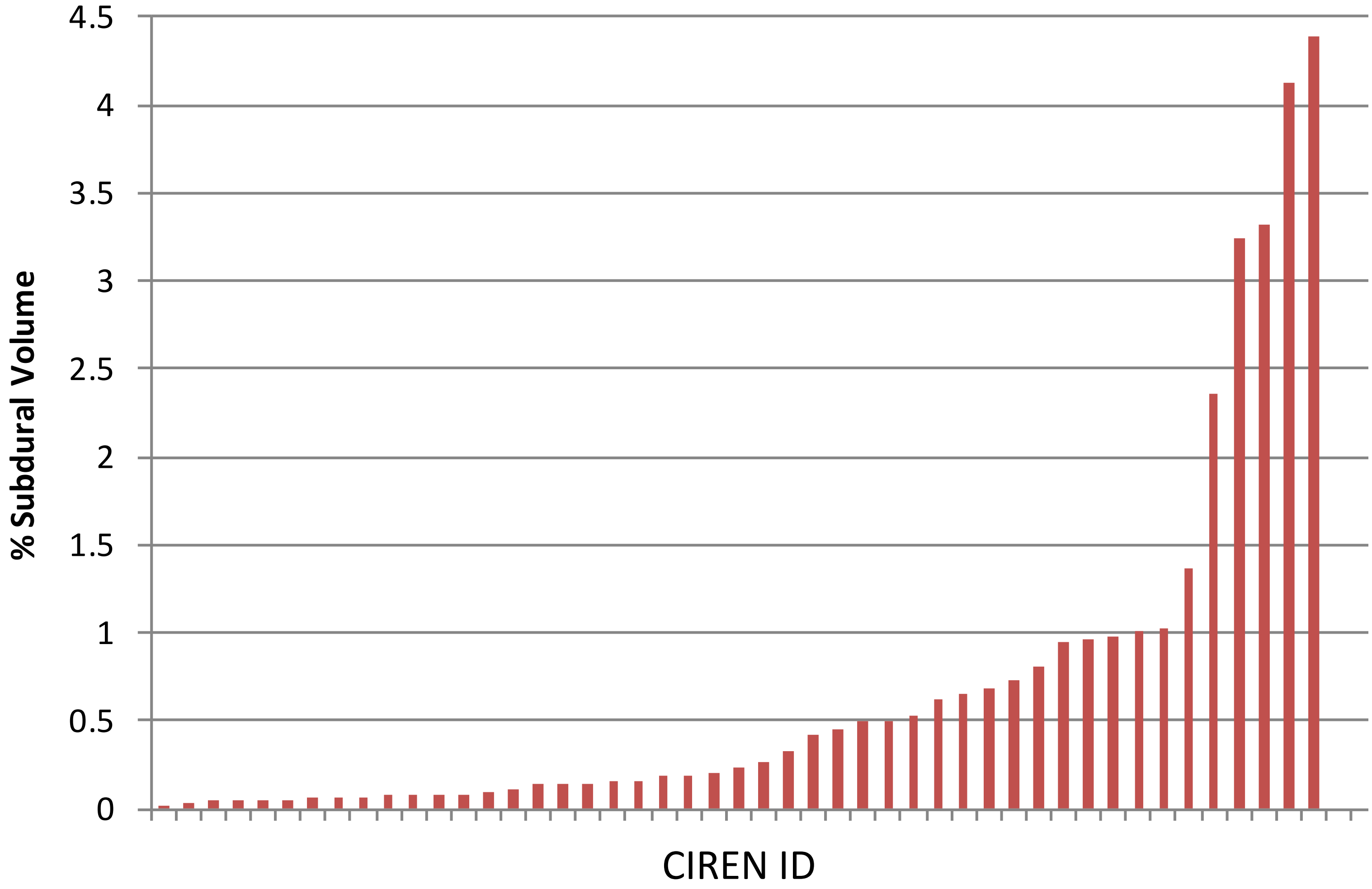

Days post crash

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

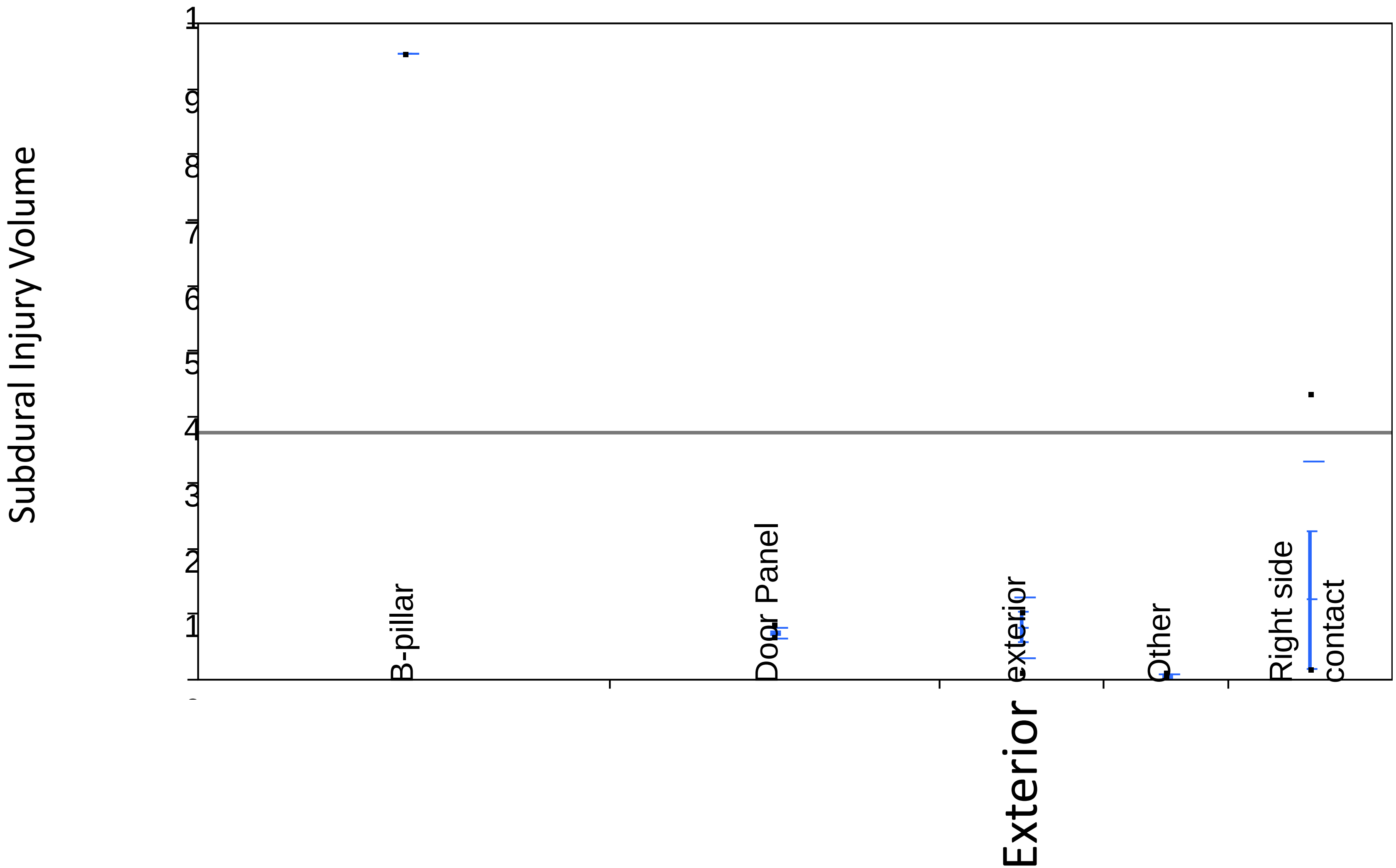
# Subdural Hematoma Volume Distribution by Case



