Med. J. Cairo Univ., Vol. 91, No. 5, Received 3/9/2023, Accepted 10/9/2023
DOI: 10.22608/MJCU. 1685-1690, December 2023
http://www.medicaljournalofcairouniversity.net/

The Role of Imaging in the Evaluation and Management of Traumatic Brain Injuries:

(Review Artical)

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Abstract

Background: Traumatic brain injury (TBI) is a significant cause of morbidity and mortality in both civilian and military populations. Routine neuroimaging has limitations in detecting subtle brain parenchymal changes, predicting prognosis, and assessing cerebral perfusion, metabolite levels, and mechanical properties after TBI. Advanced neuroimaging techniques have emerged as promising tools for the diagnosis, prognostication, and treatment of TBI.

Aim of Study: This review aims to summarize the role of advanced neuroimaging techniques in the evaluation and management of TBI. The focus is on ultrasound (US)-based techniques, magnetic resonance imaging (MRI)-based techniques, and molecular imaging-based techniques, including positron emission tomography (PET) and single-photon emission computed tomography (SPECT).

Methods: The review involves a comprehensive analysis of existing research on advanced neuroimaging techniques for TBI. The included techniques are contrast-enhanced US, intravascular US, US elastography, diffusion tensor imaging, magnetic resonance spectroscopy, perfusion-weighted imaging, magnetic resonance elastography, functional MRI, PET, and SPECT.

Results: Advanced neuroimaging techniques, such as US-based, MRI-based, and molecular imaging-based techniques, have shown potential in the evaluation and management of TBI. These techniques provide improved visualization of subtle brain parenchymal changes, allow for the assessment of cerebral perfusion, metabolites, and mechanical properties, and offer prognostic information. However, further clinical validation and larger studies are needed to establish their routine clinical use.

Conclusion: Advanced neuroimaging techniques offer valuable insights into TBI by overcoming the limitations of routine neuroimaging. US-based, MRI-based, and molecular imaging-based techniques provide additional information for the diagnosis, prognostication, and treatment of TBI. Continued research and validation are necessary to enhance the clinical utility of these techniques.

Key Words: *Traumatic Brain Injury – TBI – Neuroimaging – Ultrasound – MRI – Molecular Imaging – Advanced Techniques – Diagnosis – Prognosis – Treatment.*

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Introduction

TRAUMATIC brain injury (TBI) is a prevalent kind of damage, constituting around 40% of all injuries. An estimated 1 to 2 million persons globally get Traumatic Brain Injury (TBI). The prevalence of traumatic brain injury (TBI) is particularly high in infants and children aged 0-4 years, as well as among teenagers and young people aged 15-24 years. Additionally, there is a notable incidence of TBI among those aged over 65 years. Falls and motor vehicle accidents were the predominant factors leading to traumatic brain injury (TBI). Despite the rising incidence of TBI cases, the mortality rate has decreased. However, there has been a rise in the proportion of TBI patients with disability **[1-4]**.

Aim of Work:

The aim of this research is to provide a concise summary of the many kinds of traumatic injuries, their sequelae, and the non-invasive and invasive monitoring methods required in some cases, along with a short analysis and evaluation of existing literature. To enhance our comprehension and examination of the subject matter, we included the Computed Tomography (CT) scan data obtained from our independent research done at the GE Light Speed VCT.

Global prevalence and magnitude of traumatic brain injury (TBI):

According to Peden [5], about five million individuals die annually as a result of traumatic brain injury (TBI). Therefore, the mortality rate resulting from Traumatic Brain Injury (TBI) is at 83 per one million individuals, accounting for 9% of all recorded fatalities. Traumatic brain injury (TBI) is responsible for 12% of all cases of disability, resulting in a significant and lasting decrease in the ability to work. The prevalence of Traumatic Brain Injury (TBI) was the greatest in the United States and Canada, with a rate of 1299 cases per 100,000 people (95% confidence interval 650-1947). Europe also had a high incidence of TBI, with a rate of 1012 cases per 100,000 people.

