RADIOLOGICAL EVALUATION OF TRAUMATIC BRAIN INJURIES: REVIEW ARTICLE

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Abstract:
Background: Traumatic brain injury (TBI) is a significant health concern globally, affecting millions annually and posing a substantial socio-economic burden. The use of imaging techniques is crucial for assessing TBI, especially in cases of mild TBI where conventional modalities may not reveal structural lesions. Advanced neuroimaging methods show promise in detecting and predicting outcomes in TBI patients. **Objective:** This review aims to evaluate the effectiveness of different imaging techniques in diagnosing TBI, identify radiological markers for long-term prognosis, compare the sensitivity and specificity of various modalities in detecting different TBI types, and explore the role of advanced imaging technologies in enhancing diagnostic accuracy and monitoring TBI. **Conclusion:** While noncontrast CT remains the preferred initial imaging modality for acute moderate to severe TBI due to its speed and accuracy in detecting injuries requiring immediate attention, MRI plays a crucial role in assessing mild TBI and identifying pathologic changes associated with TBI. Advanced neuroimaging techniques like DTI, fMRI, MRS, and perfusion imaging hold promise in improving TBI evaluation and prognostication. The ongoing research in this field aims to validate the standardized role of advanced imaging techniques in diagnosing and managing TBI, offering personalized approaches for better patient outcomes.

Keywords: Traumatic Brain Injury, TBI, Imaging, MRI, CT, Radiology, Trauma

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Introduction:

Traumatic brain injury (TBI) poses a significant health and socio-economic burden globally, impacting approximately 1.7 million Americans annually [1]. It stands as the primary cause of mortality and morbidity in young individuals, encompassing injuries from sports-related incidents and rotational acceleration that can result in cerebral concussion [2].

The utilization of imaging techniques is paramount in the assessment, diagnosis, and prioritization of individuals with TBI. Recent research indicates that imaging also aids in forecasting patient outcomes. In cases of mild TBI (mTBI), conventional imaging modalities like computed tomography (CT) and magnetic resonance imaging (MRI) often reveal normal findings, devoid of structural lesions [3]. Consequently, the necessity for advanced neuroimaging methods arises to detect mTBI and forecast prognosis effectively.

Non-contrast CT scans and various brain MRI sequences (T1-weighted, T2-weighted, fluid-attenuated inversion recovery [FLAIR], diffusion-weighted, and frequently T2* imaging incorporating gradient-echo imaging or susceptibility weighted imaging [SWI]) are commonly employed for the clinical assessment of TBI. These techniques can identify acute or recent intracranial damage, as well as the long-term consequences of TBI such as encephalomalacia or chronic hemorrhage [4].

Although advanced neuroimaging techniques exhibit promise in evaluating mTBI, their standardized role in mTBI diagnosis and management remains under validation. Presently, limited evidence supports the routine clinical application of advanced neuroimaging techniques for individualized diagnosis and prognosis (class IIb recommendation) [5]. Developments in MRI-based neuroimaging methods like diffusion tensor imaging (DTI), functional MRI, magnetic resonance spectroscopy (MRS), and perfusion imaging have demonstrated potential in addressing the concerns of assessing mTBI and predicting TBI severity [6]. The ongoing exploration of advanced imaging techniques signifies an active area of research and development aimed at enhancing the evaluation and prognostication of TBI.

Objectives:

The main objectives of this review are:

1) To assess the effectiveness of different imaging techniques in diagnosing traumatic brain injuries.

2) To identify specific radiological markers that may predict long-term prognosis in patients with traumatic brain injuries.

3) To compare the sensitivity and specificity of various radiological modalities in detecting different types of traumatic brain injuries.

4) To investigate the role of advanced imaging technologies, such as MRI and CT scans, in improving the accuracy of diagnosing and monitoring traumatic brain injuries.

Routine clinical imaging:

In the context of suspected traumatic brain injury, the routine clinical imaging protocol typically involves noncontrast CT and MRI examinations, with the latter being utilized in specific scenarios [7]. When dealing with cases involving known or suspected primary vascular abnormalities, the diagnostic approach may necessitate the inclusion of noninvasive angiography techniques such as CT angiography or MR angiography, or even catheter angiography for both diagnostic and therapeutic purposes. Historically, skull radiographs were commonly employed as the initial imaging modality to assess calvarial fractures in pediatric patients; however, this practice has diminished in popularity due to the potential occurrence of significant intracranial pathology in the absence of a visible skull fracture [8].

