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 socio-economic 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**

Trauma—sometimes called the “silent epidemic”—is the most common worldwide cause of death in children and young adults. Neurotrauma is responsible for the vast majority of these cases. At least 10 million people worldwide sustain TBI each year. In the USA alone, two million people annually suffer a TBI. Of these, 500,000 require hospital care.

Of all head-injured patients, approximately 10% sustain fatal brain injury. Lifelong disability is common in those who survive. Between 5-10% 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. Missile injury results from penetration of the skull, meninges, and/or brain by an external object, such as a bullet. Gunshot wounds are most common in adolescent and young adult male patients but relatively rare in other groups.

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 calvaria 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.

### Classification of Head Trauma

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 pathoetiologically 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.

### 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?

A broad spectrum of imaging modalities can be used to evaluate patients with TBI. These range from outdated, generally ineffective techniques (e.g., skull radiographs) to very sensitive but expensive studies (e.g., MR). Techniques that are still relatively new include CT and MR perfusion, diffusion tensor imaging (DTI), and functional MRI (fMRI).

### Skull Radiography

For decades, skull radiography (whether called “plain film” or, more recently, “digital radiography”) was the only noninvasive imaging technique available for the assessment of head injury. Skull radiography is reasonably effective in identifying calvarial fractures. Yet skull x-rays cannot depict the far more important presence of extraaxial hemorrhages and parenchymal injuries.

*Between one-quarter and one-third of autopsied patients with fatal brain injuries have no identifiable skull fracture!* Therefore, skull radiography obtained solely for the purpose of identifying the presence of a skull fracture has no appropriate role in the current management of the head-injured patient. With rare exceptions, it’s the brain that matters—not the skull!

### NECT

Because of its wide availability and rapid detection of acute hemorrhage, CT is now accepted as the worldwide screening tool for imaging acute head trauma. Since its introduction almost 40 years ago, CT has gradually but completely replaced skull radiographs as the “workhorse” of brain trauma imaging. The reasons are simple: CT depicts both bone and soft tissue injuries. It is also widely accessible, fast, effective, and comparatively inexpensive.

Both standard and multidetector row CT (MDCT) are used in the initial imaging of patients with traumatic head injury. Identifying abnormalities that may require urgent treatment to limit secondary injuries, such as brain swelling and herniation syndromes, is essential.

Standard 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 (or film, if PACS is not available). The scout view should always be displayed as part of the study (see below).

MDCT is now in widespread use. Coronal and sagittal reformatted images using the axial source data are routinely performed in head trauma triage and 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 half 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 one-
third 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.

As delayed development or enlargement of both extra- and intracranial hemorrhages may occur within 24-36 hours following the initial traumatic event, repeat CT should be obtained if there is sudden unexplained clinical deterioration, regardless of initial imaging findings.

CTA

CT angiography (CTA) is often obtained as part of a whole-body trauma CT protocol. Craniocevical 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 an attempt to reduce CT overutilization in emergency departments, several organizations have developed evidence-based clinical criteria that help separate “high-risk” from “low-risk” patients. (Several of these are delineated in the boxes below.) Yet the impact on the emergency department physician ordering behavior has been inconsistent. In places with high malpractice rates, many emergency physicians routinely order NECT scans on every patient with head trauma regardless of GCS score or clinical findings.

Repeat head CT scans in trauma transfers from one hospital to another are common and add to both radiation dose exposure and cost. Inadequate data transfer from the referring hospital—not poor image quality—is the major reason for potentially preventable repeat head CT scans.

Whether—and when—to obtain follow-up imaging in trauma patients is controversial. In a large study of children with GCS scores of 14 or 15 and a normal initial CT scan, only 2% had follow-up CT or MR performed. Of these, only 0.05% had abnormal results on the follow-up study, and none required surgical intervention. The negative predictive value for neurosurgical intervention for a child with an initial GCS of 14 or 15 and normal CT was 100%. From this, the authors concluded that children with a GCS of 14 or 15 and a normal initial head CT are at very low risk for subsequent traumatic findings on neuroimaging and extremely low risk of needing neurosurgical intervention. Hospitalization for neurologic observation of children with minor head trauma after normal CT scan results was deemed unnecessary.

GLASGOW COMA SCALE

Best Eye Response (Maximum = 4)
- 1 = no eye opening
- 2 = eye opening to pain
- 3 = eyes open to verbal command
- 4 = eyes open spontaneously

Best Verbal Response (Maximum = 5)
- 1 = none
- 2 = incomprehensible sounds
- 3 = inappropriate words
- 4 = confused
- 5 = oriented

Best Motor Response (Maximum = 6)
- 1 = none
- 2 = extension to pain
- 3 = flexion to pain
- 4 = withdrawal to pain
- 5 = localizing to pain
- 6 = obedience to commands

Sum = “Coma Score” and Clinical Grading
- 13-15 = mild brain injury
- 9-12 = moderate brain injury
- ≤ 8 = severe brain injury

Appropriateness Criteria

Three major and widely used appropriateness criteria for imaging acute head trauma have been published: The American College of Radiology (ACR) Appropriateness Criteria, the New Orleans Criteria (NOC), and the Canadian Head CT Rule (CHCR).

