Intra-Cardiac MRI Catheter for EP Ablation Monitoring: Preliminary Studies

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PURPOSE

3D Myocardial Delayed Enhancement (3D-MDE) has been shown to accurately depict scar tissue created by catheter-delivered radio-frequency ablation (RFA) for the treatment of atrial fibrillation [1]. In animal models, it was shown [2] that respiratory navigator-echo-triggered 3D-MDE can be used intra-procedurally to assess the completion of left-atrial ablation lesions, although the resolution required (~1.5x1.5x1.5 mm^3), requires 10-15 minute scans, using a commercial surface cardiac-array, negatively impacting procedure workflow. In previous work [3], we showed that a catheter-mounted basket-shaped intra-cardiac MRI (ICMRI) imaging coil can provide ~10x the signal-to-noise ratio (SNR) of surface coils over a 4x4x3cm^3 FOV. Images made with that 1st generation ICMRI, however, were strongly affected by motion, and additionally, it could not be inserted in tandem with an Electrophysiology (EP) ablation catheter into the left atrium. Here we report on a 2nd generation ICMRI catheter that is intended to be used in conjunction with an EP RFA catheter, and possesses integrated motion compensation. The ICMRI catheter is designed to be inserted over an EP catheter, into the left-atrium, and the two navigated to the ablation region together. In the atrium the ICMRI is then used to monitor the thermal-dose delivery with a greater SNR and sensitivity than is possible with external coils. If successful, ICMRI can reduce the imaging overhead associated with MR imaging, allowing on-line RFA monitoring, possibly reducing the 30-50% recurrence rate of AF post-ablation [4], by ensuring complete and permanent electrical-circuit isolation. The new catheter incorporates imaging coils, a tetrahedron MR-tracking array, and prospective motion correction, and extends concepts that we developed earlier for endo-rectal prostate imaging [5],.

METHODS

An expandable ICMRI catheter tip (Fig. 1) was constructed using a plastic (PTFE) mesh, on which four 1-mm-diameter MRI-tracking coils and a larger imaging coil were mounted. Using a novel manifold push-pull mechanism, this tip can be expanded from a 4-mm folded diameter (Fig. 1 A) to 20-mm (Fig 1. B, C), deploying the 4-microcoil tracking tetrahedron and expanding the imaging loop-coil, which increases it's RF-lobe size and depth-sensitivity. Three thin 40-AWG windings were used in the loop coil. All five coils are tuned, matched and decoupled using micro-electronics mounted on the distal shaft, with RF signals led up the shaft in 46 AWG coaxial cables. The catheter shaft has a 3-mm open lumen, so that 8-French EP ablation catheters can be inserted through it. SNR testing was performed in a 1.5T scanner by placing ICMRI in an array with a 5" surface coil, placed 10cm from the target, and using Fast Spin Echo and Gradient Echo scans. Integrated motion-testing was performed with a modified 3D-MDE sequence employing an MR-tracking sub-sequence, providing 20 frames-per-sec, 1.2x1.2x1.2 mm^3 resolution translation/rotation motion-detection, and using RT-Hawk (CardioVista, Palo Alto, CA) for real-time motion compensation. Modified 3D-MDE details are contained in a separate abstract (Qin et. al). Motion compensation was tested on a moving table using an *ex-vivo* pig heart. 3D-MDE was conducted in a swine chronic infarct model [3] at 1.2x1.2x3mm^3 resolution.

RESULTS & CONCLUSION

Testing of the 2nd generation ICMRI showed that the catheter is MRI compatible (Fig. 2A), and does not produce susceptibility artifacts. SNR testing (Fig 2. A,B) demonstrated a 10x SNR gain over a 5" coil in a 2.5x2.5x1.5 cm^3 FOV, although the optimal FOV for visualizing atrial EP ablation is somewhat larger (3x3x3mm^3) than achieved with the 2-cm diameter loop coil, suggesting that use of a larger loop coil is desirable (a larger coil is currently under construction). Testing with motion phantoms provided an MR-tracking SNR of >2000 using the integrated tetrahedral array, with prospective motion-compensated images approaching the resolution of motionless images. In swine imaging, single breath-hold ventricular MDE (Fig. 2 C) was performed, detailing infarct borders in <20 sec imaging times. In conclusion, a novel 2nd generation ICMRI catheter has been developed, allowing for motion-compensated high-resolution MRI imaging during RF ablation. The catheter will be used in MR-monitored ablation of swine AF models.

