Spatial Encoding Using Readout Segmentation (SPURS): An Alternative Sampling Scheme for Single-Shot, Multiple Spin Echo MRI

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Introduction

Single-shot sequences, such as RARE (2), HASTE (3) and GRASE (4), use multiple RF refocusing pulses to reduce the susceptibility artefacts seen with EPI (1). RARE and HASTE sample each line of data with a separate spin echo. The large number of RF refocusing pulses required makes slice-selection impractical and non-selective pulses are used with a time delay after each slice to allow for spin relaxation. The spin-echo train is often long compared to tissue T_2, resulting in image blurring. GRASE samples multiple lines of data with each spin echo, so that fewer RF refocusing pulses are required, making slice-selection a possibility. However, there is a complex signal modulation in *k*-space due to a combination of T_2, T_2^* and off-resonance effects, leading to ghosting and ringing artefacts in the image [5,6]. This paper describes an alternative approach to data sampling in single-shot, multiple spin-echo imaging, which results in a substantial reduction in susceptibility artefact compared to EPI, but which avoids the type of *k*-space signal modulation seen with GRASE. The novel feature of the technique is that the data acquisition in the readout direction is divided into a number of segments, which are sampled with different spin echoes. The sequence has been given the name SPURS (Spatial encoding Using Readout Segmentation) to describe this process.

Methods

***Sequence Design*:** The SPURS sequence diagram is shown in fig. 1. The sequence performs a series of EPI readouts, using 180^o refocusing pulses to generate a spin echo at the centre of each EPI echo-train. Variable amplitude readout gradients (coloured blue) are applied before and after each EPI echo-train to produce an offset in the k_x direction. Each EPI echo-train samples a segment of *k*-space along k_x and the entire range of *k*-space along k_y.

Computer Simulation: 2D point spread functions (PSFs) were generated to compare the SPURS sampling scheme to that of GRASE. The calculations assumed a T_2 value of 90ms, a T_2^* of 65ms and a maximum gradient slew rate of 200Tm^{-1}s^{-1}. SPURS and GRASE protocols were chosen to have a similar effective TE and total sampling time and were based on a FOV of 173mm x 230mm. The GRASE protocol used 15 spin echoes with an echo spacing (ES) of 10.6ms and 7 gradient echoes per spin echo with an ES of 980µs (matrix: 105 by 128). The SPURS protocol used 5 spin echoes with an ES of 33ms and 105 gradient echoes per spin echo with an ES of 280µs (matrix: 105 x 125). A Hanning filter was used in the simulation to attenuate signal in the outermost 16 *k*-space points in each direction.

Measurements in Healthy Volunteers: The SPURS sequence was implemented on a 1.5T Siemens Sonata system using a maximum gradient slew rate of 200Tm^{-1}s^{-1}, a sinusoidal readout gradient and a blipped phase-encoding gradient. Images were acquired using the standard CP head coil with: FOV 157mm x 230mm; matrix 96 x 176; pixel size 1.6mm x 1.3mm; slice thickness 5mm; 7 spin echoes with spacing of 31ms; EPI echo train length 96 and ES 280µs; effective echo time 123ms.

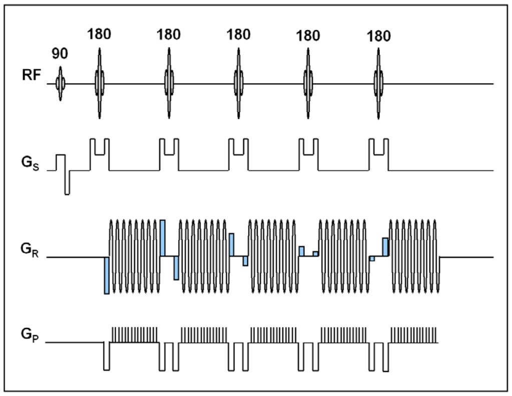

Figure 1: Pulse sequence diagram for single-shot SPURS

Results

The results from the computer simulation are shown in fig. 2, the SPURS PSF is considerably smoother than that for GRASE, which has multiple side-lobes in the phase-encoding direction. SPURS single-shot images from the volunteer study are shown in fig. 3.

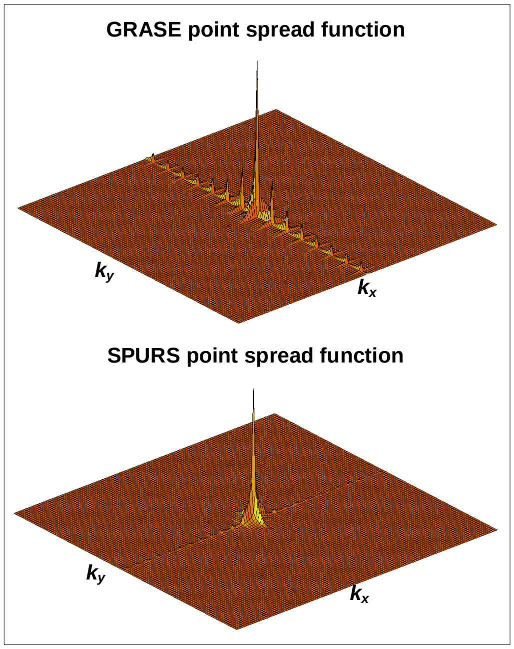

Figure 2: Comparison of computer-simulated PSFs

Discussion

The smoother PSF with SPURS arises because the *k*-space signal variation takes place along both k_x and k_y axes, affecting the PSF in both directions, but in a relatively benign fashion. With SPURS the complete k_y range is sampled at each spin echo so that T_2 decay does not have a significant effect on the PSF in the *y* direction, which is dominated by T_2^* decay, as with EPI. The readout gradient moment required to sample each k_x segment is considerably less than with EPI, allowing a substantially shorter echo-spacing to be used, thereby reducing susceptibility artefacts. The PSF in the frequency-encoding (*x*) direction is generated by T_2 decay between spin echoes and is therefore similar to the phase-encoding PSF in turbo-spin-echo (TSE). Also in common with TSE, SPURS acquires the central region of *k*-space at one echo time, leading to similar contrast behaviour. Further work is required for a detailed comparison with other techniques, including GRASE with modified *k*-space re-ordering (5).

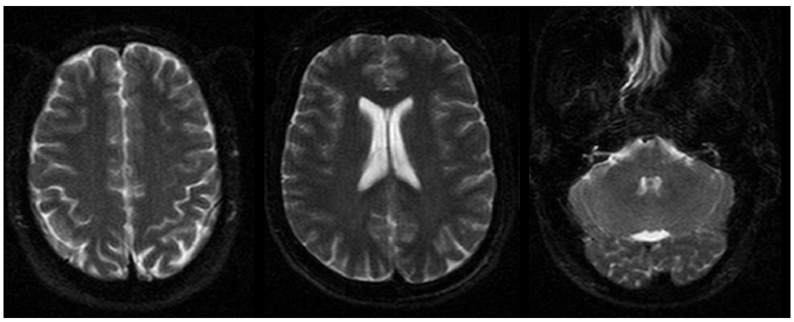

Figure 3: Single-shot, T_2-weighted images acquired with SPURS sequence

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