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Overview of Neuroradiological MRI

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Abstract. Several new techniques in MRI can detect and further analyze different diseases of the brain and spinal cord, these methods include diffusion and perfusion weighted imaging, magnetic resonance spectroscopy, functional MRI(fMRI), 3D MRI, and new sequences like fast spin echo, fluid attenuated inversion recovery, magnetization transfer imaging and fast gradient echo imaging. Until recently any information on the actual function of the brain has been restricted to that deduced from conventional MRI sequences like T1 weighted, T2 weighted and proton density weighted sequences, as most imaging MRI methods have been limited to providing only the pathological lesions related to the diseases irrespective of the time factor from the onset of the symptoms. In the past several years magnetic resonance imaging has become a major part of many neuroradiological practices. Tremendous advances in magnetic resonance imaging have resulted in dramatic improvement in both image resolution and imaging times. During this decade, an interest shifts towards the analysis of brain function or dysfunction, the focus on the brain's electrical activity has resurged. Functional evaluation techniques like fMRI, diffusion and perfusion weighted imaging, and EEG combined with 3D MRI have led to much shorter examination and analysis times, leading to further clinical utility. The use of these new MRI techniques have differed in the pediatric and adult patient groups. Use of 3D MRI along with various segmentation techniques and multimodality fusion have made possible the accurate volume estimation of pathological lesions, their 3D representations and increased overall diagnostic utility of MRI respectively. The advent of such methods for evaluating actual disease and functional activity of the brain has resulted in new clinical applications for the previous MR imaging methods and the arrival of new sophisticated imaging modalities.

1. Introduction

With the induction of magnetic resonance imaging (MRI) and computed tomography (CT) in the last two decades, simple ands fast examination methods became available which has led to a separation of neuroradiology from its parent fields. Further development of MRI with methods that allow to measure brain perfusion and visualize brain function has led this diagnostic modality back to its origin, neurology: adequate evaluation of MRI is possible in the context of all neurosciences (1). With advent of open magnets, which require close cooperation between the neuroradiologist and the neurosurgeon it is now possible to perform interventional neuroradiology with endovascular procedures of the brain. Using high resolution MRI and fMRI along with other imaging modalities like positron emission tomography (PET) and single photon emission computed tomography (SPECT) in psychiatry, it is now possible to carefully reassess the our sociological understanding to mental illnesses (2). Diffusion MR imaging serves to detect early stroke and perfusion imaging has a clinical impact in the assessment of brain tumors and cerebral ischemia (3). Fast spin echo imaging promises rapid MR imaging of the brain leading to better resolution (4) especially in small pathological lesions of brain. Magnetization transfer imaging has helped detect changes in the structural status of brain parenchyma that may not be visible with standard MRI techniques (5) in diseases like multiple sclerosis and other white matter diseases. Several segmentation techniques now help in the quantitative analysis of brain lesions and reliable three dimensional imaging (6) in diseases like multiple sclerosis, dementia, infarctions and brain tumors. Fusion of data obtained from different imaging modalities (7) like CT, MRI, SPECT and PET have enhanced the accuracy of differential diagnosis of different brain lesions. MR spectroscopy coupled with MR imaging techniques allows for the correlation of anatomic and physiologic changes with changes in the metabolic and biochemical processes occurring within a pathological brain tissue (8). This review shall discuss different MRI techniques in aiding a complete pathological and functional analysis of brain lesions in different neurological and neurosurgical diseases.

2. New MRI techniques

2.1 Diffusion MR imaging

For the first time, now it is possible to noninvasively measure and depict molecular diffusion coefficients in vivo with MR imaging. Studying molecular displacements over distances comparable to cell dimensions has provided information abut the geometry and spatial organization of the tissue compartments and about water exchange between these compartments in normal and diseased states.

Diffusion-weighted images are obtained by incorporating strong magnetic field gradient pulses into an imaging pulse sequence. In a diffusion-weighted image, structures with fast diffusion are dark because they are subject to greater signal attenuation, whereas structures with slow diffusion are bright. Quantitative diffusion images are generated from a series of diffusion-weighted images. The term apparent diffusion coefficient (ADC) is used to quantitatively describe the results of diffusion imaging in vivo. This can be used in the early diagnosis of stroke, assessment of white matter diseases and monitoring of tissue temperature changes during hyperthermia or laser surgery. principal headings.

