A five channel receive array for cardiac imaging using Hyperpolarized ^{13}C at 3T.

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Introduction

Hyperpolarized ^{13}C substrates have become a promising tool to study real-time metabolic processes *in vivo*, particularly in the heart. This was first shown using hyperpolarized ^{13}C pyruvate to characterize cardiac metabolism noninvasively in the pig using a single slice chemical shift imaging (CSI) technique [1]. Recently, rapid multislice imaging of hyperpolarized ^{13}C pyruvate and bicarbonate was demonstrated by Lau et al. [2], using a single shot spiral pulse sequence and a single-channel receiver system. For clinical application, it is important to retain the demonstrated SNR performance, but with improved coverage so that the entire myocardium can be imaged. Surface coils offer considerable gains in SNR compared to whole-body coils, but their performance is limited to the volume nearby and up to a distance of about one radius [3]. Multi-channel receiver systems can provide similar SNR performance to a single surface coil, but with increased coverage. The objective of this work was to design and characterize a five channel receiver array for hyperpolarized ^{13}C imaging of in vivo cardiac metabolism in the pig. Sensitivity maps of the coil array were computed and compared to a commercially available single channel surface coil. Hyperpolarized ^{13}C pyruvate images of the heart were also obtained to estimate the SNR *in vivo*.

Methods

Three dimensional sensitivity maps of both receiver configurations (i.e single-channel and five-channel array) were computed in Matlab (The MathWorks Inc., Massachusetts, USA), by applying Biot-Savart law, and compared. A commercially available dual-tuned ^{1}H/^{13}C surface coil (Rapid Biomedical GmbH) was used as the single channel gold standard. For the 5-channel configuration, a commercially available four-channel cardiac array (GE Healthcare, Waukesha, WI) was tuned to ^{13}C at 3T (i.e. 32.14 MHz) and use simultaneously with the dual-tuned ^{1}H/^{13}C surface coil. The same ^{13}C birdcage transmit coil (Rapid Biomedical GmbH) was used for all ^{13}C experiments. All coils were connected to the scanner through an RF interface-box with 8 pre-amplified receiver channels (Clinical MR Solutions, WI, USA).
All imaging experiments were performed on a GE MR750 3T MR scanner (GE Healthcare, Waukesha, WI). *In vivo* images were obtained in a specific pathogen free pig (25 kg) under a protocol approved by the institutional animal care and use committee. The injection was 15 mL of 160 mM pre-polarized [1-^{13}C] pyruvate as described in [2]. For anatomical reference, cardiac-gated breath-held SSFP CINE images were acquired in the short-axis view (TR = 4.2 ms, TE = 1.8 ms, FOV 24 cm, slice thickness 5 mm, spacing 5 mm, matrix size 224×224) using the dual-tuned ^{1}H/^{13}C surface coil. *In vivo* hyperpolarized ^{13}C images of the heart were acquired using the single-shot dual-gated spiral pulse sequence (with 36 cm FOV, 10 mm in-plane resolution, 1 cm slice thickness, 8192 samples over 32 ms with 250 kHz sampling [2]).

Results and Discussion

Figure 1 shows the sensitivity map for the single channel surface coil (a, b and c) and the 5-channel array configuration (d, e and f), as simulated in Matlab. The yellow lines represent the RF coils. Due to the planar geometry of the coil the sensitivity decreases with the distance as shown in Fig. 1 (a, b and c), hence the signal drops below the noise floor for the distal regions of the heart. By using the five channel array (Fig. 1 d, e and f) the sensitivity can be dramatically improved through the entire heart, permitting the improvement of the SNR in the posterior part of the heart between 3 and 4 times as seen in Fig. 1 (please note color scale).