In certain instances of suspected pediatric non-accidental trauma, skull radiographs are still conducted as part of a comprehensive skeletal survey alongside CT scans; nevertheless, this does not replace the essential role of CT imaging in cases where traumatic brain injury is clinically suspected. While radiographs may aid in distinguishing accessory sutures from actual fractures, the increasing availability of three-dimensional skull reformats in clinical settings may render this differentiation method obsolete [9]. Furthermore, the conventional CT "scout" view is often capable of serving as a surrogate radiographic image. Although transfontanel ultrasound can identify superficial lesions like extra-axial hemorrhage in neonates and has garnered support from some proponents, its utility is restricted by several blind spots, including the inability to visualize parenchymal, posterior fossa, and peripheral extra-axial lesions, and it generally does not play a significant role in the evaluation of head trauma [10].

Roles for CT and MR imaging:

Rapid imaging plays a crucial role in distinguishing patients necessitating urgent or emergent neurosurgical intervention from those who can be safely monitored or discharged. Noncontrast multi-detector CT (MDCT) has emerged as the preferred initial imaging modality following acute moderate to severe traumatic brain injury (TBI) due to its speed, widespread availability, high sensitivity to calvarial injuries and radio-opaque foreign bodies such as gunshot fragments, and its accuracy in detecting injuries requiring immediate neurosurgical attention, such as hemorrhage, herniation, and hydrocephalus. Additionally, MDCT has demonstrated utility in predicting clinical outcomes, with the findings from noncontrast CT scans being incorporated into various outcome prediction rules [11].

While MRI is generally not the first-line imaging modality for evaluating TBI due to its lower sensitivity to fractures, longer acquisition time, limited availability, and higher cost as a screening tool, it excels in detecting pathologic changes associated with even mild TBI (mTBI) and has shown promise in assessing injury severity and predicting outcomes [12]. Despite mild TBI being defined by a Glasgow Coma Scale (GCS) score of 13 or higher, patients in this category often experience persistent symptoms that can significantly impact their daily lives. Moreover, structural abnormalities on imaging are not uncommon in patients classified as having mTBI. For instance, a recent prospective study by Yuh et al. found TBI-CDE-defined pathoanatomic features in 42% of mTBI patients when combining results from initial CT scans on the day of injury and follow-up MRI scans [13].

Various guidelines, such as the Canadian CT Head Rules, New Orleans Criteria, and National Emergency X-Ray Utilization Study (NEXUS)-II, are routinely used to identify patients who may safely forego initial noncontrast CT scans. However, when imaging is deemed necessary, noncontrast CT remains the primary modality for evaluating acute mTBI. Despite this, the majority of patients with mTBI who undergo imaging will have normal noncontrast CT scans, indicating an "Uncomplicated" mTBI presentation [14].

While MDCT is recommended for patients experiencing neurological deterioration post-TBI, routine follow-up imaging has shown limited benefits. Certain factors, such as specific attributes of intracranial traumatic injury on initial MDCT, including subfrontal/temporal hemorrhagic contusion, anticoagulant use, age over 65 years, and volume of intracerebral hemorrhage (ICH) exceeding 10 cc, have been associated with a higher risk of progression. Although some institutions opt for routine follow-up MDCT in patients on anticoagulation, even in the absence of acute intracranial pathology on the initial scan, the clinical efficacy of this practice remains uncertain. A recent prospective study investigating patients with mild head trauma on anticoagulation revealed hemorrhagic changes in only 1.4% of such patients following a negative initial scan [15].

MRI often complements CT imaging and is particularly useful in the acute setting for mTBI when a patient's symptoms or neurological examination findings are not explained by CT results. Compared to CT, MRI is significantly more sensitive in detecting acute traumatic pathologies in mTBI, especially non-hemorrhagic contusions and traumatic axonal injuries (TAI). Therefore, MRI is recommended within the first two weeks of any moderate or severe TBI to sensitively assess the extent of parenchymal injury [16].

For the evaluation of subacute and chronic TBI, MRI outperforms CT in identifying parenchymal atrophy, white matter injuries, and microhemorrhages. Imaging is warranted in patients experiencing new, persistent, or worsening symptoms. In cases where MRI is contraindicated or unavailable, noncontrast CT should be conducted to assess subacute/chronic TBI [17].