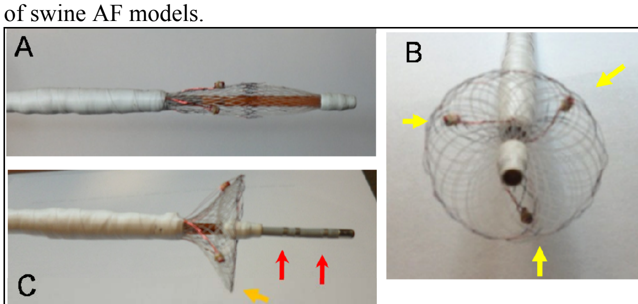

Figure 1: *ICMRI catheter. (A) Side view of distal end in the folded configuration. Manifold used for expanding tip can be seen. All catheter components are made of bio-compatible plastic and catheter is coated with an anticoagulant film. (B) Front view of the expanded catheter, showing 15-mm-diagonal tetrahedral positions of three 1-mm-diameter tracking coils (yellow arrows). The 4th tracking coil is on the catheter shaft. The PTFE mesh-skeleton is mechanically designed for repeatable deployment and folding, while carrying the coils' load. (C). Side view of the expanded ICMRI catheter with EP ablation catheter (red arrows) inserted. 20-mm diameter expanded loop imaging coil (orange arrow) projects a field towards region ablated by EP catheter, allowing real-time monitoring of ablation lesion.*

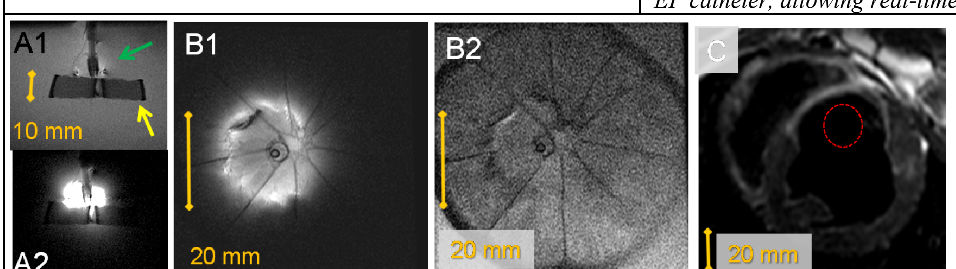

Figure 2: *(A-C) Testing ICMRI SNR with lemon phantom, using an array combining ICMRI with 5" surface coil. (A) GRE Surview along ICMRI axis taken with 5" coil (A1) and ICMRI (A2) showing a lemon slice (yellow arrow) suspended below expanded ICMRI (green arrow). ICMRI image (A2) shows bright lobe pattern of coil. FSE slice taken perpendicular to (A), 5 mm from distal tip, showing ICMRI (B1) versus 5" (B2) coil.* ICMRI provides 10x SNR over *~2.5x2.5x1.5 cm^3 FOV.*

(C) Swine chronic left-ventricular (LV) infarct. ICMRI w/cardiac array MDE imaging. Position of ICMRI coil is denoted (red dots), so nearer regions of LV are brighter

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REFERENCES:[[1]Peters et al., *Radiology* 2007, [2] Schmidt et al., *Circulation Arrhythmia and EP* 2009, [3] Schmidt et al. , *AHA scientific sessions* and *Circulation* 2004,[4] Cheema et al, *Amer. J. Cardiology* (2007), [5] Qin et al., *ISMRM proceedings* 2010.