Roemer-Optimal Reconstruction of Hyperpolarized 13C Cardiac Images with an 8 Channel Coil

William Dominguez-Viqueira[1], Benjamin Geraghty[1,2], Justin Y.C. Lau[1,2], Albert P Chen[3], and Charles H Cunningham[1,4]

[1]Imaging Research, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada, [2]Medical Biophysics, University of Toronto, Toronto, Ontario, Canada, [3]GE Healthcare, Toronto, Ontario, Canada, [4]Medical Biophyscis, University of Toronto, Toronto, Ontario, Canada

Target audience: hyperpolarized media and image reconstruction.

Purpose: Hyperpolarized ^{13}C substrates have become a promising tool to study real-time metabolic processes in the heart. Recently, extended coverage of the heart was demonstrated using rapid multislice imaging of hyperpolarized ^{13}C pyruvate and bicarbonate[1] using a single shot spiral pulse sequence and with a 5-channel receiver[2]. Roemer-optimal coil combination using a numerical model of the sensitivity maps[3,4] has been used to avoid wasting the limited polarization available for map measurements. The objective of this work was to extend this numerical estimation method to the 8-channel receiver array that will be used in human studies.. Pyruvate and bicarbonate images of the heart were acquired *in vivo* and reconstructed using Roemer-optimal channel combinations using both the simulated sensitivity maps and the sensitivity maps based on low-pass filtering and these are compared to a simple sum of squares.

Methods: A commercially available ^{13}C eight-channel 2-paddle receive-array was used in conjunction with a clamshell transmit coil (USA Instrument, Inc., Aurora, OH) on a GE MR750 3T MR scanner. *In vivo* images were obtained in pigs (25 kg) under an approved protocol. The injection was 15 mL of 160 mM pre-polarized [1-^{13}C]. for anatomical reference, cardiac-gated breath-held SSFP CINE images were acquired in sagittal view (TR = 4.2 ms, TE = 1.8 ms, FOV 24 cm, slice thickness 5 mm, spacing 5 mm, matrix size 224×224). Gated ^{13}C images of the heart were acquired in short and long axis (6 slices, single-shot 16384 samples, Tread = 64 ms, BW = 250 kHz, FA = 90°, 10 mm / 1 mm slice/gap, FOV = 24cm. Two slices were acquired each cardiac cycle in a 160 ms diastolic window[1].

The channels were combined using the Roemer optimal combination using Eq 1. Where N is the number of channels (8 in our case), S_k is the image from each individual channel, and C_k are the coil sensitivity coefficients.

$$\tilde{\rho} = \sum_{k=1}^{N} C_k^* S_k \Big/ \sum_{k=1}^{N} |C_k|^2$$

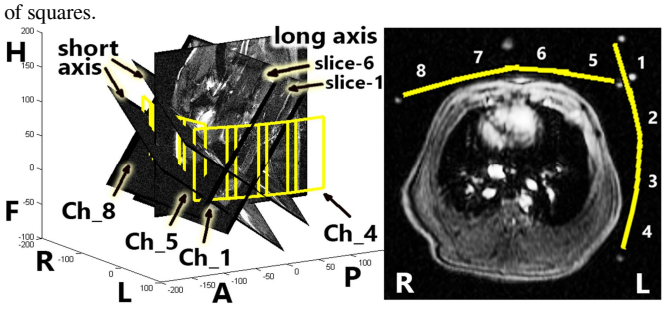

Fig. 1: Numerical space and coil position. **Right**: Axial slice showing the fiducial markers (white dots) and coil positions. **Left:** 3d position of all coils for maps calculation and slice positions for long axis and short axis slices of the

Coil coefficients were computed in Matlab (The MathWorks Inc., Massachusetts, USA) using a Biot-Savart model of the coils. Fiducial markers placed on the ^{13}C receiver coils were used to estimate coil positions in the proton images (Fig 1) and calculate 3D sensitivity maps of all eight receiver coils. For comparison, coefficients were also estimated from the central 10 × 10 kspace data points of the pyruvate images by applying a Hanning filter to each slice/channel and divided by the sum of squares of all channels. Both sets of maps were used for reconstruction using Roemer-optimal combining (Fig. 2 Roemer Biot-Savart and Roemer Low-pass filter). Also Sum of Squares of all channels was calculated for comparison (Fig. 2 Sum of Squares).

