Improving the Spatial Resolution of 3D GRASE ASL

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Introduction: 3D-GRASE provides a method for the simultaneous acquisition of a 3D volume of ASL data and has been shown to provide increased volume sensitivity compared to 2D acquisitions due to its increased sampling period [1]. However, single shot *(SS)* 3D-GRASE ASL has generally been limited to coarse in-plane resolution (~ 3 mm) to reduce off-resonance phase errors, and limited slice resolution (~ 5-8 mm) to reduce through slice decay and blurring whilst providing good coverage [2]. Recently, parallel imaging methods [3] and inner volume suppression (IVS) has been suggested to achieve high resolution BOLD based GRASE methods [4]. Here we assess the improvement in spatial resolution and coverage of SENSE accelerated background suppressed 3D-GRASE ASL achievable with multi-shot *(MS)* methods, and the use of outer volume suppression (*OVS*) with a reduced field of view *(rFOV)* to acquire high resolution data in a limited brain region, such as the visual cortex. The advantage of these methods to fMRI studies is discussed.

Methods: Subjects were scanned on a Philips Achieva 3.0 T system with body transmission and an 8-ch SENSE receive coil. 3D-GRASE images were acquired at 3x3x5mm^3 using SENSE acceleration (2.5 in slice, 1.5 in phase –factors limited by 8-ch coil) and 1.13 oversampling with *(SS)* single shot acquisition *(MS)* multi (2)-shot acquisition and *(rFOV) SS* reduced *FOV* using *OVS*. The reduced echo train length provided by *MS* and *OVS* methods was exploited to acquire images with improved spatial resolution, 2.5x2.5x3mm^3, and with increased slice number to equalise the echo train length, as outlined in Table 1. A QUIPSS II FAIR ASL sequence was implemented with post-label delay 1.4 s and TR 6s per tag/control pair. Optimised WET and sinc pre- and post-sat pulses were used to limit static signal contamination and background suppression pulses applied at 392 ms/564 ms post-labelling. A base M_0 3D-GRASE image was also acquired. Images were assessed for ghosting, distortions, blurring and SNR.

FOV	Resolution (mm^3)	SS/MS	EPI Factor	TSE Factor	TE (ms)	No. of Slices	Bandwidth (Hz)	Echo train length (ms)	Averages
192 x 204	3 x 3 x 5	SS	29	17	23	15	2719	388	40
192 x 204	3 x 3 x 5	MS	15	17 (25)	15	15 (22)	2956	263 (386)	20
192 x 128 (OVS)	3 x 3 x 5	SS	19	17	18	15 (19)	2802	298 (364)	40
192 x 204	2.5 x 2.5 x 3	SS	35	17	29	15 (12)	2433	499 (411)	96
192 x 204	2.5 x 2.5 x 3	MS	17	17 (21)	18	15 (19)	2417	310 (384)	48
192 x 128 (OVS)	2.5 x 2.5 x 3	SS	25	17	23	15	2391	397	96
192 x 92 (OVS)	2.5 x 2.5 x 3	SS	17	17 (21)	18	15(19)	2438	309(382)	96

Table 1: *GRASE imaging parameters. Numbers provided in brackets reflect the number of slices that can be acquired in an echo train length of ~ 400ms.*

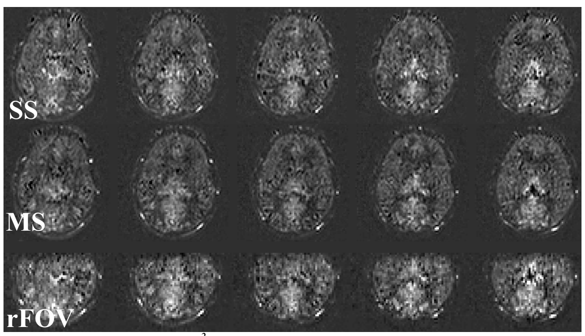

Figure 1: *SS 3x3x5mm^3 GRASE ASL difference images*, *MS 3x3x5mm^3, and rFOV SS OVS 3x3x5mm^3*

To demonstrate the applicability of *OVS* reduced *FOV* 3D-GRASE ASL a functional paradigm using a visual stimulus was performed. LED goggles were used to present a visual stimulus flashing at 8Hz, with a 30s ON period, 42s OFF period, 10 cycles were collected at 3x3x5mm^3 resolution, and 15 at 2.5x2.5x3mm^3. fMRI analysis was performed using FEAT (FSL, FMRIB, Oxford) with a 2mm smoothing kernel and high pass filter with cut-off frequency 0.01Hz. Z score maps with a corrected probability P <0.05 were formed and overlaid on PW images.

