Chemical shift independent imaging of ^{19}F contrast agents using ultrafast MRSI (F-uTSI)

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Introduction

Perfluoro-carbon compounds are in a very favourable position to be used for Molecular Imaging application by MRI and MRS. Fluorine has a high NMR sensitivity and there is little or no physiological existence of ^{19}F. Most of these compounds are also biocompatible, e.g. perfluoro-octyl-bromide (PFOB) is FDA approved as a blood substitute. However, the in vivo concentration of administered PFOB emulsions is generally low, resulting in a poor signal-to-noise ratio (SNR) Furthermore, the SNR in the MR images obtained with conventional techniques also suffers from the broad NMR spectrum containing multiple resonance lines and from chemical shift artifacts (1). In molecular imaging studies (2), the chemical shift artifact of PFOB also introduces extra ambiguities to the localization of the targeted region and quantification of the signal. In these, so called hot-spot images, multiple spots associated with the target region are obtained, instead of one single spot. Several solutions to circumvent this problem have been proposed in the literature, such as chemical shift selective imaging, chemical shift encoding, combination of the Dixon method with multi-slice imaging, as well as post-processing of non-selectively acquired images , which were either limited in their applicability, or slow and complex, or lowered the SNR even more.

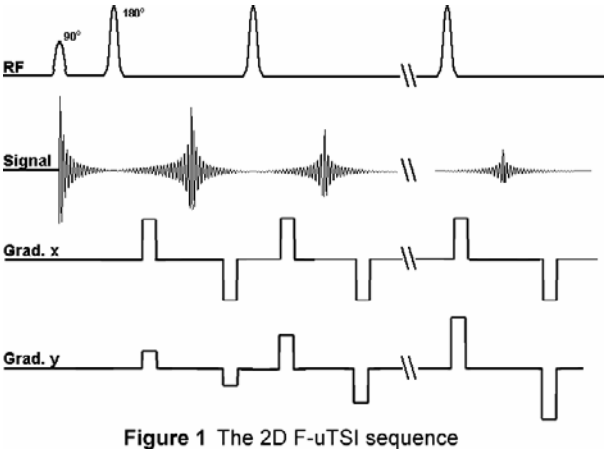

Figure 1 The 2D F-uTSI sequence

Here we present a fast ^{19}F spectroscopic imaging technique, named F-uTSI (Fluorine ultrafast Turbo Spectroscopic Imaging) that is insensitive to chemical shift artifacts, while retaining signal intensity by exploiting the whole NMR spectrum. The method is based on a multiple spin-echo method developed for spectroscopic imaging by Duyn et al (3).

Methods

The F-uTSI sequence was implemented on a Philips 3T whole body scanner (Achieva). The scanner was equipped with ^{19}F imaging and spectroscopy capabilities. The ^{19}F data were recorded using a specially designed small-volume $^{19}F/^{1}H$ double tuned coil (4). The ^{19}F images were obtained on pure PFOB.

Implementation and discussion of the F-uTSI sequence

For the implementation of the F-uTSI sequence we made use of the distinct characteristics of the PFOB spectrum. The NMR spectrum of PFOB spans a range of about 80 ppm, which corresponds to a 10 kHz bandwidth under clinical conditions (i.e. 3T), which is larger than that of ^{1}H, but still easily acquirable by RF coils currently used in clinical scanners. In addition to its large bandwidth, the PFOB spectrum contains three distinctive resonance domains, separated by about 20 and 40 ppm. Because of these relatively large gaps between the resonance lines, it is possible to acquire spectra with reasonable resolution using short sampling durations. This short acquisition time in combination with the relatively long T_2 of ^{19}F (~ 100ms), allows high numbers of echoes per excitation to be generated (a.k.a. turbo factor or multi-echo factor) (fig.1). The typical acquisition time in our experiments was 4 ms with a turbo factor of 16. To ensure maximum speed, also the slice selection gradients are cancelled. Spatial encoding is realized by employing phase encoding in 2D (projection imaging) or 3D.

On pure PFOB, the total measurement time to obtain a 2D projection image (2D F-uTSI) of 32x32 voxels can be as fast as 10 seconds (ignore T_1 effect). This is faster than the ^{1}H based spectroscopic imaging methods, where higher spectral resolutions (~1 ppm), hence longer acquisition times (~ 5 min) are required to obtain similar images (5). Since the method is fast enough, exact localization of the targeted regions can be realized by either performing two orthogonal 2D projection images consecutively or using a third phase encoding gradient. The choice between the two options is a matter of trade-off between simplicity and measurement time, for example a 3D scan with a 32x32x32 sampling grid will take 6 minutes, still longer than for the projection method.

As it is based on a spectroscopic imaging technique, F-uTSI acquires a spectrum for each voxel and integrates all the resonance lines into a single pixel in the image. By this way the chemical shift artifact problem is solved and the SNR is increased. This property of the method also allows different perfluoro compounds to be used and imaged simultaneously. F-uTSI, then, distinguishes the compounds based on their specific spectral signatures and converts acquired data into separate images.

In addition to being a high-speed spectroscopic imaging technique, F-uTSI also offers several choices in the different excitation method and k-space sampling trajectory to be used. Use of excitation and refocusing pulses tailored to fit the NMR spectrum of PFOB promise to increase the SNR by exploiting the magnetization of the system more efficiently.

The choice of the k-space sampling method is observed to have a direct impact on the image quality, resolution and SNR. Fig. 2. shows preliminary results obtained with cartesian and the so-called *pseudo*-radial sampling of the reciprocal space in comparison with a typical image obtained with the gradient-echo based Fast Field Echo (FFE) method. Note that, despite the striping artifacts of cartesian F-uTSI, both F-uTSI images are free from chemical shift artifacts.

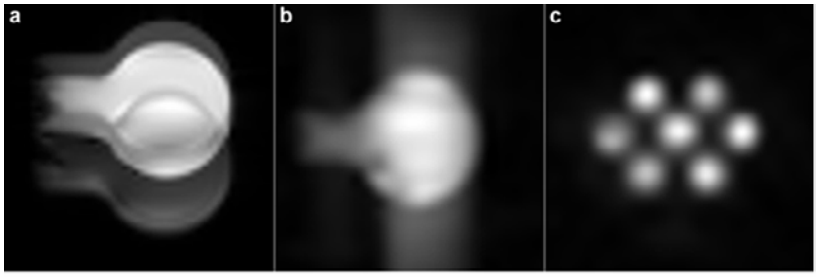

Figure 2: 2D F-uTSI examples

(a) FFE image of a PFOB bottle with chemical shift artifacts. (b) 2D F-uTSI image of the same sample with cartesian sampling. (c) 2D F-uTSI image of 7 PFOB bottles with psuedo-radial sampling

References

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