Results and Discussion: Figure 1 shows the receiver coils position defined by the yellow lines (only for visualization proposes); white dots in Fig 1. right are the signal from fiducial markers on the coils. 3D positioning of short and long axis slices of the heart are shown in Fig. 1 left as well as the 3D distribution of the channels in the image space used for the calculation of the sensitivity coefficients. Maps of the calculated coefficients agreed with the phantom images acquired.

Figure 2 shows the images of *in-vivo* hyperpolarized ^{13}C pyruvate and bicarbonate in the pig heart. To facilitate the comparison, each set of slices from the different methods were normalized to by dividing all slices with the maximum signal value found for each method. As shown in Fig. 1 left, slice 1 is at the back of the heart, distal to the coils, while slice 6 is closer to the chest wall and coils. As expected, the signal intensity is very similar for all methods for slices close to the coils (i.e slice 5 and 6), while for slices farther from the coils (slices 1, 2 and 3) the Roemer-optimal combining using the estimated maps gives higher signal in these distal areas comparing to the other 2 methods (see white arrows slice 3). Note that using the coefficients calculated with the low pass filter gave signal dropout at the back of the heart (see arrows slice 2), likely due to inadequate signal for map calculation in that area. This is not an issue for the Biot-Savart calculated coefficients since they don't depend on the image. The best results were obtained with the estimated Biot-Savart sensitivity maps, giving signal intensity that was more homogeneous throughout all slices and with up to 100% increase in SNR measured in distal areas of the heart (slices 1, 2 and 3). The method using the low-pass-filter coefficients has the disadvantage of depending on the signal intensity in each slice to estimate the coil coefficients, and in hyperpolarized experiments the signal is typically varying in time and is not reliable. Similar results were obtained for bicarbonate images but due to space we only show the Roemer Biot-Savart results (Fig. 2. last row). Due to this reason the Biot-Savart method was expected to perform better, provided that the coil positions could be accurately determined using the fiducial markers.

Conclusions: Roemer optimal reconstruction using numerically estimated coefficients using Biot-Savart resulted in better image quality than using a low-pass-filter of the acquired images. SNR improvements of up to a 100 % in areas closer to the base of the heart were demonstrated by using the Roemer reconstruction, as compared with sum-of-squares. This coil array and image reconstruction scheme may be suitable for human cardiac ^{13}C studies in the near future.

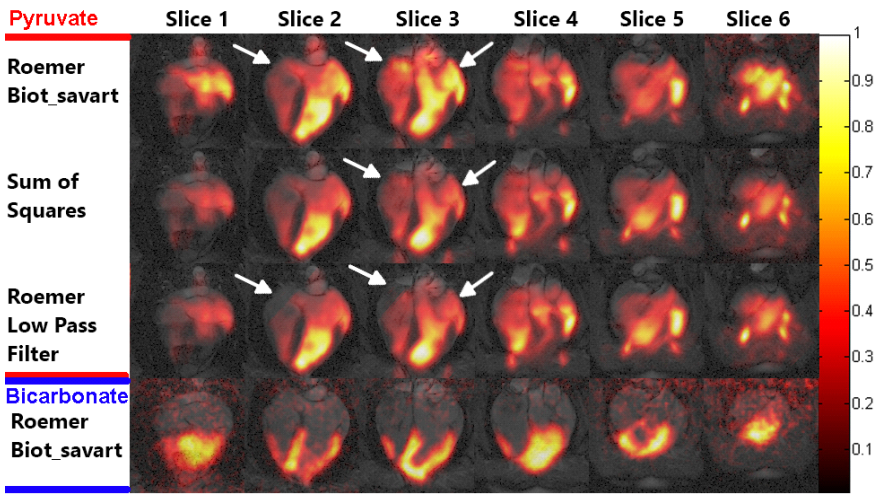

Fig. 2: *In-vivo* hyperpolarized ^{13}C pyruvate images of the pig heart (long axis) for all three reconstruction methods. All ^{13}C images were overlaid onto the corresponding anatomical images (Slices 1 through 6 from right to left). SNR improvement and signal homogeneity are noticeable in the Roemer method using estimated Biot-Savart coefficients (top row).

References: **1-** Lau et al. Rapid multislice imaging of hyperpolarized ^{13}C pyruvate and bicarbonate in the heart. MRM (64) 2010.

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4- Roemer, P.B., et al., The NMR phased array. MRM, 1990. 16(2): p. 192- 225.