The prevalence of the condition was highest in Asia (1000/100,000 individuals, 95% confidence interval [CI] 911–1113), and lowest in Africa (801/100,000 individuals, 95% CI 732–871). The South-East Asian Region had the highest yearly prevalence of Traumatic Brain Injury (TBI) with 18.3 million cases, followed by the Western Pacific Region with 17.3 million cases [6].

The incidence of Traumatic Brain Injury (TBI) in Russia varies between 1.6 and 7.2 per 1,000 individuals per year, which amounts to about 600,000 persons annually. In Kyrgyzstan, the incidence rate is 4.0 per 1,000 individuals and the death rate is as high as 11 per 100,000 individuals [7].

Regarding the development of disease, Traumatic Brain Injury (TBI) is categorized into primary and secondary brain injury. The main injuries are a result of the impact of traumatic force on the cranial bones, the protective covering of the brain, the brain tissue itself, the blood arteries in the brain, and the lymphatic system [8]. These illnesses originate from many forms of initial harm and lead to diverse cellular damage, culminating in a broad spectrum of damage processes. A head injury primarily damages the nerve cell membrane, white matter structure, vascular course, and triggers downstream damage processes such as metabolic stress and ion problems. Consequently, a comprehensive set of biochemical and molecular alterations leads to the demise of neurons [4,5].

Importance of Imaging Techniques:

Often, when a patient has a head injury and their brain CT scan reveals the presence of bleeding in the brain, it may be classified as either an intra-axial hematoma (bleeding within the brain) or an extra-axial hematoma (bleeding outside the brain; 2). Various imaging modalities are used to visualize traumatic brain injuries, including X-rays, which were historically utilized for screening purposes. However, it is important to note that X-rays may not always detect skull fractures. CT has been the favored modality in the acute situation and is most effective in identifying acute traumatic hemorrhages and skull fractures, resulting in time savings compared to Magnetic Resonance Imaging (MRI; 9,10). Magnetic resonance imaging (MRI) of the brain is not the recommended diagnostic method in urgent situations due to its time-consuming nature and limited accessibility. Diffuse axonal injury (DAI) is primarily used in certain circumstances, particularly when there is a suspicion of neurological degeneration or the presence of problems that may develop gradually and may not show improvement with therapy.

The clinical manifestation of extradural hemorrhage (EDH):

Epidural hematoma (EDH) arises from the medial meningeal artery (MMA) and is linked to a skull fracture. Specifically, the fracture of a bone damages a branch of the MMA, leading to the formation of an EDH. The bleeding occurs in the extradural gap, which is located between the outer layer of the dura (endosteal layer) and the inner table of the skull vault. The condition is characterized by a lucid interval and often occurs near the temporoparietal junction. The normal shape of an epidural hematoma (EDH) is biconvex, like a lens, and it does not extend beyond the cranial sutures. It may traverse and raise/shift venous sinuses, extending beyond their boundaries [9].

Computed tomography (CT) scan:

Typically, EDHs are seen on brain CT images. They usually have a biconvex (lentiform) shape and are most often located below the squamous section of the temporal bone. EDHs have a high density, moderate heterogeneity, and clear boundaries. Secondary signs of mass effect, such as midline displacement, subfalcine herniation, and uncal herniation, may be seen depending on the size of the mass. During a CT scan, if there is active bleeding, the non-clotted new blood will usually seem less dense, and the presence of a swirl sign (a region of lower density inside the bleed) may indicate ongoing bleeding that needs immediate attention. Occasionally, post-contrast extravasation may be seen in cases of acute epidural hematoma (EDH), whereas chronic EDH may exhibit peripheral enhancement caused by granulation and neovascularization (Fig. 1).

