SPENT: Sub Pixel Enhancement of Non-uniform Tissue and its first application to imaging of magnetically labelled cells

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Introduction SPENT (Sub Pixel Enhancement of Non-uniform Tissue) is a method that sensitises images to the level of homogeneity of magnetisation within each pixel. This can be achieved by splitting a region of acquired k-space into different 'tiles', which are Fourier transformed individually. Previously, similar techniques have been applied to image bone using a spin echo (SE) readout and proton density weighted images [1,2]. Recently, a so called 'white marker' method (similar to SPENT) has been used to image cells labelled with magnetic particles to obtain positive contrast in gradient echo (GE) images [3]. Here, SPENT images of a phantom containing different layers of cells loaded with magnetic particles are shown and the merits of this approach are discussed.

Theory The higher frequency ranges of k-space contain information on smaller structural details of the object (i.e. edges or large susceptibility differences); SPENT aims to target these regions of k-space to highlight these structural details. SPENT images are obtained by sampling different 'tiles' of k-space that are Fourier transformed individually. The tiles may be sampled in different acquisitions as illustrated in Figure 1a. Alternatively, an image is acquired at a higher resolution and the k-space data is divided into 'tiles' for separate reconstruction. A 2D data set produces 9 tiles of data and a 3D data set produces 27 sub-cubes. The off-centre tiles produce SPENT images when Fourier transformed and the central tile produces a standard image at lower resolution. The information in the SPENT images will depend on the sequence used, e.g. in the case of a SE sequence, voxels with heterogeneous magnetisation density will be highlighted, and for a GE sequence, voxels with heterogeneous magnetisation phase will be highlighted.

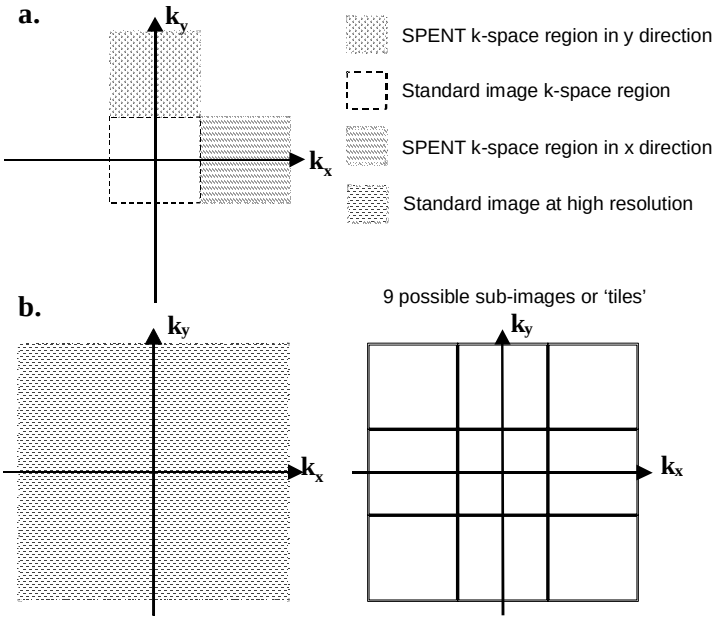

Figure 1 SPENT and high resolution image acquisitions represented in k-space
a. the different tiles in k-space are seen that are obtained with a standard sequence and with the extra SPENT gradient applied in the x and y directions respectively.
b. a high resolution image acquisition is shown. This k-space data can be divided into separate tiles forming a lower resolution image and 8 possible SPENT images.