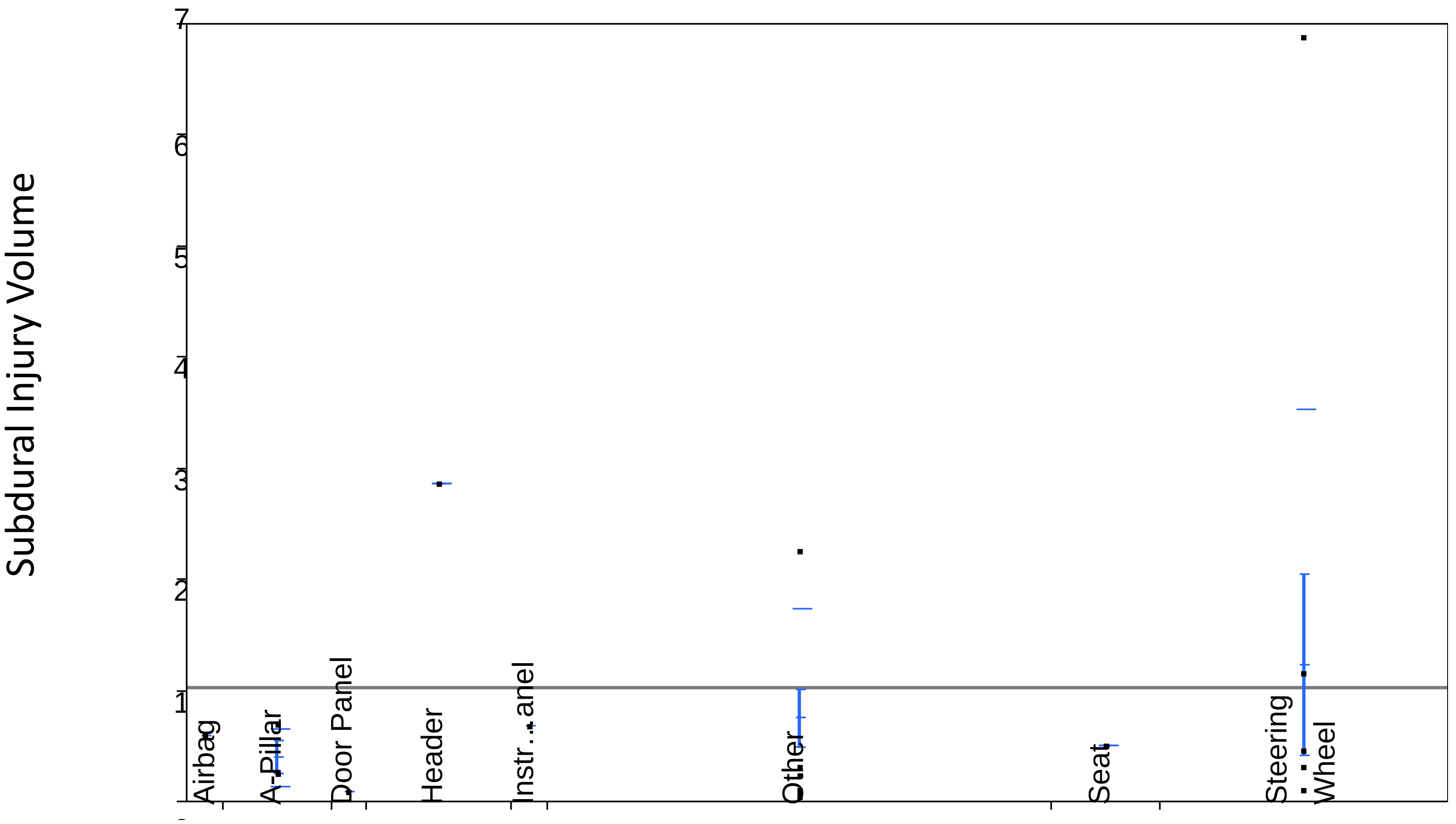
# % Subdural Hematoma Volume Distribution by Case



