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Comparison of advanced magnetic resonance imaging techniques in evaluation of brain tumors; Literature review from bench to bedside

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ABSTRACT

Magnetic resonance imaging (MRI) is a method in which high quality images as well as optimized resolution are obtained without use of X-ray or other ionizing radiation causes that nowadays physicians in all field of interests find it as a theranostic tool for medical application. A concise compendium of the fundamental physiology, physics and clinical uses of unconventional MRI techniques comprise diffusion weighted imaging (DWI), perfusion weighted imaging (PWI), magnetic resonance spectroscopy (MRS), and diffusion tensor imaging (DTI) in the setting of neuro-oncology is reviewed in this article. Advanced MR imaging techniques may also provide prognostic information and may be used to guide therapy early on in the patient's treatment, effectively improving outcomes and minimizing side effects, both in the short and long term. Also, we hope that this new technology lead to the development of novel managements and will improve our understanding of the mechanism underlying neurological disorders.

KEY WORDS: magnetic resonance imaging, brain tumors, MRI.

1. INTRODUCTION

Magnetic resonance imaging (MRI) is a method in which high quality images as well as optimized resolution are obtained without use of X-ray or other ionizing radiation causes that nowadays physicians in all field of interests find it as a theranostic tool for medical application (Koba, 2011; Rahmani Tanha, 2016). Advanced MRI methods, such as spectroscopy, perfusion, and functional imaging, have enhanced the imaging technology of brain carcinoma. As well as the anatomic or structural evidence accessible with orthodox MRI, progressive MRI methods also offer physiologic info about tumor metabolism and hemodynamics (Gharib Salehi, 2016). The authors review the physiology, techniques, and clinical applications of perfusion MRI, spectroscopy, functional MRI, and diffusion tensor imaging in the setting of neuro-oncology (Mohammadi, 2015; Rees, 2003). The imaging of brain tumors has significantly improved with the use of advanced MRI techniques, such as spectroscopy, perfusion, and functional imaging (Rahmani Tanha, 2016). Conventional MRI provides mainly anatomic or structural info about the brain. Unlike traditional imaging, progressive MRI methods also provide physiological info concerning metabolism and hemodynamics. These methods not only help in the imaging diagnosis of brain tumors, they are useful in the treatment of patients with brain tumors (Fatehi, 2015; Esenaliev, 2015). A concise compendium of the fundamental physiology, physics and therapeutic uses of progressive MRI techniques comprise of diffusion weighted imaging (DWI), perfusion weighted imaging (PWI), magnetic resonance spectroscopy (MRS), and diffusion tensor imaging (DTI) in the setting of neuro-oncology is reviewed in this article (Essig, 2012).

DWI: DWI is a form of MR imaging founded on measuring the haphazard Brownian motion of water molecules within a voxel of tissue. The association between histology and diffusion is intricate, though commonly densely cellular tissues or those with cellular swelling exhibit lower diffusion coefficients, and thus diffusion are particularly useful in tumor characterization and cerebral ischemia. Generally, many misperception occurs in the way the clinicians and radiologists mention to diffusion restriction, in which the two groups frequently don't understand each other. The main issue is that the phrase "diffusion weighted imaging" is used to signify a number of dissimilar things (Low and Gurney, 2007), like a) isotropic diffusion map (DWI), b) sequence which results in the production of DWI, b=0 and ADC maps, c) a broad term to cover all diffusion techniques counting diffusion tensor imaging.

Moreover, misperception occurs in calling abnormal restricted diffusion. This largely stems from the initial popularization of DWI in stroke, which presented infarcted tissue as high signal on isotropic maps and described it merely as "restricted diffusion. Regrettably, this short-hand is attractive and extensive rather than using the more precise but clumsier "diffusion demonstrates greater restriction than one would expect for this tissue". To make matters worse many are not aware with the idea of T2 shine-through, another cause of high signal on DWI (Rostamzadeh, 2014). A harmless and more precise way of referring to diffusion restriction is to recall that we are referring to actual ADC values, and to use terminology like "the region demonstrates abnormally low ADC values (abnormal diffusion restriction)" or even "high signal on isotropic images (DWI) is established to represent irregular

