Optimized Spectroscopic RARE at 7 Tesla Applied to Rat Brain in vivo

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Introduction: The fast spectroscopic imaging (SI) method spectroscopic RARE (spRARE) allows a short minimum total measurement time (T_{min}), high signal-to-noise ratio (SNR) per unit measurement time (SNR_t), and good signal separation, as demonstrated at 4.7 T [1]. However, although increased SNR and spectral resolution are expected with increasing B_0 field, there are many obstacles for an implementation of spRARE on high field systems:

(a) Although xyxy phase cycling [2] is applied, only limited deviations from 180° are acceptable within the train of 180° pulses. Therefore, good B_1 homogeneity and short 180° pulses are required to cover the whole chemical shift range and the volume of interest.
(b) A reduced interecho delay within the RARE train is required to break J modulation and avoid localization artifacts in phase encoding direction [3,4].
(c) Excellent water suppression is needed to suppress the effect of signal fluctuations between different k-space sampling steps along k_ω, which may cause additional noise in the frequency domain [5]. Therefore, if array coils are used for RF reception, weighted data combination [6] should be done either by using metabolite signals, the strongly suppressed water signal, or a separate data set measured without water suppression.

In the present study, spRARE was implemented on a 7 T animal scanner and applied to phantoms and rat brain in vivo, showing that the experimental problems can be solved and higher SNR and spectral resolution can be achieved as theoretically expected at higher B_0.

Method and Experimental: Two versions of spRARE were implemented. Either (i) a composite pulse or (ii) a corresponding spectral-spatial pulse was used to excite metabolite signals and to support water and lipid suppression (Fig.1). A 1-2τ-5.4-τ-5.4-2τ-1 composite pulse [7] with rectangular RF pulses of 10 μs and 54 μs duration and τ=750 μs was used for version (i). Volume preselection was achieved by three slice selective 2.5 ms 180° Mao6-pulses [8]. For version (ii), the rectangular pulses were substituted by sinc3-pulses of 300 μs duration applied under the positive periods of a symmetrically oscillating slice gradient. Volume preselection in the remaining two directions was achieved by two slice selective 180° Mao6-pulses.

Prior to RF excitation three consecutive 12 ms Gaussian saturation pulses were applied for water suppression. Constant time chemical encoding was performed by shifting the position of a non-selective 140 μs 180° pulse within a constant delay t_c between excitation and the RARE module. Further parameters were: t_c range: 61-156 ms; RARE module with 64 rectangular 180° pulses (140 μs, -600 Hz offset with respect to water) with xyxy phase cycling yielding two data sets; interecho delay: 3.0 ms; FOV: 48x48mm^2 (phantom) or 40x40mm^2 (in vivo); 3 mm slice; $N_{kx}=N_{ky}=32$, $N_{k\omega}=95$-301 for symmetric or $N_{k\omega}=48$-151 for asymmetric k_ω-sampling; TR=1.9 s; 1 or 2 accumulations, spectral width: 1333.3 Hz or 2400 Hz.

Experiments were performed on a Biospec 7T/20cm USR animal scanner (Bruker-Biospin, Germany) equipped with standard gradients BGA-12S2 (max. strength: 400 mT/m, slew rate: 4000 mT/m/ms). RF excitation and reception were done either using a quadrature volume coil (72 mm i.d.) or a combination of a linear resonator (72 mm i.d.) and a 4-channel array coil optimized for rat brain. Phantom experiments were performed on spheres or tubes filled with 50 mM solutions of N-acetyl aspartate (NAA) or glutamate (Glu). In vivo measurements were performed on the brain of Wistar rats anesthetized with 1-3% isoflurane and oxygen. Data were processed using in-house developed programs written in IDL (ITT, USA).

