

Imaging Evaluation of Acute Traumatic Brain Injury



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KEYWORDS

• Traumatic brain injury • TBI • Imaging • MRI • CT

KEY POINTS

- Multidetector CT remains the preferred first-line imaging study for moderate and severe traumatic brain injury because it can quickly identify patients who require urgent neurosurgical intervention.
- MRI is significantly more sensitive than CT for detection of pathoanatomic lesions in mild TBI.
- MRI is more sensitive than CT for many types of traumatic injuries and plays a complementary role. It is most indicated in the acute setting for mild TBI when a patient's symptoms and/or neurologic examination are not explained by CT findings.
- Emerging advanced neuroimaging techniques may improve the sensitivity for identifying mild TBI and offer prognostic information for all grades of injury.

INTRODUCTION

In the United States, traumatic brain injury (TBI) is estimated to affect 1.7 million people annually, leading to approximately 52,000 deaths and 275,000 hospitalizations. TBI plays a role in approximately one-third of all injury-related deaths.¹ Patients who survive the initial event can have debilitating long-term sequelae. TBI actually consists of multiple pathologic entities broadly defined by an "alteration in brain function, or other evidence of brain pathology, caused by an external force."² Imaging plays a crucial role in evaluation and diagnosis of TBI; particularly relevant is its role for triage in the acute setting for determination of which patients require emergent neurosurgical intervention. Thus, the treating practitioner and radiologist must be familiar with the various imaging manifestations of TBI pathology

and their impact on clinical presentation, management, and prognosis.

The damage incurred by TBI is differentiated into primary and secondary mechanisms. Primary injury is typically defined as the direct mechanical damage caused by trauma. These injuries are usually apparent acutely and include fractures, intracranial hemorrhage, contusion, and traumatic axonal injury (TAI). This type of injury is best detected with conventional computed tomography (CT) and MRI structural imaging techniques. Secondary injury mechanisms are varied, and relate to disruption of the blood-brain barrier, production of reactive oxygen species and resultant oxidative stress, metabolic dysfunction, inflammation, and excitotoxicity.^{3,4} These processes are mediated at the cellular level, which is currently below the resolution of conventional imaging;

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however, they are believed to greatly contribute to the long-term morbidity and disability associated with TBI. When severe, macroscopic manifestations of secondary injuries may become apparent as diffuse cerebral hyperemia, cytotoxic and/or vasogenic edema, and tissue ischemia.

Clinical examination remains the cornerstone of acute TBI assessment. There are numerous clinical classification systems for TBI based on symptomology and severity, the most entrenched of which is the Glasgow Coma Scale (GCS).⁵ The GCS is a clinical assessment tool with scores ranging from 3 to 15 based on three components of neurologic function: (1) eye opening to external stimuli, (2) motor response to stimuli, and (3) verbal response. TBI is commonly subdivided into mild (≥ 13), moderate (9–12), and severe grade (3–8) using the GCS (Table 1). Although the GCS score has been shown to correlate with outcomes, it has limitations. Different varieties of pathoanatomic lesions can result in low GCS scores at admission.⁶ For example, initial low GCS scores may be seen with subdural hematomas (SDHs), epidural hematomas (EDHs), cortical contusions, intracerebral hematomas (ICHs), and TAI, although these lesions may have different clinical courses

and long-term prognoses.^{6,7} Evaluation is also limited by sedation, paralysis, and pre-existing injuries. Despite these limitations, the GCS has relatively high interrater reliability and does an adequate job of quickly and accurately stratifying patients broadly based on clinical severity of injury. GCS subscores should always be reported to convey a more granular description of neurologic impairment instead of simply reporting the composite score, which is less meaningful in isolation.

In conjunction with neurologic examination and clinical history, pathoanatomic characterization of TBI lesions with imaging is critical for triage and prognostication. To standardize definitions and imaging protocols for TBI classification and to promote research, the Interagency Common Data Elements Project was established in 2008.⁸ Throughout the following descriptions of TBI injury classification and imaging protocols, we attempt to adhere to the common data element pathoanatomic terminologies and recommendations.^{9,10} We begin with a brief summary of modality-specific indications for TBI. Technical considerations and neuroimaging protocols are also examined. Characteristic findings associated with the most frequently encountered extra-axial and intra-axial pathoanatomic lesions are then described. Finally, a brief review of advanced imaging techniques for TBI evaluation is reviewed. Throughout, we highlight how standardized imaging-based characterization of pathoanatomic lesions may complement clinical assessment for optimal triage and management of patients with TBI.

Table 1 Glasgow coma scale		
Behavior	Response	Score
Eye opening response	Spontaneously	4
	To speech	3
	To pain	2
	No response	1
Best verbal response	Oriented to time, place, and person	5
	Confused	4
	Inappropriate words	3
	Incomprehensible sounds	2
	No response	1
Best motor response	Obeys commands	6
	Moves to localized pain	5
	Flexion withdrawal from pain	4
	Abnormal flexion (decorticate)	3
	Abnormal extension (decerebrate)	2
	No response	1
Total score	Best response	15
	Comatose patient	8 or less
	Totally unresponsive	3

Adapted from Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. *Lancet* 1974;2(7872):81–4.

ROUTINE CLINICAL IMAGING

Routine clinical imaging for suspected TBI typically consists of noncontrast CT (NCCT) and MRI in select cases.^{11,12} Cases of known and suspected primary vascular abnormality may require the addition of noninvasive angiography (CT angiography [CTA] or MR angiography [MRA]) or catheter angiography for diagnosis, and in some cases, treatment. In the past, skull radiographs were performed as a first-line study to evaluate for calvarial fractures in children (Fig. 1), although this has fallen out of favor because significant intracranial pathology can occur in absence of skull fracture.¹³ In some cases of suspected pediatric nonaccidental trauma, skull radiographs are still performed as part of a skeletal survey in addition to CT; however, this does not supplant the need for CT when TBI is clinically suspected. Although radiographs may help differentiate accessory sutures from fractures, this too may

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