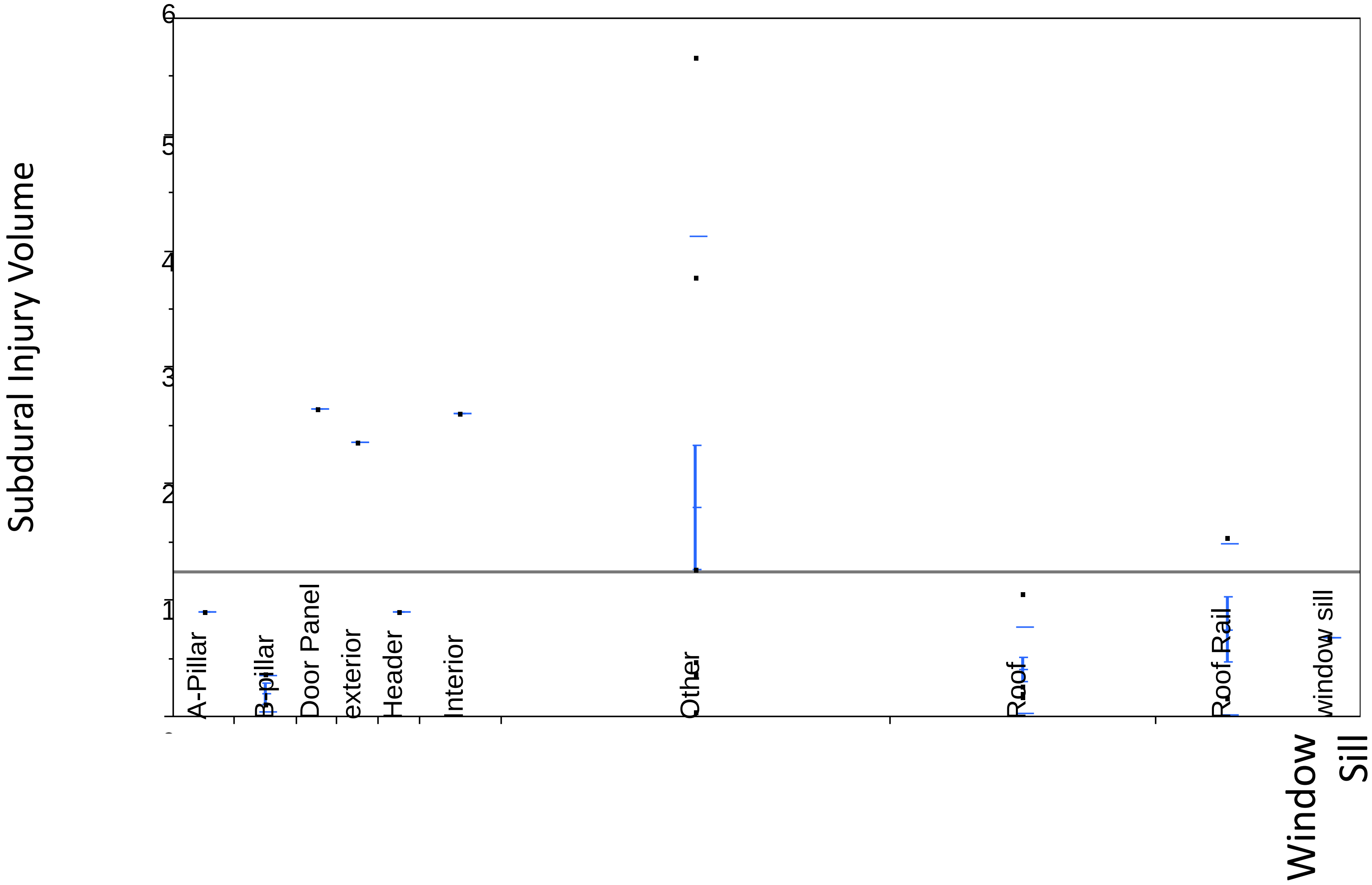
# Far Side Crash



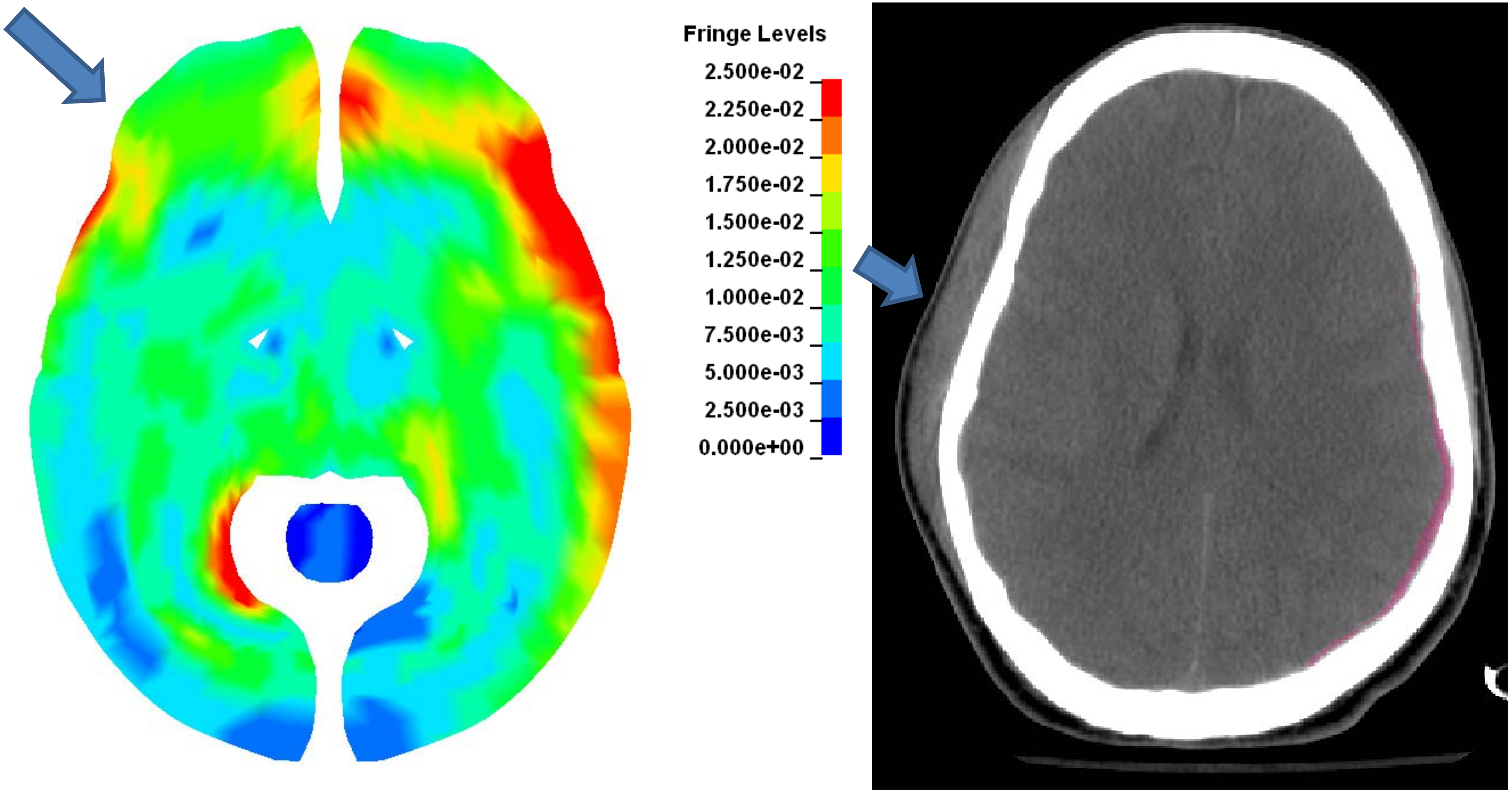
# Frontal Crash



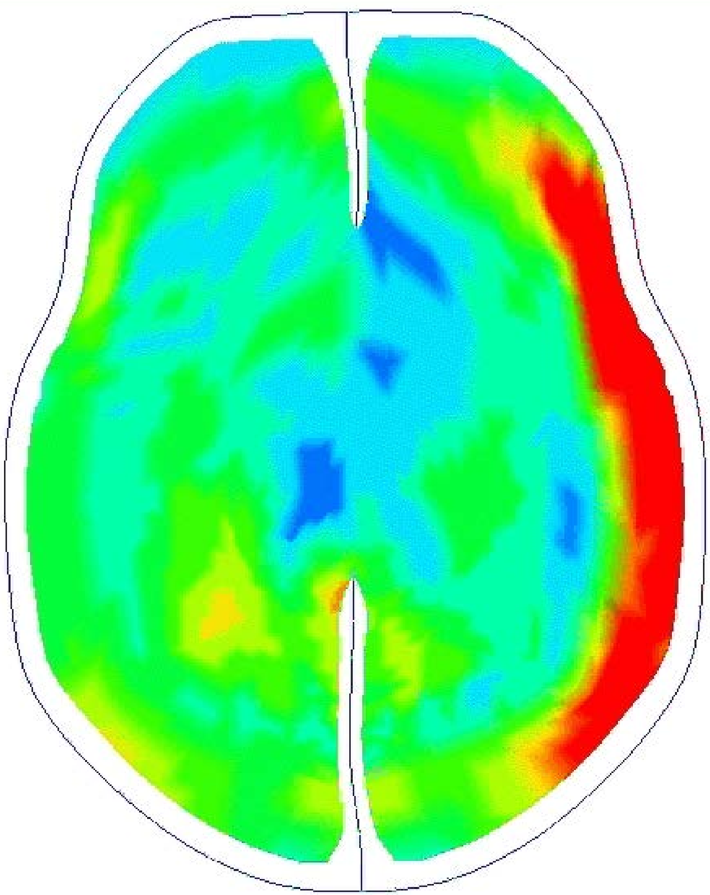
# Near Side Crash

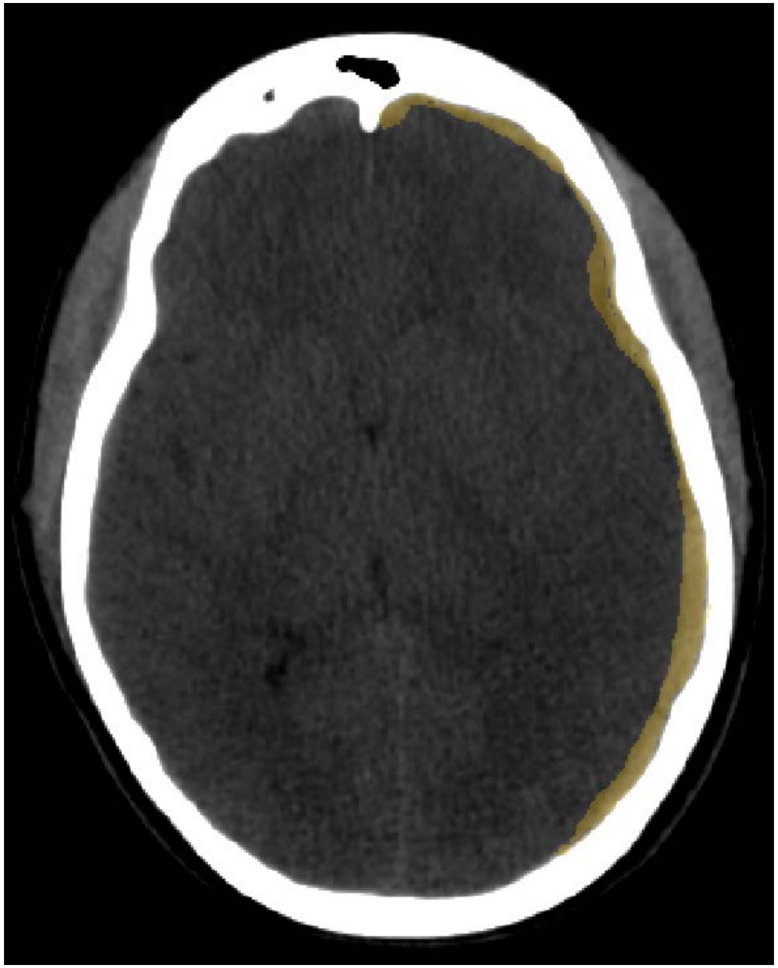


# Contrecoup, Frontal, Driver, Contact at right temporal

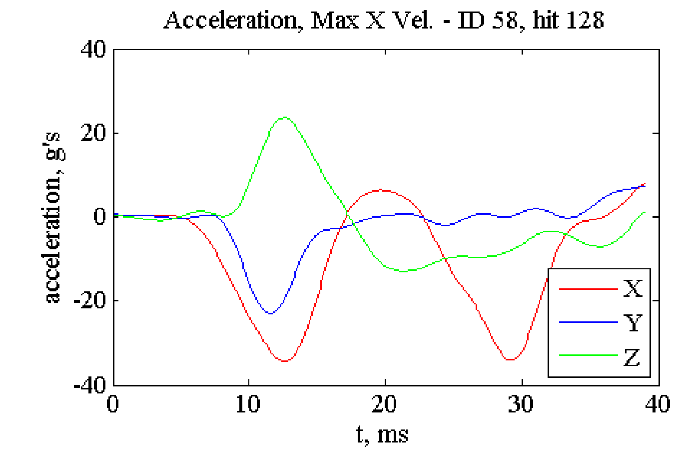


