Practical multi-mode cardiac MRI of mice and rats on a 3T clinical scanner

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Introduction: A demand exists to conduct basic science cardiac research in animal models that includes cardiac MRI (CMR) with rodents (mice and rats). While dedicated high-field small bore MRI scanners are preferred for rodent CMR, their high cost limit many research centers to image rodents with existing clinical MRI scanners. This presents a substantial challenge due to the rodent high heart rates, decreased field of view (FOV), and decreased signal strength conditions that cannot be accomplished by CMR designed for humans [1]. The k-space mapping must be modified to maximize speed, resolution, SNR, and minimize artifacts. This requires the maximum gradient strength and slew-rate available, plus an optimal design of RF pulse methods. We developed a multi-mode rodent CMR sequence and method that acquires: 1) bright blood or dark blood, high temporal rate cine, 2) inversion recovery (IR) for late gadolinium enhanced (LGE) infarct imaging or modified look-locker (LL) T1 mapping [2], and 3) T2-prepared CMR modes [3].

Methods: The rodent CMR sequence was optimized for a 70 cm diameter bore, 3 T clinical scanner (Siemens Verio). The design was primarily a spoiled multislice GRE acquisition sequence with two highly adjustable, ECG-triggered, TR_{inner} and TR_{outer} loops, and selectable RF preparation methods. The TR loops included an interleaved readout capability to allow high temporal frame rates. The available RF preparations included: 1) double inversion recovery (DIR) for dark blood cine, 2) non-selective or selective IR, and 3) Malcolm Levitt (MLEV) T2-prep with adiabatic or composite refocusing pulses. RF transmission was performed through the scanner 75 cm whole-body coil and RF receive through an 8-channel, receive-only, wrist coil (Invivo) with a custom plastic apparatus to position the anesthetized rodent. Normal C57BL/6 mice and Wistar rats were imaged in accordance with approved protocols and NIH 85-23, 1996 directive. Anesthesia was induced with 3% isoflurane in oxygen and maintained with a 1% level. Combined ECG and respiratory trigger signals were detected to gate the MRI sequence (SA Instruments, Stony Brook, NY). Common scan parameters for all CMR modes included: matrix = 128x128, slice thick = 1.0 mm, BW = 199 Hz/pixel, averages = 4-10. Mice FOV = 25x25 mm, with TR_{inner} = 13.0 ms and TE = 6.51 ms. Rat FOV = 40x40 mm, with TR_{inner} = 10.8 ms and TE = 5.4 ms. Mode-specific parameters included: 1) bright blood cine: TR_{outer} = 1 cardiac R-R period (≈140-195 ms), flip angle = 20 deg, and up to 16 TR_{inner} temporal cine frames by 2 interleaved TR_{outer} acquisitions; 2) dark blood cine: same as bright blood except TR_{outer} = 2-3 cardiac R-R (≈280-585 ms) with DIR on; 3) IR LL: TR_{outer} = 2 sec (≈10 cardiac R-R), TI = 50 ms x 15 same slice frames for 50-750 ms T1 recovery coverage, flip angle = 5 deg; 4) IR LGE: TR_{outer} = 2 sec (≈10 cardiac R-R), TI ≈ 350 ms x 3 TR_{inner} slices, flip angle = 60 deg; and 5) T2 prep: MLEV-8 (8 refocus pulses), TR_{outer} = 3 sec (≈15 cardiac R-R), TE_{T2prep} = 60 ms x 6 TR_{inner} slices, flip angle = 60 deg.

