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APPLICATION OF PERFUSION IMAGING IN PATIENTS WITH TRAUMATIC BRAIN INJURIES

Neurosurgery

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ABSTRACT

Traumatic brain injury results in lifelong disability and mortality. One-quarter to one-third of all unintentional deaths and two-thirds of trauma-related deaths in hospitals are caused by traumatic brain injury. Neuroimaging is essential to the diagnosis and treatment of traumatic brain injury (TBI), a significant problem on a global scale. In order to identify and characterise potential perfusion neuroimaging biomarkers to help with diagnosis, treatment, and prognosis, perfusion neuroimaging techniques have recently been investigated in TBI. This article reviewed the use of Xenon-CT, MRI ASL perfusion, CT bolus perfusion, and MRI bolus perfusion in acute traumatic brain injury and explored the directions for future research were.

KEYWORDS

Traumatic Brain Injury; perfusion imaging, CT, MRI

INTRODUCTION:

Traumatic brain injury (TBI), also known as acquired brain injury causes significant lifelong disability and mortality. One-quarter to one-third of all unintentional deaths and two-thirds of trauma-related deaths in hospitals are caused by traumatic brain injury (TBI). In India, more than a million people die and 1.5 to 2 million suffer injuries each year. TBIs are most frequently caused by RTAs (60%) followed by falls (20%–25%) and violence (10%). 15%–20% of TBIs are known to have alcohol use as a confounding factor at the time of injury. [1-3] According to estimates, 3.2 million individuals worldwide are dealing with TBI-related long-term disabilities.[4] For civilians, TBI is most frequently caused by motor vehicle accidents, falls, sports-related injuries, and assaults; for service members, it is most frequently caused by explosions. In order to diagnose, treat, and determine the prognosis of TBI, neuroimaging is crucial.[5]

Appropriateness Criteria have been published by the American College of Radiology to assist referring physicians in selecting the best imaging studies. The best initial neuroimaging examination, for instance, is a noncontrast Computed Tomography (CT) scan for a closed head injury with moderate to severe acuteness. [6]

A noncontrast CT scan can identify lesions that need urgent neurosurgery treatment, like an epidural hematoma. Noncontrast CT scans, however, come with some drawbacks. For instance, parenchymal contusions have been discovered to be undersized by early CT scans. [7,8]

The study of neuroimaging has progressed recently from structural imaging to the functional tissue characterization of cerebral perfusion. The physiological definition of perfusion is the blood flow in each unit of tissue volume. Since it can discriminate between regularly perfused cerebral parenchyma, ischemic penumbra, and infarcted tissue, this is frequently employed while dealing with stroke. [9-12]Alterations in the cerebrovascular parameters following TBI are thought to contribute to secondary injuries.[13] The capacity to identify possibly recoverable tissue is called "traumatic penumbra" and ischemic episodes may be crucial to improving clinical outcomes after TBI. [14-16]

Perfusion Imaging Technique Used In Computed Tomography:

Conserving flow is the core principle of perfusion computed tomography (PCT). A non-diffusible tracer, or substance that stays in the vasculature, is injected intravenously in order to monitor flow. In terms of image processing, time-enhancement curves registered to each pixel in the data set are produced using the PCT images. Key metrics such as regional cerebral blood volume (rCBV), mean transit time (MTT), and regional cerebral blood flow (rCBF), which have been confirmed to stable xenon CT, can be generated from the time-enhancement curves using processing software. [17]

The MTT, which has units in seconds, represents the typical amount of time blood needs to move from the arterial input via the brain tissue and to the venous outflow.Deconvolution is a mathematical technique used to calculate MTT. [18-20] The anterior cerebral artery is typically used as the region of interest for the reference arterial input function (AIF) that the MTT requires. The time to peak measures how long it takes for each voxel's time-enhancement curve to reach its peak when contrast enters the AIF. The time to peak, where TMax = 0 for normally perfused tissue without delay, is used to compute the Tmax. Finally, CBF is measured in millilitres (mL) of blood per 100 gm of brain tissue per minute and is the amount of blood that flows through a particular volume of brain tissue over a certain length of time.[21]

The MTT is equal to the rCBV divided by the rCBF in accordance with the central volume theory. [22] CBF is essential to the viability of the cerebral parenchyma. CBF changes can affect the electrical and metabolic activity of neurons. Even when changes in systemic pressure occur, appropriate CBF is maintained in part by cerebral autoregulation.

Imaging Of Traumatic Brain Injury In Association With Bolus Ct Perfusion:

In their investigation of PCT on admission CT scans, Wintermark et al.[23] discovered perfusion irregularities linked to juxtadural collections, cerebral edoema, and intracranial hypertension. On a delayed CT, it was discovered that the 42 perfusion anomalies were present in the same region as the contusion.A statistically significant difference between noncontrast CT and PCT's sensitivity was found (p-value 0.001). In the presence of severe trauma, the specificity of perfusion abnormalities for cerebral contusion was 93.9%. Areas with cytotoxic edoema exhibited lower perfusion, whereas vasogenicedoema might either show enhanced or decreased perfusion. Reduced rCBF was discovered to be present right next to epidural hematomas in the presence of juxtadural collections. [23,24] In Wintermark's study, intracranial hypertension was associated with high MTT, lowrCBF, and highrCBV.

