Asian Forum l: Diffusion MRI

SY13-1

Diffusion Physics for Clinical MRI

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During the past decade, there has been great research development in the area of contrast mechanisms of pathological tissues. The simplified version of consensus is that the ADC (apparent diffusion coefficient) change in the pathological tissues is caused mainly by "restricted diffusion", rather than the change in the diffusion coefficient itself. In this talk, the basic theory of water diffusion in MRI is explained first, then we will move on to restricted diffusion, and interpretation of clinical images based on this theory of restricted diffusion.

Assuming free diffusion of water, MR signal decays exponentially with so called "b-value", which is determined by the gradient waveform. In this case, the water molecules will be spread out with time following normal distribution, or Gaussian distribution. However, in many cases in the biological tissues, water molecules cannot move freely, blocked by the cell membrane. This process is called restricted diffusion, and in MR imaging, it looks as if the diffusion coefficient became smaller. Since the distribution shape deviates from the Gaussian distribution, this is also called "non-Gaussian diffusion". In recent years, it has been shown that diffusion change in pathological tissues is caused mainly by this restricted diffusion. For example, the reason of decreased ADC in the tumors is due to existence of small tumor cells (1), and ADC changes in the ischemic brain diseases is caused by changes in the cell shapes called "beading" (2).

While the simple models can be explained well by these theoretical framework, actual tumor tissues in the clinical setups is much more complex. One way of interpret diffusion changes in complex tissue like malignant tumors is to consider that many different components exist within each voxel, each having different ADC values. It is not possible to actually measure the distribution of ADC values within each voxel, but when combined with appropriate modeling, it is possible to relate the distribution with the MRI signal decay. The distribution functions used for this model include truncated gaussian distribution and the gamma distribution. The main advantage of this approach is that interpretation of the result is relatively straight forward, since ADC of each component can be related to cell size, amount of free water, or perfusion etc (3).

For two point (low and high b-values) diffusion data, the information contained within the data can be summarized to the signal intensity with low b-value, and the ADC. This information can be visualized as a scatter plot with two axes, low-b and high-b image intensities. While this approach is informative, it is not suitable for everyday diagnostic process. For that purpose, a kind of subtraction technique was proposed called WDS (weighted diffusion subtraction) (4).

References

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Keywords : Diffusion, Restricted Diffusion, Non-Gaussian

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Recent advances in Psychoradiology

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Schizophrenia is one of the most disabling mental disorders. The question of whether there are significant changes in brain anatomy and function at illness onset and over the early course of schizophrenia is a crucial issue with broad implications for prognosis, patient care, and models of illness pathophysiology. However, the major obstacle to its effective diagnosis and treatment has been our poor understanding of the underlying neuropsychopathology and, particularly the lack of biomarkers for diagnosis, prognosis and risk prediction.

Advanced psychoradiological techniques allows noninvasive investigation of brain structure and function in vivo and is increasingly playing an important role in the study of schizophrenia. Technically, the psychoradiological development such as multi-modal MR imaging has allowed quantification of brain tissue at the structural, functional and molecular levels. Using high-field MR imaging (i.e., 3.0 Tesla MR), the structural and functional correlates of a number of mental disorders have been identified. Taking advantage of novel approaches and techniques for the acquisition and analysis of MR imaging data, several clinical studies have revealed imaging biomarkers in populations that are at high risk for developing schizophrenia and diagnostic biomarkers as well as underlying pathological mechanisms. The results not only support the current focuses on biological investigation of mental disorders advocated by the U.S. National Institute of Mental Health's Research Domain Criteria (RDoC) but also provide the first step toward the translational use of psycho radiological discoveries for diagnosis, prediction of treatment response, and monitoring of therapeutic effects.

For example, multi-modal MR imaging studies of treatment-naive first-episode schizophrenia patients gave us the opportunity to examine the fundamental psychopathologies caused by the disease, irrespective of the medications. Both short-term and long-term effects of antipsychotic treatment on a patient's brain can be observed based on the connectivity analysis of the resting state fMRI data. However, the elevated prefrontal brain connectivity in schizophrenia patients appears to be a robust biomarker associated with the clinical severity of the disorder, in contrast to the results from other studies. Available evidence further indicates that 1) regionally dissociated functional and structural brain changes are already present at the onset of schizophrenia and can predict clinical outcome; 2) starting antipsychotic treatment leads to acute changes in brain anatomy and function; and 3) alterations seen in first-episode patients are different from those observed in chronic patients, and there is preliminary evidence for progressive brain changes in longitudinal studies. While current longitudinal studies of first-episode schizophrenia patients are far from characterizing changes over the full course of the disorder, these studies are providing a new understanding of dynamic changes in neural networks related to acute episodes of illness and illness progression effects in a dynamic manner. In time, a systematic understanding of these issues may provide objective methods for improved differential diagnosis based on biologically defined subgroups of patients with psychotic disorders.

In summary, psychoradiology current research research allows us to obtain various objective "radiological signs" (i.e., imaging biomarkers) of schizophrenia, which could be used in a clinical context similar to the current methods that neuroradiologists use to manage neurological diseases. These results may represent an initial step toward the use of psychoradiology findings to inform early clinical diagnosis as well as effective treatment for patients with schizophrenia.

Keywords : Psychoradiology, Schizophrenia

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Clinical application of diffusion-weighted imaging in breast

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Breast MR imaging is the most sensitive modality for breast cancer detection and has gained clinical acceptance for a range of clinical indications, including supplemental screening for women at high risk of developing breast cancer and pre-operative evaluation of extent of newly diagnosed breast cancer. However, modest specificity, its long scan time, high cost, and the use of contrast limit its clinical use and acceptance across institutions. Emerging evidence suggests that diffusion-weighted imaging (DWI) can address some of the limitations of conventional breast MR imaging by providing complementary information for lesion assessment, such as cell density, membrane integrity, and microstructure. Technical advantages of DWI include a short acquisition time, wide availability on most commercial scanners, and no need for administration of any contrast agent.

