Real-time MRI Guided Cardiac Cryo-ablation

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Target Audience: Scientists and clinicians interested in interventional MRI for cardiac RF and cryo-ablation procedures.

Purpose: Cardiac cryo-ablation is being increasingly used for treatment of atrial fibrillation and ventricular tachycardia. However, reported success rate of the procedures is moderate and serious complications (pulmonary vein stenosis, esophageal fistula, phrenic nerve and lung tissue injuries) are possible. The main causes of procedure failure are tissue recovery and gaps in ablation. Many complications may be attributed to the larger than desired extent of freeze zone. The extent of freeze zone and lesion permanency cannot be accurately evaluated by electro-physiological measurements. MRI based cryo-ablation can achieve higher success rate and reduce complications by real-time monitoring of the extent of cryo ablation and validation of tissue destruction intermediately through the procedure, and performing targeted re-ablation in acute settings if it is required. In this study, feasibility of MRI guided cardiac cryo-ablation procedure was studied.

Methods: MRI guided cryo-ablation studies were performed in canines (n=3, mean weight of 35 kg) according to protocols approved by the local IACUC. Lesions were created using two prototype MR-compatible cryo-ablation devices built for animal use: cryo-catheter with 8 mm tip and 28 mm diameter cryo-balloon (Medtronic CryoCath, Montreal, Canada). The studies were performed on a 3T Verio scanner (Siemens Healthcare, Erlangen, Germany) with real-rime (RT) MRI guidance provided by the BEAT-IRT sequence. The main steps of the MRI guided cryo-ablation procedure were as follows. Cryo-catheter was advanced into the right ventricle (RV) via the femoral vein access under RT-MRI guidance. The catheter was positioned on RV septal wall and catheter tip-tissue contact was validated. Cryo-ablation was performed for 4 minutes with simultaneous MRI monitoring of the freeze zone. After unfreezing, the catheter was withdrawn from the animal and MRI compatible cryo-balloon was advanced into the right atrium (RA). The balloon was positioned at the superior vena cava (SVC) – RA junction and inflated (Fig. 1a). 10-15 ml of 10% diluted solution of Gd-BOPTA (Bracco Diagnostic Inc., Ponceton, NJ) was injected from tip of the balloon to confirm SVC occlusion (Fig. 1b). In the case of partial occlusion, balloon was deflated, re-positioned, inflated, and occlusion was re-validated. In the case of complete occlusion, ablation was initiated and the junction was frozen for 3 minutes with simultaneous MRI monitoring of the freeze zone (Fig. 1c-e). After unfreezing, the balloon was de-inflated and withdrawn from the heart. 3D T1-weighted imaging was performed to assess the ablations and possible complications (Fig. 1f). Contrast (0.1 mmol/kg of Gd-BOPTA) was injected and 3D LGE-MRI was acquired to validate the ablations (Fig. 1g). At the end of the study, the animal was euthanized and the heart was extracted for macroscopic examination.

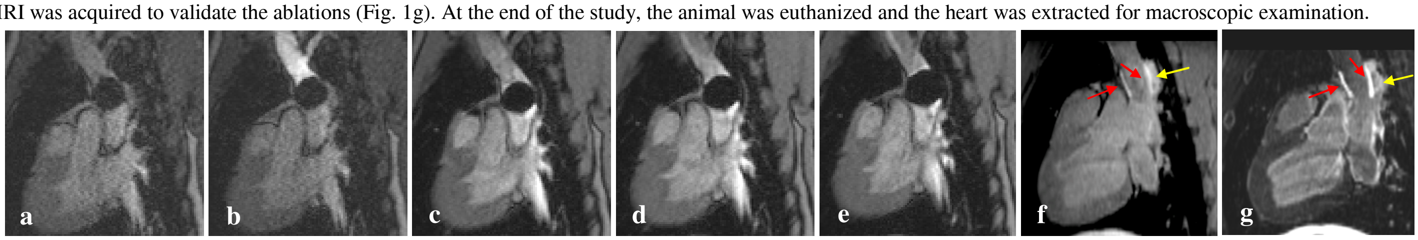

Figure 1. MRI guided cryo-ablation at SVC-RA junction. (**a**-**b**) Validation of SVC occlusion by cryo-balloon (**a**) pre contrast, (**b**) after contrast injection; (**c**-**e**) Real-time visualization of 3 minutes cryo-ablation: (**c**) pre, (**d**) 1 minute freeze, (**e**) 3 minute freeze. (**f**-**g**) Assessment of the ablation by 3D T1w and 3D LGE-MRI: (**f**) T1w (0.03 mmol/kg of Gd-BOPTA, 8 minutes after ablation) and (**g**) LGE (0.13 mmol/kg of Gd-BOPTA, 24 minutes after ablation). Red arrows indicate circumferential ablation at SVC-RA junction, yellow arrows indicate injury to the lung tissues adjacent to the junction.

