Comparison of Turbo Spin Echo and Echo Planar Imaging for intravoxel incoherent motion and diffusion tensor imaging of the kidney at 3 Tesla

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Received 5 April 2016; accepted 19 December 2016

Abstract

Echo Planar Imaging (EPI) is most commonly applied to acquire diffusion-weighted MR-images. EPI is able to capture an entire image in very short time, but is prone to distortions and artifacts. In diffusion-weighted EPI of the kidney severe distortions may occur due to intestinal gas. Turbo Spin Echo (TSE) is robust against distortions and artifacts, but needs more time to acquire an entire image compared to EPI. Therefore, TSE is more sensitive to motion during the readout. In this study we compare diffusion-weighted TSE and EPI of the human kidney with regard to intravoxel incoherent motion (IVIM) and diffusion tensor imaging (DTI). Images were acquired with b-values between 0 and 750 s/mm^2 with TSE and EPI. Distortions were observed with the EPI readout in all volunteers, while the TSE images were virtually distortion-free. Fractional anisotropy of the diffusion tensor was significantly lower for TSE than for EPI. All other parameters of DTI and IVIM were comparable for TSE and EPI. Especially the main diffusion directions yielded by TSE and EPI were similar. The results demonstrate that TSE is a

Vergleich von Turbo Spin Echo und Echoplanar Bildgebung für Intravoxel Incoherent Motion und Diffusionstensorbildgebung der Niere bei 3 Tesla

Zusammenfassung

Diffusionsgewichtete MR-Bilder werden in den meisten Fällen mit Hilfe von Echoplanar Bildgebung (EPI) aufgenommen. EPI ermöglicht die Aufnahme eines kompletten Bildes in sehr kurzer Zeit, ist dabei aber anfällig für Verzerrungen und Artefakte. Bei der diffusionsgewichteten Bildgebung der Niere mit EPI kann Gas im angrenzenden Darm zu starken Verzerrungen führen. Turbo Spin Echo (TSE) ist stabil gegen Verzerrungen und Artefakte, benötigt aber mehr Zeit als EPI, um ein komplettes Bild aufzunehmen. Darum ist TSE anfälliger für Bewegungen während der Aufnahme. In dieser Arbeit vergleichen wir diffusionsgewichtetes TSE und EPI der menschlichen Niere in Bezug auf Intravoxel Incoherent Motion (IVIM) und Diffusionstensorbildgebung (DTI). TSE- und EPI-Bilder wurden jeweils mit b-Werten zwischen 0 und 750 s/mm^2 aufgenommen. Die EPI-Bilder zeigten bei allen Probanden Verzerrungen, während die TSE-Bilder praktisch frei von Verzerrungen waren. Die fraktionelle Anisotropie des

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http://dx.doi.org/10.1016/j.zemedi.2016.12.001
www.elsevier.com/locate/zemedi

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worthwhile distortion-free alternative to EPI for diffusion-weighted imaging of the kidney at 3 Tesla.

Keywords: Echo Planar Imaging, Turbo Spin Echo, diffusion tensor imaging, intravoxel incoherent motion, kidney

Diffusionstensors war bei TSE signifikant niedriger als bei EPI. Alle anderen DTI und IVIM Parameter waren für TSE und EPI vergleichbar. Insbesondere die Hauptdiffusionsrichtungen der Diffusionstensoren waren bei TSE und EPI ähnlich. Die Ergebnisse zeigen, dass TSE im Vergleich zu EPI eine nützliche Alternative ohne Artefakte für die diffusionsgewichtete Bildgebung der Niere bei 3 Tesla ist.

Schlüsselwörter: Echoplanar Bildgebung, Turbo Spin Echo, Diffusionstensorbildgebung, Intravoxel Incoherent Motion, Niere

1 Introduction

Diffusion-weighted (DW) MR imaging is able to visualize microscopic features of tissue, such as cellular density [1], tissue anisotropy [2] or even perfusion [3,4]. Anisotropy and the main diffusion direction can be acquired via diffusion tensor imaging (DTI) [2]. DTI was initially developed for the head, but recently it found numerous applications outside the brain, namely in the kidney and other abdominal organs [5,6]. It was shown that DTI can be used to assess the renal function early after transplantation [7]. A different technique called intravoxel incoherent motion (IVIM) separates pure diffusion from perfusion or pseudo-diffusion [4]. With the help of IVIM it is possible to differentiate types of renal tumors [8] and to detect functional changes in stenotic kidneys [9]. Echo Planar Imaging (EPI) is most commonly used for the acquisition of DW images [10,11]. The main reason for using EPI with DW imaging is its high acquisition speed. With EPI it is possible to acquire a full image from a single excitation pulse and a fast sweep through k-space, thereby freezing all motion of the subject. The high acquisition speed of EPI comes at the cost of distortions and artifacts. Signal loss, chemical shift artifacts and distortion due to susceptibility interfaces between air and tissue may strongly degrade EPI image quality [12,13]. In particular, abdominal DW images can be affected by such distortions, especially regions close to the gas-filled bowel. Strong gradients are applied to create the DW contrast. These gradients may induce eddy currents that further compromise EPI image quality [11,14]. Apart from these artifacts which are related to the subject and the specific DW gradients, there are some inherent artifacts to the EPI method. So called N/2-ghosts and linear phase shift ghosts occur due to delays of the readout gradients [14]. Post processing is necessary to correct for these ghosts [15,16], which is a source of potential errors when the applied correction is inaccurate.

As an alternative to EPI a Turbo Spin Echo (TSE) readout can be used for DW imaging [17–19]. A TSE readout, also known as Fast Spin Echo (FSE), is very robust against distortions from chemical shift artifacts or magnetic field inhomogeneities. TSE is capable of acquiring an entire image free of ghosts using a single excitation only. However, because of the required refocusing rf-pulses, a TSE readout is slower than an EPI readout and consequently more susceptible to motion artifacts. Nevertheless, TSE has been used in various DW studies. For example, TSE yielded undistorted and artifact-free maps of the apparent diffusion coefficient (ADC) in the prostate [20]. Furthermore, necrotic retinoblastoma tissue could be distinguished from viable tumor tissue with DW TSE [21]. Jin et al. showed that IVIM analysis of the kidney is feasible with a TSE sequence at 1.5 Tesla [22] and TSE DTI of the brain was successfully performed by Sigmund et al. at 7 Tesla [23].

To our knowledge, no study assessed the feasibility of TSE for renal DTI and IVIM at 3 Tesla so far. In the present work we compare TSE and EPI for renal DTI and IVIM. The advantages and drawbacks of each acquisition technique are discussed.

2 Material and methods

2.1 Subjects

Seven healthy volunteers without known history of renal diseases were included in the study. All volunteers gave written informed consent prior to the MR examination. The age of the subject was between 21 and 28 years (mean ± standard deviation: 24.6 ± 2.6 years). The body mass index (weight in kilograms divided by height in meters squared) of the subjects ranged from 19.0 to 32.3 kg/m^2 (mean: 23.8 kg/m^2). The study was approved by the local ethics committee.

2.2 MRI examination

MRI was performed on a 3 T scanner with 80 mT/m maximum gradient strength (MAGNETOM Prisma, Siemens Healthcare, Erlangen, Germany). A T2-weighted half-Fourier acquisition single-shot Turbo Spin Echo sequence was used to acquire morphological images for planning of the diffusion-weighted acquisition. This morphological sequence used the following parameters: repetition time (TR) 1600 ms; echo