Improving Image Quality of Hyperpolarized 129Xe MRI with 3D Radial Acquisition and Accurate K-Space Trajectory Measurements

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Target Audience: Hyperpolarized Gas MRI, Clinical MRI Lung Imaging

Purpose: Hyperpolarized ^{129}Xe is emerging as a promising agent for breath-hold imaging of pulmonary function. However, such inherently rapid imaging presents a unique challenge of extracting maximum image information from non-equilibrium and non-renewable magnetization in a ~15 sec scan. To date the majority of ^{129}Xe studies employ a simple and fast 2D multi-slice gradient echo sequence. However, with growing interest in dissolved-phase ^{129}Xe (~2ms $T2^*$), sequences with sub millisecond TE such as 3D radial acquisitions have gained interest. In fact, the advantages of 3D radial acquisition were first illustrated ^{3}He MRI[1]. Recently, our group[2] extended this to ^{129}Xe, showing that 3D radial acquisitions produced identical ventilation defect percentages to multi-slice GRE, while also providing isotropic resolution. Moreover, radial sequences are less susceptible to artifacts from signal decay during image acquisition[3] and less sensitive to under sampling, motion, and B_0 inhomogeneity. Despite the aforementioned advantages, radial sequences have not been widely adopted in clinical applications of HP gas MRI due to practical reasons - they are not generally supported by vendors, require non-Cartesian reconstruction, and necessitate accurate knowledge of k-space trajectories. The primary aim of this work is to improve the fidelity of 3D radial ^{129}Xe MRI by accurately measuring k-space trajectories[4].

Methods: For this study, subjects inhale 1-liter of HP ^{129}Xe (85% enriched, polarized to ~10%) and a ^{129}Xe ventilation image is acquired with a 3D radial sequence using: FOV=48 cm, matrix=128^3, α=1.4°, TR/TE=5.3ms/376μs, BW=15.625kHz, 3001 radial views. After ^{129}Xe MRI, gradient trajectories are measured with ^{1}H MRI independently along each axis (k_x, k_y, and k_z) with the patient in the same position, using the scanner's body coil. For each gradient direction, a 2mm thick slice is excited 2cm off-center in the plane orthogonal to the gradient of interest, while gradients are played out identically as for ^{129}Xe MRI. Phase accumulates in the slice according to $\emptyset(r,t) = \int_0^t \gamma G_r r dt = k_r(t) r$. The phase is unwrapped to account for phase accumulation exceeding 2π and k-space position is calculated from the associated phase at each sampling point. The phase is measured twice for each gradient axis, once with the gradient of interest turned on during imaging, and once with no imaging gradients to account for phase accumulation from sources other than the imaging gradients, such as inhomogeneities and eddy currents. Subtracting the phases of the gradient-on and -off scans provides the differential phase generated by the true gradient waveform. The true k-space trajectory is calculated from the unwrapped differential phase and known slice position. Trajectories can be converted to actual gradient values by taking their derivative scaled according to gradient timing and gyromagnetic ratio. Each trajectory measurement is repeated 300 times and averaged to reduce measurement noise. After measuring k-space trajectories for each gradient axis in isolation, the actual k-space trajectory of the 3D radial ^{129}Xe acquisition is then calculated using a linear combination of the three measured gradient axes. The measured trajectories and data are gridded onto a Cartesian matrix prior to reconstruction.

Results: Figure 1 shows the measured gradient waveforms compared to those assumed from an idealized waveform. Actual gradient values clearly deviate from the assumed case, and also vary according to gradient strength. The distortions primarily occur near transitions between the ramp and plateau regions of the waveform. Such distortions lead to significant alterations in k-space position that must be accounted for in the reconstruction. The results of such considerations are shown in Figure 2 with images of the same subject reconstructed from (a) assumed ideal trajectories and (b) actual measured trajectories. The corrected image exhibits a noticeable improvement in image quality.

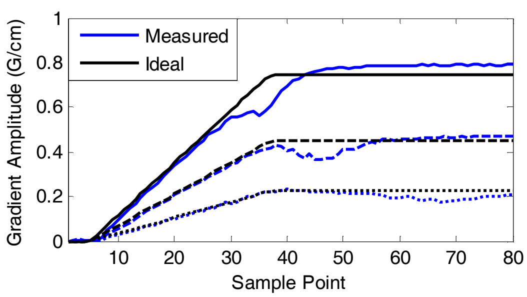

Figure 1. Measured (blue) and ideal (black) trajectories at multiple gradient amplitudes (solid=90%, dashed=60%, dotted=30%).

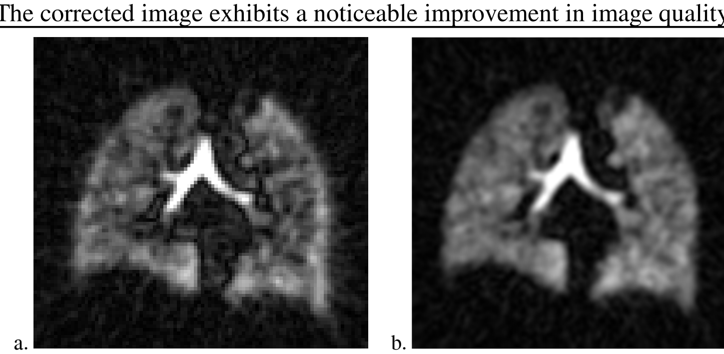

Figure 2. Same subject reconstructed with (a) ideal and (b) measured k-space trajectories.

Discussion and Conclusion: This study shows the importance of measuring k-space trajectories in 3D radial imaging of HP ^{129}Xe. Since the k-space position is related to the integral of gradients over time, deviations from the ideal gradient waveforms will compound over a given radial ray, resulting in an accumulation of k-space error. Radial k-space errors tend to manifest themselves as halos, which limits image quality by blurring image content. By developing optimized solutions for efficiently determining actual k-space trajectories, the advantages of 3D radial isotropic image acquisition can be realized and more broadly disseminated.

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References: (1) Holmes et al., MRM 2002; 59(5): p1062-71, (2) He et al., ISMRM 2013: p1451, (3) Marshall et al., NMR in biomedicine 2012; 25(2): p389–99, (4) Duyn, et al., MRM 1998; 153(132): p150–153.