Elimination of Artefacts in Fast Spin Echo Imaging Caused by T2 Decay During the Echo Train by Combining Novel K-space Ordering ('Feathering') and Parallel Imaging

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Introduction Many fast imaging methods utilise a train of echoes with data acquired at different echo times (e.g. the Fast Spin Echo FSE where one phase encoding (PE) line is acquired per echo in a train following a single RF excitation pulse[1]). The signal level of each echo in the train is modulated by T_2 relaxation. This means that the k-space data has an effective filter applied across it along the PE axis, which is defined by T_2 and the PE k-space ordering scheme[2]. The resolution of each image pixel is defined by the Point Spread Function (PSF) that is the Fourier transform (FT) of the effective k-space filter. The PSF is degraded in the PE direction, resulting in artefacts and a loss of resolution. While echo time shifting can be used, it only improves the PSF to a moderate degree and involves an overhead in imaging time. In this work, Parallel Imaging (PI) is integrated with original k-space ordering to dramatically improve the PSF in FSE data at no cost in time.

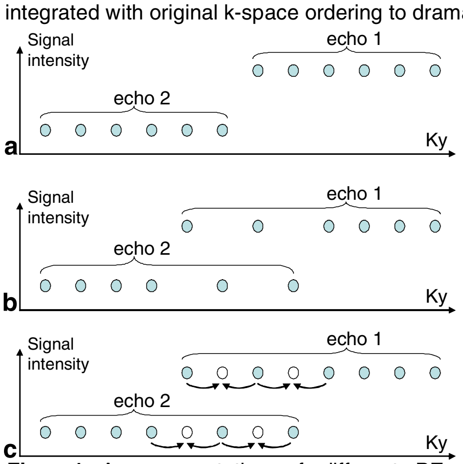

Figure1 A representation of different PE ordering schemes with data from 2 echo times **a)** A standard ordering scheme, **b)** feathered ordering scheme and **c)** PI is used to reconstruct the open circles, obtaining two data points for the same position in k-space produced at a different echo time. These are used to form two datasets, one containing the open circles and the second containing the filled circles.

Theory A discontinuity is present in the PE direction of k-space (fig. 1a) due to lines of data being acquired at different echo times. This causes significant sidebands in the PSF (fig. 2a). An overlapping region of k-space with data acquired alternately at different echo times (called 'feathering') can be used (fig. 1b)[3]. This moves the sidebands in the PSF with strong intensity to the edge of the FoV (fig. 2b). Using a PI method such as GRAPPA with the feathered data it is possible to obtain data over the region of the discontinuity from both echo times (fig. 1c). Now two datasets can be produced; both contain the original data except in the region of the discontinuity where one dataset uses the original feathering scheme (resulting PSF in fig. 2b), whereas the second uses the reconstructed feathering scheme that is offset in k-space by one point in the PE direction (resulting PSF in fig. 2c). The PSF from each dataset is complimentary with sidebands adding destructively and the main peak adding constructively (fig. 2d). This means by combining the images obtained from each dataset, the PSF can be improved without introducing artefacts.

Method All code was written in matlab (www.mathworks.com). A simple simulation was written where a 1D PE k-space filter was simulated as a matrix of 32 points. To simulate data from 2 echo times, half of these points were given a signal level of 1, while the rest were given a signal level of 0.5. The k-space order of the data was altered as in fig. 1, and the PSF calculated from the FT of the filter.

Experiments were performed on a SMIS MR5000, 4.7 Tesla / 90cm bore system, utilising a head gradient set (Magnex, UK) and a standard birdcage coil for transmission. Healthy subjects were imaged with informed consent and local ethics approval. A 4-channel head array coil (Pulseteq, UK) was used for RF reception. The FSE sequence has been previously described[3]. Here, a resolution of 352μm × 352μm x 2000μm was used, necessitating a higher receiver bandwidth of 100kHz. Other parameters were TR=3.5s, FoV=360mm×270mm, matrix=1024×768, 17 slices. The sequence employed an echo train length of 8 echoes spaced 22ms apart, with the effective TE=22ms. Images were phase corrected and a Hanning filter was applied prior to image reconstruction (FT). Two datasets were created from each slice of data following the process outlined in figure 1c with the missing data obtained using a 2 block GRAPPA[4] reconstruction. This process was followed for each coil and the square root of the sum of squares (SSQ) taken.

