Trauma Overview

*Trauma is one of the most frequent indications for emergent neuroimaging. Because imaging plays such a key role in patient triage and management, we begin this book by discussing skull and brain trauma.*

We start with a brief consideration of epidemiology. Traumatic brain injury (TBI) is a critical public health and socioeconomic problem throughout the world. The direct medical costs of caring for acutely traumatized patients are huge. The indirect costs of lost productivity and long-term care for TBI survivors are even larger than the short-term direct costs.

We then briefly discuss the etiology and mechanisms of head trauma. Understanding the different ways in which the skull and brain can be injured provides the context for understanding the spectrum of findings that can be identified on imaging studies.

**Introduction**

**Epidemiology of Head Trauma**

At least 10 million people worldwide sustain TBI each year. Approximately 10% sustain fatal brain injury. Lifelong disability is common in those who survive. Between 5% and 10% of TBI survivors have serious permanent neurologic deficits, and an additional 20-40% have moderate disability. Even more have subtle deficits (“minimal brain trauma”).

**Etiology and Mechanisms of Injury**

Trauma can be caused by missile or nonmissile injury. Nonmissile closed head injury (CHI) is a much more common cause of neurotrauma than missile injury. Falls have now surpassed road traffic incidents as the leading cause of TBI.

So-called "ground-level falls" (GLFs) are a common indication for neuroimaging in young children and older adults. In such cases, brain injury can be significant. With a GLF, a six-foot-tall adult’s head impacts the ground at 20 MPH. Anticoagulated older adults are especially at risk for intracranial hemorrhages, even with minor head trauma.

Motor vehicle collisions occurring at high speed exert significant acceleration/deceleration forces, causing the brain to move suddenly within the skull. Forcible impaction of the brain against the unyielding calvarium and hard, knife-like dura results in gyral contusion. Rotation and sudden changes in angular momentum may deform, stretch, and damage long vulnerable axons, resulting in axonal injury.
The most widely used clinical classification of brain trauma, the Glasgow Coma Scale (GCS), depends on the assessment of three features: Best eye, verbal, and motor responses. With the use of the GCS, TBI can be designated as a mild, moderate, or severe injury.

TBI can also be divided chronologically and pathoetologically into primary and secondary injury, the system used in this text. Primary injuries occur at the time of initial trauma. Skull fractures, epi- and subdural hematomas, contusions, axonal injury, and brain lacerations are examples of primary injuries.

Secondary injuries occur later and include cerebral edema, perfusion alterations, brain herniations, and CSF leaks. Although vascular injury can be immediate (blunt impact) or secondary (vessel laceration from fractures, occlusion secondary to brain herniation), for purposes of discussion, it is included in the chapter on secondary injuries.

**CLASSIFICATION OF HEAD TRAUMA**

<table>
<thead>
<tr>
<th>Primary Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Scalp and skull injuries</td>
</tr>
<tr>
<td>- Extraaxial hemorrhage/hematomas</td>
</tr>
<tr>
<td>- Parenchymal injuries</td>
</tr>
<tr>
<td>- Miscellaneous injuries</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Secondary Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Herniation syndromes</td>
</tr>
<tr>
<td>- Cerebral edema</td>
</tr>
<tr>
<td>- Cerebral ischemia</td>
</tr>
<tr>
<td>- Vascular injury (can be primary or secondary)</td>
</tr>
</tbody>
</table>

**Imaging Acute Head Trauma**

Imaging is absolutely critical to the diagnosis and management of the patient with acute TBI. The goal of emergent neuroimaging is twofold: (1) Identify treatable injuries, especially emergent ones, and (2) detect and delineate the presence of secondary injuries, such as herniation syndromes and vascular injury.

**How To Image**

**NECT**

CT is now accepted as the "workhorse" screening tool for imaging acute head trauma. The reasons are simple: CT depicts both bone and soft tissue injuries. It is also widely accessible, fast, effective, and comparatively inexpensive.

Nonenhanced CT (NECT) scans (4 or 5 mm thick) from just below the foramen magnum through the vertex should be performed. Two sets of images should be obtained: One using brain and one with bone reconstruction algorithms. Viewing the brain images with a wider window width (150-200 HU, the so-called "subdural window") should be performed on PACS.

The scout view should always be displayed as part of the study.

MDCT is now routine in trauma triage. Coronal and sagittal reformatted images using the axial source data improve the detection rate of acute traumatic subdural hematomas.

