Evaluation of new ASL 3D GRASE sequences using Parallel Imaging, Segmented and Interleaved k-space at 3T with 12- and 32-channel Coils

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Arterial spin labeling (ASL) can be combined with many different image readout sequences (1). 3D ASL acquisitions have the benefit of whole brain coverage (2) with identical timing of blood labeling and background suppression pulses (3,4) in all slices. Three new 3D GRASE ASL sequences with parallel imaging, segmented and interleaved readout schemes are evaluated without changing the Pulsed ASL (PASL) labeling and background suppression pulses. The goal was to improve image quality of 3D GRASE ASL for physiological and clinical applications.

Methods

Imaging performance was compared between the previously published single-shot ASL 3D GRASE sequence (**SS**), (5) and three new pulse sequence variants, which all have EPI echo train lengths (N_{EPI}) reduced in half for concurrent reduction in off-resonance phase errors, Fig.1. The new sequences were i) single-shot with Parallel Imaging (**PI**) Grappa IPAT factor 2 on in-plane kp ii) segmented (multi-shot) sequence (**Seg)** on in-plane kp axis, iii) interleaved single-shot sequence (**Int**) with twice as many RF refocused SE (N_{SE}) intervals, each with half as many echoes N_{EPI} as conventional SS, with the resulting pairs of EPI echo trains interleaved on kp axis in 3D k-space. For all variants (PI, Seg, Int), the base resolution is unchanged from SS.

Comparison of sequences was conducted with 12- and 32-channel (CHA) receiver head coils at 3T (Siemens, Trio). Imaging time was held constant at 1 minute (min) for the 64- and 128-matrix acquisitions by varying the number of signal averages. Acquired data matrix, FOV and in-plane resolution were: (44x64, 138x200mm^2, 3.1x3.1mm^2), (88x128, 220x320mm^2, 2.5x2.5mm^2) and (128x256, 198x395 mm^2, 1.5x1.5 mm^2), constant slice thickness 5mm and 26 slices for whole brain coverage, TR/3000ms, labeling pulse TI/1500ms, TE was sequence dependent, varying between 17ms to 29ms in 64 matrix and 30ms to 66ms in 128 matrix. Partial Fourier, 5/8th on ks slice axis, Navg 5-10, N_{SE}/16 in PI, Seg, SS and N_{SE}/32 in Int sequences. Bandwidth was 2055 Hz/pixel for 64 matrix, 1700 Hz or 2790 Hz in 128 matrix images, and 1775 Hz for 256 matrix acquisitions. Four normal volunteers were scanned with all sequences, under institutional guidelines.

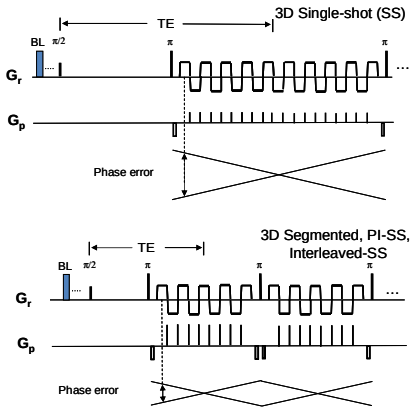
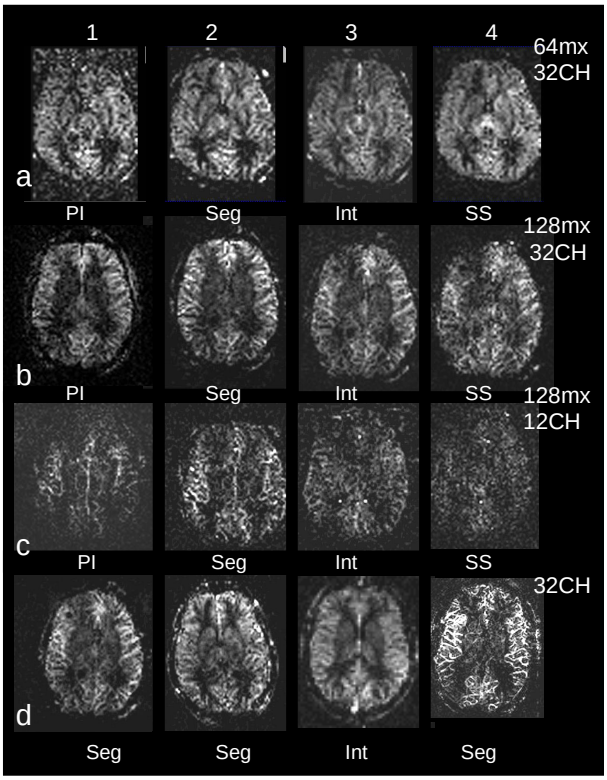


