# Improved Dark Blood Delayed Enhancement Imaging with Triple IR Preparation

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**Introduction:**
We have previously described double preparation dark blood delayed enhancement sequences [1-3] for MR imaging of myocardial viability that use a slice-selective saturation or inversion pulse followed by a time delay and a non-selective inversion pulse referred to as SR-IR or IR-IR technique, respectively. The timing depends on the T1 of viable myocardium and blood. Thus, depending on the patient's RR interval and the time after contrast agent administration one method usually works better due to the placement of slice-selective preparation and readout events within the cardiac cycle. Even though the timing is automatically calculated in these sequences and high quality dark blood images can be obtained, adjusting the parameters as function of the RR interval and the current T1 values can be challenging. Also, the theoretical infarct SNR of about 10 - 20% of $M_0$ in these sequences is lower than that of the IR TurboFLASH sequence commonly accepted as viability gold standard (GS). To overcome these limitations we developed a triple IR technique wherein a slice-selective inversion is followed by a delay, another selective inversion, a second delay, and a non-selective inversion. We hypothesized that the additional degree of freedom in sequence timing provided by the extra inversion pulse would allow better matching of the preparation scheme to the cardiac cycle resulting in improved blood exchange. Furthermore, this preparation has a theoretical infarct SNR of about 40% of $M_0$ which is similar to that of IR TurboFLASH.

**Methods:**
Figure 1 shows the relaxation curves of infarct (green), viable myocardium (red) and blood (blue) resulting from a selective inversion (SIR) played at t = 0, a second SIR at t = $T_a$ = 260 ms, and a non-selective (NS) IR at t = 478 ms ($T_b$ = 218 ms). The center of k-space is acquired at t = 668 ms ($TI_{blood}$ = 190 ms) when blood and normal myocardium are simultaneously nulled. Blood only experiences the NSIR as the selectively prepared blood has left the imaging slice prior to the readout. The T1 values were chosen as 230 ms for infarct, 490 ms for viable myocardium, and 270 ms for blood. To test our hypothesis we implemented the technique on a 1.5T Tesla clinical MRI scanner (MAGNETOM Sonata, Siemens Medical Solutions, Germany) and evaluated it in two dogs with chronic myocardial infarctions. Imaging was performed 10-30 minutes after IV injection of 0.15 mmol/Kg Gd-DTPA. A segmented image acquisition with the following sequence parameters was used: field of view 340 x 234 mm, matrix 256 x 176, TE 3.85 ms, flip angle 25 degrees, spatial resolution 1.3 x 1.3 x 6 mm, bandwidth 130 Hz/pixel, lines per segment 21. Both GS and Dark-Blood (DB) delayed enhancement images were obtained and evaluated for SNR and CNR of the infarct, myocardium, and the blood pool. We derived the relationship between $T_a$ and $T_b$ mathematically so that for a given $T_a$ the optimal $T_b$ was employed to null viable myocardium and blood simultaneously.

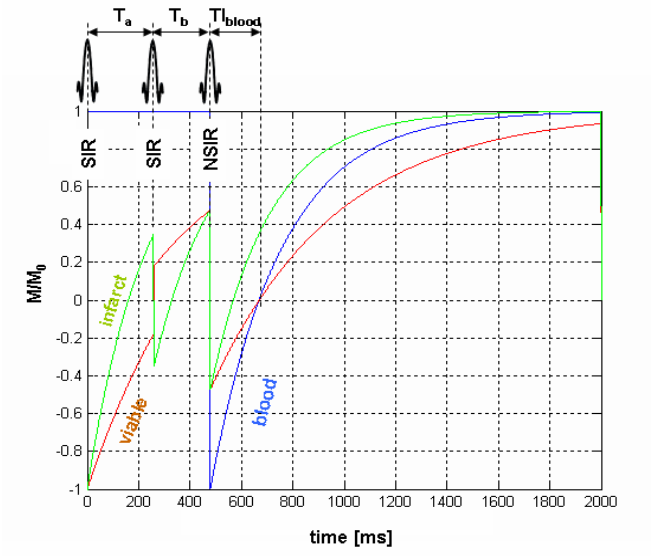


Figure 1

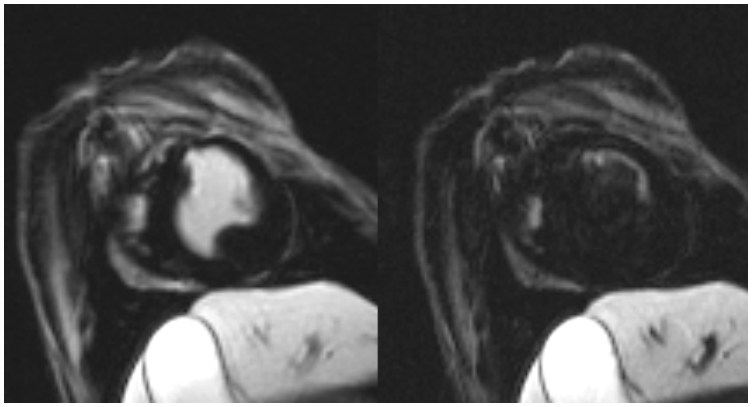

Figure 2

**Results:**
Figure 2 shows a GS image on the left, and a DB delayed enhancement image on the right. In the GS image it is difficult to discriminate the thin subendocardial infarct from the blood pool, but this is easily achieved in the DB image. SNR (mean ± stdev) measured in the GS and DB images was 59.6 ± 2.3 and 26.3 ± 4.9 in the infarct, 4.1 ± 0.3 and 5.8 ± 1.8 in viable myocardium, and 83.1± 6.3 and 3.8 ± 0.8 in the blood pool, respectively. CNR between infarct and viable myocardium was 55.5 ± 2.1 in GS and 20.5 ± 9.0 in DB. CNR between infarct and cavity was 22.5 ± 4.7 in DB. In GS the blood was brighter than the infarct. By varying $T_a$ and calculating the optimal $T_b$ we could adjust the preparation pulse timing so that the SIR pulses and readout events were played when the heart was in a similar position while at the same time ensuring proper blood exchange between the second SIR and the readout.

**Conclusions:**
We have implemented a triple IR dark blood delayed enhancement sequence and have shown that CNR between infarct and blood is dramatically improved compared to the GS while still providing sufficiently high SNR. The degree of freedom in timing not available in the double preparation DB methods gave us reliable blood signal suppression irrespective of the RR duration.

**References:**
[1] Rehwald WG, et al. *Proc Intl Soc Mag Reson Med* 2007.
[2] Salerno M, et al. Proc Intl Soc Mag Reson Med 2007.
[3] Rehwald WG, et al. JCMR 2, 2007; 101 (abstract 110).