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Neuroimaging of Acute Traumatic Brain Injury: Emphasis on Magnetic Resonance Imaging and Prognostic Factors

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Intracranial insults resulting from trauma are called traumatic brain injury (TBI) and represent a leading cause of disability and death in the United States. Of more than 1.1 million patients treated yearly in the emergency department for TBI, 235,500 patients would require hospitalization and 43% of those would suffer long-term disability related to TBI.[1] In addition, more than 50,000 deaths each year are attributed to TBI.[2] The prevalence and potential life-altering sequelae of TBI have garnered much interest in its radiologic findings, ushering in the liberal use of imaging to screen for its presence. There is also an increasing awareness that even mild TBI can lead to chronic encephalopathy and even Alzheimer or parkinsonian syndromes.[3] The emphasis on imaging of mild TBI and the use of newer modalities to evaluate prognosis is expected to increase. The purpose of this article is to review the indications for imaging as well as the findings in the acute phase of TBI, with an emphasis on magnetic resonance imaging (MRI), and a brief discussion of prognostic indicators.

Indications for Imaging

The severity of TBI is clinically categorized as mild, moderate, or severe using the Glasgow Coma Scale (GCS).[4,5] The GCS is a summation of scores based on motor, verbal, and eye function with a range of 15-3 (mild: $15 \geq GCS > 12$; moderate $12 \geq GCS > 8$; and severe: $GCS \leq 8$). In mild TBI (mTBI), the selection of patients for screening head computed tomography (CT) is not completely defined; however, the Canadian CT Head Rule and the New Orleans Criteria provide guidelines for determining patients at higher risk of occult injury.[6,7] Although these guidelines have similar sensitivities, the Canadian CT Head Rule has increased sensitivity and has been better validated.[8,9] Correct application of the Canadian Rule provides 100% sensitivity and 66% specificity (Fig. 1). A noncontrast head CT is recommended for moderate and severe TBI. CT angiography (CTA) can be used if there is suspicion for vascular injury, but contrast would obscure acute blood products (especially in the subarachnoid space), and therefore an initial noncontrast examination should always be performed. In general, MRI should be used in acute TBI when the neurologic examination findings are not explained by the CT findings. Specific indications and the utility of MRI and other advanced modalities are detailed later in the respective sections.[10] Additionally, Table 1 highlights the main modalities used in evaluating TBI.

Injuries in acute TBI can generally be grouped into primary or secondary types, based on whether they were present at the time of injury or developed later as a sequelae of the insult. The various injuries are often coincident, and such a rigid structure is somewhat arbitrary but convenient for discussion purposes.

Acute Primary Injuries

Closed Head Injuries

Mild TBI and Diffuse Axonal Injury

mTBI is defined as head injury that exhibits only mild clinical signs—a GCS of between 15 and 12. Although there are criteria to screen this group of patients for more serious occult injury with CT, the signs of mild TBI are not often seen on routine clinical imaging.[11] Diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) have demonstrated remarkable findings in mTBI. DWI assesses relative differences in the Brownian motion of water, irrespective of directionality, using a scalar value called the apparent diffusion coefficient (ADC). DTI adds the component of directionality to compute a tensor that can be presented via various metrics, most commonly fractional anisotropy (FA), which can aid in characterizing white matter pathology. Both ADC and FA are considered markers of axonal function.[12] Even mTBI has been

