Effective velocity spoiling for black blood imaging of the heart

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INTRODUCTION

The suppression of intravascular signal ("black blood") is important for the clinical evaluation of cardiac chambers and vessel walls in cardiovascular MRI, and is commonly performed using double inversion preparation (1) or spatial saturation of upstream blood (2). Both techniques rely strongly on the inflow of nulled blood and the outflow of fresh blood and consequently become less effective for thick imaging slab and in-plane flow. To address this problem, a black blood preparation sequence has been proposed for carotid and aortic vessel wall imaging which utilizes motion sensitizing gradients to dephase blood spins prior to imaging (3-5). The objective of this study was to investigate the flow spoiling mechanisms using flow phantom experiments and to develop effective velocity spoiling for black blood fast gradient echo imaging of the heart.

METHODS

The black blood preparation module is based on the Stejskal-Tanner diffusion weighted sequence (Fig.1a). In the presence of motion sensitizing gradients, two dephasing mechanisms can be distinguished: 1) phase shift due to random thermal motion (diffusion), and 2) phase shift due to bulk motion (velocity encoding). While both mechanisms can lead to signal attenuation, the diffusion effect is negligible compared to the velocity encoding effect for the reported b-values on the order of 1 s/mm^2 (3-5). For example, given $D_{water} = 2.2 \times 10^{-3}$mm^{2}s^{-1} (room temperature), the theoretical signal attenuation due to diffusion is 1-exp(-bD) = 0.2%. To demonstrate this point experimentally, two preparation sequences using bipolar gradients, BIPOLAR1 and BIPOLAR2 (Fig.1bc), were implemented in addition to the original UNIPOLAR sequence (Fig.1a). Fig.1 shows b-value and field of speed FOS (the velocity corresponding to a velocity induced phase shift of 2π (6)) for the three preparation sequences assuming rectangular gradients for simplicity. Note that BIPOLAR1 and BIPOLAR2 have same b-value, but different FOS.

Imaging experiments were performed on a flow phantom (consisting of a silicon 9.7-mm-diameter straight tube driven by tap water) and in humans using a 1.5T GE SIGNA Excite MR scanner. The implemented preparations were incorporated into an ECG-triggered segmented k-space 2D fast gradient echo sequence (slice = 8 mm, 256x256 matrix). The effect of b-value, FOS, voxel size, and flow pattern (parabolic/turbulent) on flow spoiling was investigated. Both FOS [cm/s] and b-value [s/mm^2] were calculated for the actual trapezoidal gradient waveforms.

RESULTS

Fig.2 shows the velocity tagged images of parabolic flow obtained with square pixel size of 0.23 mm. Note that BIPOLAR1 (FOS=0, b=0.4) (Fig.2b) did not introduce any observable dephasing and its effect was identical to that of BIPOLAR1 with G=0 (FOS=0, b=0) (Fig.2d), demonstrating that the diffusion effect is negligible for the chosen b-value. BIPOLAR2 (FOS=15, b=0.4), however, created a cosine modulated longitudinal magnetization, as did UNIPOLAR (FOS=15, b=0.4), giving rise to the observed concentric rings on the image (Fig.2ac). Note that the rings were more concentrated and thinner toward the edge of the tube due to higher velocity gradient. Increasing b-value up to 10 s/mm^2 while fixing FOS=15 cm/s provided the same result. These data demonstrated that the spin dephasing was introduced by velocity encoding and not by diffusion for b-value ~ 1-10 s/mm^2.

Fig.3. illustrates the increased spoiling effect obtained with smaller FOS (due to more rapid intravoxel dephasing), larger voxel size (due to increased signal averaging effect), or complex (turbulent) flow (due to random phase effect). Note that the spoiling is less effective in the case of coherent flow such as at the center of the tube (Fig.3a-d).

Fig.4 shows the short axis and four chamber images acquired in a healthy volunteer with and without flow spoiling, demonstrating effective black blood preparation both within the heart and in the surrounding vasculature.

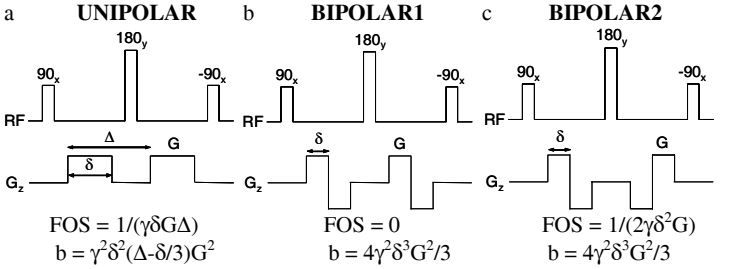

Fig.1. Three preparation sequences. Note that BIPOLAR1 and BIPOLAR2 have same b-value, but different field of speed.

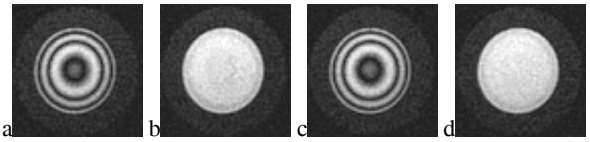

Fig.2. Velocity tagged images obtained with a) UNIPOLAR (FOS=15, b=0.4), b) BIPOLAR1 (FOS=0, b=0.4), c) BIPOLAR2 (FOS=15, b=0.4), and d) BIPOLAR1 with G=0 (FOS=0, b=0). Square pixel size = 0.23 mm.

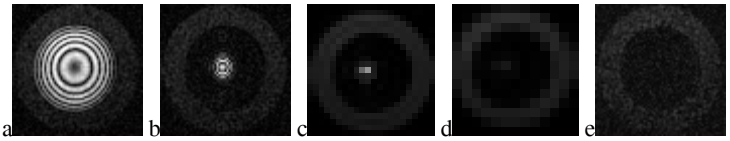

Fig.3. Increased dephasing and spoiling effect obtained with smaller FOS of a) 7.5 b) 1.0 at a fixed pixel size of 0.23 mm, with larger pixel size of c) 0.7 mm d) 1.2 mm at a fixed FOS of 1.0, or e) with turbulent flow.

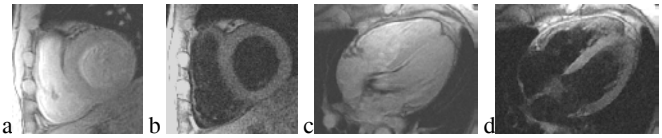

Fig.4. Short axis and four chamber image of the heart acquired without (ac) and with (bd) flow spoiling.

CONCLUSION An effective black blood preparation module has been developed for fast gradient echo imaging of the heart. Our phantom data have demonstrated that the primary mechanism behind flow spoiling is velocity induced dephasing of moving spins. Consequently, FOS is a more appropriate parameter than b-value for characterizing the motion sensitizing gradients and their spoiling effect. The effectiveness of flow spoiling depends on FOS, voxel size, and flow pattern, which should be optimized for different organs and vascular territories.

REFERENCES 1. Edelman RR et al. Radiology 1991;181:655-660. 2. Felmlee JP et al. Radiology 1987;164:559-564. 3. Sirol M et al. Circulation 2004;109:2890-2896. 4. Koktzoglou I et al. ISMRM 2006. p 652. 5. Kirpalani et al. ISMRM 2006. p 651. 6. Moran PR. MRI 1982;1:197-203.