PHASE-CYCLED SEGMENTED CENTER-OUT ECHO PLANAR SPECTROSCOPIC IMAGING SEQUENCE

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Introduction: Commercial gradient systems enable the concomitant echo planar spectroscopic imaging (EPSI) acquisition of up to 8 *k*-space lines within one spectral dwell time Δt at 3 Tesla [1]. Temporal non-uniformity of the sampling of *k*-space lines, resulting from the necessity to periodically cancel gradients, can lead to spectral Nyquist ghosts [2]. If the spectral bandwidth is less than 5.3 ppm, Nyquist ghosts of water (4.65 ppm) or fat methylene (1.3 ppm) signals may impair the quantitation of metabolites of interests. Segmented center-out *k-t*-trajectory combined with phase-encoding flybacks takes advantage of *k*-space damping to reduce the convolution of spatial and temporal encoding by privileging the uniform sampling of *k*-space lines that are near the center of *k*-space (Fig. 1) [3]. Alternating the center-out direction, a feature required to help reducing the pitch and loudness, may create an additional source of spectral Nyquist ghosting. Spectra acquired with double-shot center-out EPSI may exhibit Nyquist ghost of water with intensity comparable to that of the NAA singlet. This Nyquist water artifact can be mitigated by averaging with a 16-step EXOR phase cycle (Fig. 2). We investigated the efficiency of the phase-cycling scheme by comparing the Cramér-Rao lower bounds (CRLB) of glutamate concentrations in presence or absence of water Nyquist ghost near 2.35 ppm.

Methods: A healthy volunteer (w 32y) was examined at 3 T after informed consent on a TIM Trio (Siemens) with a circularly polarized head coil. Segmented center-out EPSI was performed with four shots, 8 OVS slabs, 16×16 matrix, 240×240 mm^2 FOV, 120×120×15 mm^3 VOI (Siemens WIP450 shim), voxel size 15×15×15 mm^3 (3.4 mL), TR 1.7 sec, TE 30 ms, N_p 256 spectral points, zero filling, 16-step EXOR phase cycling, 2 dummy scans, 1 water template scan, 1 water reference scan, 64 averages (NA) separately stored. By adjusting the flyback gradient and the ADC dwell-time (DW), two spectral bandwidths were achieved: 4.483 ppm (DW 20 µs, Δt 1.81 ms) and 5.714 ppm (DW 15µs, Δt 1.42 ms). The forward and reflected ADCs of the water reference and water suppressed scans were first corrected with a linear phase correction based on the water template scan and then Fourier transformed. The first phase cycling step of EXOR was averaged to simulate spectra without phase cycling (1 to 4 averages, yielding total times of 22, 29, 36, 43 sec respectively), otherwise EXOR cycles were added (16, 32, 48 or 64 averages, with total times of 2.1, 3.9, 5.7, 7.5 min respectively). Voxels with severe fat contamination were excluded. The corresponding recombined spectra of 20 voxels were quantified by LCModel [4] with water reference scans to yield concentrations, assuming that the supra-ventricular axial slice predominantly contained white matter.

Results: Without phase cycling, although the water Nyquist ghost is less pronounced in four-shot segmented center-out EPSI (Fig. 3, right, 3 averages, expected at 2.4 ppm), spurious signals are visible between 3.6 and 4 ppm. With 16 steps EXOR phase cycling, NAA, creatine, total choline, glutamate and myo-inositol are quantified in 2.1 min. The CRLB reported by LCModel for the glutamate concentration was only taken into consideration when it was less than 100%. The average CRLB of the glutamate concentration was not affected by the position of the water Nyquist ghost: expected at 2.4 ppm (BW 4.483 ppm, blue in Fig. 4) and 1.8 ppm (BW 5.714 ppm, green in Fig. 4) respectively. In both cases, the CRLB improves with the square root of the product of the ADC dwell-time and averages. Without phase cycling the spread of CRLB values is much larger.

