Improving Non-contrast Enhanced SSFP Angiography with Compressed Sensing

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Introduction: Flow-independent angiography relies on T1, T2 differences to generate the desired blood-to-background contrast [1]. Thus, it can be a useful tool for depicting vessel morphology without contrast agents and in cases of slow flow. Recently, segmented (interleaved) k-space acquisitions and centric phase-encode ordering were coupled with magnetization-prepared 3D balanced (b)SSFP [2] to produce these angiograms. Because the desired contrast after preparation is transient, there is a trade-off between contrast and scan time efficiency. We propose to accelerate the acquisitions with compressed sensing [3], using the savings in scan time to improve contrast or to increase resolution.

Methods: Fat and muscle are the major background tissues in the extremities. Alternating repetition time bSSFP [4] is used for fat suppression. The magnetization is prepared using a segmented BIR-4 pulse (T2-Prep) [5]. A linear ramp of RF pulses dampening the transient oscillations [6] and centric square-spiral phase-encode ordering [7] are used to capture the generated contrast. The magnetization preparation is repeated to restore the initial contrast and another interleaf of phase encodes is acquired after each preparation [2]. The transient signal is shown in Fig.1 for arterial and venous blood, and muscle.

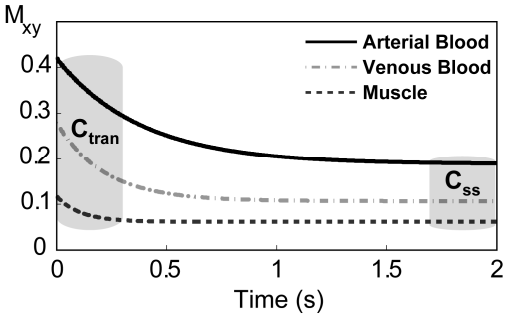

Figure 1. The transient bSSFP signal following T2-preparation for arterial blood (T1/T2=1000/200 ms), venous blood (1000/100 ms) and muscle (870/47 ms). The initial blood-to-muscle contrast is C_{tran}~5, whereas the steady-state contrast is C_{ss}~3.

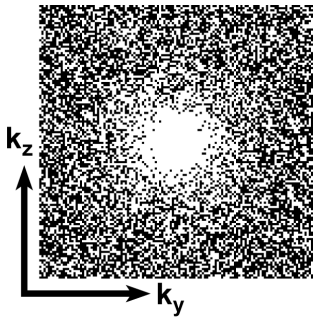

Figure 2. The phase-encode mask shows the variable-density randomly undersampled (a factor of 2) trajectory.

The number of excitations can be reduced by randomly undersampling the phase-encodes with a decreasing density towards the periphery of k-space (Fig.2). The resultant undersampling artifacts appear as a noise-like interference. This interference can be removed through compressed sensing using total variation [3], if the image has a sparse representation. Therefore, the sparsity in MR angiograms, where blood is the most significant source of signal, can be exploited to recover the missing samples. The scan time saved by decreasing the number of excitations can be used to increase the number of interleaves (N) and thereby reduce the number of phase-encodes per interleave. This will result in improved (more T2-prep-dominant) contrast, which also increases the sparsity of the image and the efficiency of compressed sensing. Alternatively, the same savings can be used to extend the k-space coverage to improve image resolution.

3D lower leg images were acquired on a 1.5 T GE scanner with the following parameters: $\alpha=60^{o}$, 19.2 cm FOV, TR=4.6 ms, ±125 kHz BW, 80 ms T2-Prep, and 4 s recovery time between the interleaves. To demonstrate improved resolution, fully-sampled 1x1.4x1.4 mm^3 and undersampled (a factor of 2) isotropic 1 mm data were each acquired with N=4 and a scan time less than 0:50. To demonstrate enhanced contrast, a fully-sampled acquisition with N=4 and an undersampled acquisition (factor of 2) with N=14 were each performed with 1 mm^3 resolution and comparable scan times less than 1:30.

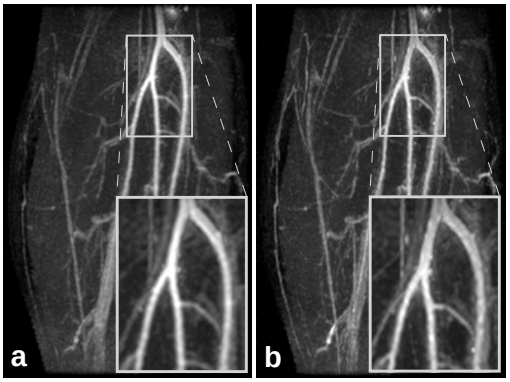

Figure 3. MIPs for the fully-sampled **(a)** and accelerated **(b)** acquisitions showing improved resolution in **(b)**.

Results: The improved resolution of the accelerated acquisition is shown in Fig. 3. The compressed-sensing image exhibits improved edges and better visualization of small vessels. Figure 4 displays the enhanced contrast through increased number of magnetization preparations. 49.5 % higher arterial blood/muscle and 32.9 % higher arterial/venous contrast are achieved with increased T2-weighting in the accelerated acquisition.

Conclusion: Flow-independent angiograms can be acquired with improved contrast or higher resolution employing variable-density random undersampling and exploiting image sparsity. Magnetization-prepared contrast can be better captured with the scan efficiency of bSSFP.

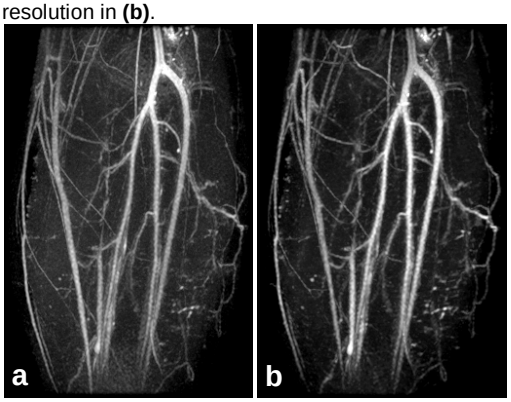

Figure 4. MIPs for the fully-sampled **(a)** and accelerated **(b)** acquisitions demonstrating enhanced contrast in **(b)**.

References:

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