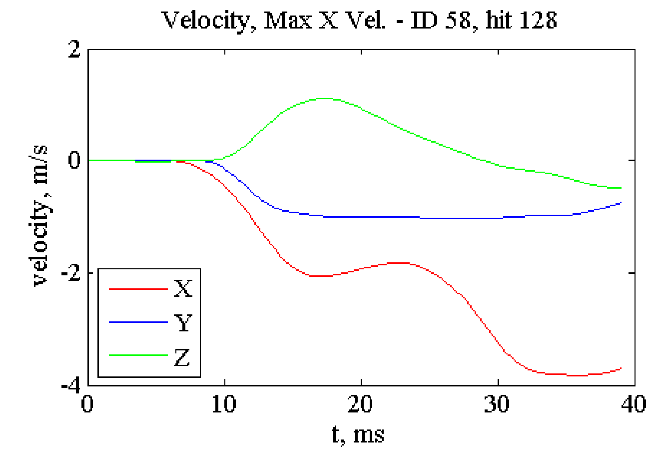
# Coup – Right Front Passenger

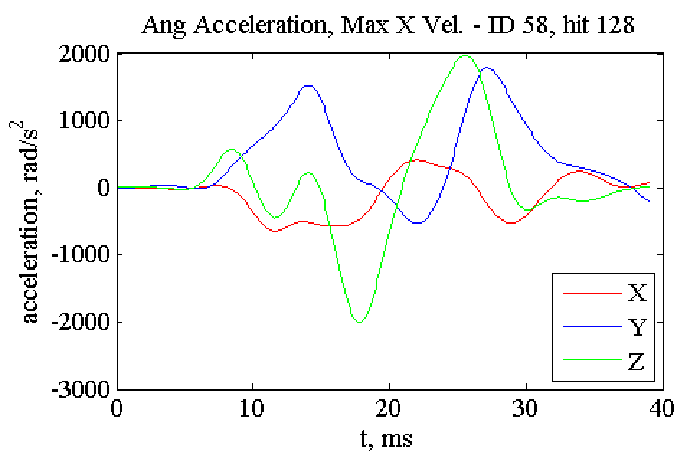


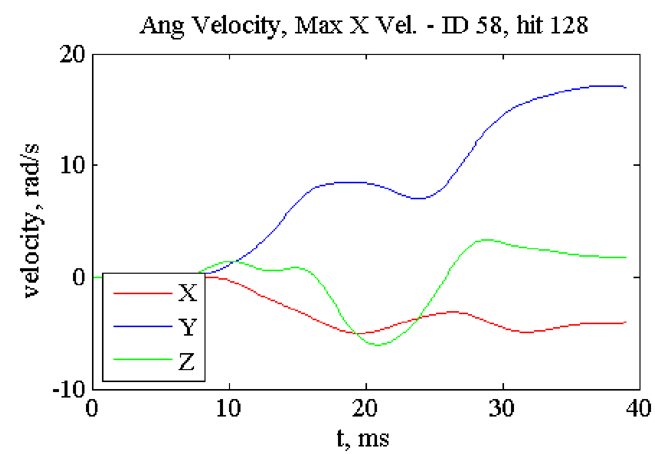


# Max isolated velocity- X



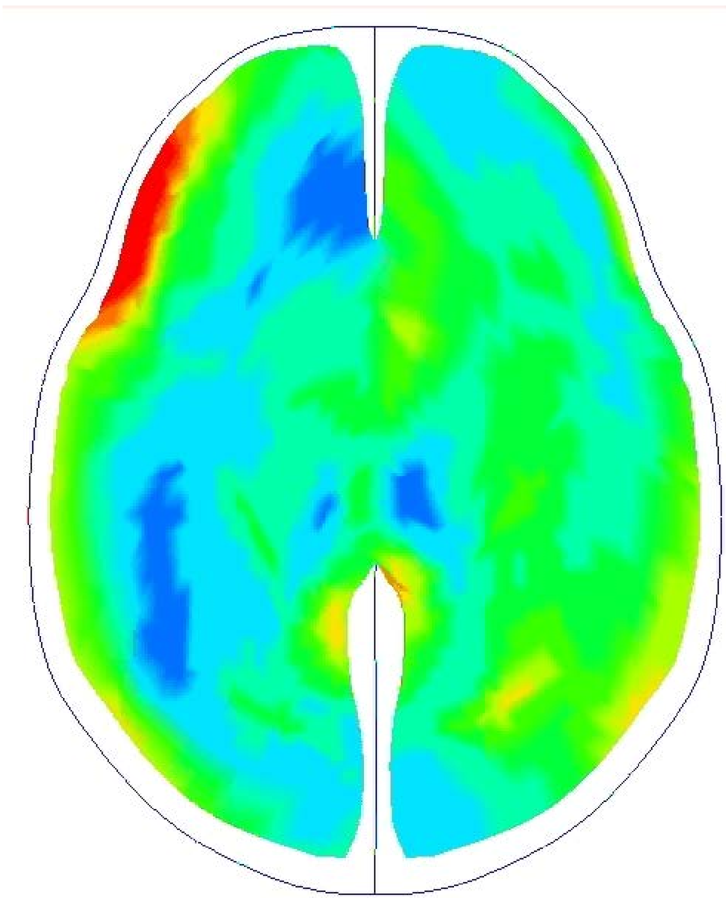



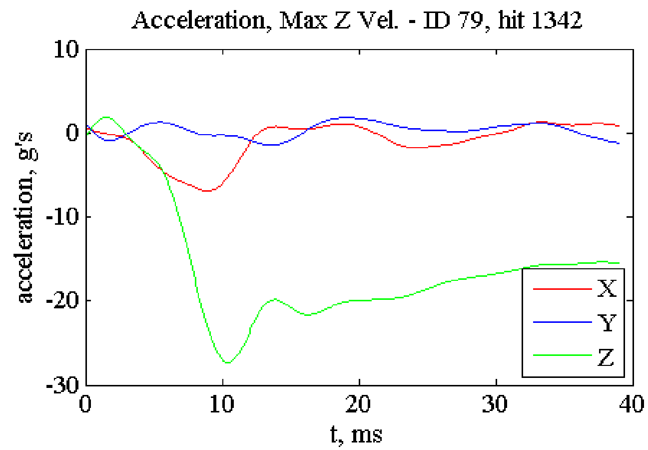



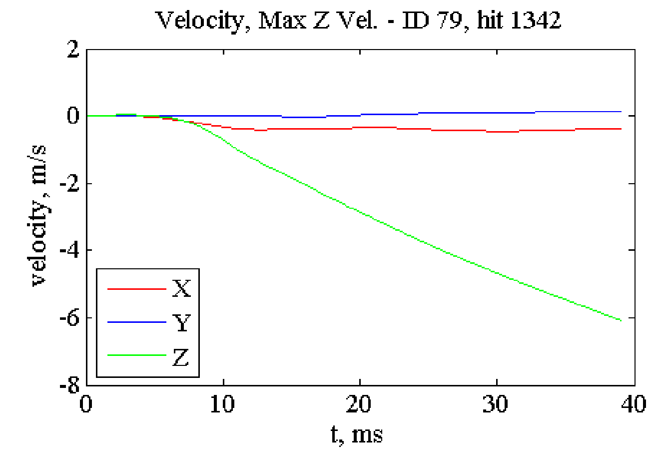

