Simultaneously Acquired ^{23}Na Single- and Triple-Quantum Imaging in Rat in vivo at 9.4 T

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Target audience: Researchers interested in the applicability of multi-quantum filtered imaging techniques

Purpose: Multi-quantum filtered spectroscopic imaging methods [1,2] utilize the spin-3/2 characteristic of ^{23}Na nuclei to generate multi-quantum coherences reflecting on the binding of $^{23}Na^{+}$ to macromolecules. In this work, a spectroscopic density-adapted radial imaging modality using time proportional phase increments (DA-PR-TPPI) [3] was applied to an animal study to simultaneously acquire single-quantum and triple-quantum signal under identical condition. We aimed at acquiring high resolution in vivo rat head images within a reasonable time frame. This method may be applied to monitor the single- and triple-quantum signal development in diseases such as stroke and cancer in future studies using animal models, paving the way to the implementation of the method in a clinical setting. The simultanesouly acquired single- and triple-quantum images would lead to a deeper understanding of metabolic processes in healthy and diseased tissue and potentially become the basis to new treatment approaches on a molecular level.

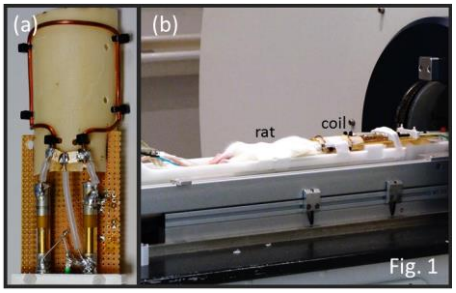

***Figure 1**: (a) Custom-made ^{23}Na bent surface coil (b) Anaesthetized rat on heated bed attached beneath the coil.*

Materials/Methods: Experiments were performed on a 9.4 T preclinical MR system (BioSpec, Bruker, Germany) using a custom-made ^{23}Na saddle surface coil for animal experiments (**Figure 1**). A healthy Sprague Dawley rat was scanned.

Pseudo 2D readout: Pseudo 2D gradient readout (infinitely thick slice) was chosen over 3D readout to achieve high spatial resolution while greatly reducing t_{scan}. Furthermore, pseudo 2D was preferred over normal 2D readout, since a slice selection gradient simultaneous to pulse application leads to longer TE and possibly to coherence loss.
DA-2DPR(-TPPI) experiments: DA-2DPR-TPPI pulse scheme is depicted in **Figure 2**. SQ and TQ images were obtained by performing Fourier Transform along the SQ and TQ frequency of the spectrum, respectively. DA-2DPR-TPPI SQ and TQ ^{23}Na images of rat head were acquired additional to a DA-2DPR ^{23}Na image and ^{1}H reference images. The following parameters were used in DA-2DPR-TPPI rat experiments: TR = 80 ms, t_{scan} = 59 min, averages = 3, slice = coronal, t_{acq} = 8 ms, spokes = 200, in-slice resolution = 1x1 mm^2, Δt_{evo} = 800 µs, phase steps = 8, phase cycles = 4, gradient delay = 9 ms, TE = 9.08 ms.

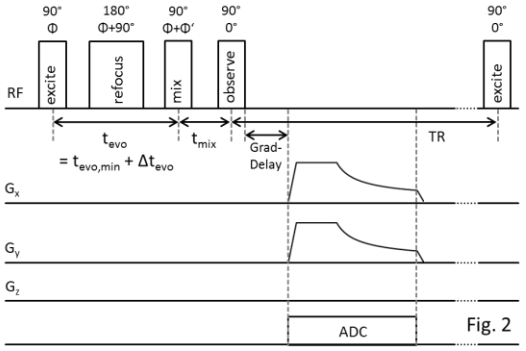

***Figure 2**: Sequence diagram of DA-2DPR-TPPI. The t_{evo}-FID in the t_{evo}-domain is sampled by incrementing t_{evo} with Δt_{evo}. Fourier Transform of the t_{evo}-FID yields the spectrum in which the SQ and the TQ frequency are determined. The final SQ and TQ images are obtained by performing Fourier transform along the SQ and the TQ frequency, respectively.*

