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Review

Research progress of reduced field of view diffusion weighted imaging of magnetic resonance in medical diagnosis

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Abstract

Diffusion weighted imaging (DWI) of magnetic resonance has the advantages of radiation-free, high-contrast, multi-sequence, multi-angle imaging, and etc. It is an emerging functional MRI technology, which can be used to study diseases at the molecular level without the contrast agent injection. In the mid-1980s, DWI was first applied to the human body, and then rapidly developed to be applied to all body systems (1). Currently, single-shot planar echo imaging (SS-EPI) sequences are widely used in the clinical application of DWI; however, the image resolution is not good enough. Moreover, it is easy to produce magnetic sensitivity effect and magnetic resonance artifact, which leads to image artifacts, deformation and distortion, especially for minor lesions (2). Reduced field of view DWI (r-FOV DWI) adopts two-dimensional selectively excitation radio frequency technology to stimulate only a small range of interest areas, which reduces image folding and artifacts, and provides high-resolution images. This is especially important for examination of organs and parts with small size and fine structure, with significant changes in the magnetization rate near the anatomical parts or susceptible to involuntary physiological movements. In this paper, the principles of DWI of small field and its progress of applications in various organs are reviewed.

Key word: Diffusion-weighted imaging; Reduced FOV; Image quality; Diagnosis

Introduction

Diffusion-weighted imaging (DWI) is a functional MRI technology, which reflects the tissue microstructure by detecting the direction and extent of water molecule diffusion in the tissue (3). The dispersion degree is represented by the dispersion coefficient (DC), and the b value is the diffusion sensitivity coefficient in the unit of s / mm^2, reflecting the sensitivity degree of water molecule dispersion. The formula is $b=\gamma^2G^2\delta^2(\Delta-\delta/3)$, where the magnetic rotation ratio, diffusion sensitive gradient field intensity, duration of gradient field intensity and interval time of the two gradients are respectively expressed as "γ", "G", "δt" and "Δ". At present, for the evaluation of malignant or benign tumors, the most widely used DWI technique is single-shot echo-planar imaging DWI (SS-EPI DWI). However, SS-EPI DWI has limitations, such as the multiple phase encoding lines, long readout time and narrow bandwidth in the phase direction, which may easily lead to poor image resolution and image distortion. In order to overcome the shortcomings of conventional DWI and improve the spatial resolution, Kim (4) et al. first proposed the reduced field of view DWI (r-FOV DWI) theory in 2006 at the 14th international magnetic resonance conference, using 2 d space selective RF pulse (two - dimensional spatially selective radiofrequency pulses, 2 d RF) in the phase encoding direction to reduce the FOV, which can shorten the length of EPI echo chain and meanwhile 180° back pulse technology was used to excite water signals selectively, effectively restrain the vision outside signals and fat, which may be advantageous for eliminating chemical shift artifact and for detection of small lesions. (Figure 1)

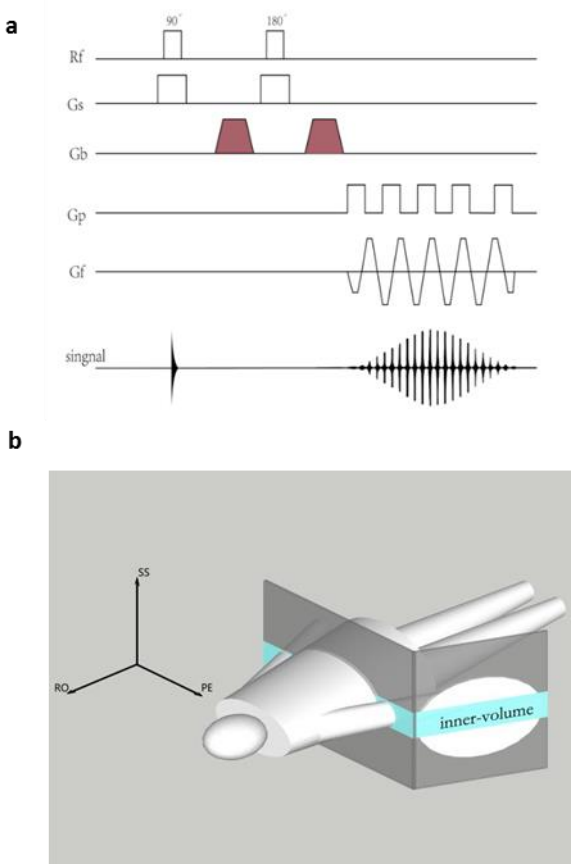

Figure 1. a) Schematic diagram of 2D echo-planar RF pulse; b) Schematic diagram of r -FOV DWI