Off-axis pulses magnitudes are less than 30% of the primary pulse

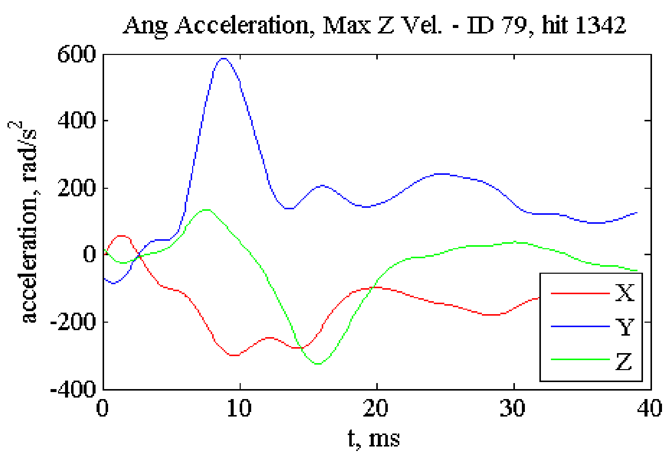
# Contrecoup – Frontal, Driver

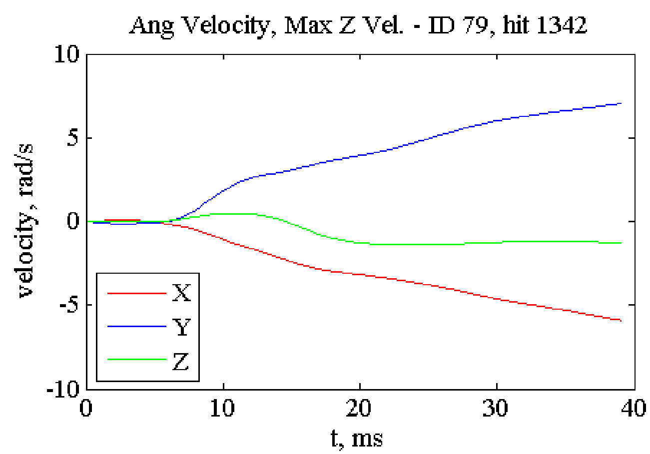


# Max isolated velocity- Z



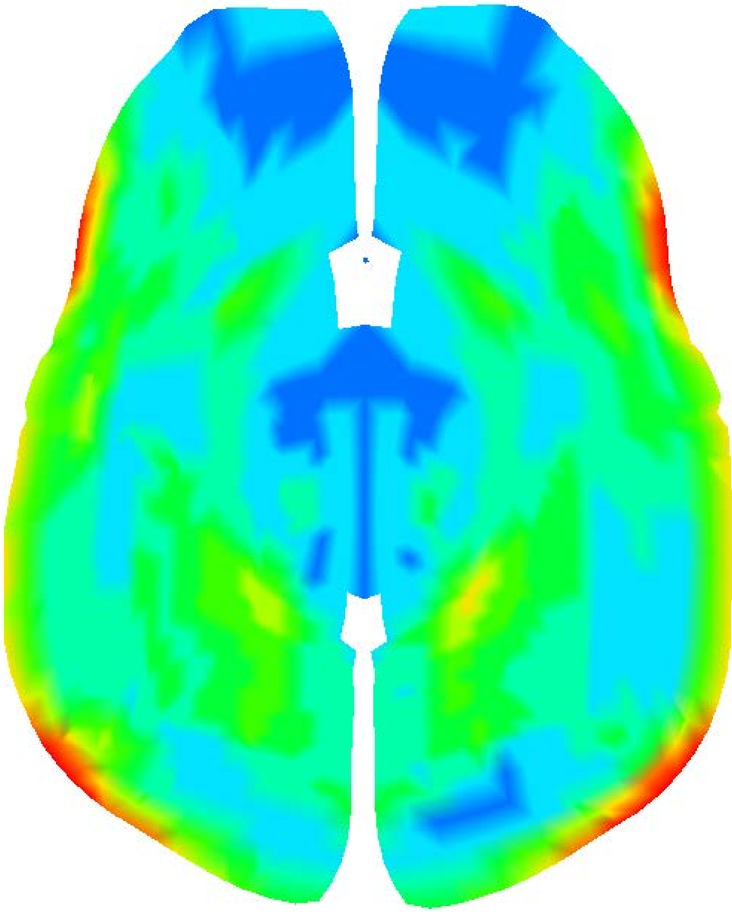



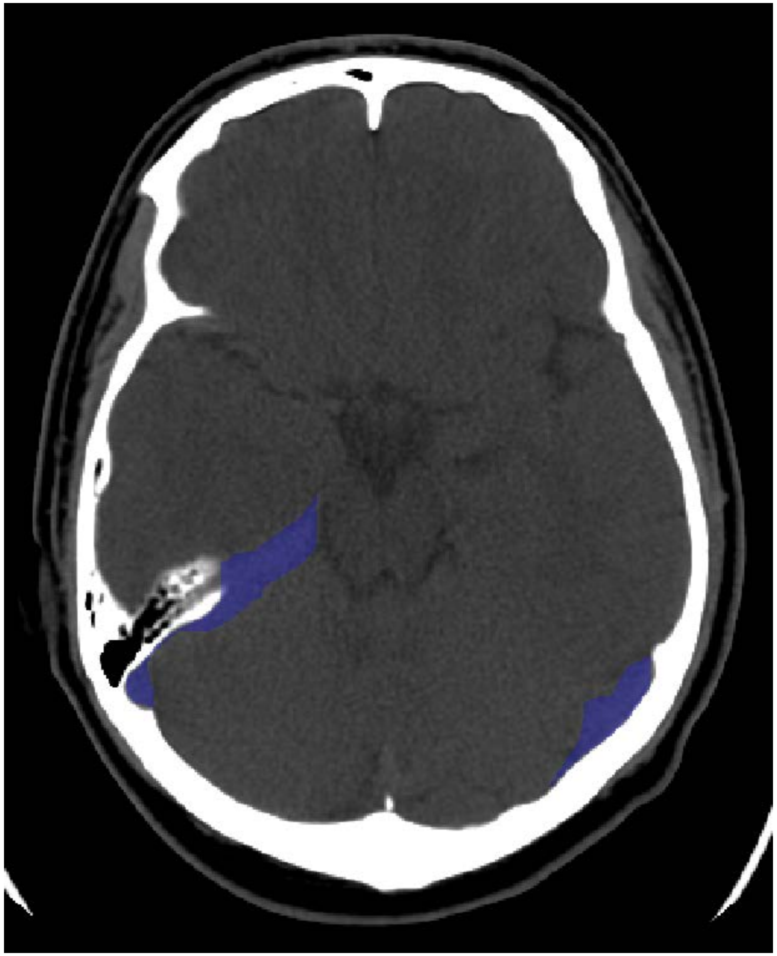