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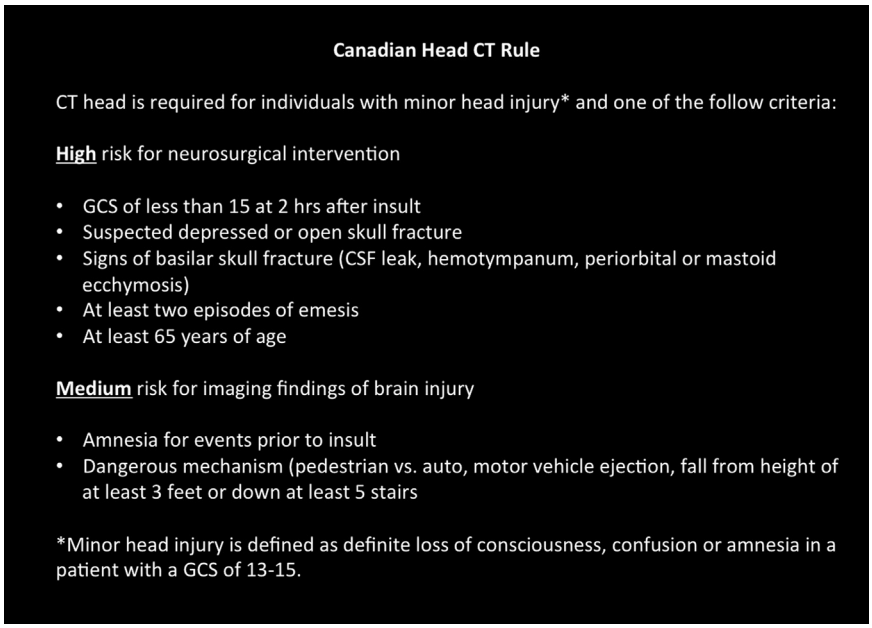

Figure 1 Canadian CT Head Rule.

found to demonstrate abnormal FA and ADC, which can persist for years after the initial insult.[13-15]

Diffuse axonal injury (DAI) is a shearing injury of axons due to rotational acceleration-deceleration force. This force produces stretching and laceration of nerve fibers, which is an underlying cause of immediate loss of consciousness as well as low GCS scores.[16] Classically, DAI is identified on CT when there are focal areas of hemorrhage in characteristic areas such as the corpus callosum or corticomedullary junctions. Despite this injury's clinical significance, the initial CT and conventional T1- and T2-weighted MR images are relatively insensitive to its detection. Fluid-attenuated inversion recovery (FLAIR) images increase the detection of vasogenic edema associated with some DAI lesions.

Newer imaging techniques have also shown promise in the evaluation of DAI. MR susceptibility-weighted imaging (SWI) sequences are sensitive to local alterations in magnetic field, which can be caused by the presence of iron, such as from hemoglobin.[12] SWI is sensitive for the detection of even small foci of blood, which can be markers of DAI.[17] Although SWI can detect microhemorrhages, it has been shown to underestimate the amount of DAI[18] (Fig. 2). DWI has shown more promise in the evaluation of DAI in the acute period and detects more lesions than standard or SWI MR sequences[10,19,20] (Fig. 3). It has also been shown to predict functional status on discharge.[18,21] The restricted diffusion associated with many acute DAI lesions may be secondary to ischemia, and trauma-induced axotomy with formation of retraction balls and decreased axonal transport among other factors.[22] DTI has been used to demonstrate white matter abnormalities—manifested as abnormally decreased FA—in the absence of abnormalities on standard MRI, but the significance of these findings has not yet been clinically demonstrated.[12,16,17,23]

Table 1 Summary of Modality Usage in Traumatic Brain Injury (TBI)

Imaging Modality	Indications in TBI
Skull radiographs	• Not recommended in TBI
Computed tomography (CT)	• Triage of acute TBI meeting indications such as the Canadian Head CT Rule. • CT angiography (CTA) in suspected vascular injury • Evaluation of skull fractures
Magnetic resonance imaging (MRI)	• Acute TBI where neurologic findings not explained by CT • Subacute and chronic TBI • MR angiography (MRA) for suspected dissection or other vascular injury • Diffusion-weighted imaging (DWI) sequences for infarct and diffuse axonal injury (DAI) • Susceptibility-weighted imaging (SWI) sequences for DAI
Advanced modalities	• Diffusion tensor imaging (DTI), MR spectroscopy, positron emission tomography (PET), single-photon emission tomography (SPECT) have not yet demonstrated clinical utility, although they may have long-term prognostic value in subacute and chronic TBI