1．Research progress of r -FOV DWI in the head and neck tumors

Malignant neck nodes and recurrence from post-therapeutic changes in the head and neck region may be discriminated by r-FOV DWI because of the apparent diffusion coefficient (ADC) (5). However, there are a large variety of tissue types present, such as fat, muscle, air, glandular tissue, and bone in the head and neck region. The variety can cause motion artifacts, susceptibility, and chemical shift effects, leading to low quality DWI scans (6). Research has shown that, compared to SS-EPI DWI, the scores of image distortion and lesion identification were both higher in r-FOV

DWI, and with a reduction ADC values in r-FOV DWI emerged for both lesion and muscle, which can improve the diagnostic accuracy for the study of specific tumoral areas (7). R-FOV DWI can significantly improve image quality, especially for small lesions. For example, when studying normal pituitary glands and pituitary macroadenomas, r-FOV DWI exhibits better image quality compared with SS-EPI DWI, however there was no significant difference in ADCs of macroadenomas between the two methods (8). Whereas, there have been some studies indicating a reduction in ADC values with r-FOV DWI (9, 10). In general, r FOV DWI can not only show more anatomical details, but also more accurately define the scope of tumor lesions.

2 . Research progress of r -FOV DWI in spinal cord

Conventional magnetic resonance imaging (MRI) is typically unaltered within the first hour following acute spinal cord infarction included T2w images which typically require 1–2 days to develop and the detection of acute myelopathy showed a low sensitivity when T2-weighted imaging was used alone (11, 12). Major functional disability may be caused by spinal cord damage. Diffusion tensor imaging methods may be used to detect alteration of the spinal cord structural integrity. However, the DTI-based diffusivity measures are sometimes not consistent with detection results of abnormalities (13-15). Diffusion-weighted imaging (DWI) with single-shot echo-planar imaging (EPI) can detect cytotoxic edema in acute spinal cord infarction. However, the accuracy and spatial resolution may be reduced due to some limitations, such as signal distortions caused by chemical shift, susceptibility differences, the small size of the spinal cord, partial volume effects, magnetic field inhomogeneities, as well as movement caused by breathing (16-18). A study has shown that r-FOV DWI not only can allow for acquisition of high-resolution images with reduced scan time but also a more detailed analysis of the spinal lesion. The detailed analysis may be critical to attribute the lesion to a particular vessel territory (16), as another study indicated r- FOV methods decreasing the readout duration needed for imaging (19). Recently, there was a novel 2D ss-DWSTEPI-r-FOV sequence developed for high-resolution UHB-r DWI of localized anatomic structures with significantly reduced distortion induced by nonlinear static field inhomogeneity which increases the contrast between white matter and gray matter and improves the resolution and SNR (17).

3 . Research progress of r -FOV DWI in thyroid

The incidence of thyroid cancer is the highest among malignant diseases of the endocrine system and is still rapidly increasing (20, 21). The clinical focus of thyroid nodules is to distinguish the benign from the malignant, and recent reports have shown that diffusion-weighted imaging (DWI) is valuable in differentiating malignant from benign thyroid nodules (22, 23). However, due to the superficial position of thyroid in the head and neck, the existence of a wide range of gas-tissue interface, as well as respiratory, swallowing, vascular pulsation

