Parallel MRI for Regridding Multi-Shot Diffusion Data

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INTRODUCTION

A single shot EPI readout is commonly used in diffusion weighted imaging to avoid motion artefacts. Signal decay restricts the echo train length and this limits resolution. Furthermore, the small phase encode bandwidth leads to susceptibility artefacts. Parallel MRI enables image reconstruction from an acquisition with phase encodes omitted and this allows a shorter echo train length without loss of resolution. For example, with a speed-up factor of 2, alternate phase encode lines are skipped and the EPI train length is halved. This halves the susceptibility problem (in the sense that the pixel shift for two different resonant frequencies is halved) and gives a shorter echo time [1]. The scope for these improvements is the same as the coil "speed-up" factor and is limited to the order of 2-3. To achieve greater resolution, or reduced susceptibility artefacts, multi-shot, segmented EPI readouts may be used. In this case, motion requires that some segments be rejected and others shifted in k-space before image reconstruction. This leads to an irregular sampling of k-space with gaps potentially larger than the Nyquist limit [2]. One strategy to reduce the chances of a large gap is to acquire multiple averages [2]. Here we use parallel MRI to 'predict' missing k-space and cope with large gaps.

METHODS

A navigated multi-shot (MSH) diffusion weighted sequence was implemented on a Philips Intera 1.5T. The segmented EPI readout was followed by a 2D navigator mapping the centre of k-space. Data were acquired from a volunteer using a 6-element head coil, no cardiac gating, 6 diffusion directions, 3 repeats of the diffusion weighted (b=1000) images, phase encode left-right and 128x128 matrix. Coil profiles were determined from the b=0 images which are normally free of motion artefact. To simulate data collection from a single coil, the complex data from each element was added with a phase term to prevent destructive interference. We also acquired a single shot (SSH) image using a SENSE reduction factor of 2.4 for comparison. Due to the increased phase encode bandwidth, the MSH has a further factor 3 reduction in susceptibility artefact.

Data was regridded row-by-row by solving for **R** the matrix equation **S**=**CR** where **S** is the irregularly sampled k-space data and **C** is a convolution matrix. With one coil, **C** amounts to a sinc regridding. With multiple coils, **C** is composed of cyclic repetitions of the k-space of the coil sensitivities. The cyclic shifts are irregular and correspond to the irregular sampling.

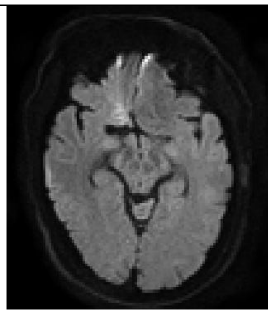
RESULTS

The multi-shot sequence shows reduced distortion compared to the single shot even though the SSH is already improved by a factor of 2.4 due to the use of SENSE (Fig. 1). The total amount of data and hence the SNR is not comparable between the MSH and SSH images, but is the same for the two MSH images.

Figure 1. Isotropic DW images.

Single shot, SENSE factor 2.4 (right).

Multi-shot (below).



Single coil regridding.

Multi-coil regridding.

For a given diffusion direction and image row, the condition number of **C** was always lower for the multi-coil reconstruction. This implies less noise amplification in the multi-coil regridding. If more averages are used, this statement remains true but the benefit is reduced.

DISCUSSION

Using multiple coils enables k-space regions lacking data to be regridded with a lower condition number, leading to improved MSH diffusion weighted images. The method is particularly suited to acquisitions with few averages per image, as might be used in higher field systems where the SNR is higher (and susceptibility problems are worse), or if many directions are desired.

REFERENCES

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