Current Trends in the Imaging of Diffuse Axonal Injury

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Introduction to Traumatic Brain Injury (TBI)

- Defined as damage to the brain from an external mechanical force.
- Examples of such forces include rapid acceleration or deceleration motions, impact injuries, or penetration by a projectile
- Incidence: 200-225/100,000
- 12% of all U.S. hospital admissions are TBI-related

Our Patient: MC

- CC: Traumatic Brain Injury

HPI: 23 y/o M with unknown medical history transferred from an outside hospital s/p high speed (~100mph) motorcycle vs. bus accident. Pt was helmeted. In the field, GCS 3. Negative tox screen.

GCS- Glasgow Coma Score

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On Admission- Patient MC: CT Imaging

Axial non contrast CT imaging showing hyperdensity (green box) in left frontal lobe consistent with a hemorrhagic contusion. No other signs of hemorrhage were seen acutely.
3 Days Later- Patient MC : MRI T2 Flair

Axial T2 weighted Flair MR imaging showing hyperintense signal in the right and left grey-white matter interface and splenium of the corpus callosum.

Axial T2 weighted Flair MR Imaging showing hyperintense signal in the right posterior limb of the internal capsule and a left frontal lobe contusion.

Images from PACS, BIDMC

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3 Days Later- Patient MC: MRI T2 Flair

Axial T2 weighted Flair MR imaging showing hyperintense signal in the corpus callosum

Images from PACS, BIDMC
3 Days Later - Patient MC: MR Susceptibility Weighted Imaging

Axial SW MR imaging showing hypo-intense signal in the right and left grey-white matter interface and a left frontal lobe contusion.

Axial SW MR imaging showing hypo-intense lesions in the right grey-white matter interface and splenium; left frontal lobe contusion.

Areas of Hemorrhage

Images from PACS, BIDMC

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3 Days Later - Patient MC: MR Susceptibility Weighted Imaging

Axial T2 weighted SW MR imaging showing hypo-intense signal in the corpus callosum

Images from PACS, BIDMC

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Diffuse Axonal Injury

Biomechanics, Pathogenesis, Stages of Damage, and Long-term Consequences
Diffuse Axonal Injury (DAI)

- Severe head trauma can produce diffuse axonal injury characterized by punctate hemorrhagic or non-hemorrhagic lesions primarily in white matter tracts.
- Common sites: Parasagittal white matter, grey-white matter junctions of the cerebral cortex, corpus callosum, and brainstem.
- Occurs in 40-50% of patients hospitalized for TBI.
- Affects more than 2 million people every year.


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DAI and its Long-Term Consequences

- 26,000 deaths/yr are due to DAI
- 20,000-45,000 surviving patients/yr suffer neurobehavioral or physical impairments
- Average hospital cost per patient: $117,000
- Direct health care costs: $25 billion/year

Biomechanics of DAI

- Commonly referred to as a shear force injury
- Rapid head motions produce inertial forces which cause rotational acceleration of the brain leading to shearing and strain of axons
- Rapid stretch of an axon leads to damage to the neuron’s cytoskeleton. Axonal transport continues until local inflammation causes further cytoskeleton breakdown
Pathogenesis of Microscopic Axonal Changes

- Increased cytoskeleton damage + protein accumulation = axon disconnection
- Axon disconnection leads to irreversible damage
- Pathologic Feature: Bulb formation

Brain Injury

Influx of Na\(^+\) and Ca\(^{2+}\) through respective channels

Axonal Swelling

Axonal cytoskeleton damage

Accumulation of axonal transport proteins within swellings

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Histopathology of DAI

Top: Low power view of hematoxylin-eosin stain demonstrating DAI and petechial hemorrhages

Below: Silver stain of the same area indicating the axonal terminal bulbs.


