T_1s for Nothing and Flips for Free: Mapping Hyperpolarized Magnetization Decay with No Extra Data Collection

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As hyperpolarized (HP) media rise in prominence in both basic and applied science, quantification remains a challenge, because magnetization decays due to signal detection (RF pulses) and T_1 relaxation. Currently, there are no widely used methods to account for magnetization decay without added scans to calibrate flip angle and T_1. This calibration requires increased study time and consumes additional HP magnetization [1]. To make HP MR practical and quantitative, robust methods must be developed to correct magnetization decay without increasing experimental difficulty or cost and without wasting additional HP magnetization.

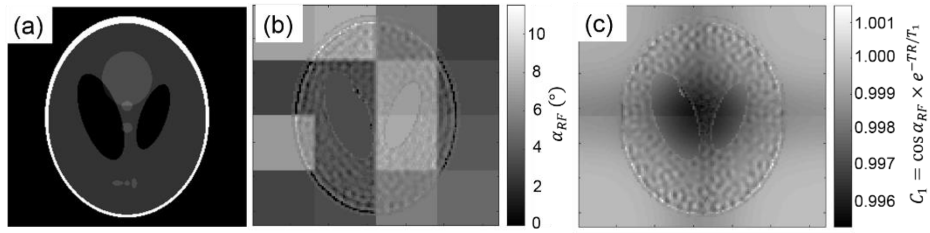

Fig. 1. ***(a)*** Digital phantom used for simulating HP signal decay and radial keyhole image reconstruction. ***(b)*** Flip angle (α_{RF}) map extracted from *(a)* decaying as in a sharply varying grid according to $cos\ \alpha_{RF}^{n-1}$. ***(c)*** HP decay including relaxation ($C_1 = cos\ \alpha_{RF}^{n-1} \times e^{-(n-1)TR/T1}$) extracted from *(a)* assuming smoothly varying flip angles and sharply varying T_1.

The secret to correcting magnetization decay may lie with the pulse sequence used for acquisition. For applications subject to motion artifact, (e.g., lung imaging), sequences that sample k-space using center-out trajectories have become common, because they oversample the center of k-space [2,3]. For hyperpolarized media, these "radial" sequences have the additional advantage of sampling the center of k-space (i.e., MR signal intensity) with each RF excitation. Thus, when imaging HP nuclei, magnetization decay dynamics are encoded in k-space simultaneously with spatial information. Herein, we propose a method by which hyperpolarized magnetization decay is obtained from raw MR image data without collecting any additional data collection.

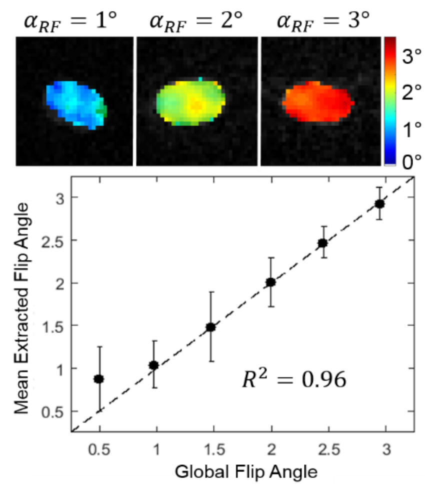

Fig. 2. ***Top:*** Flip angle maps of bags of HP ^{129}Xe gas obtained using radial imaging and keyhole reconstruction. Nominal flip angles are stated above images. ***Bottom:*** Mean of regional α_{RF} vs. global flip angle extracted by fitting k-zero decay. Bars are standard deviations of regional α_{RF}.

In short, we use a keyhole method [4] to create two under-sampled images from two temporal subsets of data acquired during a single radial scan (i.e. first N/2 scans and last N/2 scans). The ratio of the resulting images is then used to calculate the factor by which magnetization is decayed during each acquisition period, thus giving a voxel-by-voxel map of attenuation. This method was tested via simulation (Figure 1) and by imaging HP ^{129}Xe contained in Tedlar bags (Figure 2). In both cases, voxel-by- decay terms were accurately extracted using the radial keyhole method. Further, our method of decay quantification was successfully applied *in vivo*. While limited to human, HP ^{129}Xe ventilation MRI in this study (Figure 3), radial keyhole is a general approach for correcting magnetization decay and will improved image quality and quantitative accuracy in a wide range of HP MR experiments.

$$S = \frac{M_0 \sin\alpha_{RF}}{N}\frac{1 - {C_1}^N}{1 - C_1}$$

$$C_1 = cos\,\alpha_{RF} \times e^{-TR/T1}$$

$$S_0 = M_0 \sin\alpha_{RF}$$

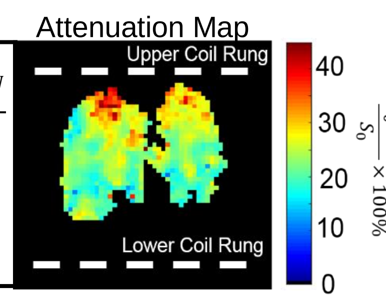

Fig. 3. Mapping HP magnetization attenuation. ***Left:*** Equations governing HP magnetization and signal intensity in a reconstructed radial image of a hyperpolarized substance. ***Right:*** Attenuation map $[(S_0 - S)/S_0]$ from a HP ^{129}Xe image of healthy human lungs (α_{RF} = 2.3°). Image was acquired using a 2-element saddle coil and a Philips 3T Ingenia scanner.

References

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