Efficient ^{19}F imaging of Multi-Spectral-Line Contrast Agents: Aliasing serves to minimize time encoding

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Introduction

^{19}F MRI [1] has a high potential in the field of molecular imaging and in pharmaceutical research. In particular, it allows the direct quantification of nano-particles [2] or fluorinated (anti-cancer) drugs [3]. However, ^{19}F MRI is generally complicated by strong chemical shift (CS) artifacts of the multi-line spectra with a range of around 100 ppm. Many counter measures have been described, which typically lead to reduced SNR (line selection/saturation), long imaging time (CS encoding), or the need for complex and potentially unstable calculations (matrix inversion [4], deconvolution [5], iterative reconstruction [6]). Time encoding [7], typically applied in echo-planar acquisitions (EPSM[8], EPSI[9]), forms the basis for an efficient imaging scheme, which overcomes these shortcomings. The number of encoding steps needed to cover the full chemical shift range is minimized taking advantage of aliasing effects.

Methods

A series of N images taken with small TE increments ΔTE is the basis for CS artifact removal (c.f. Fig.2a). The spectral bandwidth b of this acquisition is given by $b = 1/\Delta TE$, while the spectral resolution is determined by $\Delta f = 1/(N\,\Delta TE)$. For a known and fixed MR spectrum of a contrast agent (c.f. Fig.1), the spectral resolution and bandwidth can be adjusted such that each resonance line coincides with one of the N spectral windows. If the chemical shift δ of a component exceeds the bandwidth, it is aliasing back into the encoded spectral region. Spectral resolution is fine-tuned to project these resonance lines to an empty spectral window such that no line mixing occurs. In an ideal case, the number of necessary echo-time increments equals the number of resonance lines. Thus, no spectral window is encoded which contains mere noise. In the present case, 8 encoding steps were chosen for 7 resonance lines, allowing for fast FT. The study was performed on a 3T whole-body scanner (Achieva, Philips Medical Systems) operated at 120 MHz for ^{19}F, using a transmit/receive coil (∅14cm) and a spherical phantom filled with pure PFOB ($C_8F_{17}Br$, clinically relevant contrast agent: synthetic blood substitute). A 3D gradient-echo sequence with 15° flip-angle and TR=14.3 ms is chosen for demonstration. The echo-time is varied in 8 steps, TE=2.4 ms...11.9 ms, with increments of ΔTE=1.354 ms leading to b=739 Hz and Δf=92.3 Hz. 32 slices à 2 mm are recorded with an in-plane resolution of 0.9 mm (matrix 128^2) and a pixel bandwidth of 500 Hz. The PFOB line with δ=-58 ppm (CF_2Br) is not fully excited because of the used RF excitation bandwidth.

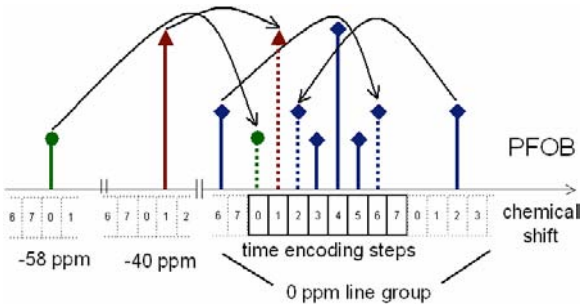

Figure 1: Time encoding scheme using aliasing to minimize the encoding steps but still cover the full chemical shift range of a ^{19}F contrast agent, e.g. Perfluoro-octyl-bromide (PFOB).

Results and Discussion

A selection of the 3D imaging data (one slice, 3 encoding steps) is shown in Fig.2. After a voxel-wise FT in the time encoding direction (Fig.2b) all CS components are separated but still dislocated as indicated by the added circles. As the shift is known via the spectrum and the pixel bandwidth, it can be compensated by sub-pixel translations (Fig.2c). The individual (but fixed) phase offsets of all components were set to zero, and the final image (Fig.2d) was obtained by a complex sum. The cross section in Fig.2d shows that SNR is increased by adding signals of all spectral lines. While 8 averages of the strongest resonance line result in a SNR of 18 (i), a nearly 3-fold increase to SNR = 48 is obtained for the combination of all lines without loss of spatial resolution. The method is robust against local off-resonances due to magnetic field heterogeneity, because of the voxel-wise separation of CS components.

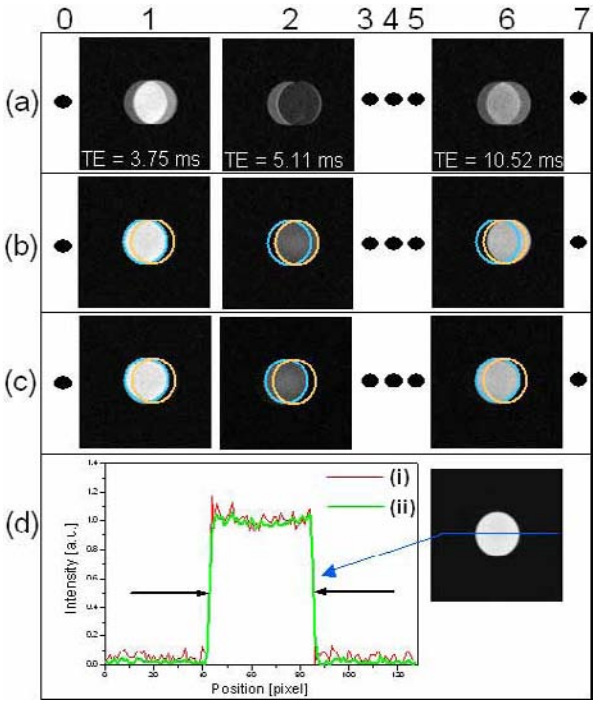

Figure 2: Illustration of the method with selected slices from a 3D ^{19}F phantom imaging experiment: 8 initial images with echo time increments (a) are Fourier-transformed voxel-wise (b), the chemical shift is compensated by sub-pixel accuracy translation (c) and finally images are re-phased and coherently added (d). The cross section in (d) shows 8 averages of the strongest spectral line (i) in comparison to the complex sum of all spectral components (ii).

Conclusion

A novel approach for efficient imaging of ^{19}F contrast agents has been demonstrated, which allows to combine all spectral lines into a single image without the need to encode the full chemical shift range. The method can easily be applied to echo-planar imaging to exploit the full benefit of time-efficiency increase.

References

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