

# **Black-Blood Imaging of the Human Heart Using Rapid STEAM MRI**

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## **Introduction**

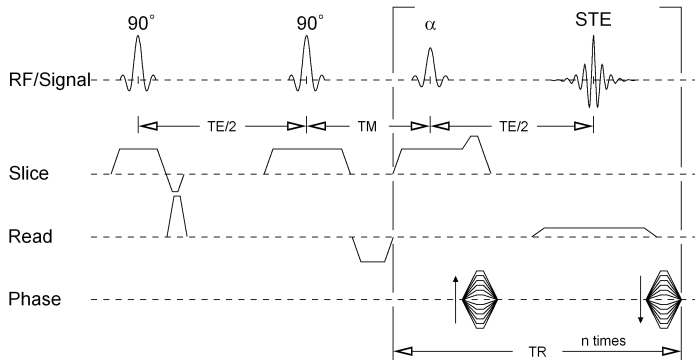
Adequate delineation of cardiac morphology remains a challenge. The image quality achievable by double inversion-recovery techniques [1,2] depends on the inversion time, imaging time, and stability of the heart rate. The approach may also lower the signal-to-noise ratio (SNR) of the desired signal from the myocardial wall and limits the number of simultaneously acquired sections in a multi-slice study, e.g. see [3,4]. Alternatively, high-speed STEAM (stimulated echo acquisition mode) MRI [5] offers inherent flow suppression due to the dephasing of moving spins [6]. The purpose of this work was to redesign rapid STEAM MRI sequences with use of state-of-the-art equipment in order to evaluate its potential for blood-free multi-slice imaging of the myocardial wall.

## **Methods**

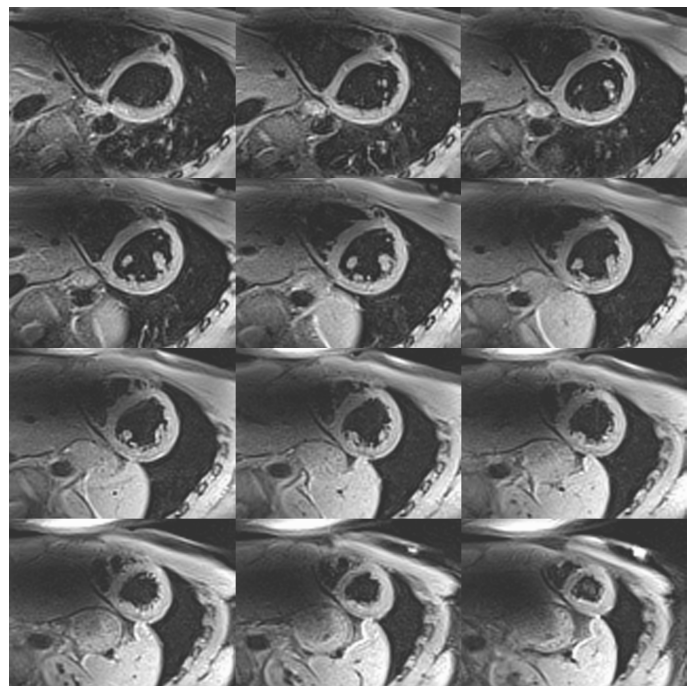
**Subjects.** Six male volunteers (20-32 years) with no known disease participated in the study. Written informed consent was obtained in all cases and procedures conformed fully to institutional guidelines.

**MRI.** All studies were performed on a 3 T MRI system (Magnetom Tim Trio, Siemens, Erlangen, Germany) equipped with a 32-channel receiver system and 40 mT m<sup>-1</sup> gradients. Heart images were recorded with use of a 6-element body matrix coil in combination with 6 or 9 elements of a 24-element spine matrix coil. Data acquisition was ECG-synchronized to end diastole and multi-slice studies were performed during a single breath hold in expiration. Fat suppression was applied in all cases.

**Rapid STEAM MRI.** A high-speed version of the basic STEAM MRI sequence may be obtained by distributing the longitudinal magnetization prepared by the leading two RF pulses into multiple portions. This may be accomplished by replacing the third 90° RF pulse with a series of RF pulses (RF spoiled) with flip angles lower than 90° [5]. The corresponding series of stimulated echoes may then be differently phase-encoded. A schematic diagram of a single-shot STEAM MRI sequence optimized for cardiac applications is shown in Fig. 1 (without preceding optional modules for fat suppression and spatial pre-saturation).



**Fig. 1.** Rapid STEAM MRI of the heart. The slice-selective longitudinal magnetization prepared by the first two 90° RF pulses is read out as a series of stimulated echoes (STE) using low-flip angle RF pulses ( $\alpha$ ); TE = echo time of the STE, TM = first middle interval, TR = duration of the repetitive readout interval, n = number of phase-encoding steps (or readout intervals)



**Fig. 2.** Contiguous rapid STEAM MR images of the human heart at 2.0 mm resolution (short-axis views from base to apex). Twelve fat-suppressed sections of 6 mm thickness were obtained from two breath holds with use of a segmented 3-shot STEAM MRI sequence yielding 6 sections in 18 heart beats (single breath hold).

## **Results and Discussion**

Although multi-slice single-shot images from individual heartbeats are possible, the most promising and robust strategies with improved SNR and resolution emerged from segmented k-space acquisitions. Accordingly, multi-shot STEAM MR images were acquired from a few heartbeats in a single breath hold. A typical example is shown in Fig. 2 combining two breath hold acquisitions (6 sections using 3 segments each) for a contiguous coverage of the heart in short-axis views.

Rapid STEAM images of the human heart are free from any contamination by flowing blood. In fact, it should be noted that a clear delineation of the heart muscle required ECG synchronization to end diastole as movements during data acquisition may corrupt the resulting image. The soft-tissue contrast of the images is predominantly given by T1 attenuation (and spin density). Noteworthy, this T1 contrast behaves in close analogy to the T2 contrast in fast spin-echo MRI. Based on these preliminary results, rapid STEAM MRI of the heart presents as a simple technique for unrestricted multi-slice imaging of the myocardial wall with efficient flow suppression.

## **References**

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