ASSESSMENT OF MYOCARDIAL RADIOFREQUENCY ABLATION LESIONS WITH 3D HIGH RESOLUTION FREE-BREATHING T2 MAPPING

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Introduction: Radiofrequency ablation (RFA) has become first-line therapy for many cardiac arrhythmias. Differentiating between viable myocardium, pre-existing scar and injured tissue (necrosis or edema) in both ventricles and atria following RFA can help in predicting the recurrence of arrhythmias. High-resolution MR imaging techniques such as late gadolinium enhancement (LGE) are well-established for the delineation of lesions.[1] Lesions are depicted with a dark non-enhancing core, surrounded by an enhancing boundary. More recently, quantitative techniques such as T2 mapping have been demonstrated for the evaluation of acute injury.[2-4] Here we present, high-resolution, 3 dimensional (3D) whole-heart free-breathing T2 mapping for the post-procedural detection of RF ablation lesions and correlate the results to high-resolution LGE *and ex vivo* validation.

Purpose: To validate quantitative assessment of RFA lesion size using high-resolution free-breathing T2 Mapping.

Methods: *Animal Model:* Under an IACUC-approved protocol, RF ablation lesions were induced in Yorkshire swine (N = 6, 80-100 lbs). For all animals, imaging was performed on the day of ablation, within 2 hours. Three animals were sacrificed after imaging. The remaining 3 animals were imaged again at days 2 or 4,7,14, and 21 post RFA. On the last day of imaging, all animals were given the same dose of Gadolinium-based contrast (Magnevist, Berlex, 0.02 mL/kg) as used for in vivo PSIR-LGE, and sacrificed 20 min post infusion. The hearts were arrested with KCL and after the excision, the ventricles were filled with rubber (Task5™) to keep the heart in the natural unloaded shape and improve *in vivo* to *ex vivo* registration. To avoid sample dehydration and susceptibility artifacts generated from the tissue-air interface, the heart was submerged in perfluorocarbon, (Fluorinert-77, 3M). After imaging the sample was fixed in 10% buffered formaldehyde for future histopathological analysis. *Ex vivo* images were used as a gold standard for lesion location, and segmented using Seg3D2. *RFA Procedure:* A detailed geometry of the left and right ventricles was acquired by the EnSite NavX system (St. Jude Medical, St Paul, Minnesota). Using a 4 mm tip 7F non irrigated ablation catheter and a clinical RF generator (Atakr, Medtronic, Minneapolis, Minnesota) single RF lesions were created along the endocardial surface, primarily in the LV, but also in the right ventricle (RV). Ablation lesions were created in a linear interrupted fashion using a power-controlled mode at 15-30 W for 30s each. All ablation sites were tagged using the EnSite NavX system. In one animal, a new series of RF ablation lesions was created on Day 21 post initial ablation, and before imaging, creating a model with both old and new lesions. *Imaging Protocols:* All imaging used an Achieva 3T TX system (Philips Healthcare, Best, Netherlands) and a 32-channel cardiac phased array (InVivo, Gainsville FL). 2D Breath-hold T2W (Black-blood T2-STIR)[5] and 3D whole-heart free breathing T2-mapping[2] of the ventricles were carried out before the injection of contrast agent (0.2 mmol/kg, Magnevist). Three interleaved volumes were acquired with T2Prep TEs = 0, 25, 45 ms (3D T2-mapping imaging parameters: TR/TE 4/1.2 ms, flip angle 18°, voxel size 1.25×1.25×5.0 mm^3 interpolated to 0.98×0.98×2.5 mm^3). Phase sensitive inversion recovery[6] (PSIR-LGE) using an independently respiratory-navigated sequence[7] was acquired post infusion (3D PSIR imaging parameters: TR/TE 5.6/2.7 ms, flip angle 18°, voxel size 0.75-0.99×1.27×3.0 mm^3 interpolated to 0.74×0.74×1.5 mm^3). T1-W GRE MRI was performed (acquired resolution 0.25x0.25x0.50mm, TE=2.3ms, TR=12ms, scan duration: 1hr) as an *ex vivo* correlate to LGE. *Post processing:* 3D T2 maps were calculated per voxel using linear regression of the log-transformed T2-prepared volumes. 3D T2 maps from the manually segmented left ventricle (LV) are represented in 2D using bull's eye plots with 90 radial segments per slice and spanning whole LV. Images were manually registered for small shifts present between scan sessions.