Imaging protocol included RT-MRI, 3D T1w, and 3D LGE sequences. The parameters for the different scans were as follows: RT-MRI: 2D turbo-FLASH sequence with resolution=1.8x2.4 mm, slice thickness=4 mm, TR/TE=3.5/1.5 ms, flip angle=12°, acceleration factor R=2, 4 frames per second; 3D T1w: respiratory navigated, ECG triggered, saturation recovery prepared 3D GRE with resolution=1.25x1.25x2.5 mm, TR/TE=2.8/1.3 ms, flip angle=17°, TI=150 ms, R=2; 3D LGE: respiratory navigated, ECG triggered, inversion recovery prepared 3D GRE with resolution=1.25x1.25x2.5 mm, TR/TE=3.1/1.4 ms, flip angle=14°, R=2, and TI=250-330ms.

Results: Figure 1 illustrates the main steps of cryo-ablation of SVC-RA junction. Significant increase in freeze zone was observed during 3 minutes cryo-ablation. Diameter of freeze zone increased from 25 mm at start of the ablation (Fig. 1c) to 33 mm at end of ablation (Fig. 1e). T1w images acquired 8 minutes after the ablation demonstrated circumferential ablation with no gaps at SVC-RA junction (Fig. 2a-b). Injury to lung tissues adjacent to the ablation site was detected (Fig. 2a-b). It should be noted that good contrast between injured and normal tissues in these T1w images was achieved using a very small dose of contrast (0.03 mmol/kg) injected for validation of SVC occlusion. LGE images acquired after additional contrast injection (0.1 mmol/kg) demonstrate high contrast between ablated and normal tissues (Fig. 2c-d). SVC-RA ablation and injury of adjacent lung tissue detected by T1w and LGE-MRI were confirmed by tissue pathology (Fig. 2e-f). Circumferential ablation with no gaps at SVC-RA junction was achieved in two animals. In one study, cryo-ablation was aborted because of equipment malfunctioning.

Successful focal cry-ablations of RV septal wall were achieved in all animals. Figure 3 illustrates focal 4-minute cryo-ablation of RV wall. Diameter of freeze zone increases during the first minute of freeze (Figs. 3a-b) and stay about the same later during freeze (Figs. 3c-d). Dimension of freeze zone is well correlated with LGE-MRI (Fig. 3e) and tissue pathology.

Discussion and Conclusion: MRI based cryo-ablation system was implemented and validated in animal studies. The system allows real-time catheter navigation, confirmation of catheter tip–tissue contact and vessel occlusion by cryo-balloon, real-time monitoring of a freeze zone, and intra-procedural assessment of lesion formation and collateral damage. Additional studies are planned to validate feasibility of the proposed technique to pulmonary vein isolation – the main component of catheter ablation treatment for atrial fibrillation.

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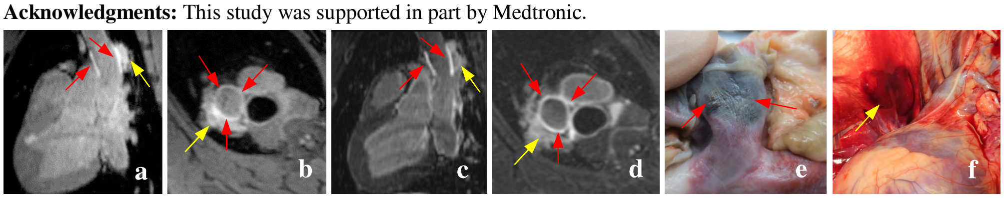

Figure 2. Assessment of SVC-RA junction ablation. (**a**-**b**) T1w MRI: (a) sagittal and (b) axial views; (**c**-**d**) LGE-MRI: (c) sagittal and (d) axial views; (**e**-**f**) Tissue pathology: (**e**) SVC-RA lesion, (**f**) injury to lung tissue. Red arrows indicate circumferential ablation at SVC-RA junction. Yellow arrows indicate injury to lung tissue.

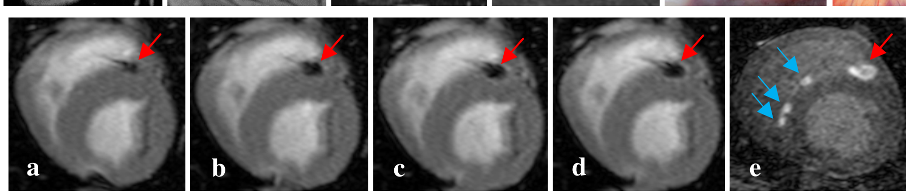

Figure 3. Cryo-ablation of septal wall of the right ventricle using MRI compatible cryo catheter: (**a**) pre, (**b**) 1 minute freeze, (**c**) 2-minute freeze, (**d**) 4-minute freeze, (**e**) LGE-MRI demonstrating acute lesions created using cryo (red arrow) and RF (blue arrow) catheters.