limited diffusion on ADC maps". The physical perspective, as opposed to free diffusion of water kept inside a container, diffusion of water inside a voxel of brain tissue, for instance, is hindered chiefly by cell membrane boundaries, and thus represents the collective water diffusion in a number of compartments include: a) diffusion within the intracellular fluid (such as within the cytoplasm generally and within organelles); b) diffusion within extracellular fluid (such as interstitial fluid, intravascular, lymphatic, and various biological cavities e.g. ventricles of the brain); and c) diffusion between intra and extracellular compartments. The contribution of each one of these will depend on the tissue and pathology. For instance, in severe cerebral infarction it is believed that the reduction in ADC values is the result of a combination of water moving into the intracellular compartment (where its diffusion is obstructed by organelles than it is in the extracellular space) and the resultant cellular swelling narrowing the extracellular space. Similar mechanisms result in low ADC values in highly cellular tumors (e.g. small round blue cell tumors (e.g. lymphoma/PNET) and high grade gliomas (GBM)). Clinically, DWI has a basic and critical role in the following clinical situations such as a) early identification and differentiation between of different stages of stroke; b) differentiation of epidermoid cyst from arachnoid cyst; c) differentiation of abscess from necrotic tumors; d) differentiation of herpes encephalitis from diffuse temporal gliomas; e) assessment of the extent of diffuse axonal injury; f) grading of gliomas and meningioma; and g) assessment of active demyelination. Theoretically, the gradient coil used to produce the diffusion necessity not be a separate gradient or gradients from those used for spatial encoding. The degree of diffusion weighting is reliant chiefly on the area under the diffusion gradients and on the interval between the gradients. Other aspects comprise the effect of the spatial localization gradients and the size of the voxels comprise of: stationary water molecule - unaffected by the diffusion gradients and hence retain their signal, and moving water molecule - acquire phase info by the first gradient but are not rephased by the second, hence losing their signal (Demaerel, 1999).

PWI: Brain tumors can induce angiogenesis or the formation of new blood vessels. Hypoxia, which occurs as a tumor outgrows its blood supply, can produce angiogenic cytokines; these cytokines are responsible for angiogenesis. Tumor vessels that are produced in this manner are histologically abnormal and more permeable than normal. They are also disorganized and tortuous. These vascular abnormalities and altered flow dynamics lead to changes in blood volume and flow, which are exploited in MR perfusion imaging (Coutts, 2003). The most common perfusion technique is T2* dynamic susceptibility imaging. The CBV is estimated from the area encompassed by the curve, which is inverted in this case, since there is signal loss. The CBV is normalized to uninvolved portions of the brain. In cases in which an arterial input function is not determined, only a relative CBV (rCBV) can be calculated. Dynamic vulnerability perfusion imaging is founded on the premise that contrast material remains within the intravascular compartment. This corrective method still leads to underestimation of the rCBV. Another method, sloping baseline, leads to artifactually high rCBV. Using T1-weighted dynamic perfusion imaging can eliminate the problem with the breakdown of the BBB and permeability. MR perfusion can help classify and localize developed grade components of tumors in guiding stereotactic biopsy and can also provide a noninvasive estimate of tumor grade. Since the enhancing or even the T2 borders of gliomas do not represent the true margins of the tumor, MR perfusion can be more sensitive in defining the true extent of gliomas than can anatomic MR imaging. Better delineation of tumor borders can help in radiation and surgical planning (Rostamzadeh, 2014). MR perfusion imaging will perhaps have a role in better defining tumor margins for radiation and surgical preparation (Saberi, 2016). The size of rCBV is more valuable in assessing response to radiotherapy in patients treated with stereotactic radiosurgery (SRS). The vascularity of metastases can decrease within a few weeks of treatment; however, the volume of enhancement might not change for several months (Lansberg, 1999).

MRS: Proton MRS provides biochemical and metabolic information about tumors and normal brain. The info obtained from 1H-MRS is exclusive and independent of that obtained from other MRI techniques. Tzika revealed that there is no correlation between the metabolic profile of tumors and other imaging parameters, such as enhancement, diffusion, and rCBV. Spectroscopy can be done in single- or multivoxel (MRS imaging) forms. The 2 most frequently used approaches for volume selection/excitation are stimulated echo acquisition mode (STEAM) and point-resolved spectroscopy sequence (PRESS). Generally, shorter echo times are better achieved with STEAM; however, it is more sensitive to motion. In theory, for the same total echo time, the signal of PRESS is twice as great as that of STEAM; PRESS is also less sensitive to motion. With improving software, PRESS seems to be the most frequently used technique of volume selection in clinical practice at present time. The benefit of single-voxel 1H-MRS is its short acquisition time (approximately 5 minutes). The disadvantage is that it lacks spatial resolution and cannot be used to better define the true extent of a glioma. Histologically, gliomas are heterogeneous, and, therefore, single-voxel spectroscopy cannot be used to map regional metabolic variation. These are the choline (Cho)-containing compounds, creatine (Cr), N-acetylaspartate (NAA), lactate, and lipid. The choline peak reflects cell membrane turnover. Creatine is a good surrogate for energy synthesis, and NAA is a marker that is exclusive to neuronal cells. Lactate results from anaerobic metabolism and is detected in necrotic tumors and infarcted tissue.

