# LOCALIZED MR-SPECTROSCOPY IN ARBITRARILY SHAPED VOXELS USING PARALLEL EXCITATION PULSES WITH LARGE SPECTRAL BANDWIDTH

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**Introduction:** Multi-dimensional spatially selective excitation (SSE) offers great potential compared to conventional single-voxel localization techniques in magnetic resonance spectroscopy (MRS) due to the possibility of selecting arbitrarily shaped voxels of interest (VOI). Such arbitrary VOIs can be adapted to anatomical structures and can help maximizing the signal-to-noise ratio (SNR) while minimizing partial-volume effects. However, the use of SSE for MRS is frequently hampered by the long durations and the limited bandwidth of the excitation pulses making them susceptible to off-resonances and leading to a bad definition of the excited volume for different spectral components. A first approach to overcome the problem of long pulse durations in MRS by using multi-band Parallel Excitation (PEX) / Transmit SENSE [1,2] had been presented in [3]. The present study combines segmented SSE pulses with parallel transmission in order to achieve real broadband excitation of arbitrarily shaped target voxels while simultaneously limiting the pulse duration and the number of segments needed for sufficient spatial resolution of the target. This will particularly be useful in ultra-high field animal MRS where SSE pulses with high spatial resolution and very large bandwidth are needed due to the small animal geometries and the large frequency shifts of the spectral components. Furthermore, it is desirable, due to the low intrinsic SNR of the very small VOIs, to exploit the full volume of interest and not only a cuboid inner voxel.

**Materials and Methods:** The experiments in this study were carried out on a BioSpec 9.4 T animal scanner (Bruker BioSpin MRI, Ettlingen, Germany) with 8 transmit- and receive-channels in combination with an 8-element volume-array used for transmission and reception. Excitation of the VOIs was performed with PEX pulses based on a 2D-radial k-space trajectory (similar to the trajectory presented in [4]) designed for an excitation matrix of 64 x 64 points within the field of excitation (FOX) and consisting of only 20 radial lines corresponding to an acceleration factor of 3.2. For all experiments the trajectory was segmented in a way that only one of the radial lines with a duration of 0.618 ms was played out per excitation resulting in a high excitation bandwidth of the PEX pulses. PEX pulse calculation was performed in the small-tip-angle regime using the method from [5]. Selection in the third dimension was achieved by a $B_1$-shimmed slice selective refocusing pulse. For imaging the selected voxels the two pulses were played out within a simple spin echo sequence and an intermediate image was acquired for each segment of the PEX pulse. For spectroscopic acquisition one FID per excitation segment was recorded after the localization pulses. The final images and spectra were obtained by complex summation of the acquired datasets corresponding to the different excitation segments. On the receive side the data from the 8 array elements was combined by a pixel-wise sum-of-squares in the imaging case. In the spectroscopy case a complex summation of the FIDs was performed with a global phase offset for each receive channel.

In a first series of experiments the spatial fidelity of the localization was assessed for a broad range of chemical shifts. Therefore, an "L"-shaped target region (Fig. 1a; FOX: 5.2 x 5.2 cm; slice thickness: 2 mm) was excited in a homogeneous $T_1$-doped water bottle with different offset frequencies of the 2D-PEX pulse in the range of 0 to 6000 Hz (corresponding to 0 – 15 ppm) relative to the proton resonance frequency in the water and a 2D-image of the excited voxel was acquired.

The second series of experiments was performed in a spectroscopy phantom consisting of a small tube (diameter 10 mm) filled with 100 millimolar aqueous lactate solution concentrically immerged into a larger tube (diameter 27 mm) filled with 100 millimolar aqueous citric acid solution. Images and proton NMR spectra were acquired from a voxel with circular cross section within the inner tube and from a voxel with annular cross section covering a region within the outer tube only which would not be feasible with conventional cuboid MRS localization (Fig. 2a-e; FOX: 3.2 x 3.2 cm; slice thickness: 5 mm; excitation flip angle: 10°; acquired spectral range: 4000 Hz; spectral resolution: 0.488 Hz; 50 averages per excitation segment for the spectroscopic acquisition; VAPOR water suppression; as postprocessing only 0$^{th}$ and 1$^{st}$ order phase correction was performed).

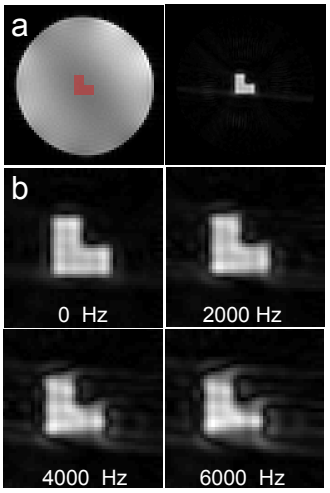


**Fig. 1:** PEX (accel. factor 3.2) of an „L"-shaped target region in a homogeneous water bottle (a). Zoomed images of the excited region for different offsets of the PEX pulse frequency (b).

