A Robust Method for Estimation of Regional Pulmonary Parameters in the Presence of Noise

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INTRODUCTION: Hyperpolarized helium-3 magnetic resonance imaging (HP ^{3}He MRI) is a powerful tool for analyzing pulmonary structure and function. It is capable of measuring the partial pressure of oxygen (P_AO_2) and oxygen depletion rate (ODR) in the lungs. Inherent noise in the image data can skew the estimation of these parameters, and thus limits the clinical usefulness of their estimation. Commonly used techniques for increasing the signal-to-noise ratio (SNR) in the image work by grouping adjacent voxels together into bins and averaging. This approach degrades spatial resolution and may exclude useful edge points from the analysis. This work presents a technique for simplifying data with principal component analysis (PCA) and clustering points nonspatially. This method, which is referred to here as PCA-based clustering, does not degrade spatial resolution and yields more accurate estimations of regional oxygen parameters in a simulated rabbit lung than the traditional binning technique.

METHODS: All animal studies were approved by the University of Pennsylvania's IACUC. The data was obtained from a New Zealand rabbit in a single imaging session. The animal was intubated with an endotracheal (ET) tube. Anesthesia was induced by a ketamine injection, and hourly injections throughout the experiment maintained the anesthesia. The rabbit was placed supine in a solenoid coil and inserted into the bore of a 1.5T clinical MRI scanner (Magnetom Sonata; Siemens Medical Solutions, Erlangen, Germany). HP ^{3}He gas was prepared in a prototype commercial polarizer (GE Healthcare, Durham, NC).

Immediately before imaging, a 60 mL tidal volume of gas consisting of helium and oxygen in a 4:1 ratio was delivered to the rabbit via the ET tube. A multislice 2D gradient echo sequence was used to acquire images with the following scanning parameters: FOV, 160 mm; ST, 7mm; repetition time/echo time, 6.2/2.8 milliseconds; resolution, 64x64; and scan delay, D*t*/*t*, 0.4/6 seconds. A single-acquisition method for estimating P_AO_2 and ODR was used, as previously described [1]. Using the data obtained from an image series taken within a breath hold, P_AO_2 and ODR were estimated. These estimated values were considered to be the "real" results, and the equations for P_AO_2 and ODR were solved backwards to obtain a "noiseless" image series. This noise-free synthetic data was used to assess the usefulness of the PCA-based clustering method. Noise was added to the synthetic image series so that SNRs ranging from 1000/1 to 3/1 were obtained. Noise corresponding to each SNR was added 100 times. P_AO_2 and ODR were estimated during each noise iteration using both traditional binning and PCA-based clustering methods. The first step in PCA-based clustering was creating an 8-dimensional data space from the noisy image data in which each point represented the signal intensity of a pixel at various time points. This space was projected into two dimensions by PCA. A K-means algorithm was used to cluster points in this reduced data space, and oxygen parameters were again estimated. The root mean square (RMS) error between the estimated value assigned to each voxel by the clustering algorithm and the "true" value of the voxel was calculated.

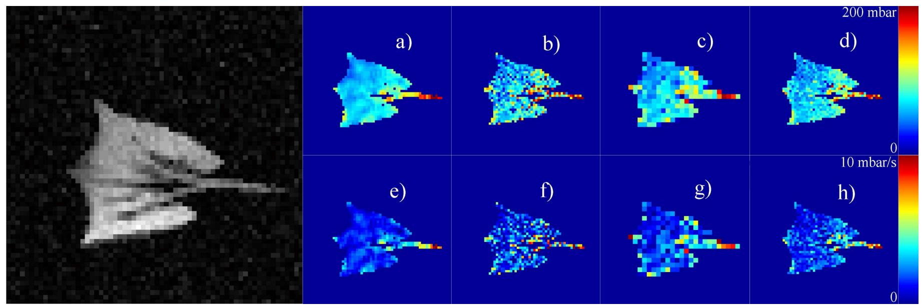

Fig. 1. Regional estimations of P_AO_2 (top row) and ODR (bottom row). The image at the left is a signal intensity image (SNR = 20/1) for reference. Frames a and e display "true" parameter maps derived from noiseless synthetic images. Frames b-d and f-h display estimations made with a pixel-by-pixel analysis, spatial binning (2x2 bins, 192 bins), and PCA-based clustering (192 clusters), respectively.

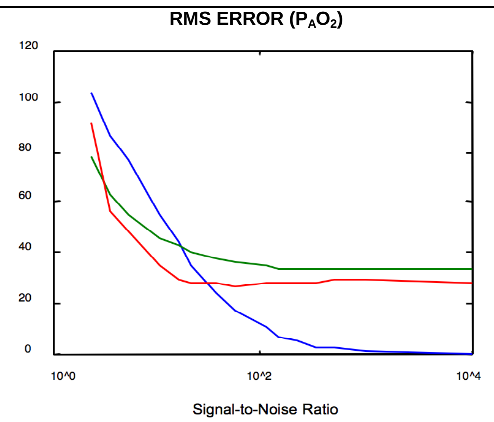

Fig. 2. RMS Error calculated between "true" value and estimated value for each pixel at various SNRs. Green line represents spatial binning, red represents PCA-based clustering, and blue is a pixel-by-pixel fit. 6 clusters are used for both spatial binning and PCA-based clustering. Error bars are too small to be visible.

RESULTS AND DISCUSSION: At high SNRs (between 1000/1 and 70/1), a pixel-by-pixel fit with no data clustering yields the most accurate results. However, at intermediate SNRs that are typically encountered in experimental data (between 70/1 and 10/1), the PCA-based clustering method is generally more accurate. When SNR is extremely low, the spatial binning method may give the most accurate results. A qualitative inspection of the images obtained when using the various methods shows that the PCA-based approach preserves spatial information and yields parameter maps that resemble "true" parameter values (Fig. 1). Even when a large number of spatial bins are used, there is a noticeable loss of anatomical detail. These results demonstrate that PCA-based clustering is an efficient method for increasing SNR without sacrificing anatomical detail. In a synthetic data set, it gave rise to more accurate estimations of regional oxygen parameters than existing techniques at SNRs typically encountered in imaging studies (less than 100/1 but higher than 10/1). It may be a valuable tool for analyzing noisy HP ^{3}He MRI lung data.

REFERENCE: [1] Fischer *et al*, Acad Radiol 12, pp. 1430-39.