Reducing blurring artifacts in 3D-GRASE ASL by integrating new acquisition and analysis strategies

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Introduction: Arterial Spin Labeling (ASL) can be combined with various image readout sequences. 3D-GRASE ASL has been shown to provide cerebral blood flow (CBF) maps with high spatial resolution and a constant inflow time (TI) for the whole brain[1,2]. Due to an excessively long echo train relative to T_2 decay, single-shot 3D-GRASE is affected by severe blurring along the partition-encoding direction. Multi-shot approaches are increasingly employed to reduce blurring, though for high number of shots the sensitivity to motion increases and SNR can potentially be reduced as the number of averages for a fixed acquisition time needs to be accordingly decreased[3]. We present a pipeline to minimize the blurring effect, combining a multi-shot 3D GRASE-ASL sequence with a deblurring algorithm applied in the data-processing stage.

Materials and Methods: ***Acquisition:*** four healthy volunteers (27-40 years) were scanned on a Siemens 3T Skyra using a FAIR labeling scheme with a single inversion time (TI=1800ms). Three different multi-shot 3D-GRASE readout schemes were used with parameters described in Table 1. Other parameters: two BS pulses, FOV=240x240mm^2, 3.5x3.5x5mm^3, 20 partitions, 2min 55sec acquisition time. ***Analysis:*** the deblurring procedure in this study extends the methods already introduced for minimizing blurring in multi TI datasets[4,5], by exploiting the multiple averages acquired at a single TI:

Number of shots	8	4	2
TR (ms)	3500	3500	3500
TE (ms)	12	21.1	30.5
EPI factor	13	31	51
Turbo factor	15	15	15
Echo train length (ms)	186	327	473
Averages	3	6	12

Table 1. *Main parameters for 3D-GRASE ASL.*

Step 1. The Point Spread Function (PSF) whose width describes the blurring was estimated by: 1) calculating residuals by subtracting in each voxel the signal average; 2) for each average (m) and x,y position, calculating the variation in residuals along the slice direction(z), i.e. ($R_{xym}(z)$); 3) calculating $R_{xym}(z)) - \langle R_{xym}(z)\rangle_z$; 4) performing a Fourier Transform along the z direction; 5) taking the mean along x,y,m of the result (producing a vector with the same dimension as the number of partitions); 6) calculating the autocorrelation function; 7) fitting this with a Lorentzian; *Step 2.* This PSF was used in a Lucy-Richardson iterative deconvolution procedure, under the assumption of Gaussian noise[6] to deblur the difference images. CBF maps were then calculated from the original and deblurred difference images using the general kinetic model[7]. For quantitative assessment of the performance of the 3 readouts and deblurring algorithm, the gradient magnitude was calculated at every voxel. This analysis provides information about the level of spatial detail *vs* smoothness in each image. A simulated CBF brain image was defined and also analysed with the gradient magnitude, for determining the distribution of these values in an idealized unblurred image. This was created from a high-resolution anatomical scan of each subject, using the partial volume maps from a segmentation procedure which was downsampled to the ASL native space.

Results: Figure 1 shows native (pre) and deblurred (post) ASL difference images in one subject. In native data, blurring is reduced as the number of shots increases. The deblurring algorithm further appears to reduce blurring in all datasets, including the 8-shot. Figure 2 quantifies the level of detail in the CBF images for the same subject. Mean and standard deviation of the gradient magnitude values increase as the number of shots increases, and also on application of the deblurring algorithm. Whilst 2-shot$_{pre}$, 2-shot$_{post}$ and 4-shot$_{pre}$ are significantly different from the simulated brain or 8-shot$_{pre}$ results, no significant differences are detectable for 4-shot$_{post}$ and 8-shot$_{post}$ compared to simulated brain or 8-shot$_{pre}$, supporting visual appearance of improvement. Results from other subjects were consistent with the ones presented here.

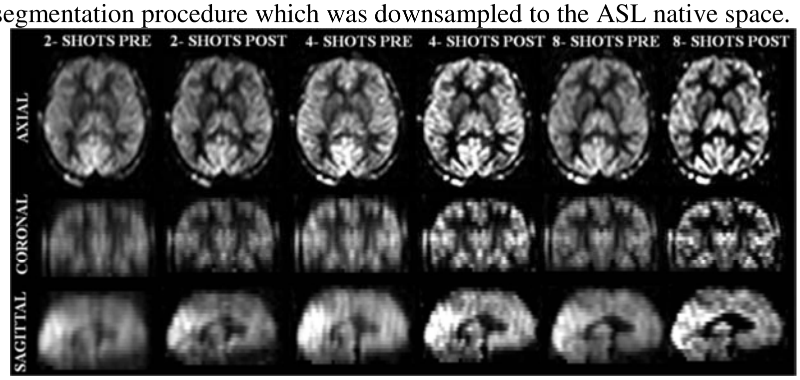

Fig 1. *3D views of ASL difference images for subject #4 (with same scaling).*

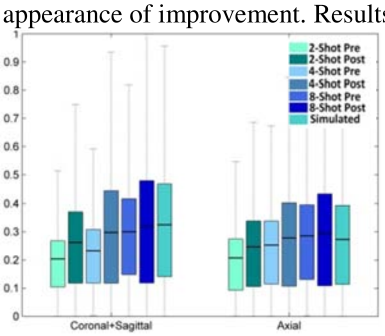

Fig 2. *Gradient Magnitude values.*

Discussion and Conclusions: As expected the 8-shot acquisitions showed the least blurring but allowed fewer averages, which can results in SNR loss and increased motion sensitivity that could be detrimental in a clinical setting. The deblurring algorithm is effective for all acquisition schemes tested, even for the 8-shot, and we recommend its use whenever 3D-GRASE is used as readout for ASL. In our study the 4-shot acquisition plus deblurring method appeared to give the best trade-off in terms of motion sensitivity (related to number of shots) and data quality, as confirmed by qualitative and quantitative analyses. The proposed strategy allows halving of the number of shots, and achievement of similar spatial detail as the 8-shot acquisition with twice the number of averages.

References: 1) Gunther M et al, MRM 2005, 54: 491-498. 2) Fernandez-Seara M et al, MRM 2008, 59:1467-1471 3) Feinberg D et al, ISMRM 2009,622. 4) Chappell MA et al, MRM 2010,63:1357-1365. 5) Boscolo Galazzo I et al, ESMRMB 2013, 332. 6) Lucy LB, Astron J 1974, 79:745-754. 7) Buxton R et al, MRM 1998, 40:383-396.

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