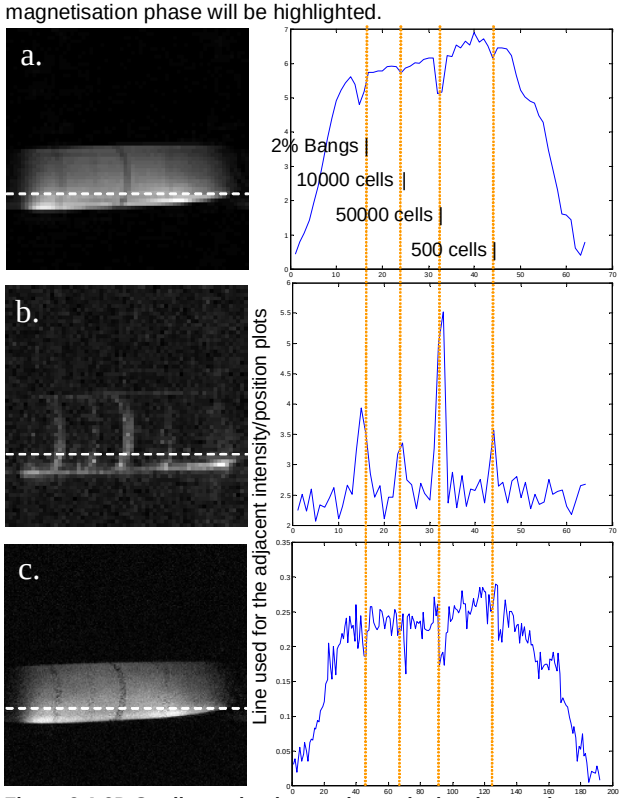

Figure 2 A 3D Gradient echo data set is manipulated to produce a SPENT image with positive contrast
a. Central 1/3³ of k-space is Fourier transformed producing a 64³ image, one slice of which is shown.
b. Sum of the 26 SPENT images (each is the Fourier transform of one of the 26 off centre k-space cubes), the same slice as in *a.* is shown
c. High resolution image (from the Fourier transform of the full k-space data set), a slice from the same part of the object as *a. & b.*

Method Experiments were performed with a 2.35T, 20cm bore, SMIS spectrometer. A high resolution 3D spoiled GE sequence was used to image a phantom TR/TE=50/12, flip angle=20°, FoV=(6cm)^3. The phantom consisted of 2% agar with 4 layers placed 1 cm apart, consisting of firstly 2% Bangs solution, secondly, a layer containing 10000 labelled cells, thirdly, a layer with 50000 cells, and lastly, a layer with 500 cells. The Ntera2 cells were labelled by incubation with 1 µm-Bangs particles for 24 hours. The 3D-GE phantom data set was processed to produce 27 separate sub-cubes of data that were Fourier transformed individually. Additional images were obtained using a 7T, 12cm bore Bruker spectrometer of similar phantoms to obtain both SE and GE SPENT and standard images.

Results Different images produced from the same dataset are shown in Figure 2. From the top down: a) a low resolution image using the central 1/3 of k-space, b) a SPENT image produced by summating images obtained from all 26 off centre k-space cubes, c) a high resolution image using the full k-space data. Next to the images are the corresponding 1D signal profiles through the slice (at the position indicated). The combined SPENT image b) shows different, positive contrast.

Discussion SPENT images can be obtained by dividing k-space from a high resolution data set and Fourier transforming the subsets separately. The subsets will have a different effective echo time. Alternatively, the subsets of data may be obtained with the same echo time in separate acquisitions. This can be applied to any pulse sequence. SE and GE SPENT images were obtained in a phantom demonstrating 'positive' contrast of magnetically labelled cells, an example using 3D-GE images is shown in Figure 2. The labelled cells appear more obvious in the SPENT image than in the high-resolution GE image. This is due to both the removal of the bulk object contrast and the signal averaging that occurs in combining the SPENT images. The relative merits of this contrast and the different data acquisition / image combination strategies require further analysis. One of the main advantages of this method compared to other 'white marker' methods is that the SPENT images can be derived from a high resolution anatomical scan, which usually needs to be acquired anyway, making this approach simple and time-efficient.

1. Carmichael, D. W. et al, 2002, *Proc.10th Annual Meeting of the ISMRM*, 296.
2. Carmichael, D. W. et al, 2004, *Proc.12th Annual Meeting of the ISMRM*, 803.
3. Corstine, A.J. et al, 2004, *Proc.12th Annual Meeting of the ISMRM*, 163.

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