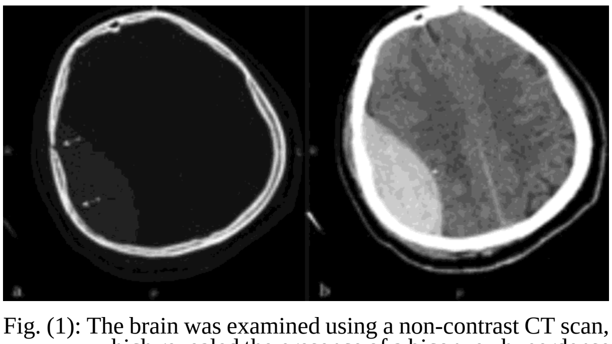

Fig. (1): The brain was examined using a non-contrast CT scan, which revealed the presence of a biconvex hyperdense collection outside the brain tissue. This collection is connected with a fracture and is compatible with an extradural hematoma.

MRI:

The MRI scan reveals a displaced dura, which shows as a dark line on both T1 and T2 sequences. This characteristic helps differentiate it from a subdural hematoma. Acute epidural hematoma (EDH) appears with the same intensity as surrounding tissues on T1 scan and exhibits varying intensities ranging from less severe to more intense on a T2 sequence. Early subacute epidural hematoma (EDH) looks dark on T2 imaging, but late subacute and chronic EDH appears bright on both T1 and T2 sequences. In cases when the epidural hematoma (EDH) originates from a vein, the intravenous contrast might cause displacement or blockage of the venous sinus.

Angiography is hardly performed. The presence of a tram-track indication is caused by the extravasation of contrast material from the middle meningeal artery (MMA) into the parallel middle meningeal veins.

Subdural hemorrhage (SDH) is caused by the rupture of bridging veins. Hemorrhaging in the subdural space refers to the accumulation of a significant volume of blood, which may exert pressure on the underlying brain without producing immediate complications due to the spacious nature of this area. Spontaneous subdural hematoma (SDH) in older individuals may either have no symptoms or manifest as a moderate headache or temporary but recurring neurological impairments, which are referred to as pseudodementia. A concavo-convex form is characterized by a concave inner margin and a convex outer edge. The presence of an acute subdural hematoma (SDH) along the walls of the superior sagittal sinus might cause the walls to seem denser, while the contents appear substantially less dense, mirroring the Empty Delta sign seen in sinus thrombosis (Fig. 2).

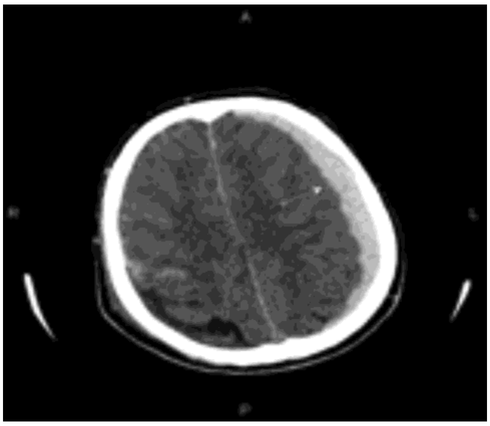

Fig. (2): Axial non-contrast CT scan of the brain reveals a thick curved collection of blood, known as a hyperdense crescentic hematoma, that spans over the lines where the skull bones meet, indicating an acute subdural hemorrhage.

Comma-shaped subdural hematoma (SDH) refers to the presence of SDH along the falx cerebri, which extends along the tentorium cerebelli. Not restricted just to cranial sutures, but specifically confined to Dural folds such as the falx cerebri, falx cerebelli, and tentorium cerebelli. Subacute subdural hematoma (SDH) is a condition when there is bleeding near the brain that has a high density, making it difficult to identify. In such cases, magnetic resonance imaging (MRI) is a more effective diagnostic tool. Chronic subdural hematoma (SDH) or subdural hygromas are characterized by the presence of bilateral hypodense (low density similar to cerebrospinal fluid) crescent-shaped collections. Elevated amounts of cerebrospinal fluid (CSF) may be seen in the event of a recent hemorrhage. Observing subdural hemorrhage (SDH) in neonates and babies may indicate the possibility of non-accidental damage or Battered baby syndrome **[11]**.