ACR Criteria. Emergent NECT in mild/minor CHI with the presence of a focal neurologic deficit and/or other risk factors is deemed “very appropriate,” as is imaging all traumatized children under 2 years of age. Although acknowledging that NECT in patients with mild/minor CHI (GCS ≥ 13) without risk...
factors or focal neurologic deficit is “known to be low yield,” the ACR still rates it as 7 out of 9 in appropriateness.

**NOC and CHCR.** Both the NOC and CHCR attempt to triage patients with minimal/mild head injuries in a cost-effective manner. A GCS score of 15 (i.e., normal) without any of the NOC indicators is a highly sensitive negative predictor of clinically important brain injury or need for surgical intervention.

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**NEW ORLEANS CRITERIA IN MINOR HEAD INJURY**

CT indicated if GCS = 15 plus any of the following
- Headache
- Vomiting
- Patient > 60 years old
- Intoxication (drugs, alcohol)
- Short-term memory deficits (anterograde amnesia)
- Visible trauma above clavicles
- Seizure

Adapted from Stiell IG et al: Comparison of the Canadian CT head rule and the New Orleans criteria in patients with minor head injury. JAMA 294(12):1511-1518, 2005

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According to the CHCR, patients with a GCS score of 13-15 and witnessed loss of consciousness (LOC), amnesia, or confusion are imaged, along with those deemed “high risk” for neurosurgical intervention or “medium risk” for brain injury.

Between 6-7% of patients with minor head injury have positive findings on head CT scans. Most of these patients also have headache, vomiting, drug or alcohol intoxication, seizure, short-term memory deficits, or physical evidence of trauma above the clavicles. CT should be used liberally in these cases, as well as in patients over 65 years of age, children under the age of two, anticoagulated patients, and patients with loss of consciousness or focal neurologic deficit.

Recent studies have also shown that compliance with established imaging guidelines such as the CHCR is poor, particularly in busy EDs that handle large trauma volumes. Despite efforts to educate urgent care physicians about limiting patient exposure to ionizing radiation and using clinically based risk stratification, nonenhanced head CTs remain one of the most frequently overutilized imaging studies.

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**CANADIAN HEAD CT RULE IN MINOR HEAD INJURY**

CT if GCS = 13-15 and witnessed LOC, amnesia, or confusion

High risk for neurosurgical intervention
- GCS < 15 at 2 hours
- Suspected open/depressed skull fracture
- Clinical signs of skull base fracture
- ≥ 2 vomiting episodes
- Age ≥ 65 years

Medium risk for brain injury detected by head CT
- Antegrade amnesia ≥ 30 minutes
- “Dangerous mechanism” (i.e., auto-pedestrian, ejection from vehicle, etc.)

Adapted from Stiell IG et al: Comparison of the Canadian CT head rule and the New Orleans criteria in patients with minor head injury. JAMA 294(12):1511-1518, 2005
Trauma Overview

(1-2A) Scout view in a 66y woman with a CT head requested to evaluate ground level fall shows a posteriorly angulated C1-odontoid complex.

(1-2B) The 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 and/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 extraxial blood. The most common extraxial hemorrhage is traumatic subarachnoid hemorrhage (tSAH), followed by sub- and epidural hematomas. The prevalence of 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 can’t do bone algorithm reconstruction 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 (1-3).

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. And remember: nondisplaced linear skull fractures that don’t 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.

(1-3A) Axial NECT in an 18y man who fell off his skateboard shows a small right epidural hematoma that also contains air. (1-3B) Two-millimeter bone algorithm reconstruction in the same case shows a nondisplaced linear fracture of the squamous temporal bone adjacent to the epidural blood and air.

(1-3C) Coronal (left) and sagittal (right) bone CTs reconstructed from the axial source data show the temporal bone fracture is comminuted and crosses the mastoid and middle ear. (1-3D) Bone CT with shaded surface display in the same case nicely shows the squamous, mastoid aspects of the nondisplaced but comminuted fracture.
CTA

CTA is generally indicated if (1) basilar skull fractures cross the carotid canal or a dural venous sinus (1-4); (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)
  - Traumatic subarachnoid hemorrhage
- 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
- Any fractures cross a vascular channel?
Selected References

Introduction

Epidemiology of Head Trauma


Imaging Acute Head Trauma

How To Image?


Who and When To Image?


Arab AF et al: Accuracy of Canadian CT head rule in predicting positive findings on CT of the head of patients after mild head injury in a large trauma centre in Saudi Arabia. Neuroradiol J. 28(6):591-7, 2015