Conclusion: Segmented center-out EPSI combined with EXOR phase cycling effectively reduce water Nyquist ghosts in a relatively short acquisition time and enables the detection of the *J*-coupled resonance of glutamate.

References: [1] Posse 2009 *MRM* 61:541; [2] Metzger 1997 JMR 125:166; [3] Labadie, ISMRM 2010, p. 3384; [4] Provencher 1993 MRM 30:672.
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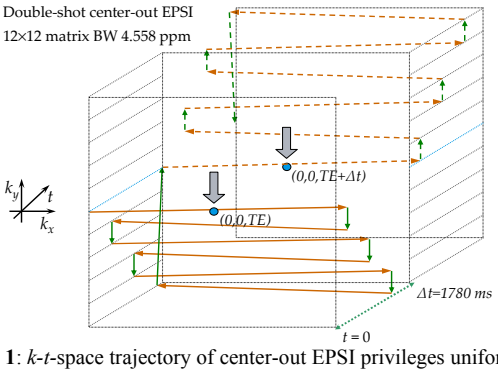

Fig 1: *k-t*-space trajectory of center-out EPSI privileges uniform time sampling of lines near k-space center.

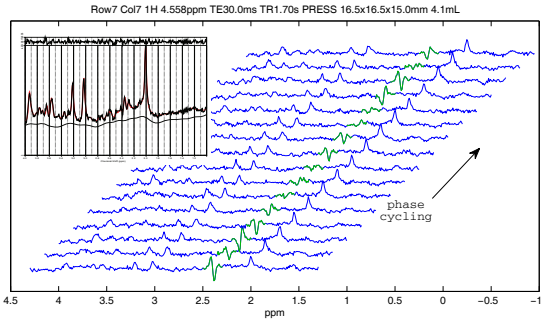

Fig 2: Single EXOR phase cycling steps of a 12×12 double-shot center-out EPSI with BW 4.558 ppm. The water Nyquist ghost expected at 2.73 ppm (green) does not appear in the LCModel residuals (insert plot) of the combined spectrum (NA 160).

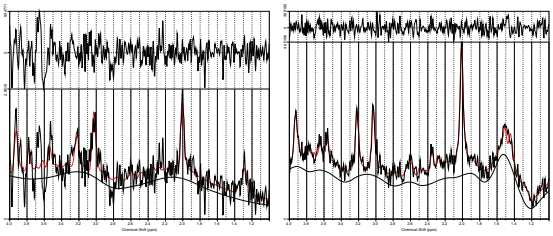

Fig 3: Four shots center-out EPSI with BW 4.483 ppm without (NA 3, TT 36 sec, left) and with EXOR phase cycling (NA 16, TT 2.1 min right). With phase cycling, a ghost between 3.6 and 4 ppm is clearly reduced yielding following concentrations in mmol/L (%SD): creatine 3.89 (5%), t-choline 1.29 (6%), NAA 7.17 (3%), myo-inositol 3.28 (11%), glutamate 4.66 (19%).

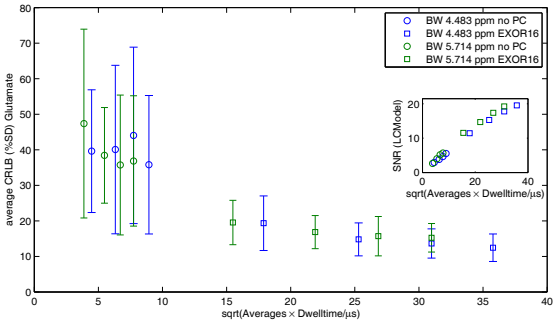

Fig 4: The average SNR of 20 voxels, as estimated by LCModel, is almost proportional to square root of the product of ADC dwell-time and average (insert). The average CRLB of glutamate concentration is following the same trend regardless of the expected position of the Nyquist water ghost (squares).