A New Short TE 3D Radial Sampling Sequence: SWIFT-LiTE

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Introduction: Ultrashort echo-time (UTE) imaging (1) and sweep imaging with Fourier transformation (SWIFT) (2) are techniques for imaging hard tissues with short T_2 relaxation times on the order of a few tens to hundreds of microseconds, due to their very short acquisition delays (in the range of 0.01-0.5 ms). Such short T_2 components are not easily detected with conventional imaging techniques (e.g., gradient echo sequences) since the shortest achievable TE is typically in the range of 1-2 ms. However, implementation of UTE and SWIFT on standard clinical MRI systems can be challenging due to unique sequence and hardware requirements. In some cases, achieving short TE < 1 ms (not ultrashort TE) is all that is required. This can be relatively easily accomplished with the new sequence introduced here, which is called SWIFT-LiTE (SWIFT with Limited TE). SWIFT-LiTE is basically a 3D radial sampling sequence and can effectively cover the short TE range of > ~0.5 ms. In this sequence, data are acquired right after excitation, not during excitation as in SWIFT. However, the readout gradient is applied during excitation as in SWIFT, which is different from conventional 3D radial sampling sequences used for human studies, including 3D UTE. Here, SWIFT-LiTE is demonstrated in human brain imaging.

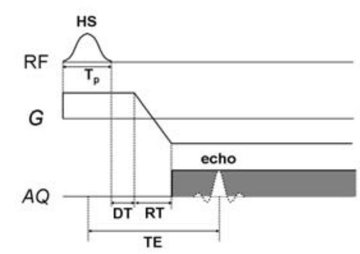

Fig.1 Sequence diagram of SWIFT-LiTE

Methods: The basic sequence diagram of SWIFT-LiTE is shown in Fig.1. A phase-modulated hyperbolic secant (HS) pulse (3) is used to excite a low tip angle in the presence of a gradient which defines a spoke of this 3D radial acquisition. After excitation, this (slab-selective) gradient is inverted to create an echo for readout . Acquisition begins as soon as the gradient fully ramps up to the readout plateau. Radial samplings are arranged with isotropic angular spacing to cover a sphere in k-space, having a spiral shape of view orders (4). Referring to our previous work (5), when the HS pulse is used for slab-selective excitation and readout is performed in the same direction with a gradient of opposite polarity to the slab-selective gradient, a pseudo-echo is produced in which each isochromat has its own unique local rephasing time during acquisition. When the magnitude of the readout gradient is the same as that of the slab-selective gradient, the pseudo-echo is theoretically expected to have the same duration as the HS pulse, which is much shorter than the acquisition time itself. As a result, the echoes used to fill k-space in radial directions (i.e., the spokes) are asymmetric in terms of the origin of k-space. To reduce the potential for truncation artifacts in the reconstructed image, a short delay time (DT) is introduced between HS excitation and the gradient ramp.

Experiments: For initial testing and evaluation of SWIFT-LiTE, human brain imaging was performed using a 90 cm 4T magnet (OMT, Oxfordshire, UK) interfaced to an imaging spectrometer (model Unity Inova, Varian, Palo Alto, CA). RF transmission and reception were performed with a TEM head resonator. Imaging of normal human volunteers (n=4) was performed according to the procedure approved by the Institutional Review Board. The HS pulse had the following parameters: pulse length (T_p) = 0.25 ms, pulse bandwidth (= acquisition bandwidth) = 80 kHz, and flip angle = ~4°. The ramp time (RT) was set to be 0.2 ms. DT = 0.1 ms. TR/TE = 10 ms/0.65 ms. Acquisition time = 3.96 ms. Scan time = ~8 min. The spherical field-of-view (= slab width) = 45 cm. Matrix size = 450×450×450. 8 spirals of view orders were interleaved to generate 48,000 projections with NEX = 1. After using correlation, as done in SWIFT (2), to remove the non-linear phase in each spoke (i.e., the known non-linear phase produced by the HS pulse), images were reconstructed using gridding and Fourier transformation,.

Results: The new 3D radial short TE pulse sequence was successfully implemented and tested with standard imaging equipment. Examples of SWIFT-LiTE images of human brain (proton density weighted) are shown in Fig.2. The SWIFT-LiTE sequence produced high quality brain images without correcting for variable gradient switching delays, eddy currents, or other instrumental imperfections. The shading in the orbital-frontal area is due to B_1 inhomogeneity of the coil.

Discussion and Conclusions: Appealing features of SWIFT-LiTE include its ease of implementation (e.g., without hardware modification) and its apparent tolerance to experimental imperfections (e.g., gradient delays and eddy currents). Although a HS pulse was used for excitation here, it is possible to use other conventional pulses like a sinc pulse. However, the HS pulse has the advantages of delivering a flat and broad excitation profile with reduced peak power for a given bandwidth, and the non-linear phase variation it produces in each spoke helps to prevent unwanted stimulated and spin echoes. Although SWIFT-LiTE can attain short TE > ~0.5 ms, not ultrashort TE, it is expected to have utility for musculoskeletal imaging because hard tissues such as cortical one, tendon, menisci, and ligaments etc, have a majority of short T_2 components on the order of a few hundreds of microseconds to a few milliseconds. Furthermore, the ability to image hard tissues is not the only reason to achieve short TE in clinical MRI. For example, when dynamic contrast enhanced (DCE) MRI studies are performed at high magnetic field, T_2^* effects occurring with TE > 1 ms GRE acquisitions can distort time-intensity curves, which leads to erroneous estimates of pharmacokinetic parameters.

References: (1) Robson et al., J Comput Assist Tomogr 27(2003):825-846 (2) Idiyatullin et al., JMR 181(2006):342-349 (3) Silver et al., Nature 310(1984):681-683 (4) Sam, et al., MRM 32(1994):778-784 (5) Park, et al., MRM 55(2006):848-857

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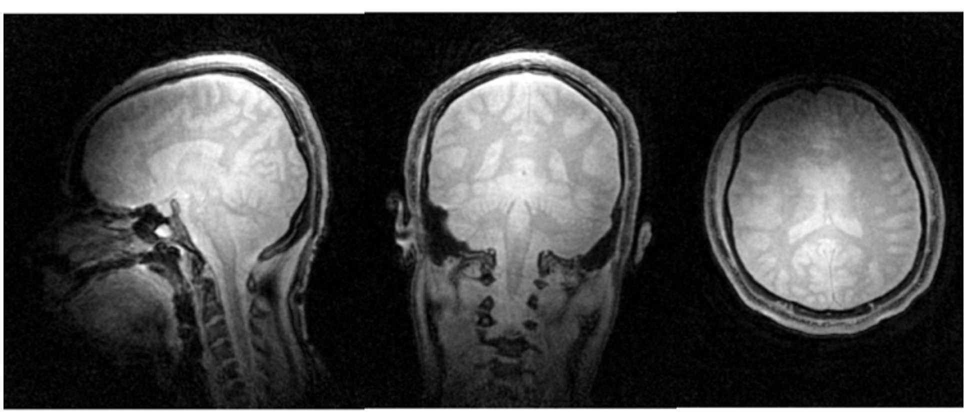

(a) (b) (c)

Fig.2 Examples of SWIFT-LiTE images of human brain at 4T. (a) Sagittal view (b) Coronal view (c) Axial view. Raw images are shown without intensity correction. The shading artifact in the orbital-frontal area is due to B_1 inhomogeneity. The images are essentially free of ghosting, streaking, and other artifacts. The FOV has been cropped slightly for better visualization.