Lesion diagnosis and characterization

The most widely explored clinical application of DWI for breast imaging is a supplemental diagnostic tool to dynamic contrast-enhanced MRI (DCE-MRI) in differentiating between malignant and benign lesions to reduce false positives and unnecessary biopsies. Numerous groups have demonstrated significantly lower ADC values in malignant versus benign lesions. ADC measures are complementary to DCE-MRI parameters for classifying suspicious breast lesions and can increase the accuracy of conventional breast MRI assessment. DWI reflects tissue microstructure, and emerging evidence suggests that quantitative ADC assessment may provide accurate tumor characterization, both in terms of histologic composition and biological aggressiveness, which is essential for selecting appropriate treatment.

Monitoring and Predicting Treatment Response

Cytotoxic effects of chemotherapy including cell lysis, apoptosis, and necrosis cause alterations in cell membrane integrity and reduced tumor cellularity, resulting in a less restrictive environment for diffusing water molecules. Thus, increasing tumor ADC values may reflect cell death and favorable response to treatment. Such cytotoxic changes precede changes in tumor size or perfusion, suggesting DWI has potential to provide early indication of treatment efficacy. It has been demonstrated that treatment-induced changes in breast tumor ADC values can differentiate responders and nonresponders early in the course of treatment, after only the first cycle of chemotherapy.

Noncontrast MR Screening

There may also be a role for DWI as an alternative to DCE-MRI for breast cancer screening. This screening application is particularly timely given increasing breast density legislation raising awareness of the limitations of mammography in dense breasts. Moreover, there are growing health concerns related to the long-term use of gadolinium contrast agents used in DCE-MRI.

Conclusions

The technique is relatively easy to incorporate into clinical breast MR imaging protocols and provides complementary information to DCE-MRI examinations and may have value as an alternate MRI screening tool for detecting cancer without the need for any contrast agent. However, there are obstacles to routine clinical application of breast DWI related to technical challenges and the lack of standardization of imaging approaches across institutions.

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Imaging of Bone Metastases Using Whole Body MRI Including Whole Body Diffusion Weighted Images (DWI)

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In aging societies, metastatic tumor tends to be a common disease. For imaging the metastatic bone tumor, X-ray, CT, MRI, Bone scan, FDG-PET are used. No modality is versatile. Hence multimodalities are combined. It is well known that the advantage of MRI is good soft tissue and bone marrow contrast. Both sensitivity and specificity are excellent for diagnosing metastatic bone tumor. However, the disadvantage of MRI is narrow field of view and long examination time

To solve these problems, whole body MRI (WB-MRI) has been developing since the end of the 20th Century. In 2004, Takahara et al presented DWIBS (Diffusion Weighted Whole Body Imaging with Background Body Signal Suppression), which is similar to FDG-PET image. This was an epoch-making paper and since then, the adaption of DWI to the whole body images has been common. In this presentation, I am going to introduce the WB-MRI protocol in our department. Before explaining the protocol, we have to know the areas of predilection for metastatic bone tumor. The spine is the most important and frequent. The pelvic bone, proximal portion of the humerus, femur are the next common sites. WB-MRI should cover these areas absolutely. Below are the imaging parameters we are using:

Total spine sagittal T1WI and STIR images. These are the most important to detect spinal metastases. Imaging times are 2minutes 28 seconds. and 4 minutes 4 seconds, respectively. Body coronal T1WI. These images cover scapulohumerus, pelvis and proximal femur, which are also the common sites of metastases, next to the spine. Imaging time is about 1 minute 40 seconds. Axial diffusion weighted images from neck to bottom of pelvis are shown. B value is 0 and 1000 mm2/s. Total imaging time is about 13 minutes. Additionally, coronal reconstruction and radial MIP images of DWI, and coronal fused images with T1WI and DWI are obtained.

Metastatic bone tumors have been histologically classified into osteolytic, osteoblastic and mixed patterns, corresponding to their radiologic patterns. However, since MRI has been used as one of the diagnostic modalities, intertrabecular spreads that are invisible radiologically have become detectable. Radiologists should know that a finding of osteosclerotic change of metastatic lesions have two possibilities:

One is osteoblastic metastasis itself, and the other is the reactive ossification of chemotherapy. These two conditions are completely different. DWI can differentiate these two conditions. The former reveals as high intensity; the latter as decreased signal intensity. However it is difficult to differentiate these two conditions on conventional MR sequence only or CT.

We emphasize that WB-MRI including DWI is a reliable method for detecting bone metastases and also for exact evaluation in monitoring the chemotherapeutic effect.

Keywords : Bone metastases, Whole body MRI, DWIBS, Spine, Axial Skeleton

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Asian Forum 1: Diffusion MRI - DWI application for glioma prognosis prediction

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Diffusion weighted image (DWI) has been considered as a tumor cellularity index, and utilized in various ways in brain tumor research, especially in glioma. DWI usage in glioma research can be roughly divided into prediction of glioma grades, genetic subtype (ex: MGMT promoter methylation status or IDH gene mutation status), and prognosis. In this talk, previous researches that dealt with DWI as prognostic imaging biomarker will be briefly reviewed, and further application of DWI for glioma prognosis prediction will be discussed.

Keywords : Glioma, Prognosis, Diffusion weighted imaging, Imaging biomarker