Reduction of motion artefacts in multi-shot 3D GRASE Arterial Spin Labelling using Autofocus

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Synopsis

Multi-shot 3D acquisition schemes offer an efficient method to obtain ASL data with good SNR and spatial resolution. However, multi-shot techniques are susceptible to motion-induced artefacts that can severely degrade image quality. In this work, we investigate the use of the autofocus algorithm to correct k-space phase inconsistencies caused by inter-shot motion, and demonstrate its effectiveness at improving image sharpness and removing artefacts in motion-corrupted 3-shot 3D GRASE data. As such, autofocus offers a retrospective approach to improve the quality of multi-shot ASL data, with the associated improvements in CBF quantification accuracy and reproducibility.

Purpose

To use an automatic iterative optimisation reconstruction approach (autofocus) to reduce motion artefacts in multi-shot 3D GRASE arterial spin labelling data by improving between-segment k-space phase consistency.

Introduction

Arterial spin labelling (ASL) is a non-invasive MRI technique for measuring tissue perfusion[1,2]. For applications in the brain, fast 3D imaging methods, such as 3D GRASE or 3D stack-of-spirals, have been recommended in order to minimise acquisition time and enable repeat measurements for averaging and SNR improvement[3]. To achieve acceptable brain coverage, 3D techniques can acquire the entire 3D k-space in a single shot[4], but this typically leads to a poor point spread function and signal blurring along the second phase-encoding (PE) dimension. More typically, 3D data sets are acquired using a multi-shot approach, with the echo train duration of each individual acquisition being limited to 300ms or less[3]. While this improves the intrinsic resolution of the images, it introduces motion-sensitivity because the different shots are acquired several seconds apart. Subject movement between shots leads to ghosting and loss of resolution in the images. Autofocus[5,6] is a retrospective motion-correction approach whereby trial phase corrections are iteratively performed on raw k-space data and then evaluated according to a particular cost function (e.g. an image quality metric), typically after reconstruction. Here, we investigate using autofocus to reduce motion artefacts and improve image quality in multi-shot 3D GRASE ASL images.

Methods

MR acquisition: Data from a healthy volunteer were acquired on a 3T Tim Trio (Siemens Healthcare, Erlangen). Background suppressed FAIR Q2TIPS 3D GRASE ASL volumes were acquired with the following parameters: TE=26.84ms; TI1/TI2=800/2000ms; spatial resolution=3.1x3.1x5mm^3; acquisition matrix 128x104x12, with 5/8 partial Fourier applied the second PE and segmentation applied in the primary PE direction (3 shots), resulting in an echo train duration of 215ms; 140° refocusing pulse flip angle; TR=4s. Data were acquired in batches of 4 repeats: during the first batch, the subject was asked to remain as still as possible; during the second batch, the subject was asked to make translational head movements during the first and third repeat. Raw k-space data were exported and processed in Matlab (The MathWorks, Inc., Natick, MA, United States).

Autofocus algorithm: It is known from the Fourier shift theorem that translations in the image domain correspond to phase ramps in the frequency domain. Therefore, the autofocus algorithm applies trial phase ramps to the acquired raw data to compensate for rigid body translations that have occurred between the acquisitions of the different k-space segments. After each shift and following reconstruction, the image quality of the resulting image is quantified using a quality metric (image entropy). Minimizing the entropy of an image reduces blurring and removes ghosts from otherwise reduced signal intensity regions, and this forms the basic principle of the autofocus method[5,6]. To avoid a lengthy brute-force optimization, a basic iterative algorithm was implemented whereby the algorithm starts applying phase shifts in a coarse grid, which is iteratively refined (Figure 1). This allows the algorithm to start with a large range of possible phase ramps and then iterate down to very small phase increments to correct motion at the sub-pixel level.

Results

The autofocus algorithm was able to converge to an optimal minimum-entropy solution for the 3-shot 3D GRASE data sets. Figure 2 shows the effect of applying the autofocus algorithm to one of the ASL control acquisitions with intentional subject movement. Two main improvements are clear: (i) blurring is reduced, which is apparent as a visible increase in image 'sharpness' when comparing Fig 2a and 2b, and (ii) image ghosting is also reduced, as demonstrated by the difference (pre-post correction) images in Fig 2c.

Discussion

Autofocus is a post-processing algorithm that can be applied retrospectively to motion-corrupted MRI k-space data. For many applications, the computational overheads associated with the approach make it impractical. However, for multi-shot 3D data, because intra-shot motion can be neglected, the limited number of shots makes the method much more feasible. In the data presented here, a three shot acquisition has two degrees of freedom (as the first shot is used as the reference position), and therefore the iterative algorithm converges quickly on an optimal solution. In the work presented here as a proof of principle, motion was restricted to in-plane translation, but extension of the method to 3D translations and rotations is straightforward. Future work will investigate the effect of autofocus correction on CBF quantification and reproducibility.

Conclusions

We have demonstrated the use of autofocus to improve image quality in multi-shot 3D GRASE ASL acquisitions.

Acknowledgements

DLT is supported by the UCL Leonard Wolfson Experimental Neurology Centre (PR/ylr/18575). We would also like to acknowledge the EPSRC (EP/H046410/1) and the UCLH/UCL CBRC Strategic Investment Award (Ref. 168).

References

1. Detre et al, Magn Reson Med 23; 37-45 (1992)

2. Barker et al (eds), Clinical Perfusion MRI: Techniques and Applications. Cambridge University Press (2013)

3. Alsop et al, Magn Reson Med 73; 102–16 (2015)

4. Guenther et al, Magn Reson Med 54; 491-498 (2005)

5. Atkinson et al, IEEE Trans Med Imaging 16; 903-910 (1997)

6. Atkinson et al, Magn Reson Med 41; 163-170 (1999)

Abstract ID: 5645

Figures

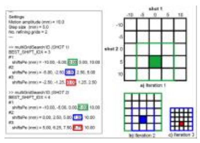

Figure 1: "Multi-grid" autofocus for a 3-segment acquisition. As the iteration process proceeds, the shift step size decreases as the algorithm homes in on the optimal solution. One of the three shots is considered to be in the reference position (shot 0), and therefore trial shifts are only applied to the other two shots (shots 1 and 2).

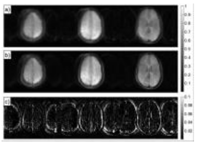

Figure 2: Result of applying the autofocus algorithm to control multi-shot 3D-GRASE images (3 slices from the same subject). a) Standard reconstruction b) Autofocus reconstruction c) Difference between a) and b). Scale bar shows image intensity in arbitrary units. A clear reduction in image blurring and ghosting can be seen after application of autofocus.