Results and Discussion: Both sequence versions yielded similar spectrum quality. However, alternative (i) using composite pulses ensured superior water suppression and allowed narrower slices than alternative (ii) using spectral-spatial pulses. The quality of spatial localization was tested on phantoms. Good localization was achieved for signals of uncoupled spins (water, NAA) and J-coupled spins (Glu), both in read (y) and phase encoding (x) direction. This means the B_1 field and the refocusing profile of the 140-μs-pulses are sufficiently homogeneous. It allowed to use uniform phase encoding of only two consecutive echoes (and not four), enabling a larger matrix size in phase encoding direction [9]. Fig. 2 shows a metabolic image measured on a spherical 37mm-phantom filled with 50 mM Glu (with an air bubble at the top) and calculated from the Glu4-CH_2 signal (2.35 ppm). The spectrum of Fig.2 demonstrates that effective homonuclear decoupling and very high spectral resolution can be achieved at 7 T. For this data set, the largest number of $N_{k\omega}$ steps ($N_{k\omega}=301$) was used for the chosen t_c value of 136 ms, which is optimal to detect Glu. Thus it is possible to separate the 3 and 3' proton signals of Glu at 2.04 and 2.12 ppm [10]. The use of symmetric k_ω-encoding and the subsequent use of magnitude spectra is a convenient way to avoid phase correction of in vivo spectra [1]. However, using asymmetric k_ω-encoding is an interesting alternative, particularly if the potential of a higher spectral resolution at higher B_0 is exploited. As a consequence of k-space symmetry, the same spectral resolution can be obtained by phase corrected spectra calculated from data with asymmetric k_ω-sampling [9]. Additionally, T_{min} is reduced to 50 %, while the SNR_t is constant. If the array coil was used for RF reception, the data sets were successfully combined using the maximum intensity of metabolite signals [6], despite the rather low SNR in in vivo measurements. For symmetric k_ω-sampling, the combination was done on the magnitude spectra, whereas for asymmetric k_ω-sampling an automatic phase correction was performed before. Fig.3 shows a typical in vivo spectrum (nominal voxel size: 1.25x1.25x3 mm^3) measured on rat brain within 5:40 minutes using $t_c=102$ ms optimized for the detection of myo-inositol (m-Ins). The main signals are assigned to NAA, Glu, total creatine (tCr), total choline (tCho) and m-Ins.

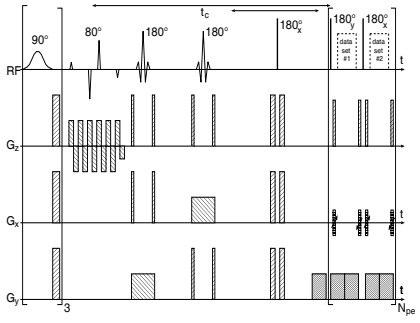

Fig.1: Scheme of the optimized spRARE sequence implemented at 7T.

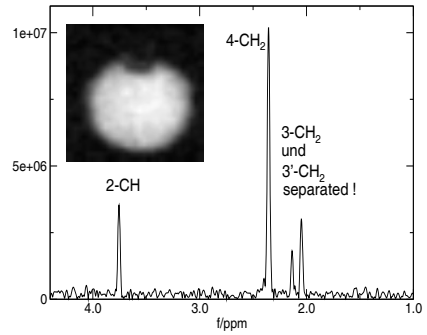

Fig.2: (a) spRARE spectrum and image of the 4-CH_2-signal measured on a Glu phantom ($N_{k\omega}=301$).

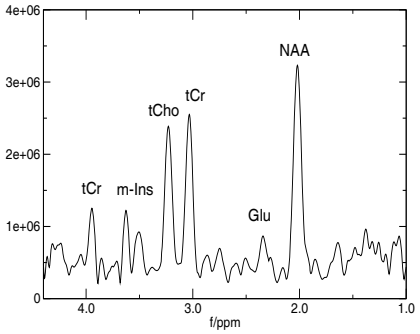

Fig.3: Typical in vivo spRARE spectrum with $t_c=102$ ms, $N_{k\omega}=175$ and SW=2400 Hz.

Conclusion: The fast SI method spRARE can be implemented on a state-of-the-art 7 Tesla animal scanner. Experimental problems occurring at higher B_0 can be solved which allows to take advantage of the better spectral resolution and higher SNR that can be obtained with increasing field strength.

References: [1] W. Dreher et al., MRM 47, 523(2002). [2] A.A. Maudsley, JMR 69, 488(1986). [3] A. Allerhand, J. Chem. Phys. 44, 1(1966). [4] D. Mayer et al., MRM 57, 967(2007). [5] W. Dreher et al., MRI 17, 611(1999). [6] L.L. Wald et al., MRM 34, 440(1995). [7] Z. Starcuk et al. JMR 66, 391(1986). [8] J. Mao et al., JMR 79, 1(1988). [9] W. Dreher et al., Proc. ISMRM 2003, p.517. [10] V. Govindaraju et al, NMR Biomed. 13, 129 (2000).