MADE: A Dark-Blood Delayed Enhancement Sequence to Improve Detection of Subendocardial Infarcts (Motion Attenuated Delayed Enhancement)

M. Salerno[1], F. H. Epstein[2], and C. M. Kramer[1,2]

[1]Department of Medicine, Cardiology, University of Virginia, Charlottesville, VA, United States, [2]Department of Radiology, University of Virginia, Charlottesville, VA, United States

Introduction: Delayed enhancement imaging using an inversion recovery FLASH pulse sequence has become the gold standard for imaging myocardial infarction. However, subendocardial infarcts are sometimes difficult to detect as they may have similar image intensity as the ventricular cavity, especially when imaging at earlier time points after gadolinium injection. A pulse sequence for dark-blood delayed enhancement imaging using a double inversion technique has been described by *Rehwald et al.* [1-3]. The sequence relies on precise timing of non-selective and selective inversion pulses and is sensitive to incomplete exchange of blood and changes in T_1 relaxation of the blood and myocardium. Motion-sensitizing gradients have been used to create dark blood images of blood vessels [4] and recently, the ventricular cavity [5], but have never been applied post-contrast for infarct imaging.

Purpose: To develop a dark-blood delayed enhancement pulse sequence based on motion sensitizing gradients (MADE) which would not rely on complete blood exchange and would be relatively insensitive to changes in relaxation times.

Methods: The MADE sequence was developed by adding a driven equilibrium module using either a BIR-4 composite 0-degree rf pulse or a sequence of three rectangular rf pulse (90x-180y-90-x) (RECT) with motion sensitization gradients between the component pulses. This module was placed between the inversion pulse and a segmented FLASH readout (Fig 1). The duration of the BIR-4 preparation and RECT preparation were 13-15ms and 5-7ms depending on the desired amount of motion sensitization. The duration was chosen to minimize T_2 and strain-induced signal loss. The effective b-value of the preparations was between 0.08 and 0.25 s/mm2. To evaluate the signal evolution and contrast properties, the sequence was simulated with the following relaxation times: T_{1blood}=T_{2blood}=280ms, $T_{1infarct}$=250ms, $T_{2infarct}$=50ms; $T_{1normal}$=390ms, $T_{2normal}$=50ms. For the simulations it was assumed (based on prior experiments) that 90% of the blood signal could be attenuated with the preparation. The technique was tested in a canine model of chronic infarction using a 1.5T MR scanner (Magnetom Avanto, Siemens Medical Solutions). Images were obtained 5-10 minutes after injection of 0.15 mg/kg of Magnevist. Sequence parameters included field of view 300 mm, matrix 192 x 114, TE 2.7 ms, TR 5ms, spatial resolution 1.6 x 2.4 x 10 mm, lines per segment 12, bandwidth 400 Hz/pixel, acquisition duration 16 heartbeats.

Results: Figure 2 shows the T_1 relaxation curves of blood, myocardium and infarct for the MADE sequence. Figure 3 demonstrates that the sequence has a fairly flat response for infarct-to-blood and infarct-to-normal myocardium contrast. The contrasts for infarct-to-normal myocardium and infarct-to-blood are 27% (as compared to 32% for IR FLASH) and 24% (as compared to 8% for IR FLASH) of M0. Figure 4(a) shows a standard bright-blood IR-FLASH delayed enhancement image; There is an infarct in the inferior wall which is difficult to distinguish from the blood pool ($CNR_{infarct\text{-}blood}$=1.6, $CNR_{infarct\text{-}normal}$.=21). Figure 4 (b-c) shows images from the BIR-4 and RECT preparations. The $CNR_{infarct\text{-}blood}$ are 13 and 17 respectively and the $CNR_{infarct\text{-}normal}$ are 12 and 16 respectively. Overall there was a 25% decrease in infarct SNR, a 40% decrease in CNR $_{infarct\text{-}normal}$, but a >700% increase in CNR $_{infarct\text{-}blood}$.

Conclusions: We have developed a new dark-blood delayed enhancement pulse sequence (MADE) which attenuates the blood pool based on motion sensitization. Future work will include optimization of the motion-sensitizing preparation to better define the myocardial and ventricular borders. In a canine model of chronic infarction, this technique improves delineation of subendocardial infarction.

References:

[1] Rehwald WG et al. *J Cardiovasc Magn Reson.* 2007; 9:101-2.
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[4] Koktzoglou I et. al , *J Magn Reson Imaging* 2006;23:699-705
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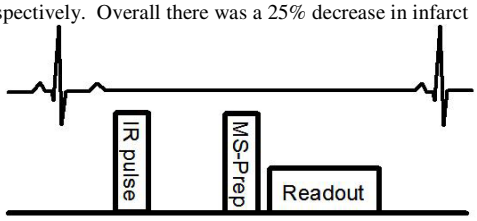

Fig 1: MADE Sequence Schematic

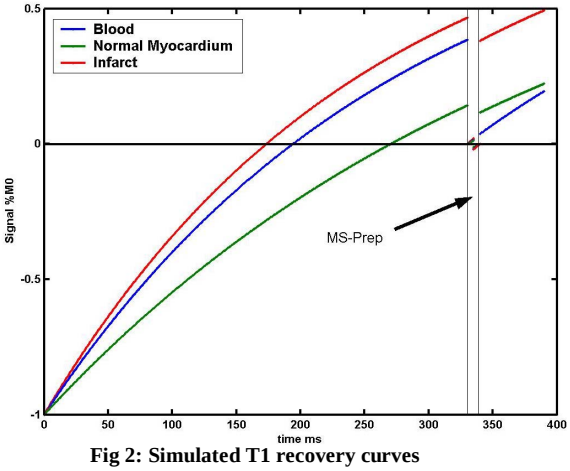

Fig 2: Simulated T1 recovery curves

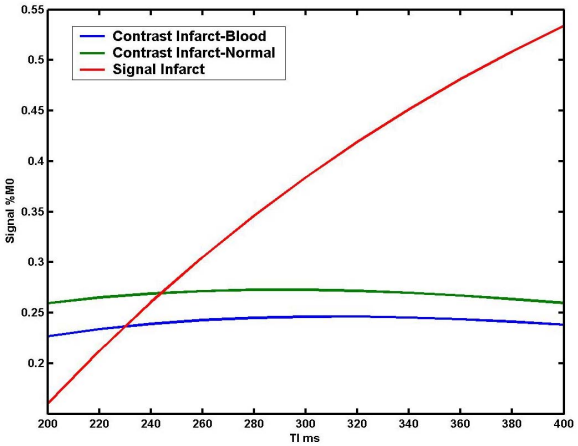

Fig 3: Contrast curves and infarct signal

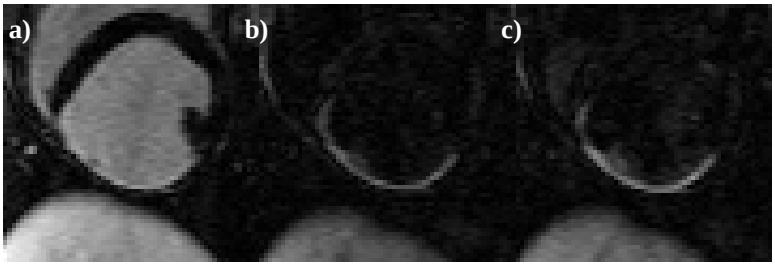

Fig 4: (a) IR FLASH (b) BIR4 MADE (c) RECT MADE