# Automatic Heart Rate Dependent Timing Adjustments in Dark Blood Turbo-Spin Echo Sequences With and Without STIR Preparation

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**Introduction:**

The inversion time TI to null blood in standard dark-blood turbo-spin echo (TSE) and in STIR (short τ inversion recovery) TSE sequences depends on the patient's heart rate and the trigger pulse used. A coarse manual adjustment so that the dark-blood (DB) preparation is played immediately after the R-wave and the TSE readout occurs during diastasis is often sufficient for nulling blood at normal heart rates (55 -75 bpm) imaging every other heart beat (trigger pulse 2). Unfortunately, in patients with higher heart rates (> 80 bpm) and particularly when playing a slice-selective STIR pulse in addition to the DB preparation, image quality is degraded. This is partially due to imperfect blood nulling but mainly due to the poor alignment of the STIR preparation slab with the readout slice. Using a non-selective STIR pulse alleviates this problem, but the optimal time for nulling blood is harder to determine as in this setting blood experiences two inversion pulses per acquired echo train. To overcome this difficulty we developed an algorithm that iteratively calculates the optimal $TI_{blood}$ based on the patient's current heart rate and sets the trigger pulse, time of DB preparation, time of readout, and temporal resolution to optimal values. The algorithm was implemented into a standard TSE pulse sequence and tested in 37 patients and volunteers on a MAGNETOM Avanto (SIEMENS Medical Solutions, Erlangen, Germany) clinical MR scanner. Images using the standard technique (coarse manual timing adjustment and slice-selective STIR) and the new approach (algorithm-adjusted timing with non-selective STIR) were acquired, randomized and scored for image quality. Image quality improved significantly (30% when scored on a 3-point scale) and sequence setup became simpler and faster.

**Methods:**

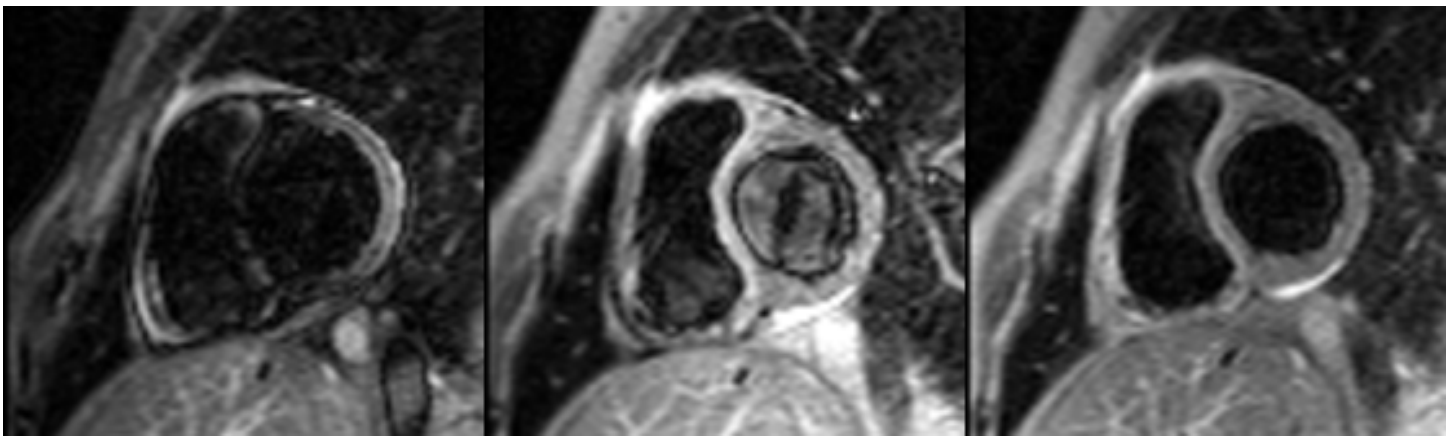
The algorithm is invoked upon pressing the capture cycle button in the user interface, which gets the patients heart rate from the gating EKG. Step A: Depending on the current heart rate (captured RR) the trigger pulse is set to 1, 2, or 3 (1 if HR < 48 bpm, 3 if HR > 100 bpm). Assuming full relaxation of blood magnetization at the time of DB preparation, the $TI_{blood}$ seed value is determined. Step B: Using this seed value the actual blood signal at the beginning of the tse readout $M_{bloodRO}$ is found by simulating the magnetization recovery and inversion over many heart beats until the signal has reached steady state. $TI_{blood}$ is now modified (reduced initially) and the iteration is repeated until the new steady state is found. The iteration finishes when $M_{bloodRO}$ is 5% of $M_0$ or less; $TI_{blood}$ for the current heart rate is found. A similar algorithm is used for DB preparation without and with the non-selective STIR pulse. Step C: The optimal $TI_{blood}$ and the captured RR are then used to determine whether the timing can be accommodated in one or two heart beats. A set of timing rules is implemented to ensure that DB preparation and readout occur when the heart is in approximately the same position while sticking as closely as possible to the optimal TI found in step B. Step D: The optimal temporal resolution is calculated. It is 70 ms for a heart rate of 60 bpm and below, 40 ms for 100 bpm and above, and linear in between. The echo train length (ETL) is set accordingly. Overall scan time is not affected significantly as the increased number of required heart beats due to better temporal resolution is compensated by the shorter RR. The iterative search is repeated whenever the capture cycle button is pressed or when changes in timing (e.g. due to slice thickness) alter the sequence timing.

In 37 cardiac patients and volunteers 74 basal short-axis STIR images were acquired with the standard sequence (slice-selective STIR) and the new sequence using the described algorithm and non-selective STIR. All images were randomized and evaluated qualitatively by two trained observers and scored for quality on a scale of 1 to 3 (1 poor, 2 ok, 3 good).

**Results**:

In all studied subjects, image quality improved by 30% from an average of 1.67 points to 2.17 points on the 3-point scale. Operation of the new sequence did not require much knowledge about cardiac mechanics and magnetization recovery as the timing was automatically set by the algorithm. Figure 1 shows three STIR images from a normal volunteer acquired with the standard (slice- selective STIR, left), the non-selective STIR without (middle), and the non-sel. STIR with algorithm-adjusted timing (right, RR 950 ms). Parameters were TE 78 ms, echo spacing 2.7 ms, bandwidth 1240 Hz/pixel, ETL 23, matrix 192 x 93, slice thickness 8 mm, DB prep thickness 24 mm, fov 360 x 230 mm, trigger pulse 2. The ventricular septum and parts of the right ventricular free wall drop out in the standard sequence due to poor slice registration (left), but are well depicted when using the non-selective STIR pulse (middle). However, the blood is no longer properly nulled resulting in artifacts along the endocardial border. Combining non-selective STIR with algorithm-adjusted timing yielded homogeneous myocardium and optimally suppressed blood (right).

Figure 1:



standard STIR | non-selective STIR without algorithm-adjusted timing | non-selective STIR with algorithm-adjusted timing

**Conclusion:**

We presented a modified pulse sequence for the acquisition of dark blood and STIR TSE images that allows for a much simplified operation of the user interface and delivers overall better image quality. The scanner operator does not need to possess an intricate knowledge of cardiac mechanics and MR physics to obtain the best possible image quality. This automated timing is not limited to TSE dark blood imaging and similar approaches can be implemented into other pulse sequences to simplify their operation, increase the robustness of image quality, and speed up the cardiac MR exam.