Results: Non-interleaved cine time-per-slice was ≈4-6 minutes depending on ECG and respiratory gating rates. Interleaved cine successfully doubled the temporal rate, but also at cost of doubled acquisition time. The 8-channel wrist coil provided sufficient receive signal strength provided the scanner transmit was carefully tuned. Fig 1 presents example result cine, end-diastole, long and short-axis images. Both bright and dark blood modes in panels A-D provided good volumetric and wall thickness data. However, panels E&F, from an arrhythmic rat, show that mis-triggered dark blood cine can leave non-suppressed blood artifacts that can degrade contrast and data accuracy. The IR LL needed 10 averages (≈15-25 minutes scan time) for a suitable SNR. Fig 2 presents IR LL results from a water-deprived (dehydrated) mouse with an estimated myocardial T1 = 662 ms. Each of the IR LGE and T2-prep modes gave multislice (6-slice) acquisitions within an ≈13 minutes scan time (data not shown).

Conclusions: This CMR method applies multiple modes of cine, IR, and T2w imaging to rodents on a clinical scanner for low-cost basic science research. This allows serial, non-invasive quantification of cardiac function, necrosis, tissue T1, and edema for both short and long-term tracking studies. The sequence can be easily modified to add a T2*-weighted mode for added capability.

References: [1] Gilson WD, Kraitchman DL, Cardiac magnetic resonance imaging in small rodents using clinical 1.5 T and 3.0 T scanners, Methods, 2007; [2] Nacif MS, et al, Myocardial T1 mapping with MRI: Comparison of look-locker and MOLLI sequences, JMRI, 2011; [3] Beyers RJ, et al, T2-weighted MRI of post-infarct myocardial edema in mice, MRM, 2011.

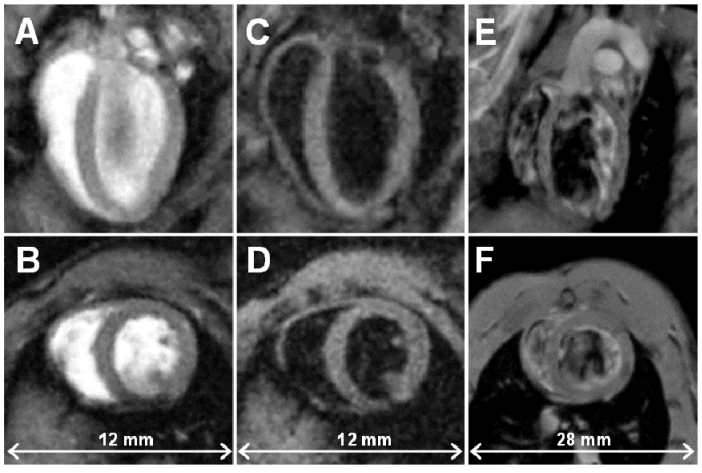

Fig 1. Example result cardiac cine, end-diastole image frames of long-axis (top row) and short-axis (bottom row). Panels A&B, mouse bright blood; panels C&D, mouse dark blood; panels E&F, rat dark blood cine.

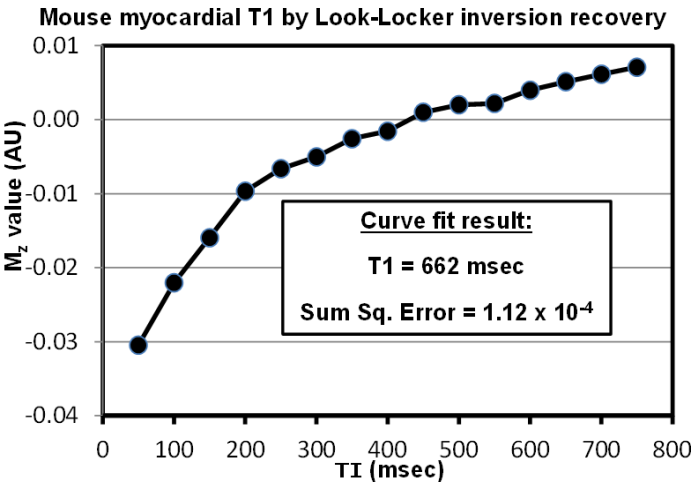

Fig 2. A graphic example result of mouse myocardial T1 recovery curve acquired by Look-Locker inversion recovery, with a curve fit result T1 = 662 msec.