Dual-Density and Parallel Spiral ASL for Motion Artifact Reduction

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Introduction: Arterial spin labeling (ASL) is particularly sensitive to flow and motion artifacts, because it is fundamentally a subtractive technique. Background suppression is a valuable method for reducing ASL motion artifacts, but residual artifacts can remain. Single-shot spiral scanning with signal averaging is often used for ASL, because it is more robust to motion than interleaved methods. However, single-shot spiral scans suffer from limited spatial resolution and greater susceptibility artifacts. In this work, we develop two alternative spiral ASL methods: dual-density interleaved spiral scanning and dual-density single-shot parallel spiral imaging. We then compare the flow and motion robustness of these two techniques to conventional constant-density single-shot and interleaved spiral scans.

Methods: The first hypothesis of this study was that fully sampling the center of k-space during each acquisition with a dual-density spiral scan would improve the flow and motion robustness of interleaved spiral ASL. The second hypothesis was that a dual-density single-shot spiral scan reconstructed using the SPIRiT non-Cartesian parallel imaging technique [1] would yield higher spatial resolution while maintaining the motion robustness of a conventional single-shot scan.

The four sequences were designed to have the same scan time for this study. The sequences were as follows: (1) Single-shot constant-density spiral scan with 12-ms readouts, 3 signal averages, and 4.8-mm spatial resolution. (2) Interleaved constant-density spiral scan with 8.1-ms readouts, 1 signal average, and 3.3-mm spatial resolution. (3) Single-shot dual-density spiral scan with the first 20% of an 8.1-ms readout sampled at Nyquist and the remaining 80% sampled at 1/3 of Nyquist, 3 signal averages, and 3.8-mm spatial resolution. This method has a parallel acceleration factor of just under 3. (4) Interleaved dual-density spiral scan with 3 rotated versions of the gradients in (3), 1 signal average and 3.8-mm spatial resolution. All signal averaging and subtraction was performed on the complex raw data prior to image reconstruction. Online gridding reconstruction with correction for inhomogeneity and concomitant gradient effects was performed for each sequence. The data from sequence (3) was also reconstructed using SPIRiT in Matlab without off-resonance correction. Tag-control difference images without further processing were evaluated for artifacts.

The study was performed on a 3T Siemens Trio scanner using a 12-channel head coil and custom spiral FAIR pulse sequences. The sequences used a z-axis BIR-4 flow suppression preparation sequence (50 mT·ms^2/m) and spectral-spatial excitation pulses. The following parameters were common to the sequences: TR = 4s, TI = 1s, TE = 3.8 ms, FOV = 200-220mm, slice thickness = 8 mm, and slice selective inversion thickness = 24 mm. Three normal volunteers were imaged and each sequence was repeated three times for each volunteer, for a total of nine acquisitions for each sequence. Informed consent was obtained prior to imaging.

Results: All images for single-shot sequence (1) had negligible motion artifacts, but were of lower spatial resolution. All of the single-shot parallel images from sequence (3) also had negligible motion artifacts after reconstructing with SPIRiT. The majority of the images acquired using sequence (4) had negligible artifacts, but some of the images had unacceptable artifacts associated with variable signal in the large vessels. The images acquired using sequence (2) had the greatest likelihood of vessel-related signal artifacts. Worst-case images using each technique are shown in Fig. 1.

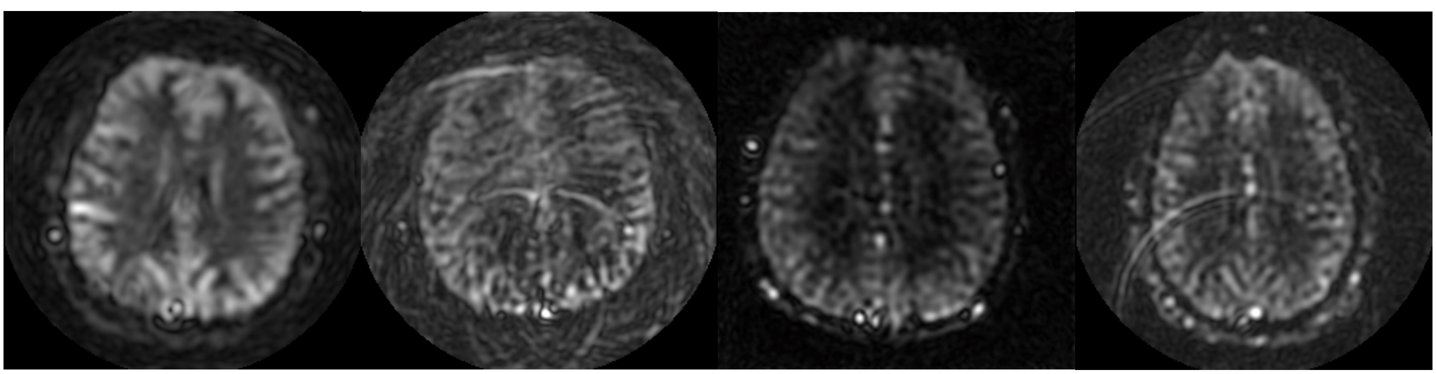

Figure 1. Worst-case images using each technique, selected from different volunteers. Left to right: Sequence (1), (2), (3), and (4). Sequence (3), dual-density single-shot parallel spiral ASL, yielded the best overall results.

Conclusions: Single-shot dual-density parallel spiral ASL reconstructed using SPIRiT yielded the best overall combination of spatial resolution, image quality and motion robustness. Dual-density spiral ASL showed somewhat improved motion robustness relative to constant-density spiral ASL, but the improvement was less than expected. It may be possible to reconstruct this data differently to improve motion robustness, given that each acquisition is equivalent to a rotated version of sequence (3). Sequence (3) showed good motion robustness, even though the data from the different averages was subjected to complex averaging. An alternative method would be to average single-shot magnitude images. Future work will include reconstructing the dual-density single-shot images using other parallel reconstruction algorithms, to see if SPIRiT intrinsically suppresses motion artifacts more than other algorithms. One limitation of this study is that the spatial resolution and thus SNR varied between sequences, which may account for some of the perceived differences in artifact level. Overall, dual-density parallel spiral ASL shows promise for robust ASL acquisition.

References: [1] Lustig et al. MRM 2010 64(2):457-71.
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