**Results:** The images in Fig. 1 show that up to an offset frequency of about 2000 Hz (5 ppm) the target region is excited with good spatial fidelity. At larger offsets the excited voxel begins to show significant deviations from the target pattern in the form of shifting, blurring and geometric deformation.

In the spectroscopy phantom the target VOIs could also be excited with very good spatial selectivity (see Fig. 2a-c). Only very little spurious excitation can be noticed in the outer volume of the voxels. This is also confirmed in the spectra acquired from these voxels. In the spectrum from the inner circular voxel (Fig. 2d) one can clearly see a duplet at ~1.2 ppm as well as a quartet at ~4 ppm originating from the lactate while the two duplets between 2.5 and 3 ppm coming from the citric acid are barely above the noise floor. The complementary situation can be found in the spectrum from the outer annular voxel (Fig. 2e) where the two strong duplets from the citric acid can be seen and nearly no signal from the lactate peak groups.

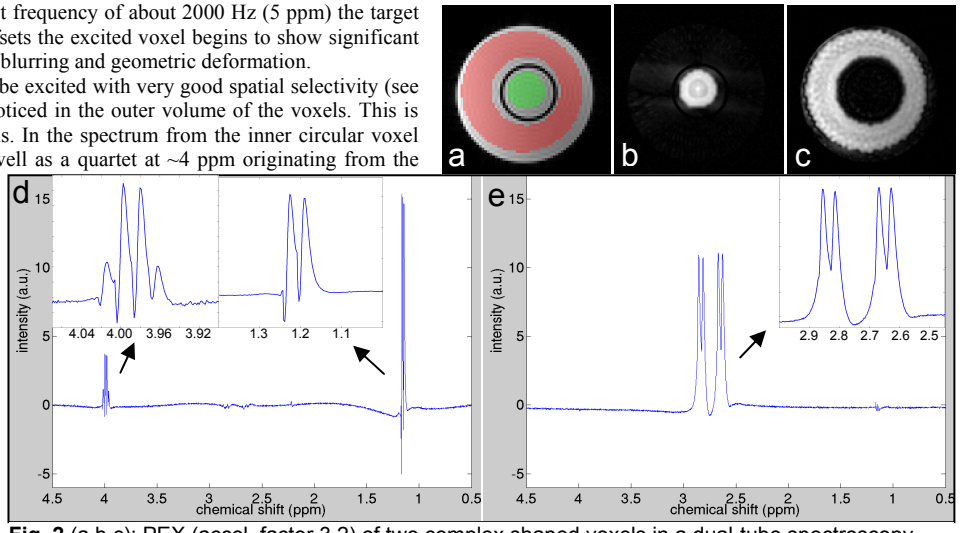


**Fig. 2** (a,b,c): PEX (accel. factor 3.2) of two complex shaped voxels in a dual-tube spectroscopy phantom. (d,e): $^1$H-NMR spectra acquired from the voxels (b) (lactate) and (c) (citric acid).

**Discussion and Conclusions:** The results of this study show that MR spectroscopy based on segmented PEX pulses can be performed in arbitrarily shaped voxels with good spatial selectivity and sufficient spectral bandwidth on high field animal MRI systems. The usage of PEX allows achieving the same spatial resolution and spectral bandwidth with significantly fewer segments than in the single channel case which results in reduced acquisition time. Most frequently, the remaining segmentation has no adverse effect on the SNR efficiency since the summation of the FIDs corresponding to the different segments provides an intrinsic averaging effect which is generally required due to the low intrinsic SNR in animal MRS. However, if additional averages per segment are needed to achieve sufficient SNR, PEX-based MRS provides an advantage in terms of scan time only if the acceleration factor exceeds the number of averages per segment. Therefore, PEX will particularly be interesting for MR spectroscopy based on three-dimensional SSE-pulses exciting arbitrary 3D-voxels since the required number of segments will dramatically increase in this case. Further investigations will focus on such 3D-PEX-based MRS as well as on the application of the technique for small animal MRS in vivo.

**References:** [1] Katscher et al., MRM 2003, 49:144-150 [2] Zhu, MRM 2004, 51:775-764 [3] Ullmann et al., ISMRM 2009, p. 2602 [4] Qin et al., MRM 2007, 58:19-26 [5] Grissom et al., MRM 2006, 56:620-629.

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