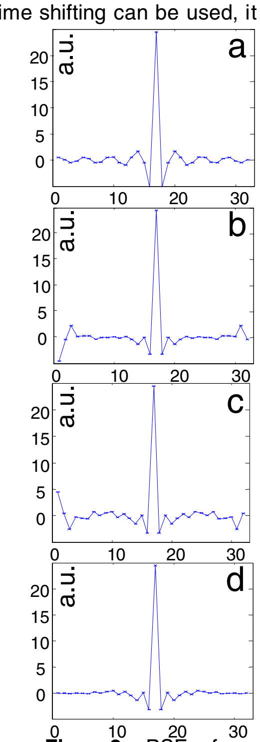

Figure2 PSF from different PE ordering schemes with data from 2 echo times. **a)** A standard ordering scheme, **b)** feathered ordering scheme, **c)** Offset feathered ordering scheme, and **d)** PSF from combination b+c

Results and discussion The results of the simulation (fig. 2) demonstrated that the combination of two feathered datasets offset by one k-space point (fig. 2d) is better than either no feathering (fig. 2a) or one feathered dataset (fig. 2b & 2c). A SSQ FSE image from a single feathered data set (fig. 3a) is compared to a reconstruction of the same data by creating two offset feathered datasets with GRAPPA before adding the images together. To clearly view the difference between the original image (fig. 3a) and the new image (fig. 3b) they were subtracted and displayed (fig 3c). The ghosting due to the feathering method has been removed. There is little cost in SNR from this process because only a few lines of k-space are reconstructed with GRAPPA where the feathering is applied. An alternative approach would be to perform a weighted average of the two datasets in the feathered region to create a smooth transition between data from different echo times. This would mimic echo time shifting, with the advantages that the phase coherence of both spin echo and stimulated echo pathways can be maintained to compensate B_1 inhomogeneity and no increase in echo train duration is required. Previous work to remove artefacts with PI were mainly focused on EPI and required an apriori model of the 'PSF'[5]. In this work, artefacts are removed without a model of the PSF; instead the PSF is manipulated by using both PI reconstruction methods and PE k-space ordering. This method may be applied to improve the PSF of other multi-echo sequences.

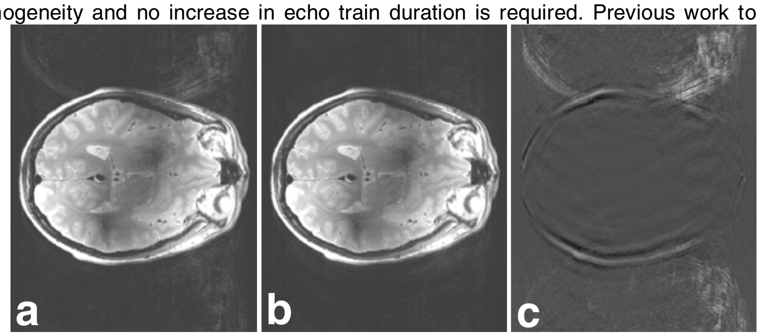

Figure 3 Artefact removal in FSE SSQ images of 4-coil data
a) Image obtained using the feathering method, **b)** Image obtained by combing two images with feathering offset by one k-space point, **c)** difference image a-b. NB The same data was used in images 'a' and 'b'.

References **1.** Hennig J et al, 1986. RARE imaging: a fast imaging method for clinical MR. MRM. 3:823-33. **2.** Mulkern RV et al, 1990. Contrast manipulation and artifact assessment. MRM. 8:557-566. **3.** Thomas DL et al, 2004, High Resolution Imaging of the human Brain at 4.7 T: Implementation and Sequence Characteristics. MRM 51:1254-64. **4.** Griswold et al, 2002, Generalised Autocalibrating Partially Parallel Acquisitions (GRAPPA). MRM 47:1202-1210. **5.** Kellman et al, 2001, Ghost artifact cancellation using phased array processing. MRM 46:335-343.

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