Cellular and myelin breakdown products result in prominent lipid peaks. In tumors, choline-containing compounds are increased, and NAA is reduced comparative to uninvolved or normal brain tissue. This pattern of metabolic change is the spectroscopic mark of brain cancers. Although this is an attractive concept, there are no studies to show benefits, changes in failure patterns, or improved survival. MRS is utilized more and more by different groups in assessing response to therapy in patients with primary brain tumors or metastases. In the perienhancing region, T2 prolongation is partially because of cancer infiltration (nonenhancing tumor) in patients with high-grade gliomas. Whereas in the case of metastases, the hyperintensity surrounding the region of enhancement is due to vasogenic edema or nonspecific treatment effects rather than infiltrating tumor. Therefore, elevated levels of choline and/ or rCBV surrounding a peripherally enhancing mass reflect tumor infiltration in a high-grade glioma. This limits the utility of MRS in differentiating residual/recurrent tumor from radiation necrosis, as is the case with MR perfusion. This is chiefly vital for early detection of management fall backs so that an ineffective treatment can be modified prior to a important development of disease (Barberi, 2000).

DTI: Although other MRI techniques are able to directly visualize the exact location of a functional area of the brain adjacent to a brain tumor, there is a limitation in that the technique can depict activation only in the cortical gray matter. Therefore, the information provided to the operating neurosurgeon is limited to the cortex. There are 2 main reasons why preoperative identification of white matter tracts is important. This task becomes even more difficult with the inevitable presence of mass effect and infiltration of normal structures by tumor. Consequently, the neurosurgeon may assume that the majority of the tumor to be resected is anterior to the corticospinal tract, only to discover during the operation that in reality, the corticospinal tract is posterior to the tumor and that the initial approach taken has been incorrect. The elements of the tensor are used to yield a mean diffusivity map (D) and the fractional anisotropy (FA). *D* is an indicator of free water fraction. *FA* is used to measure the fraction of the total magnitude of *D* that is anisotropic and has a value of 0 for isotropic diffusion ($\lambda_1=\lambda_2=\lambda_3$) and 1 for complete anisotropic diffusion ($\lambda_1 >0$; $\lambda_2=\lambda_3=0$). Therefore, it describes deviation from isotropic diffusion. Previous studies have shown that neoplasms and surrounding edematous brain have an increase of free water fraction (high *D* value) and loss of structural organization (reduced *FA* value). A number of recent developments have led to a new application of DWI termed diffusion tractography. This application uses diffusion tensor data to identify specific white matter tracts as opposed to white matter tracts in general. The aptitude to precisely outline specific tracts traversing the corona radiata and other nebulous white matter structures has already had an impact on the treatment of brain lesions. A number of recent publications have shown remarkable images of specific white matter tracts in normal subjects using diffusion tractography. However, this technology has just made its appearance and will no doubt expand even further (Haller, 2008).

2. CONCLUSION

Advanced MR imaging techniques can provide additional diagnostic indices beyond anatomic information that is typically generated with conventional MRI. The integration of advanced imaging techniques (such as DWI, PWI, MRS, and DTI) will offer increasingly detailed information about pathologic processes (Moser, 2009). While the utility of MRS in diagnosis and evaluation of treatment response of brain tumors (Fatehi, 2016). The neuroradiologist now has the tools needed to exploit a body of imaging information, including the likely histology of a lesion, cellularity, capillary density, and metabolic profiles-information that is essential to understanding tumor characteristics and to developing appropriate differential diagnoses. Studies revealed MRS has not been widely accepted as a routine clinical tool. Finally, carefully designed, multicenter trials obeying standards of evidence-based medicine have not yet been finished, and as a result MRS is merely relatively occasionally used for tumor evaluation outside of major academic medical centers. Advanced MR imaging techniques may also provide prognostic information and may be used to guide therapy early on in the patient's treatment, effectively improving outcomes and minimizing side effects, both in the short and long term (Fatehi, 2016). Furthermore, it is hoped that such thorough data will assist in the advance of novel managements and will improve our understanding of the mechanism underlying neurological disorders.

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