Results/Discussion: The DA-2DPR-TPPI (**Figure 3a&b**) SQ image of rat head indicates high signal level in the eyes due to the high amount of free ^{23}Na+; the eyes in the TQ and the DA-2DPR image (**Figure 3c**) have much less pronounced signal intensity compared with surrounding tissue. ^{1}H images (**Figure 3d-f**) indicate that although jaw tissue signal might be mixed with brain signal in the coronal view, the B1 profile of the saddle coil is much less homogeneous in the region below the brain, thus resulting in difficult SQ/TQ-TPPI coherence formation underneath the brain. The pseudo 2D coronal outline of the brain can thus be approximately attributed to brain tissues only.

Conclusion: A simultaneously acquired SQ and TQ spectroscopic imaging modality with time proportional phase increments was successfully applied to rat head in vivo. Spatial resolution of 1 mm was achieved with a t_{scan} of under an hour. This reasonable time and spatial resolution might enable future monitoring of SQ/TQ development in diseases such as stroke and cancer and thus lead to a deeper understanding of metabolic processes in healthy and diseased tissue.

References: [1] Tsang et al. Magn Reson Med. 2012; 67:1633-1643 [2] Mirkes et al. Magn Reson Med. 2016; 75:1278-1289 [3] Schepkin et al. J Magn Reson. 2017; 277:162-168 [4] Nagel et al. Magn Reson Med. 2009; 62(6):1565-1573

Fig. 3 Simultanesouly acquired SQ and TQ ^{23}Na imag

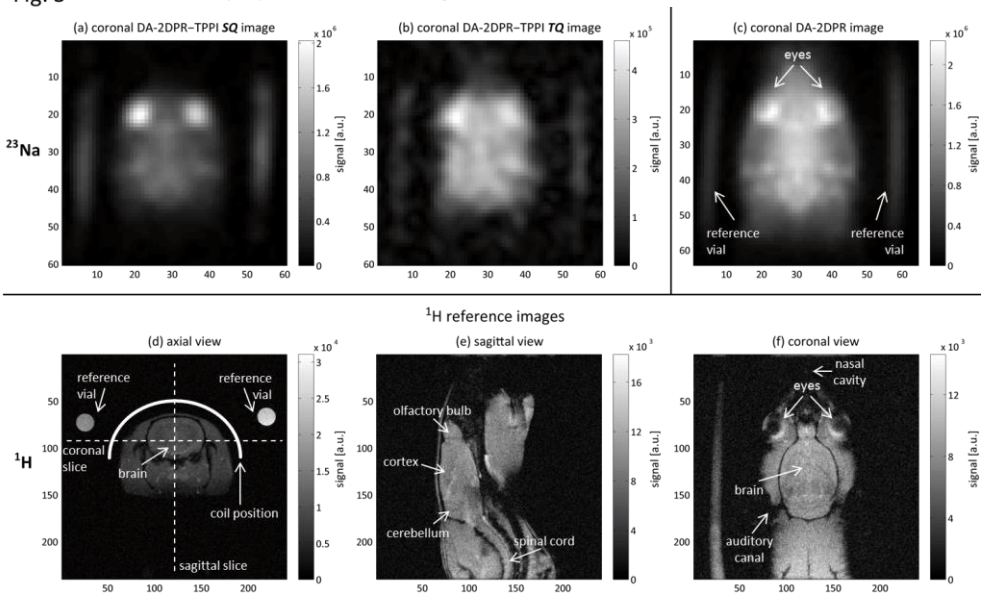

***Figure 3**: ^{23}Na (a) SQ and (b) TQ rat head in vivo DA-2DPR-TPPI images. Free ^{23}Na ions in the eyes contribute to high SQ signal. TQ image is noisier due to much lower signal level. (c) DA-2DPR image. ^{1}H images of (d) axial, (e) sagittal and (f) coronal view.*