Even when there is no obvious cerebral injury on the admission head CT, perfusion imaging showing immediate blood volume and flow deficits is linked to worse outcomes.[24] PCT was shown to provide additional information in 60% of patients with severe TBI and to change care in 10% of patients. [25] PCT may be able to tell whether areas of hypodensity on a CT scan are necrotic or viable. PCT also sheds light on cerebral vascular autoregulation, which may be utilized to direct therapy and assess the efficacy of treatment. [26]

The radiation dose that comes with PCT is one of the main obstacles. Every institution should strive to maintain radiation exposure as low as is practically possible because radiation safety is of the utmost significance (ALARA). The intravenous infusion of contrast material, which can cause allergic reaction or renal impairment, is another danger associated with PCT.[27]

Perfusion Imaging Technique Used In Magnetic Resonance Imaging:

There are two primary methods for performing cerebral perfusion in MRI. The exogenous and endogenous techniques.An exogenous, non-diffusible contrast agent, like gadolinium-based contrast agents, is injected intravenously in bolus perfusion MRI.There are two primary subcategories of non-diffusible brain perfusion imaging: DSC (dynamic susceptibility weighted contrast) imaging and DCE (dynamic contrast enhancement) imaging. In DSC, thebolus temporarily reduces the signal's amplitude due to the contrast bolus's T2* effect as it passes through the vasculature. As a result, the signal is weaker and the contrast is higher. A gadolinium-based contrast agent must be injected intravenously at a rate of about 4 mL per second for a standard DSC bolus MRI scan.The bolus in DCE promotes T1 shortening in the blood pool and in any location where accumulation results from leakage outside the arteries. As a result, the signal and contrast are both boosted.[28]

Imaging Of Traumatic Brain Injury In Association With Bolus Perfusion Mri:

Voxelwise analysis of regional cerebral blood flow (rCBF) maps in a research by Liu et al. revealed scattered perfusion deficits in the cerebellum, cingulate gyrus, cuneus, and temporal gyrus in TBI patients compared to normal controls.[29]

DSC was done on 18 individuals with subacute TBI (mean of 10 days after TBI) in a different study by Garnett et al. On conventional MRI imaging, six of the 18 patients showed obvious contusions, and each of these six patients had considerably lower rCBV in the contused regions. Despite having worse clinical outcomes, these five patients did not have more severe injuries than the other patients.[13]

In general, it can be challenging to do an MRI scan after trauma. Patients could have unstable hemodynamics. Patients might not be able to get their permission for an MRI because the scans are naturally lengthy. The MRI safety questionnaire may also be impossible for trauma patients to complete because they are asleep or because they have known MRI contraindications. This makes using MRI in a trauma scenario fundamentally difficult.

Arterial Spin Labeling (ASL):

Quantitative data on the CBF and perfusion are provided by the non-invasive MR imaging technique known as arterial spin labelling (ASL). Williams et al. successfully used the method for the first time in a rat CBF model.[30-33]

Measurements of ASL-based CBF have been compared to conventional radiotracer perfusion methods, such as HMPAO SPECT[34], PET[35], and Xe-CT[36]. This adaptable method also produces repeatable outcomes that are supported by multicenter clinical trials. ASL differs from conventional perfusion imaging methods in several appealing ways. ASL is best for imaging in paediatric and pregnant patients because it doesn't expose patients to radiation and employs endogenous water protons in place of contrast chemicals. Additionally, ASL modelling enables the determination of absolute CBF, which is useful for longitudinal research and studies that compare various MRI scanners.[37,38]

Imaging Of Traumatic Brain Injury In Association With Arterial Spin Labeling (ASL):

Since its introduction, ASL has been extensively employed in a wide range of clinical settings, including those involving stroke, arteriovenous malformations, dementia, epilepsy, CNS malignancies, and infections. [39] Several TBI perfusion research on both human and animal subjects have also used ASL. One of the first animal studies using ASL to examine the influence of TBI on CBF in rats following controlled cortical impact was carried out by Kochanek et al. in 2002. (CCI). When they compared CCI subjects to sham-surgery subjects, they discovered an 80% reduction in CBF in the ROIs right next to the lesion.[40]

Ge and colleagues[41] examined the longterm effects of mild TBI on regional CBF and neuropsychological performance on a 3T scanner utilising a True FISP ASL labelling sequence. The authors detected a marked drop in CBF in the patients in bilateral thalami and caudate nuclei but not in putamen Additionally, the individuals' cognitive function modifications were favourably linked with the CBF changes. In a study by Kim et al.[42], matched controls and 27 individuals with TBI were compared with healthy controls in terms of their resting CBF. The largest volume losses also occurred in the thalami and posterior cingulate gyri, where they identified a global, non uniform hypoper fusion with substantial localised declines.