Results: Figure 1 shows example 3x3x5mm^3 3D-GRASE ASL images for *SS*, *MS* and *rFOV*, no significant increase in ghosting is seen for the *MS* acquisition. Through plane blurring has been reduced using *MS* and *rFOV* (apparent in slice 1) and the SNR improved, *SS*:*MS*:*rFOV* = 1:1.4:1.9. Figure 2 shows 2.5x2.5x3mm^3 *SS* GRASE FAIR images acquired using outer volume suppression and a reduced *FOV*. The use of background suppression in conjunction with an *OVS* pulse removes foldover artifacts when employing a reduced *FOV*. The reduced *FOV* allows an increase in the spatial resolution without increasing shot length, or reduced through-plane blurring. Figure 3A shows visual activation and B the corresponding the time course of activation obtained from the visual paradigm. At 2.5x2.5x3mm^3 3D-GRASE ASL can be seen to provide good SNR for detection of change in blood flow on activation.

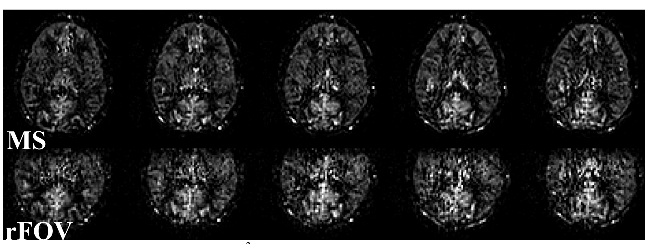

Figure 2: *MS 2.5x2.5x3mm^3 GRASE ASL difference images* rFOV SS *2.5x2.5x3mm^3 GRASE ASL difference images with OVS.*

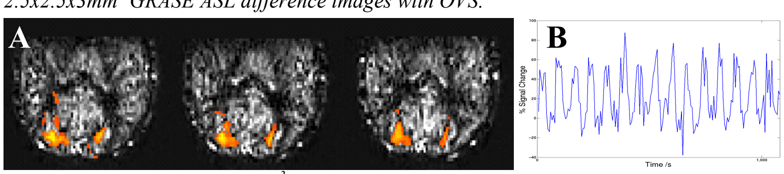

Figure 3*: (A) SS, 2.5x2.5x3mm^3 GRASE ASL difference images acquired with OVS and a reduced FOV, shown with visual activation overlaid. (B) Time course of visual activation.*

Discussion: We have demonstrated that the spatial resolution of 3D-GRASE ASL can be improved using either a multi-shot acquisition, which compromises temporal precision, or outer volume suppression with a reduced *FOV* to maintain temporal resolution. In 3D-GRASE, due to all slices being acquired simultaneously, a single *OVS* slab can be applied to achieve a reduced *FOV*; 2D-EPI with sequential slice acquisition would require a rest-slab per slice (increasing SAR and acquisition time). We have applied *rFOV SS-OVS* 3D-GRASE ASL to a visual paradigm, where it has been demonstrated that at improved spatial resolution the response to visual stimulation can clearly be detected. *rFOV* reduces shot length, which can be used to collect an increased number of thin slices with good coverage and future studies will use *SS-OVS* 3D-GRASE to acquire higher spatial resolution data. For example, to study retinotopic mapping. Multi-shot methods will be used to improve spatial resolution for pharmaceutical or resting state studies. **References:** [1] Gunther *et al*. MRM 54:491-498 2005. [2] MacIntosh *et al.* ISMRM 17, 33, 2009. [3] Feinberg *et al*. ISMRM 17, 623, 2009. [4] Feinberg *et al.* NeuroImage, Volume 47, S195, 2009. **Acknowledgements:** This work was supported by the MRC.