Subarachnoid hemorrhage (SAH) is often caused by head trauma, resulting in bleeding that is seen in the basal cisterns and sulcal spaces. Subarachnoid hemorrhage (SAH) may occur due to the rupture of tiny pial arteries, the spread of blood from a contusion or hematoma into the subarachnoid space, or the diffusion of intraventricular hemorrhage **[12]**. CT presents as elongated or winding regions/finger-like projections of increased density that match the shape of the brain's grooves and fluid-filled spaces - often seen in the Sylvian fissures and interpeduncular cistern. MRI is less effective in detecting abnormalities in the acute stage compared to CT scans. FLAIR scans may show sulcal hyperintensity. Magnetic resonance imaging (MRI) is more effective in detecting sub-acute and chronic subarachnoid hemorrhage (SAH) **[13]**.

Parenchymal contusions may be categorized as either hemorrhagic or non-hemorrhagic. Observed in regions of the brain next to rugged osseous surfaces, therefore often observed in the orbitofrontal and temporal regions of the brain. The CT scan reveals indistinct areas of increased density (indicating blood) with significant areas of decreased density around them (indicating substantial periblood edema). Contusions may be seen on MRI as indistinct regions with varying signal strength on both T1-weighted and T2-weighted images. The signal intensity depends on the age of the lesions **[14]**.

DAI, or Diffuse Axonal Injury, is a condition that is often seen in situations when a head injury patient has a non-improving altered sensorium, while having a normal first CT scan. It may be considered a significant factor in the patient's medical history. Diffuse Axonal Injury (DAI) refers to the shearing stress or strain put on the brain as a result of rotational acceleration and deceleration forces that occur during a road traffic collision. When a neuron experiences a shearing force, it will detach from its point and the connection between the cell body and neurofilament will be disrupted. This is a permanent and irrevocable cessation. The term used to describe a diffuse damage occurring at the axonal level is termed Diffuse Axonal damage (DAI).

The dorsolateral brainstem:

On T2W/FLAIR images, non-hemorrhagic foci of diffuse axonal injury (DAI) appear as concentrated areas of increased brightness in the brain. MRI is the preferred method of investigation for diagnosing diffuse axonal injury (DAI) in individuals who are 13 years old.

Pneumocephalus is often caused by trauma, indicating a basal skull fracture with air entering from the paranasal sinuses. Tension pneumocephalus is a condition where air accumulates in the subdural space and exerts pressure on the brain tissue below. This often happens due to a ball-valve system that allows air to enter the subdural area but prevents it from escaping. The Mount Fuji sign refers to the phenomenon where air causes the frontal lobes to split and compress, resulting in an enlarged gap between the two halves of the brain that resembles the shape of Mount Fuji in Japan. The recommended course of action is immediate surgical decompression as a kind of treatment. A CT scan is the preferred diagnostic procedure. CT scans of the brain are the most effective way to see skull fractures. CT scans are not only very sensitive in detecting fractures, but they also provide detailed information about the extent of the fractures and enable precise surgical planning. Moreover, it is acquired simultaneously with the imaging of the brain.

Excessive force may result in bone fractures occurring at or around the point of contact, leading to injury to the underlying tissues inside the skull, including the membranes, blood vessels, and brain. A simple fracture is characterized by the presence of a single bone fragment, whereas a complex fracture occurs when there are two or more bone pieces. Here, we provide a comprehensive list of the prevailing forms of skull fractures. Linear fractures are the most common kind and often do not need any intervention for the fracture itself. These thin lines have a shape that does not induce movement of bone fragments and seldom need immediate action. These fractures are the least hazardous. Generally, they do not result in the loss of consciousness. It may result in harm to the membranous arteries and the development of epidural hematoma (EDH).

Complications:

Long-term consequences of head trauma include: Encephalomalacia/gliosis, chronic subdural hematomas/cerebrospinal fluid hygromas, chronic traumatic encephalopathy, depression, anxiety, and alcohol misuse. Elevated susceptibility to schizophrenia, bipolar illness, and organic mental diseases. Severe mass effect may lead to displacement of the midline, which is linked with a worse prognosis. Cerebral herniation need immediate treatment and hydrocephalus can be a long-term consequence unrelated to the mass effect.