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## Stages of DAI

<table>
<thead>
<tr>
<th>Stage</th>
<th>Areas Affected</th>
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| I     | - parasagittal regions of the frontal lobes  
       | - periventricular temporal lobes  
       | - internal and external capsules  
       | - cerebellum |
| II    | Stage I areas + corpus callosum |
| III   | Stage I + Stage II areas + dorsolateral quadrants of the rostral brain stem |

Imaging Modalities for Diffuse Axonal Injury
Imaging of DAI: CT

CT imaging is first line for any neurotrauma

Benefits
- Widely available in most hospitals in the US
- Comparatively inexpensive
- Good, quick test for injuries that require immediate surgical attention

Drawbacks
- Initially 50-80% of pts with DAI will have normal CT scans
- Less sensitivity for detecting DAI


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Examples of DAI on CT Imaging: Companion Patient TC

- HPI: 22 y/o F being found down in the road, entangled with her bicycle, unresponsive, unhelmeted, pupils unequal. Initial CGS was 4 upon arrival to ED.
Companion Patient TC:
Axial Non-Contrast CT Imaging

Areas of Hemorrhage
Soft Tissue Edema

Images from PACS, BIDMC
Companion Patient TC: Axial Non-Contrast CT Imaging

Areas of Hemorrhage
Soft Tissue Edema

Images from PACS, BIDMC
Companion Patient TC:
Axial Non-Contrast CT Imaging

Areas of Hemorrhage

Images from PACS, BIDMC
More Examples: Non-Contrast CT Imaging showing Hemorrhagic DAI Lesions


Black arrows: areas of hemorrhagic foci
Imaging of DAI: MRI

- MRI has greater sensitivity in detecting DAI
- Commonly used techniques include Flair, DWI, and GRE, and SWI*
  - Kinoshita et al.- DWI sensitivity in detecting DAI is comparable to Flair
  - Tong et al.- Number of hemorrhagic DAI lesions seen on SWI was 6 times greater than that on conventional T2* weighted 2D GRE imaging and the volume of hemorrhage was approx 2 fold greater

* Flair- Fluid Attenuated Inversion Recovery
  DWI- Diffusion weighted Imaging
  GRE- Gradient Recalled Echo
  SWI- Susceptibility Weighted Imaging
T2 MR Imaging of DAI

Sagittal T2-weighted MR image showing hyper-intense signal within the corpus callosum (white arrows)

MR Flair: Conspicuity of DAI Lesions

MR DWI: Conspicuity of DAI Lesions


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More Lesions are seen on Susceptibility Imaging: Comparing T2 and SWI

A) Axial T2 MRI
B) Axial Susceptibility-weighted MRI

Small hemorrhagic shearing injuries in the left frontal subcortical white matter (Black arrows)


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More Lesions are seen on
Susceptibility Imaging: Comparing T2 and SWI

C) Axial T2 MRI

D) Axial Susceptibility-weighted MRI

Hemorrhagic shearing foci (open arrows) in the left frontal white matter, right subinsular region, and left splenium

The Emergence of MRI Diffusion Tensor Tractography (DTT)

- DTT is rapidly becoming another modality to look for DAI in the acute phase.
- Modality can characterize white matter integrity by measuring fractional anisotropy (FA).
- Fractional anisotropy is the degree of alignment of the underlying nerve fibers (ratio: 0 to 1).

Using DTT for Long-Term DAI Follow-up

- Skoglund et al.
  - 22 y/o F with closed head injury. Comparison images of Axial T2 and DTT at 6 days post-injury and 18 months post-injury
  
  - Results: In follow-up imaging, conventional MRI showed no pathology. However, in DTT imaging, FA values had improved but did not normalize.
  
  - Conclusion: MR-DTT may be more sensitive to DAI than conventional MR imaging.


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Results: Long-Term DAI Follow-up with DTT

- a) 6 days post injury- Axial T2 MR image showing hyper-intense lesion in left pons
- b) 18 months post injury- Axial T2 MR image showing no lesion
- c) 6 days post injury- Axial DTT image showing decreased blue intensity
- d) 18 months post injury- Axial DTT image showing moderately improved blue intensity


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Fractional Anisotropy in Long-Term DAI Follow-up

- FA values on left side improve 18 months post-injury but do not normalize to right-sided values

- Key:
  - dx – Patient’s right side
  - sin – Patient’s left side

Summary

- Diffuse Axonal Injury is caused by traumatic brain injury and can be characterized by punctate hemorrhagic or non-hemorrhagic lesions primarily in white matter tracts.
- MRI is now the imaging of choice for detecting DAI. SWI and DWI are the best techniques.
- DTT holds promising results as an imaging modality for the acute and long-term follow-up of DAI patients.
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References


