Formation of Primary Spin Echoes During Global Coherent Free Precession Improves Longevity of "Memory" Effect

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Introduction

We have previously described the GCFP (global coherent free precession) technique [1, 2] to generate angiograms directly analogous to invasive catheterization. The main limitation of this approach is that signal "memory" is only about 200 ms, principally because GCFP is based on gradient echoes for which signal decays at a rate proportional to T2*. Spins experience different local T2* values while they travel downstream and dephase as function of this history. Phase encoding accuracy depends on these local variations as well. We hypothesized that the formation of primary spin echoes, instead of or in addition to gradient echoes, would keep the spins in phase and thereby enhance the "memory" effect, allow visualization of blood flow deeper into the distal vasculature, and deliver more accurate phase encoding.

In practice, however, creating primary spin echoes is difficult because of the need to maintain the delicate balance of global phase coherence in the presence of three-dimensional blood flow before, during, and after the application of 180° refocusing pulses. To address these complexities we constructed a flow phantom and evaluated different combinations of flow compensated gradient waveforms.

Methods

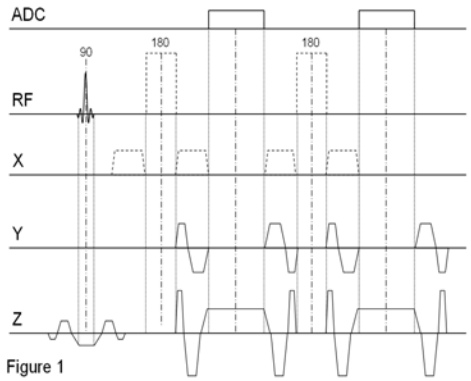


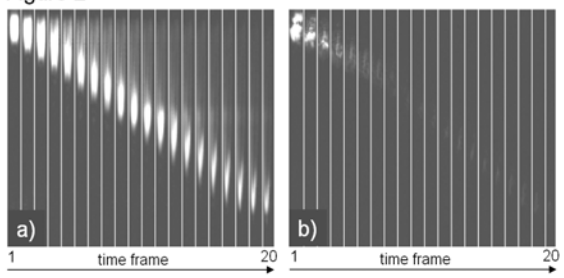
Figure 1

The flow phantom employed water with a constant velocity of 160 mm/s allowing the collection of 20 frames before the excited spins leave the field of view (fov). Figure 1 shows one of the many spin echo (SE) GCFP pulse sequences investigated and consists of a single upstream slice-selective 90° excitation (2 cm thick) followed by repeated non-selective 180° refocusing pulses and readout gradients on z (projection imaging). Note that all gradients on y- and z-axis were flow-compensated and spoilers (not flow-compensated) were played in x-direction (which had no flow-component). Parameters were fov 400 x 33 mm, matrix 192 x 16, TE 4.97 ms, and temporal resolution 80 ms. 20 frames were collected during 1600 ms. For comparison to traditional gradient echo (GRE) GCFP, the sequence was repeated with the same parameters and velocity but without refocusing pulses and spoilers (dotted RF and gradient pulses). Filling distance and signal to noise (SNR) of the traveling bolus were measured in its center for both SE-GCFP and GRE-GCFP sequences.

Results

The bolus of excited spins was visible for 20 frames in SE-GCFP, but only for 3 in GRE-GCFP. Fig 2 shows 20 temporal frames from left to right for a) SE-GCFP and b) GRE-GCFP. Filling distances were 283 mm and 48 mm, respectively. In the first frame, SNR was four times higher for SE-GCFP, see fig 3. In frame 7, SNR for GRE-GCFP had fallen below 10% of that of the first frame of the same sequence, but remained high for SE-GCFP. The longevity of signal "memory", defined as signal remaining above 10% of its initial value, was approximately 200 ms for GRE-GCFP (as expected), but was over 1500 ms for SE-GCFP. Bolus shape was maintained throughout all 20 frames for SE-GCFP indicating precise phase encoding, but not even for the first frame in GRE-GCFP.

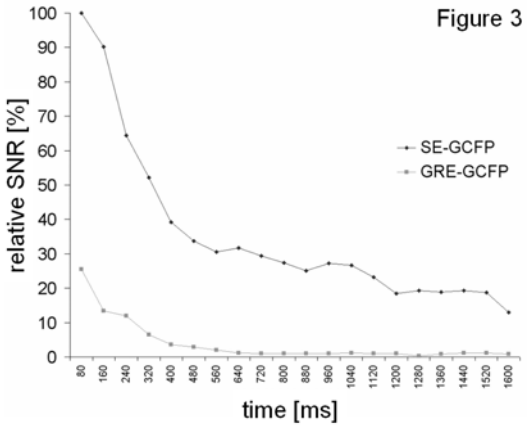
Figure 2



Conclusion

Our findings establish that spin echoes can be formed during GCFP despite the complexity of maintaining global phase coherence in the setting of multi-dimensional blood flow. The phantom data demonstrate that formation of spin echoes dramatically increases signal "memory", implying that in vivo images will allow visualization of blood flow much further than previously demonstrated for GRE-GCFP. Limitations of SE-GCFP include increased SAR and increased TR. Additional investigations will be needed to establish a balance between SAR, TR, and signal longevity for GCFP in humans.

Figure 3



References

[1] Rehwald, WG, Chen, E-L, Kim RJ, Judd, RM: Non-invasive cineangiography by magnetic resonance global coherent free precession; Nature Medicine, 10: 545-549, 5, May 2004

[2] Klem I, Rehwald, WG, Chen, E-L, Kim RJ, Judd, RM: Noninvasive assessment of blood flow based on magnetic resonance global coherent free precession; Circulation, 111: 1033-1039, March 2005