Role of vascular imaging following traumatic brain injury:

The role of vascular imaging in the assessment of traumatic brain injury is crucial for identifying potential arterial or venous injuries. Although intravenous contrast administration is typically not required for TBI evaluation unless there is suspicion of vascular injury, non-contrast CT findings can help identify patients at higher risk for such injuries. Specific indicators of arterial injury risk include skull base fractures, especially those involving the carotid canal, as well as accompanying symptoms like epistaxis, LeFort II and III facial fractures, high cervical spine fractures, low Glasgow Coma Scale (GCS) score, or traumatic axonal injury (TAI) [18].

For suspected arterial injuries, either CT angiography (CTA) or magnetic resonance angiography (MRA) can be used for initial screening, with CTA being increasingly preferred due to advancements in multidetector CT technology and its ability to provide high-quality, rapid 3D images of contrast flow. In cases where conventional catheter angiography is necessary for diagnosis and treatment, it may be recommended [19]. Conversely, venous injuries should be considered in patients with skull fractures extending into adjacent dural venous sinuses, such as occipital fractures reaching the transverse sinus. Evaluation for dural venous sinus thrombosis can be conducted using CT venography (CTV) or MR venography (MRV) [20].

Pediatric imaging following traumatic brain injury:

When it comes to pediatric imaging following traumatic brain injury, it is important to consider the unique vulnerabilities of children to ionizing radiation. While efforts should be made to minimize unnecessary radiation exposure, diagnostic head CT should not be avoided when clinically indicated, even with concerns about radiation dose. Utilizing dedicated pediatric CT protocols can help reduce radiation doses, while MRI, which does not involve ionizing radiation, may require general anesthesia in children due to longer scan times and motion sensitivity. Future advancements in "rapid" MRI exams with shorter imaging times may help address these challenges, but further research is needed to ensure diagnostic accuracy comparable to CT and standard MRI [22].

Imaging finding of traumatic brain injury:

Intracranial pathology can be subdivided to anatomic location, the most basic distinction being whether it localizes to the brain parenchyma (intra-axial) or outside the brain tissue (extra-axial) [23].

Extra-axial lesions:

Three intracranial, extra-axial spaces—epidural, subdural, and subarachnoid spaces—are potential sites for posttraumatic pathology, most often hemorrhage. . NCCT is excellent at detecting acute hemorrhage, which appears hyperdense to the surrounding brain parenchyma typically measuring between 50 and 70 Hounsfield units. In general, the density of a hematoma decreases as it ages, which can create challenges for identifying subacute and chronic hemorrhages that may appear isodense to the surrounding brain parenchyma [24].

Intra-axial injury:

Intra-axial injuries refer to lesions within the brain parenchyma. Primary traumatic intra-axial lesions include the cortical contusion, intracerebral hematoma, TAI and brain stem injury. There are also secondary intra-axial injuries that can occur as a result of brain swelling and ischemia. While CT and MR are both quite sensitive for identification of extra-axial traumatic injury, MRI has a dominant role in evaluation of intra-axial pathology, as non-hemorrhagic and very small lesions can be occult on CT [25].

Conclusion:

In conclusion, traumatic brain injury (TBI) presents a significant health and socio-economic burden globally, with advanced imaging techniques playing a crucial role in diagnosis and prognosis. While conventional imaging modalities like CT and MRI are valuable in assessing TBI, advanced neuroimaging methods such as diffusion tensor imaging (DTI) and functional MRI show promise in enhancing TBI evaluation and prognostication. The standardized role of advanced imaging in mTBI diagnosis and management is still under validation, with ongoing research focused on improving the accuracy of TBI diagnosis and monitoring. Noncontrast CT and MRI remain essential tools in the clinical assessment of TBI, with MRI particularly useful in detecting pathologic changes associated with mild TBI. Vascular imaging is crucial for identifying potential arterial or venous injuries post-TBI, with CT angiography and magnetic resonance angiography being valuable screening tools. In pediatric cases, efforts to minimize radiation exposure while ensuring diagnostic accuracy are essential. Overall, the continued exploration of advanced imaging techniques signifies a promising avenue for enhancing the evaluation and management of traumatic brain injuries.

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