Three-dimensional shaded surface displays are helpful in depicting skull and facial fractures. If facial bone CT is also requested, a single MDCT acquisition can be obtained without overlapping radiation exposure to the eye and lower 1/2 of the brain.

Head trauma patients with acute intracranial lesions on CT have a higher risk for cervical spine fractures compared with patients with a CT-negative head injury. Because up to 1/3 of patients with moderate to severe head injury as determined by the GCS have concomitant spine injury, MDCT of the cervical spine is often obtained together with brain imaging. Soft tissue and bone algorithm reconstructions with multiplanar reformatted images of the cervical spine should be obtained.

**CTA**

CT angiography (CTA) is often obtained as part of a whole-body trauma CT protocol. Craniocervical CTA should also specifically be considered (1) in the setting of penetrating neck injury, (2) if a fractured foramen transversarium or Facet subluxation is identified on cervical spine CT, or (3) if a skull base fracture traverses the carotid canal or a dural venous sinus. Arterial laceration or dissection, traumatic pseudoaneurysm, carotid-cavernous fistula, or dural venous sinus injury are nicely depicted on high-resolution CTA.

**MR**

Although MR can detect traumatic complications without radiation and is more sensitive for abnormalities, such as contusions and axonal injuries, there is general agreement that NECT is the procedure of choice in the initial evaluation of brain trauma. Limitations of MR include acquisition time, access, patient monitoring and instability, motion degradation of images, and cost.

With one important exception—suspected child abuse—using MR as a routine screening procedure in the setting of acute brain trauma is uncommon. Standard MR together with susceptibility-weighted imaging and DTI is most useful in the subacute and chronic stages of TBI. Other modalities, such as fMRI, are playing an increasingly important role in detecting subtle abnormalities, especially in patients with mild cognitive deficits following minor TBI.

**Who and When To Image**

Who to image and when to do it are paradoxically both well established and controversial. Patients with a GCS score indicating moderate (GCS = 9-12) or severe (GCS ≤ 8) neurologic impairment are invariably imaged. The real debate is about how best to manage patients with GCS scores of 13-15. In places with high malpractice rates, many emergency
Scout view in a 66-year-old woman with a CT head requested to evaluate ground-level fall shows a posteriorly angulated C1-odontoid complex.

Head CT in the same case (not shown) was normal. Cervical spine CT was then performed. The sagittal image reformatted from the axial scan data shows a comminuted, posteriorly angulated dens fracture.

Trauma Imaging: Keys to Analysis

Four components are essential to the accurate interpretation of CT scans in patients with head injury: The scout image plus brain, bone, and subdural views of the NECT dataset. Critical information may be present on just one of these four components.

Suggestions on how to analyze NECT images in patients with acute head injury are delineated below.

Scout Image

Before you look at the NECT scan, examine the digital scout image! Look for cervical spine abnormalities, such as fractures or dislocations, jaw &/or facial trauma, and the presence of foreign objects. If there is a suggestion of cervical spine fracture or malalignment, MDCT of the cervical spine should be performed before the patient is removed from the scanner.

Brain Windows

Methodically and meticulously work your way from the outside in. First, evaluate the soft tissue images, beginning with the scalp. Look for scalp swelling, which usually indicates the impact point. Carefully examine the periorbital soft tissues.

Next, look for extraaxial blood. The most common extraaxial hemorrhage is traumatic subarachnoid hemorrhage (tSAH) followed by sub- and epidural hematomas. The prevalence of...
(1-2A) Axial NECT in an 18-year-old man who fell off his skateboard shows a small right epidural hematoma that also contains air.

(1-2B) Bone algorithm reconstruction shows a nondisplaced linear fracture adjacent to the epidural blood and air.

(1-2C) Reconstructed coronal (L) and sagittal (R) bone CTs show the fracture comminuted and crosses the mastoid and middle ear.

tSAH in moderate to severe TBI approaches 100%. tSAH is usually found in the sulci adjacent to cortical contusions, along the sylvian fissures, and around the anteroinferior frontal and temporal lobes. The best place to look for subtle tSAH is the interpeduncular cistern, where blood collects when the patient is supine.

Any hypodensity within an extraaxial collection should raise suspicion of rapid hemorrhage with accumulation of unclotted blood or (especially in alcoholics or older patients) an underlying coagulopathy. This is an urgent finding that mandates immediate notification of the responsible clinician.