Off-axis pulses magnitudes are less than 30% of the primary pulse

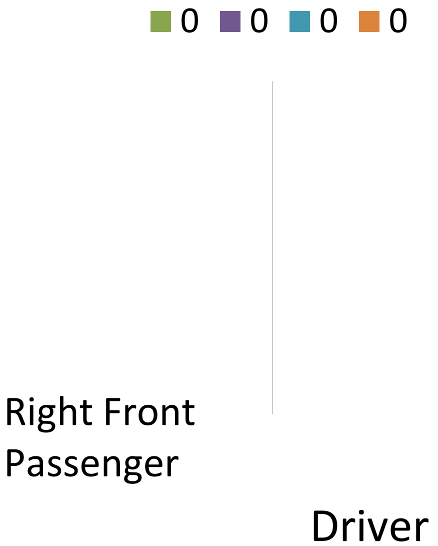
# Frontal contrecoup – Frontal, Driver

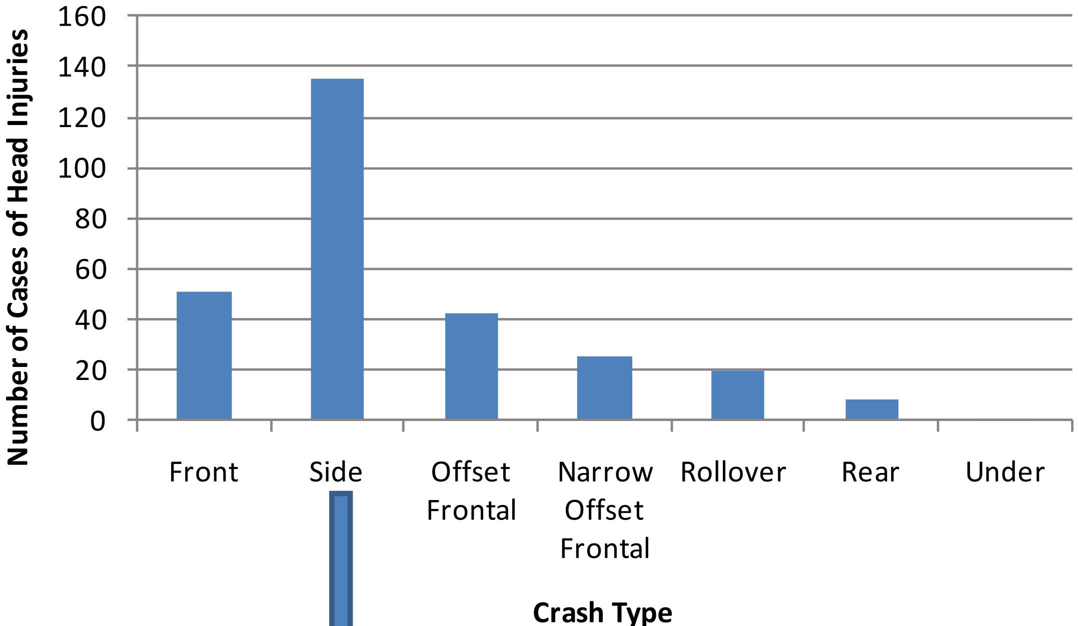




# Study Group

| | |
|---|---|
| Passenger Car | 128 |
| Truck | 20 |
| Van | 10 |
| SUV | 31 |




| | |
|---|---|
| Far Side | 35 |