Figure 2 shows hyperpolarized [1-^{13}C] pyruvate and bicarbonate images of a pig heart *in vivo,* using both receiver configurations. To facilitate the comparison all images where divided by the standard deviation of the noise in the background to show SNR maps. As expected the SNR in the areas close to the chest wall (i.e. where the surface coil is located) is quite similar using both coil configurations. Note similar SNR scales in the right ventricle (pyruvate images) and in slices closer to the apex (last two slices on the right) are almost the same for both coil configurations for each metabolite. The SNR differences were more apparent on slices closer to the base of the heart as expected by the simulations. A 15 to 20% increase in SNR was measured in distal areas of the heart using the 5-channel configuration and a sum-of-squares reconstruction as shown by the color scale in Fig.2 (first 2 slices on the left). Even though a 20% increase in SNR is a modest improvement, note that the investigated areas are relatively close to the chest wall where the single channel surface coil still provided good sensitivity. Furthermore, pig anatomy is quite different from humans in that the heart is much further from the torso posterior, so that posterior coils have little benefit. In the future, slices closer to the base of the heart or long axis images, will be compared and are expected to show a larger difference as shown in the simulated maps in Fig 1.

Conclusions

A single channel and a 5-channel array ^{13}C receive coil were simulated in Matlab and compared with *in vivo* measurements. SNR improvements of 15 to 20 % in the slices closer to the base of the heart, were demonstrated by using the 5-channel coil array in this work. This coil configuration will allow imaging of the most distal areas of the heart with better SNR than using the 1-channel coil. This coil array may be suitable for human cardiac ^{13}C studies in the near future. Also with the multichannel data we will investigate parallel imaging techniques for hyperpolarized ^{13}C.

References:

1- Golman et al. Magn Reson Med (59) 2008.
2- Lau et al. Magn Reson Med (64) 2010.
3- Dominguez-Viqueira et al. Magn Reson Med. August 2012.

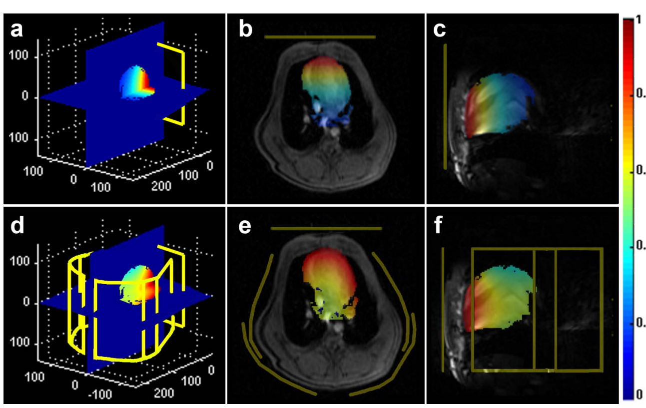

Fig. 1: Magnetic field simulation for the single surface coil (**a**, **b** and **c**) and the 5-channel array coil (**d**, **e** and **f**). **a** and **d** are the 3D field distribution. **b** and **e** are the field distribution overlaid to an axial anatomical image of a pig heart. Similarly **c** and **f** are the sagittal field distribution.

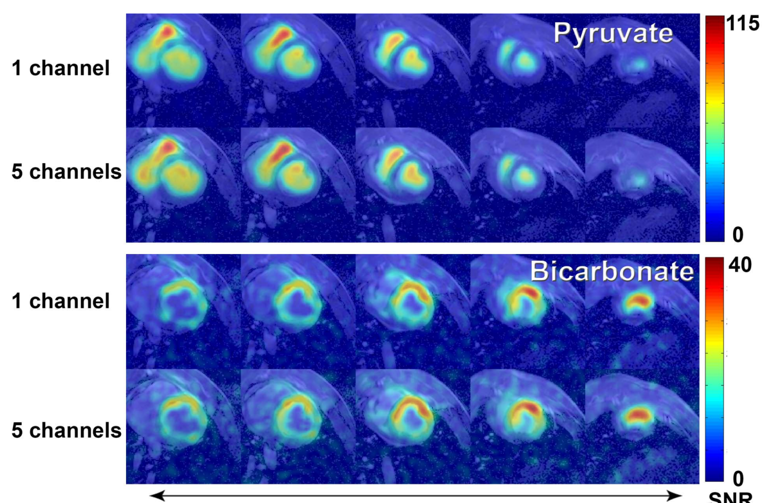

Fig. 2: *In-vivo* hyperpolarized ^{13}C images of the pig heart from base (right) to apex (left). Pyruvate images in the top row and bicarbonate bottom row. Top half of each row are images obtained with the single-channel coil and bottom half with the 5-channel array. SNR differences in the posterior aspect of the heart are noticeable.