Limited FOV MR thermometry using a local cardiac RF coil in atrial fibrillation treatment

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Introduction

Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice and a major cause of stroke. It affects quality of life and continues to be associated with increased mortality and significant morbidity despite advances in antiarrhythmic drug therapy. Terminating and/or suppressing atrial fibrillation can be done by creating lesions around the Pulmonary Vein ostia within the left atrium [1, 2] using radiofrequency (RF) ablation. The formation of these lesions (extent and impact) cannot yet be properly visualized either in the current clinical procedure or under the developmental alternative MRI-guided procedure.

MRI could offer more than post-ablation visualization and RF catheter guidance such as applying MR thermometry [3] during the ablation procedure allowing the visualization of the lesions as they form. This would further improve the outcome of this critical arrhythmia treatment. However, MRI of lesion formation and thermometry within the heart must be acquired rapidly to overcome heart motion. In order to achieve this goal the development of a local RF heart coil that would allow the acquisition of coil-sensitivity limited field of view (FOV) MR lesion or temperature images in less than 200 ms per image with high sensitivity is required and was investaged in this study.

Figure 1: Local cardiac coil. It includes one tuning capacitor, one matching capacitor, and one PIN didode in series with a small hand-wounded inductor for active decoupling.

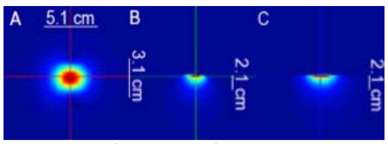

Figure 2: Signal profile maps acquire with the local cardiac coil in the three orthogonal directions of a large homogeneous agar phantom: A. Coronal view; B. Sagittal view; C. Transversal view. The sensitivity region of this coil was approximately a 5-cm-by-2-cm-by3-cm ellipsoidal shape.

Methods

A 2-cm diameter single loop coil was designed to fit within the left atrium (LA) of a pig. Tinned copper 16 AWG wire was used to form the inductor loop of the coil for availibility, ease of construction, and testing. The coil was made receive-only using the minimum number of components in the loop to keep the coil as small as possible (Fig. 1). It was coated with at least 3 thin layers (1-mm thick total) of polydimethylsiloxane (PDMS) to allow its use *in vitro* and *in vivo*. The coil characteristic changes were assessed throughout the development as the diferent coils were tuned and matched appropriately for either the inner volume of the LA, the heart's surface, or equivalent phantoms.

The coil was further tested in the MR enviroment to assess the feasibility of MR thermometry measurements during RF ablation procedures on both static and moving phantoms. A large phantom was composed of agar, sodium chloride, and copper sulfate for sample uniformity and coil characteristics determinations, whereas pieces of meat were used to mimick *in vivo* conditions. Pumping air in and out of a balloon underneath the phantoms created the motion.

MRI scans were performed on a 3T TIM Trio scanner and a 3T Verio scanner (Siemens Healthcare, Erlangen, Germany) using Gradient Echo (GRE) pulse sequence techniques for both signal-to-noise ratio (SNR) determination and temperature measurement. Pre-ablation images were used as reference for the temperature measurements. The parameters used for SNR determination were similar to those used for MRI thermometry to allow a functional comparison (TR= 13.5 ms, TE= 6.59 ms, pixel size 1.5 x 1.5 mm^2, 3-mm slice). The limited and large FOV were 32 x 256 mm^2 and 152 x 256 mm^2, respectively. Both magnitude and phase images were acquired for every measurement. The magnitude images were used to generate SNR maps and profiles in the three orthogonal directions (Fig. 2) whereas the phase images were used to generate longitudinal thermal maps (Fig.3a). The phase image data was reconstructed and processed with an in-house MATLAB (Version 7.9; Mathworks, Inc.; Natick, MA) program to allow the display of the temperature measurements and their relative changes over time compared to the reference frame (Fig 3b).

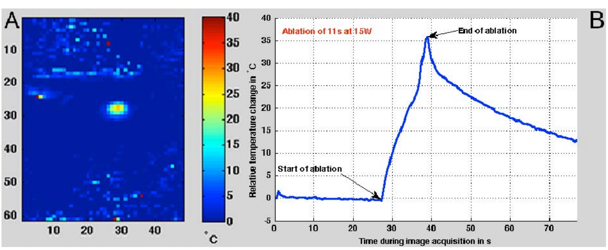

Figure 3: Limited FOV temperature measurement in a piece of meat: A. temperature map in the meat in the perpendicular plan to the catheter tip position at the end of the RF ablation; B. temperature evolution over time in 1 pixel at the center of the ablation as it is occurring and beyond.

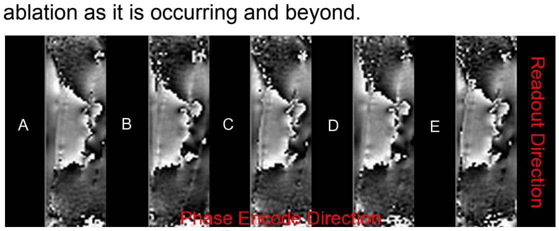

Figure 4: Limited FOV phase images in a moving phantom throughout time without gating: A through E are phase images acquired during a moving cycle in the phase encode direction (1 Hz). The limited FOV allows the fast acquisition of the images reducing aliasing and motion artifacts.

Results and Discussion

The local coil was tuned at a higher frequency than ^1H resonance frequency (123.23 MHz at 3T) to compensate for the shift induced by the PDMS coating and the loading of the coil. The match was also optimized to be lower than -20 dB when the coil was coated and loaded. The insertion of the coil in a live pig LA has shown that the resonance frequency of the coil does not shift with the cardiac cycle. The match variations were cyclic, but minimal and remained consistently lower than -20 dB.

The SNR gain attainable with a static phantom using the local coil compared to the chest and spine surface coil combination was 26 times for identical scan parameters and time. The coil signal profile was uniform (Fig. 2) over a region larger than a standard RF ablation burn (0.5-to-1-cm in diameter and 1-to-3-mm deep), but smaller than the sensitivity region of the chest and spine surface coils. The local coil's small sensitivity region allowed limited FOV imaging acquisition at least 4 times faster than the surface coil combination could allow without aliasing.

Stable MR phase images (necessary to obtain temperature maps) were acquired within 230 ms on a limited FOV imaging volume (< 3 cm in the phase encode direction) with a local RF coil in a moving phantom (Fig. 4). The motion was in the phase encode direction with an amplitude between 0.5 and 0.75 cm.

Conclusions

The local cardiac coil was successfully constructed, coated, and used to perform MR thermometry in static and moving phantoms. This coil showed a 26-fold improvement in sensitivity and at least a 4-fold decrease in acquisition time compared to the surface coil arrays used at 3T. Ongoing work is now focused on 1) assessing the accuracy of the MR thermometry method, 2) testing the coil *in vivo*, and 3) assessing the requirements for the development of catheter-mounted local coils.

References [1]. Marrouche, N.F., et *al.*, J Am Coll Cardiol, 2002. 40(3): 464-74. [2]. Marrouche, N.F., *et al.,* Circulation, 2003. 107(21): 2710-6. [3]. Rieke, V., et *al.*, JMRI, 2008. **27**: 376-390.

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