| Near Side | 97 |

# Preliminary Research: Top 10 Major Intracranial Injuries in CIREN

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

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

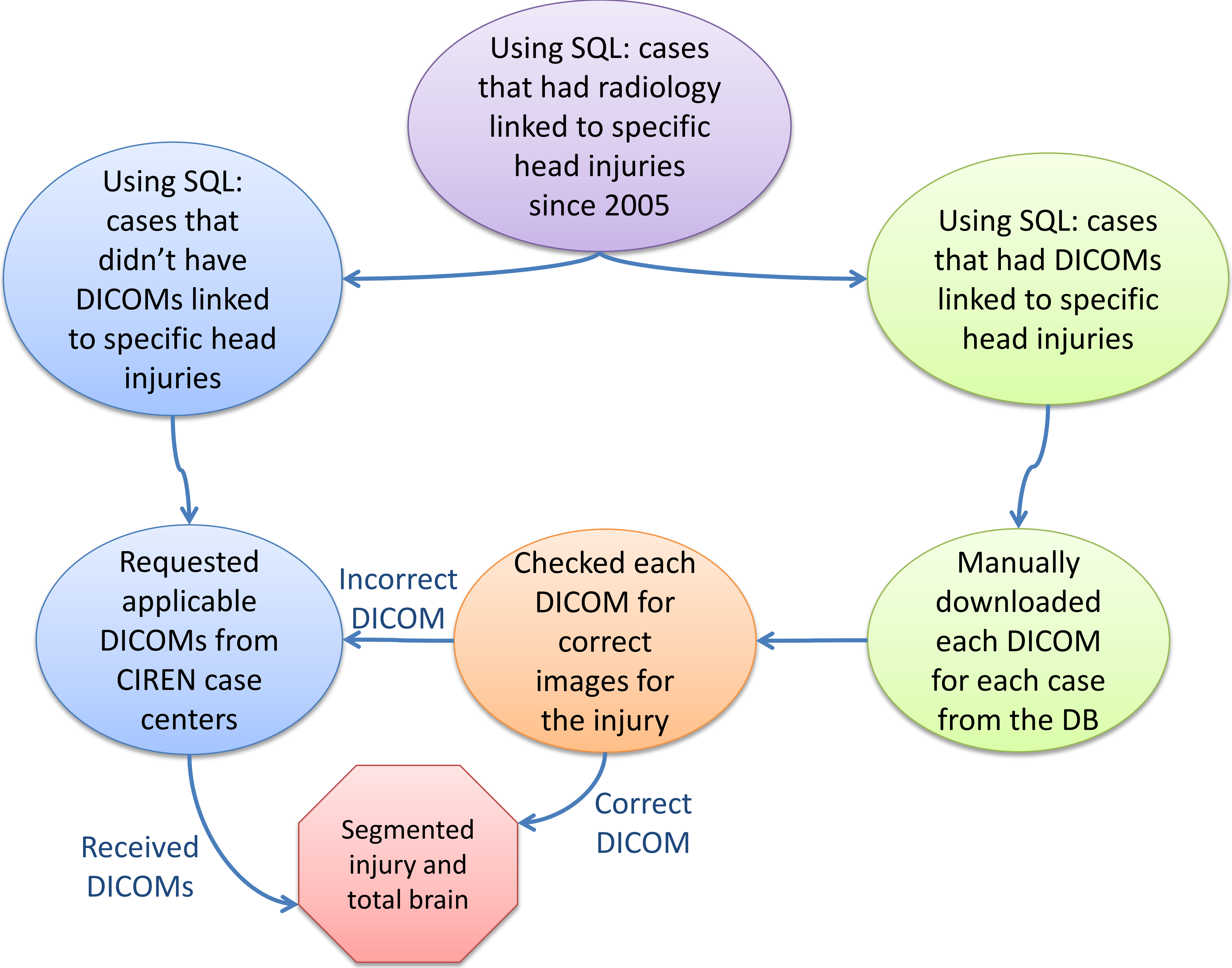
* Indicates AIS codes found on both CIREN and NASS-CDS top 10 lists