Diagnostic imaging techniques used for Traumatic Brain Injury (TBI):

As previously mentioned, CT scans are essential for evaluating patients with traumatic brain injury (TBI) in the early stages. They provide prompt and crucial information that directly influences the treatment of acute TBI patients **[7,2]**. The CT scan shows the presence of a hematoma, displacement of the midline, compression of the ventricles, hydrocephalus, and depressed fractures, all of which need surgical treatment. Computed tomography (CT) enables us to prioritize patients who need surgical intervention as opposed to conservative therapy. CT imaging data are often compared to MRI as a benchmark or associated with the clinical outcome after six months.

MRI surpasses CT in its ability to identify minor abnormalities and treat injuries in the posterior fossa and brainstem. MRI is recommended for individuals experiencing neurological symptoms that cannot be explained by abnormalities seen by CT scans or for patients with moderate traumatic brain injury who continue to have symptoms. Observations of hemorrhage and traumatic intracranial hematoma indicate that an increase in traumatic intracranial hematoma often occurs sooner in the post-traumatic period, namely during the first 24 hours. Consequently, if the first CT scan reveals abnormalities such as hematomas, it is advisable to do a follow-up head CT scan to confirm the stability of the abnormality.

The sensitivity and specificity of CT are inferior to those of MRI when using Gradient Echo Sequences (GES) or Susceptibility weighted imaging (SWI). If a head CT scan shows no abnormalities, but there is a difference between the results of the scan and the symptoms reported by the patient, it is advisable to have a brain MRI to accurately evaluate traumatic brain injury (TBI). Common MRI procedures for traumatic brain injury (TBI) consist of T1-weighted sagittal pictures, coronal fluid-attenuated inversion recovery (FLAIR) images, T2-weighted axial images, coronal gradient echo (GRE) or susceptibility-weighted imaging (SWI) images, and diffusion-weighted imaging (DWI). Administering intravenous contrast is not required for evaluating traumatic brain injury (TBI) using MRI (16). Functional imaging investigations using single-photon emission computerized tomography (SPECT) or positron emission tomography (PET) scans have been used to assess patients with moderate traumatic brain injury (TBI) in cases where computed tomography (CT) or magnetic resonance imaging (MRI) did not reveal any observable abnormalities.

The use of imaging in predicting damage or prognosis in traumatic brain injury (TBI):

As previously mentioned, imaging is crucial for patients with traumatic brain injury (TBI). However, it is important to exercise care when determining the imaging needs of patients with head trauma, taking into consideration the potential risks associated with ionizing radiation and the total medical expenses involved. CT scans are responsible for around 45% of the total radiation dosage received by the US population from all medical X-ray exams. This issue is especially grave in juvenile patients who have experienced trauma. While radiation exposure is a risk for both adults and children, children are more susceptible to radiation and have a greater life expectancy, resulting in more opportunities for radiation-related illnesses. It is highly recommended to follow the pediatric head CT protocol supported by professional organizations such as the American College of Radiology, Society of Pediatric Radiology, American Academy of Pediatrics, and American Academy of Family Physicians when a pediatric patient requires a head CT scan following a trauma.

Head CT may be safely avoided in predicting Traumatic Brain Injury (TBI) without any negative outcomes. Three often referenced prediction criteria are the New Orleans Criteria (NOC; 17), the Canadian Head CT Rule (CCHR), and the CT in Head Injury Patients (CHIP) rule. When a patient has a head injury that is mild to severe, it is necessary to do a head CT scan to determine the severity of the damage and if surgery is required. In order to ensure that patients with mild traumatic brain injury (TBI) are properly identified, it is crucial to accurately distinguish between those who need surgical intervention for serious TBI and those who do not. This may be achieved by establishing a clear definition for the group of patients with TBI, while minimizing the risk of overlooking any patients who require surgical intervention. Several prediction rules exist for mild traumatic brain injury (TBI).