and other physiological movements, the image produces artifacts and distortions. To overcome this challenge, a study has demonstrated that the r-FOV DWI produces higher quality images and higher repeatability in ADC measurement. This study enrolled ten healthy human volunteers performed on a 3T magnetic resonance imaging study which included r-FOV and conventional full field of view DWI scans whose apparent diffusion coefficient (ADC) value of thyroid glands based on the regions of interest were calculated and image quality was evaluated (24). Intravoxel incoherent motion (IVIM) parameters derived from reduced diffusion-weighted imaging (DWI) has the ability to separate tissue diffusivity from microcapillary perfusion. Recent research has suggested that IVIM-DWI could be used to quantitatively detect malignant thyroid nodules. The IVIM parameters (D, pure diffusion; f, perfusion fraction; and D*, pseudo-diffusion) were measured. The D and f values in the malignant nodules (D = [0.72±0.14] $\times 10^3$ mm^2/s, [29.94±7.36] %) were significantly lower than those in the benign nodules (D = [1.23±0.35] $\times 10^3$ mm^2/s, [36.00±8.35] %) ($P<0.0001$, $P = 0.012$) and the D* values had no significant difference between the malignant and benign nodules (25, 26). Although literature about r-FOV DWI application especially for thyroid lesions is very limited, it has been shown that the image quality obtained from the reduced field DWI is better and the diagnostic efficiency is higher.

4 . Research progress of r -FOV DWI in pancreatic gland

Pancreatic cancer is expected to be the second most common cause of cancer death in the US by 2030, with about 55400 new diagnoses and 44330 deaths in 2017 according to the American cancer society (27, 28) and it is a highly lethal disease called the king of the tumor, with 5-year survival in patients as low as 6% in the US and to a natural tendency toward very early spread along the perineural pathways, resulting in a high early recurrence rate (29, 30). The patients with pancreatic cancer remain asymptomatic until the tumors reach advanced stages because the early symptoms are not specific (27) , so it is of great significance for patients with pancreatic cancer to have early diagnosis. It is known that DWI is up to now the only functional technique which measures the microscopic mobility of water molecules in the tissues without contrast injection. However, with the increase of magnetic field intensity, the susceptibility effects become more serious. The motion of the breathing and the vessel as well as the deep location in the abdomen makes the image quality obtained by conventional DWI in 3T of the pancreas near the gas very poor. There is a result showing that the resolution of r-FOV DWI image is obviously improved compared with the large FOV, and a significant lower ADC (31). According to the literature, intravoxel incoherent motion (IVIM) imaging is relatively a new technology first proposed by Le Bihan et al. in 1986. IVIM is a potential useful tool for differential diagnosis of benign and malignant LN in rectal cancer (32, 33). Not only the IVIM-derived parameters are reliable in differentiation among solid pancreatic lesions and normal pancreas but also useful for differentiating

between metastatic and non-metastatic lymph node stations in pancreatic ductal carcinoma (3, 34). To some extent, the ADC_{total} and *f* derived from IVIM parameters have diagnostic value in identifying PDAC and NPC, however only the *f* which is higher than ss-EPI IVIM-DWI can distinguish between the two in r FOV IVIM-DWI, and the difference has a statistically significant (35).

5. Shortage and envisage of researches of r -FOV DWI

There are still some problems in r-FOV DWI, for example, because of the small field of vision, lesions outside the field of vision are easy to be missed. So, it is necessary to localize lesions on the basis of conventional wide field sequence to cover all the tissues, meanwhile, reduced field DWI was combined to improve the detection rate of small lesions. Nowadays, the long scanning time of small field limits the wide application of this sequence in clinic. The number of excitation signals decrease as the field of view decreases, even at 3T magnetic resonance, the signal noise ratio will decrease. It is hoped that this problem can be solved in future studies. The number of r-FOV DWI cases studied in other parts of the body is small, and larger clinical trials are needed to prove its application prospect. At present, IVIM-DWI is widely used in many fields, and many literatures have shown that this technology has great potential to distinguish between benign and malignant diseases. However, the application of r-FOV IVIM-DWI is very few based on published articles, it could be another research direction in addition to distinguish different pathological types.

Declarations

1) ***Consent to publication***
We declare that all authors agreed to publish the manuscript at this journal based on the signed Copyright Transfer Agreement, and followed publication ethics.

2) ***Ethical approval and consent to participants***
Not applicable.

3) ***Disclosure of conflict of interests***
We declare that no conflict of interest exists.

4) ***Funding***
None

5) ***Availability of data and material***
We declare that the data supporting the results reported in the article are available in the published article.

6) ***Authors' Contributions***
Authors contributed to this paper with the design (RBX), literature search (XLL), drafting (XLL), revision (RBX and XLL), editing (XLL) and final approval (RBX).

7) ***Acknowledgement***
None

8) ***Authors' biography***
None

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