In acute ischemia, ADC decrease significantly within minutes, and this decrease develops progressively within the first hour. In subacute ischemia the ADC in white matter increases to about two- or threefold above its normal value. The increase is due to the presence of vasogenic edema, in which bulk water motion occurs in the extracellular space. In chronic ischemia low diffusion has been seen on diffusion images. Thus diffusion imaging offers the unique opportunity of noninvasively study ischemia during its various stages. Diffusion imaging may also help detect encephalomalacic cysts.

2.2 Perfusion MR imaging

By introducing a tracer into the circulation and monitoring its concentration in a tissue over time using MRI, one can determine the rate of delivery of the tracer and hence the blood flow to this tissue. In clinical imaging. Gadolinium-DTPA has been used as a tracer.

When the Gadolinium-DTPA reaches the brain capillaries it induces a difference in magnetic susceptibility between the blood compartment and the brain tissue, where the contrast agent dose not penetrate because of the blood brain barrier. Diffusion of water through the internal gradients produce a low signal attenuation. Ultrafast imaging technique such as echo planar imaging (EPI) can monitor the first passage of contrast agents through the brain tissue within a few seconds of time. Thereafter the quantification of blood flow is performed, a procedure not so easy.

Perfusion imaging has widespread applications in tissue characterization, treatment monitoring in brain tumors and function sudies. It has been used to differentiate active recurrent brain tumors from fibrous tissue occurring secondary to operation or radiotherapy. Also its use has been important in evaluating infarctions and ischemic conditions. Perfusion weighted imaging provides an inexpensive, safe, reliable, and accurate technique in evaluating blood flow measurements in brain compared to PET.

2.3 Functional MR imaging (fMRI)

The first attempt to investigate brain activity was made in 1991 (9). Studies have been performed at 1.5 Tesla MR units using EPI and conventional fast gradient echo images. The most common approach has been the Blood Oxygen Level Dependent contrast technique (10). Using the cooperation of the patient, who is told to perform certain tasks, different brain centers can be activated.

Initial fMRI studies have demonstrated activation in the primary cortices like the visual, sensorimotor and auditory cortices. MR signal changes in these cortices have been correlated with the rate of stimulation. FMRI detects activation during higher order cognitive functions such as language tasks, motor learning, motor ideation, or visual mental imagery (11).

Functional MRI has been used to study certain clinical problems like presurgical mapping, imaging of the epileptic foci, monitoring recovery after stroke or head trauma and following treatments using neuropharmaceutical agents. In addition to being a tool to study anatomy of the brain, it is becoming a powerful functional tool to understand, detect and manage functional disorders of the brain (12).

2.4 Magnetic resonance spectroscopy (MRS)

MR imaging and MR spectroscopy are basically one and the same technique, differing only in the manner in which the data are processed. In MR imaging the signal obtained in the time domain is used to generate an image, whereas in MR spectroscopy the Fourier transform of MR signal in the time domain is used to generate a frequency domain spectrum of components that make up the image (13).

Two important factors in in vivo MRS are the volume localization technique used and how the signal measurement is affected by the type of localization procedure employed. At present there are two types of single volume localization techniques used in clinical MRS and they are the stimulated echo acquisition mode (STEAM) and point resolved spectroscopy (PRESS) techniques.

MRS is used in the clinical field at present in differentiating brain tumors from brain infarctions or inflammatory white matter diseases. Also it is used in the better understanding of the metabolite type produced in infarctions, ischemia, and tumors. The potential clinical applications today are the differentiation of cancerous from non-cancerous tissue, infarcted from the normal tissue and necrosis from recurrent tumor.

2.5 MR segmentation techniques

Segmentation is the process of assigning labels to pixels in 2D images or voxels in 3D images. The effect is that the image is split up into segments also called as regions or areas. In medical imaging this is essential for quantification of outlined structures and for 3D visualization of relevant image data (6).

The segmentation techniques can be classified into manual, semiautomatic and automatic techniques. Manual technique is too tedious to be used in clinical trials. Automatic segmentation techniques suffer from the inaccuracies created by the inpriori knowlegde fed into the technique. Semiautomatic segmentation is the best of all because of its ease, fastness and manual intervention.

For clinical purposes segmentation techniques using MRI has been widely used in phase three trials in multiple sclerosis, and in monitoring brain infarctions, brain tumors, dementia and brain atrophy. Reliable 3D images constructed from the segmented images helps understand the relation between the lesions and surrounding normal brain structures.