Look for intracranial air (“pneumocephalus”). Intracranial air is always abnormal and indicates the presence of a fracture that traverses either the paranasal sinuses or mastoid.

Now, move on to the brain itself. Carefully examine the cortex, especially the "high-yield" areas for cortical contusions (anteroinferior frontal and temporal lobes). If there is a scalp hematoma due to impact (a “coup” injury), look 180° in the opposite direction for a classic “contre-coup” injury. Hypodense areas around the hyperdense hemorrhagic foci indicate early edema and severe contusion.

Move inward from the cortex to the subcortical white and deep gray matter. Petechial hemorrhages often accompany axonal injury. If you see subcortical hemorrhages on the initial NECT scan, this is merely the "tip of the iceberg." There is usually a lot more damage than what is apparent on the first scan. A general rule: The deeper the lesion, the more severe the injury.

Finally, look inside the ventricles for blood-CSF levels and hemorrhage due to choroid plexus shearing injury.

**Subdural Windows**

Look at the soft tissue image with both narrow (“brain”) and intermediate (“subdural”) windows. Small, subtle subdural hematomas can sometimes be overlooked on standard narrow window widths (75-100 HU) yet are readily apparent when wider windows (150-200 HU) are used.

**Bone CT**

Bone CT refers to bone algorithm reconstruction viewed with wide (bone) windows. If you cannot do bone algorithm reconstructions from your dataset, widen the windows and use an edge-enhancement feature to sharpen the image. Three-dimensional shaded surface displays (3D SSDs) are especially helpful in depicting complex or subtle fractures.

Even though standard head scans are 4-5 mm thick, it is often possible to detect fractures on bone CT. Look for basisphenoid fractures with involvement of the carotid canal, temporal bone fractures (with or without ossicular dislocation), mandibular dislocation (“empty” condylar fossa), and calvarial Fractures. Remember: Nondisplaced linear skull fractures that do not cross vascular structures (such as a dural venous sinus or middle meningeal artery) are in and of themselves basically meaningless. The brain and blood vessels are what matter!

The most difficult dilemma is deciding whether an observed lucency is a fracture or a normal structure (e.g., suture line or vascular channel). Keep in mind: It is virtually unheard of for a calvarial fracture to occur in the absence of overlying soft tissue injury. If there is no scalp “bump,” it is unlikely that the lucency represents a nondisplaced linear fracture.

Bone CT images are also very helpful in distinguishing low density from air vs. fat. Although most PACS stations have a region of interest (ROI) function
that can measure attenuation, fat fades away on bone CT images, and air remains very hypodense.

**CTA**

CTA is generally indicated if (1) basilar skull fractures cross the carotid canal or a dural venous sinus (1-3); (2) if a cervical spine fracture-dislocation is present, especially if the transverse foramina are involved; or (3) if the patient has stroke-like symptoms or unexplained clinical deterioration. Both the cervical and intracranial vasculature should be visualized.

Although it is important to scrutinize both the arterial and venous sides of the circulation, a CTA is generally sufficient. Standard CTAs typically show both the arteries and the dural venous sinuses well, whereas a CT venogram (CTV) often misses the arterial phase.

Examine the source images as well as the multiplanar reconstructions and maximum-intensity projection (MIP) reformatted scans. Traumatic dissection, vessel lacerations, intimal flaps, pseudoaneurysms, carotid-cavernous fistulas, and dural sinus occlusions can generally be identified on CTA.

### HEAD TRAUMA: CT CHECKLIST

#### Scout Image
- Evaluate for
  - Cervical spine fracture-dislocation
  - Jaw dislocation, facial fractures
  - Foreign object

#### Brain Windows
- Scalp swelling (impact point)
- Extraaxial blood (focal hypodensity in clot suggests rapid bleeding)
  - Epidural hematoma
  - Subdural hematoma (SDH)
  - tSAH
- Pneumocephalus
- Cortical contusion
  - Anteroinferior frontal, temporal lobes
  - Opposite scalp laceration/skull fracture
- Hemorrhagic axonal injury
- Intraventricular hemorrhage

#### Subdural Windows
- 150-200 HU (for thin SDHs under skull)

#### Bone CT
- Bone algorithm reconstruction > bone windows
- Do any fractures cross a vascular channel?

Selected References: The complete reference list is available on the Expert Consult™ eBook version included with purchase.