Conclusion:

The clinical prediction guidelines usually use clinical symptoms and risk variables such as age, headache, vomiting, drunkenness, forgetfulness, post-traumatic seizure, evidence of skull fracture, GCS score, and progression of GCS score after trauma. The main focus of this study is to examine abnormalities in head CT scans as the major result, and the secondary outcome is the need for neurosurgical intervention.

These prediction methods vary in terms of specificity, but they have a 100% sensitivity in diagnosing lesions that need neurosurgical intervention. The specificity values for NOC, CCHR, and CHIP are 24%, 32%, and 23%, respectively. The comparison between the NOC and CCHR reports reveals that both assessments have a high level of sensitivity in predicting the need for neurosurgical intervention. However, the CCHR report exhibits a greater degree of specificity compared to the NOC report.

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دور التصوير فى تقييم وإدارة الإصابات الدماغية التى تحدث نتيجة الإصابات: استعراض

الخلفية: الإصابة الدماغية الناتجة عن الإصابات الدماغية (TBI) هى سبب كبير للمرضية والوفيات فى السكان المدنيين والعسكريين على حد سواء. للتصوير العصبي الروتيني قيود في اكتشاف التغييرات الدماغية الدقيقة، وتوقع النتائج، وتقييم تروية الدماغ، ومستويات المتابعات، والخصائص الميكانيكية بعد الإصابة بـ TBI. ظهرت تقنيات التصوير العصبى المتقدمة كأدوات واعدة لتشخيص وتوقع النتائج، وعلاج TBI.

هدف العمل: يهدف هذا الاستعراض إلى تلخيص دور تقنيات التصوير العصبى المتقدمة فى تقييم وإدارة TBI. يركز الاهتمام على تقنيات الأشعة فوق الصوت (US)، وتقنيات التصوير بالرنين المغناطيسى (MRI)، وتقنيات التصوير الجزيئى، بما فى ذلك التصوير بالتصوير الإيجابى بالإنبعاث الإيجابى (PET) والتصوير بالتصوير الحساس للإشعاع الفردى (SPECT).

الطرق: يتضمن الاستعراض تحليل شامل للأبحاث الحالية حول تقنيات التصوير العصبى المتقدمة لـ TBI. تشمل التقنيات المدرجة تقنيات تحسين الأشعة فوق الصوت، والأشعة فوق الصوت داخل الأوعية، والتصوير بالأشعة فوق الصوت، وتصوير الألياف العصبية المنتشرة، وتصوير الرنين المغناطيسى الطيفى، وتصوير التروية الوزنى، وتصوير الرنين المغناطيسى الطيفى، وتصوير الرنين المغناطيسى الميكانيكى، وتصوير الرنين المغناطيسى الوظيفى، وPET، وSPECT.

النتائج: أظهرت تقنيات التصوير العصبي المتقدمة، مثل تقنيات الأشعة فوق الصوت، وتقنيات التصوير بالرنين المغناطيسى، وتقنيات التصوير الجزيئى، إمكانية فى تقييم وإدارة TBI. توفر هذه التقنيات تصويرًا محسنًا للتغييرات الدماغية الدقيقة، وتسمح بتقييم تروية الدماغ، والمتابعات، والخصائص الميكانيكية، وتقدم معلومات نتائجية. ومع ذلك، يتطلب الأمر مزيدًا من التحقق السريرى وإجراء دراسات أكبر لتأكيد استخدامها السريرى الروتينى.

الاستنتاج: تقنيات التصوير العصبى المتقدمة تقدم رؤى قيمة حول TBI من خلال التغلب على قيود التصوير العصبى الروتينى. تقنيات الأشعة فوق الصوت، والأشعة المغناطيسية، وتقنيات التصوير الجزيئى توفر معلومات إضافية لتشخيص وتوقع النتائج، وعلاج TBI. البحث المستمر والتحقق الدورى ضروريان لتعزيز الفائدة السريرية لهذه التقنيات.