Results: RFA lesions were easily detected by T2 Mapping, as shown in Figure 1. Low power (or low heat dose) lesions were also detected. These lesions faded over the 3 week period of imaging (Figure 2, inferolateral red arrow). Most edema dissipated by Day 7, and lesion size decreased significantly from Day 0 to Day 21 as injured tissue was resorbed. The extent of edema surrounding a lesion greaty exceeded the size shown by PSIR-LGE. However, lesion size as depicted by the TE_{T2prep}=0 (non-T2-prepared volume) highly correlated with the core non-contrast enhanced (necrotic core) regions observed with PSIR-LGE (Figure 2), and decreased minimally in size from Day 0 to Day 21.

Discussion: The primary goal of this work was to establish high-resolution quantitative 3D T2 mapping as a tool for RFA lesion detection in the heart. We have shown that T2 Mapping provides sufficient sensitivity to identify the edematous regions surrounding lesions. A secondary goal was to determine whether T2 mapping had sufficient sensitivity to separate between the edematous region surrounding the lesion core and the necrotic regions. This would yield more accurate MR assessment of RFA lesions and more therapeutically relevant imaging. The non-T2-prepared images (bottom row in Figure 2) could provide a metric for the size of the lesion core early after RF ablation (excluding edematous tissue) *without the need for contrast agents*. However, more work, including histology/pathology, is required to determine whether the multi-contrast/quantitative nature of T2 mapping is sufficiently sensitive to separate ablated tissue or edematous tissue immediately after ablation.

References: [1] Dickfeld T, et al. JACC 47(2):370; [2]Ding et al. ISMRM 2011; [3]Ghugre et al. MRM, 66(4), 2011; [4]Verhaert, et al, JACC CV Imaging, 4(3);269, 2011; [5] Simonetti et al. Card Radiol 1996199:49; [6] Kellman et al. MRM 2002 47:372; [7] Lee et al. ISMRM 2011.

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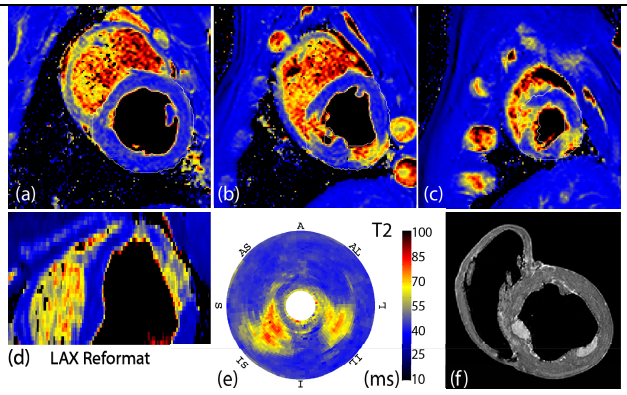

Figure 1: Sample short axis basal, mid and apical T2 maps (a-c), along with long axis (LAX) reformat (d) obtained form the 3D datasets. This animal was imaged at Day 0 post RFA. The lesions are clearly visible in the Bull's eye plot of the whole LV T2 (e), making the extent of edema induced by the ablation procedure easily quantifiable. The heart was excised after imaging and high-resolution *ex vivo* imaging was used to determine lesion volume (f). The color scale used for the Bull's eye plot also applies to the T2 Maps in (a-d) and in Figure 2.

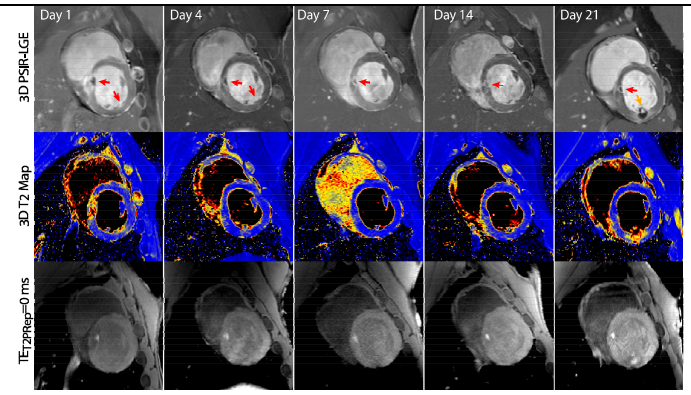

Figure 2: Representative slices from sequential imaging sessions at Days 0-21. Multiple lesions were created in this animal (red arrows) on Day 0, which were clearly visible on both PSIR-LGE and T2 Maps. T2 Maps easily detected edema from the ablation processes. The smaller lesion in the inferolateral wall faded by Day 7 indicating the lesion was insufficient in creating permanent tissue injury. By Day 21, there was little to no residual edema. However, this animal had a fresh lesion applied on the inferolateral wall on Day 21 (orange arrow). Additionally, the non-T2 prepared (bottom row) volume provides correlation with the dark (non-enhancing) lesion core observed with PSIR-LGE, which in turn correlates with the size of the lesion by Day 21.