# Preliminary Research: Top 10 Major Intracranial Injuries in NASS-CDS

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

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

* 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
Using SQL: cases that had DICOMs linked to specific head injuries
Requested applicable DICOMs from CIREN case centers
Incorrect DICOM
Checked each DICOM for correct images for the injury
Manually downloaded each DICOM for each case from the DB
Received DICOMs
Segmented injury and total brain
Correct DICOM

# CIREN Cases without DICOMS

2005-2010 All Cases
(Jan. 2011 data extracts)
1657 cases

Took Jan 2011 case list and joined with injuries file

369 cases with skull fx or 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

146 cases without DICOMS for each skull fx/ brain inj

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

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

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

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

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

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

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

Brain Only = 158
(1 case with only MR)

Skull Only = 30

Brain & Skull = 56

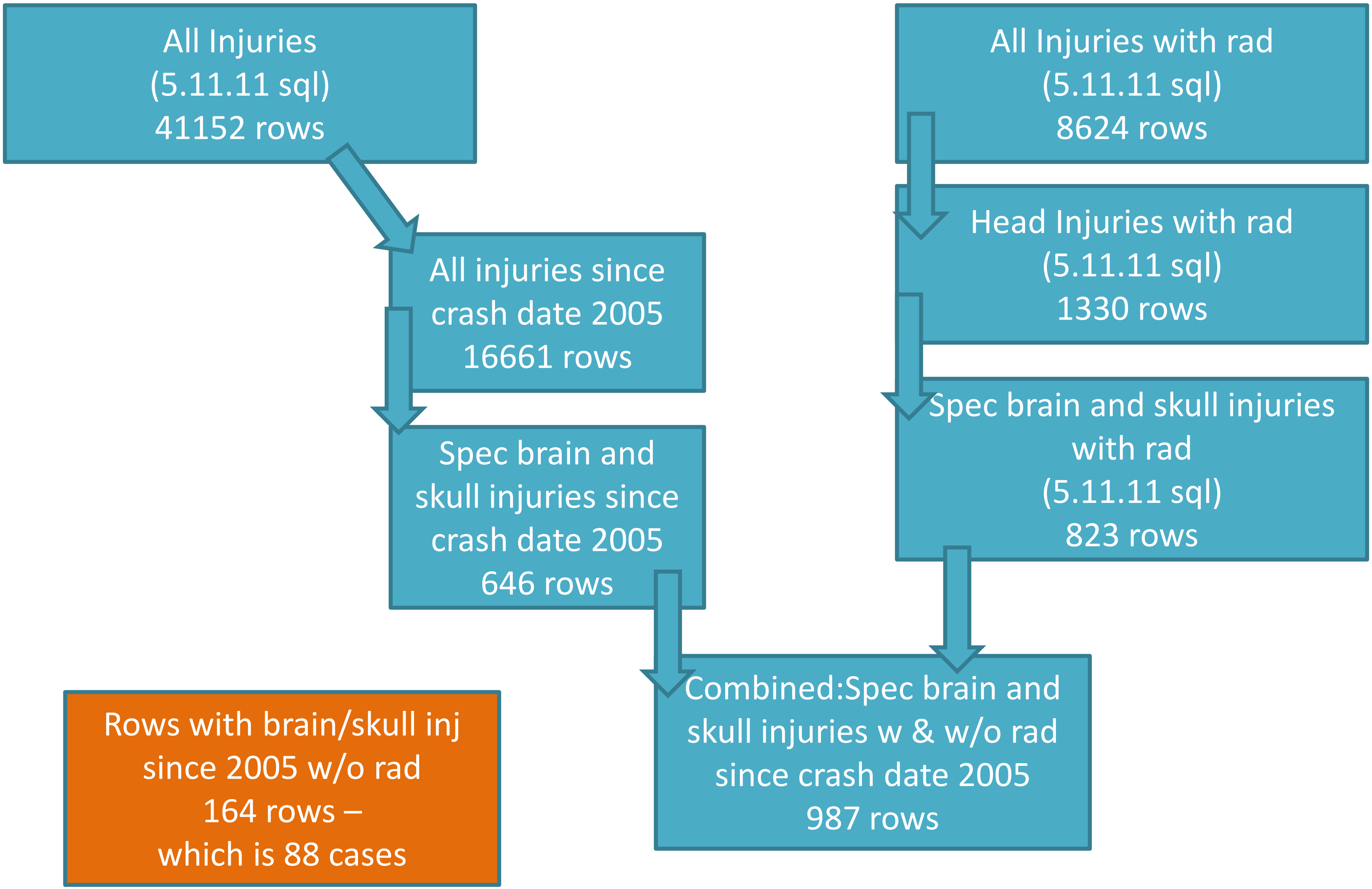
Legend

= 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.

# CIREN without DICOMS



# WFU CIREN Team

## CIREN Staff

Katie Kennedy

Study Coordinator

Summer Harris

Research Assistant

Michael Burke

Crash Investigator

Bill Martin

Project Manager

## Engineers

Joel D. Stitzel

Engineering PI

Kathryn Loftis

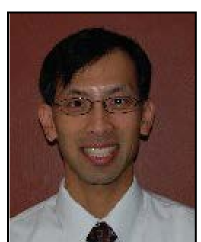
Research Engineer

## Engineer/Imaging Support

Stefan Duma

Warren Hardy

Clay Gabler



Josh Tan

Kerry Danelson

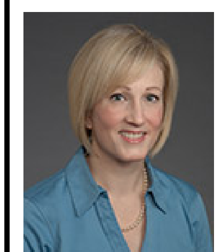
## Medical Personnel

Wayne Meredith

Medical PI

Shayn Martin

Trauma Physician



Lynn Anthony

Radiologist

Judy Smith

Trauma Nurse

WAKE FOREST UNIVERSITY
SCHOOL of MEDICINE