Fig. 1, 3D GRASE pulse sequence with shorter RF pulse intervals to reduce off-resonance phase errors. Gs axis is not shown. ASL labeling and background suppression (BL)

Results: Images were evaluated in terms of ghosting, distortions, susceptibility artifacts, non-specific artifacts, blurring and SNR (mean signal in cortex / mean air). The SNR averaged across subjects, increased using the 32-channel coil compared to the 12-channel coil (PI, Seg, Int, SS):
12-Cha 64-matrix (7.5, 7.6, 10.6, 10.8) **12-Cha 128-matrix** (8.0, 13.0, 5.6, 5.6)
32-Cha 64-matrix (22.3, 15.1, 18.1, 18.0) **32-Cha 128-matrix** (20., 21.6, 40.0,15.9) for SNR normalized by 1 minute scan time.



General findings in image performance were as follows. The PI and Seg images had much less blurring than SS images due to shorter echo train time (ETT) and reduced T2 dependant PSF broadening on the 3D volume slice axis, ETT (PI, Seg, Int, SS) in 64 matrix: (294ms, 281ms, 544ms and 478ms), and in 128 matrix: (496ms, 483ms, 1100ms, 1049ms). The total number of echoes, i.e. echo train length (ETL) was halved in PI and Seg compared to SS and Int: 352 vs 704 echoes in 64 matrix, and 704 vs 1408 echoes in 128 matrix acquisitions. In SS 128 matrix images, the late TE/65ms reduced SNR (Fig.2, b4, c4), further contributing to severely degraded image quality.

The PI parallel imaging was least reliable due to ghosting and signal loss in some acquisitions, (Fig 2, a1). Seg images had an additional low level ghost but there were no identifiable flow artifacts which can occur in segmented anatomic images without velocity moment nulling. The larger FOV in 128-matrix images allowed for swapping the phase axis from R-L to A-P with much less physiologic stimulation and this permitted faster gradient switching and higher signal bandwidth (BW) that reduced distortions and artifacts at 2790 Hz (Fig 2, b2) vs 1700 Hz (Fig 2, d1).

The 256 matrix, 1.5x1.5mm^2 resolution images had insufficient SNR in 1 min scans, but produced reliable images (Fig 2, d4) in 4:50 min acquisitions using the 32-channel coil, SNR/20.6. Similarly, 3 min scan times improved Seg and Int images (Fig 2, d2, d3). All 128 and 256 matrix images were noticeably improved in quality with the higher SNR of 32-channel head coil (Fig 2, b1-4, c1-4), with less apparent changes in lower resolution 64 matrix images.

Conclusion: In summary, all 3 new variants of 3D GRASE ASL provided shorter RF pulse intervals in the CPMG spin echo sequence, reducing susceptibility artifact. The concurrent shortening of ETT in PI and Seg sequences substantially reduced through-plane blurring compared to conventional SS, whereas Int sequence slightly worsened blurring. Image distortions were reduced in 128 matrix scans as the larger FOV enabled higher BW. The SNR gains from the 32-channel coil and receiver system enabled higher resolution ASL images. While clinical scan times will likely differ from 1 min, the improvement in image quality of each sequence should translate.

Fig.2. Compares 1 of 26 images from each sequence in different matrix size (mx), **Row a – c)** constant 1 min acquisitions, 3D parallel image single-shot (PI), segmented (Seg), Interleaved single-shot (Int), single-shot 3D (SS).

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