The scope of TBI studies utilising ASL was widened by Doshi et al.[43] to include ER patients who were experiencing the early stages of TBI with scan delays between 3 and 10 days. In the caudate, putamen, and ventral pallidum of the individuals with TBI, they discovered elevated rCBF using ASL and susceptibility weighted imaging. Despite the wide variation in delayed scan times among subjects, the authors attribute the increase in rCBF to these factors.

Football players and participants in non-contact sports (such as golfers) were subjected to MRI scans in a recent study (i.e., volleyball players). Cortex, white matter, basal ganglia, thalami, and hippocampi volumes were identical in both groups. The CBV in the hippocampal and thalamic regions of the volleyball players was much higher than that of the football players, indicating that CBV may be a more accurate measure for identifying TBI. [44]

ASL's intrinsically low signal-to-noise ratio (SNR) and temporal resolution present a technological barrier when used for TBI imaging. [45]In areas with significant magnetic susceptibilities, EPI can experience visual distortion. Shorter acquisition durations are possible with more recent pulse sequences like turbo-ASL[46] and single-shot ASL[47], but signal interpretation is more difficult.[48]

CT Perfusion In Association With Stable Xenon In Traumatic Brain Injury:

Inhaling stable Xenon gas is another method of performing perfusion CT imaging instead of injecting iodinated contrast. Images are taken in Xenon Perfusion CT during the Xenon gas's wash-in and wash-out phases. A 13–17 minute technique that consists of four axial slices, each measuring 5 mm thick and spaced 20 mm apart, has been tested in numerous experiments.[49-51]

In a research with 90 patients who had TBI, the results of a Xe-CT conducted 1-3 days after TBI were associated. MTT was measured, with the average of the right and left hemispheres assessed at the level of the basal ganglia as the region of interest.[52]

Another study looked at whether early CBF could predict neurologic prognosis in 12 hours of traumatic brain injury as judged by the Glascow Outcome Scale (GOS).The significance of early perfusion imaging following TBI is highlighted by this finding. The biggest issue in recent years has been the lack of steady, high-quality Xenon in the United States. As a result, Xe-CT clinical trials and research are currently suspended.[51]

Future Prospects Of Research In The Field Of Perfusion Imaging:

Positive outcomes have been seen in animal studies using neuroprotective techniques. Such pre-clinical achievements, however, have not been able to translate into better clinical outcomes in clinical TBI trials. [53-56]Clinically TBI is more variable than in consistent models in animal studies which is a potential explanation for this. Early perfusion alterations are significant in TBI because of their prognostic relevance. Therefore, early post-TBI perfusion changes should be one topic of future study.[51,53,57]

A snapshot of the blood flow at the time of tracer injection is provided by the tracer distribution at the time of imaging. Despite the fact that ictal single photon emission computed tomography (SPECT) imaging is well known to be useful for seizure localization[58], a recent systematic review article of SPECT imaging at TBI found only one study that was carried out within 12 hours of the TBI out of 19 longitudinal and 52 cross-sectional studies.[59,60]This study demonstrated hypoperfusion following TBI and discovered a correlation between the hypoperfusion and forgetfulness. [60]

An ongoing TBI study supported by the Department of Defense is examining early perfusion alterations in severe TBI. The experiment's layout mimics a real-world scenario when a soldier gets injured in battle and later undergoes SPECT-CT imaging after receiving a radiopharmaceutical injection. Reduced perfusion was detected at the cortical impact location in our TBI animal trials, which is similar with the hypoperfusion noted by other research groups. Spatial resolution of SPECT-CT is a drawback of this method. High spatial resolution collimators will be used in next studies.[61]

The significant variety of TBI makes it difficult to determine an individual treatment that works; however, perfusion imaging opens up new possibilities for the identification of injuries that could otherwise go undetected with traditional imaging.[62] More precise diagnosis and associated therapies can be made using perfusion imaging. Building typical age-stratified perfusion imaging images may be a future research project. With the help of a normative database, clinically applicable classifications of TBI can be obtained, leading to a more precise diagnosis through computer guided diagnosis. The act of teaching a computer system to "learn" from prior experience, when perfusion parameters (for example, CBV values) are linked to specific outcomes, is known as machine learning.[63–66] Future therapy options may be determined by an integrated strategy that includes the best structural imaging, perfusion imaging, and clinical factors.

CONCLUSION :

Traumatic brain injury has become a significant problem on the global scale. Being a highly sensitive emergency condition, TBI needs prompt diagnosis and treatment planning to save a life. Neuroimaging plays a major role to identify the severity and assess the prognosis. Perfusion imaging has opened a new horizon in this field. Future research works are expected to explore many more applications of this technology.

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