Design of a robust method for suppression of ghosting artifacts due to long T1 species in cardiac imaging

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Background: In cardiac imaging, delayed enhancement with ECG-gated, segmented inversion recovery (IR) TurboFlash (Fast Low Angle SHot) is considered the gold standard for detecting myocardial infarctions (MI). With this sequence, image data is acquired when signal of viable myocardium is nulled, leading to bright infarcted tissue and dark myocardium in the images due to the differences in T1. Since the myocardium is dark, even the faintest bright artifact can complicate diagnosis. In segmented mode, the repeated IR pulses cause oscillations in the amplitude and phase of any species with T1 values greater than the interval between two IR pulses (IR-period, typically 2xRR). These oscillations cause bright ghosts in the image and can often appear in locations that interfere with the detection of MI. The standard method for suppressing these artifacts involves the application of dummy heartbeats '+HB' (same IR, readout, and recovery HB as during imaging, but without acquiring data (gray 'dummy acq.' box in **figure 1 a)** prior to image acquisition, attempting to force the system to steady state and thus prevent the oscillations. For mid-range T1 species such as myocardium (**figure 1a)**, red line), this approach is sufficient, but not for very long T1s, such as pericardial effusion, cerebrospinal fluid, and saline breast implants (blue line, **figure 1a)**), see also patient example in **figure 2 b)**. Placement of saturation slabs is not possible because it would destroy the region of interest (ROI). Previous suppression methods have used a pre-saturation pulse before the first IR at 50% of the IR-period. This does suppress the artifacts, but fails in the case of arrhythmia. Also, depending on the IR period and the exact T1 value of the species, the optimal position to reach steady state is not exactly 50% which complicates implementation. Therefore, we developed and tested a new and simpler method for artifact suppression and compared it with the standard +HB method and the pre-suppression plus HB method (+Pre+HB) in simulations, phantoms, and patients. The method uses a saturation pulse applied after each image acquisition (black 'data acq.' boxes in **figure1**) and the dummy HB (+Po+HB), see **figure 1 b**).

Methods: <u>Simulations:</u> All simulations were done using MATLAB (Mathworks). For the simulations, the heart rate was set to 60 bpm (RR interval = 1000 ms), inversion time TI = 300 ms (to null the signal from second shortest T1 sample), FLASH readout with a flip angle of 5 degrees, matrix of 128 x 128, 15 segments and four different round compartments, each with a different T1 (**figure 2a**). The magnetization recovery was modeled using the Bloch equations. +Po+HB was modeled by setting the magnetization to zero right after the read-out. +Pre+HB was modeled by setting the magnetization to zero at time RR before the first IR pulse. The efficiency of artifact suppression was quantified by taking the ratio of the mean ghosting signal in the artifact ROI (red dashed rectangle, **figure 2a**) outside the sample to the signal in the shortest T1 species in the blue dotted "signal ROI" having minimal signal loss due to the absence of ghosting. The ratio was called artifact ratio 'ATR'. <u>Phantom Experiments:</u> A phantom containing 1% agarose gel was created with four compartments, each with a different T1 (**table 1**). This phantom was imaged on a MAGNETOM Avanto clinical MR scanner (Siemens) using a segmented IR TurboFlash sequence with the parameters described above and a bandwidth of 399 Hz/px and an echo spacing of 8.5ms. The suppression efficiency was assessed as described above. <u>Patient Example</u>: The images were taken on a MAGNETOM Verio using the following parameters: TI 340 ms, trigger pulse 2, fov 360 x 270 mm, matrix 256 x 125, segments 21, flip angle 17°, receiver bandwidth 399 Hz/pixel, TE 1.66 ms, echo spacing 4.4 ms, RF spoiling on, slice thickness 6 mm.

T1 value (ms)	ATR +HB	ATR +Pre+HB	ATR +Po+HB
145	0.0600	0.0600	0.0600
430	0.0837	0.0787	0.0834
890	0.0762	0.0288	0.0586
2890	0.7567	0.2985	0.0200

Results: In the simulation, the new +Po+HB method suppressed long T1 artifacts much better than the standard +HB method, and better than +Pre+HB. The simulated image results are shown in **figure 2a**, and the numerical results in **table 1**. They were verified in the phantom shown in **figure 2a**. The improvement in artifact suppression was most dramatic for the long T1 species, where the new Po+HB method provided a 97.3% improvement in artifact suppression (ATR) compared to +HB alone. **Figure 2b** corroborates these results in a patient with saline breast implants (white arrows) where imaging without dummy HBs and without any suppression (-HB) caused unacceptable artifacts, +HB still caused substantial ghosting (red arrows), and +Pre+HB reduced yet noticeable ghosting. The new +HB+Po completely eliminated all artifacts.

Conclusions: The combination of post-suppression module and leading dummy heart beats (+Po+HB) allows for a significant reduction (>95%) in the ghosting artifacts from long T1 species and thus improves clinical image quality. It is simple to implement into existing scanner software.