2.6 Three dimensional MRI (3D MRI) and multimodal image fusion

Three dimensional imaging is now widely available and used often to aid in the comprehension and application of volumetric data to diagnosis, planning and therapy. Models of the image data can be visualized by volume or contour surface rendering and can yield quantitative information (14).

3D presentation of the bone and skin surface of the skull serves to orient the viewer , while planar reformations and/or transparent projections can be applied for the assessment of the brain structures of interest. Overlaid 3D MRI image-guided neuronavigation techniques that allow navigation during operative procedures have demonstrated their usefulness (15). Combined assessment of three dimensional anatomical and functional images (SPECT, PET, MRI and CT) is useful to determine the extent of lesions in the brain (16).

Analysis, visualization, method characteristic image processing and image synthesis is needed not only for the interpretation of the images but also for performing effective consultations with clinical colleagues and computer supported therapy planning and control strategies in radiological and clinical practice (17).

2.7 Fast spin echo (FSE) imaging and other new MR sequences

FSE imaging is a modified rapid-acquisition relaxation–enhanced technique that affords rapid MR imaging while retaining true spin-echo contrast features. By manipulating the echo train length, echo spacing and order of phase encoding, images may be obtained many times faster than with conventional spin echo images.

Fast fluid attenuated inversion recovery (fast FLAIR) is being increasingly used in detecting subarachnoidal haemorrhage in addition to detecting brain parenchymal lesions situated near the cerebrospinal fluid spaces. Magnetization transfer images are being increasingly used to detect subclinical lesions in the white matter which are not detected by conventional MRI (5)

The use of these new techniques are mainly focussed now in diseases like multiple sclerosis, AIDS and epilepsy. The use of FSE has reduced the imaging times considerably, an advantage to the sick patient.

3. MR imaging in specific diseases

3.1 Epilepsy

The development of MR imaging with its outstanding sensitivity and specificity in identifying structural and pathological abnormalities has made the neuroradiological contributions in the presurgical work-up of patients with drug resistant epilepsy of extreme importance (18) . Multiplanar high resolution T1- and T2-weighted FSE images, fast gradient echo or hybrid images, FLAIR, magnetization transfer, MR angiography, MR perfusion, MR diffusion weighted imaging, fMRI and 3D acquisition images for morphological details and coverage of the entire brain has made MRI invaluable in epilepsy. The various disease detected are mesial temporal sclerosis, focal migration disorders, dysplastic lesions and low-grade tumors, phakomatosis, and vascular anomalies. MRI is being used for placing depth electrodes. Never before epilepsy could be diagnosed so well as now.

3.2 Human immunodeficiency virus type 1 (HIV-1)

Advances in MR imaging techniques and MR spectroscopy provide noninvasive diagnostic approaches to this disease. Cerebral inflammation appear as high intensity lesions on T2-weighted images and lactate, often present in macrophages associated with inflammatory lesions can be visible on spectroscopy. Diffusion MR imaging shows the physiologic changes associated with disease states. The typical focal inflammatory lesions are caused by toxoplasmosis, lymphoma, cryptococcoma, tuberculoma, sypilitic gumma, bacterial abscesses, cytomegalic virus infections and progressive multifocal encephalopathy. Both MRS and diffusion weighted imaging can be used to monitor these disease states (19).

3.2 Pediatric diseases

Diffusion imaging holds great promise for the evaluation of hypoxic-ischemic injuries related to perinatal birth injury (20). It can detect early changes as early as 1 hour after onset of the symptoms. A primary examination in hydrocephalus patients is a detailed MRI and cerebrospinal flow studies using phase contrast MRI. All anomalies of the brain optic pathways and spinal cord can be diagnosed using MRI.

4. Trends in MR imaging

A current trend in clinical MR imaging has been to move towards more open magnet designs. Open MR systems have the advantage of cost, ease of use, and niche applications like trauma and interventional . Open systems are also more accomodating to the claustrophobic and obese patients. Considerable progress has been made in MR imaging guided interventional and intraoperative MR imaging (21). Functional MR imaging will offer images of the entire brain in real time, and at a modest cost to the neurologists, psychologists and psychiatrists. Diffusion MR imaging is being actively used in early stroke diagnosis.

MR spectroscopy is becoming a routine for several clinical assessments. Spectroscopy with other nuclei like carbon-13, nitrogen-14, fluorine-19 etc. present major challenges associated with low natural abundance. Overall, MRI with its versatility has been able to meet every challenge encountered in the field of neuroradiology.

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