Common SENSE: A new method for performing single-shot segmented EPI

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Introduction Gradient Echo EPI (GE-EPI) suffers from a number of problems related to the duration of its readout. Blurring occurs because of T_2* decay during the readout. Distortion is the result of local susceptibility gradients and chemical shifts that cause an error in the assignment of spin position that depends on the phase encoding bandwidth. Both of these problems are exacerbated at higher field strengths where susceptibility gradients are stronger and, correspondingly, T_2* is shorter. In segmented GE-EPI, lines of data acquired in separate readouts are interleaved in k-space. This has been used to reduce the effective readout time (*TRO*) and increase the phase encoding bandwidth. Single-shot segmented methods (e.g. Mesh[1]) often have significant discontinuities in both phase and amplitude between adjacent k-space lines, which causes severe ghosting artefacts in the resulting images. Multi-shot segmented methods are more robust to ghosting, but normally entail a penalty in temporal resolution. Additionally, sensitivity to subject motion is increased when data from different shots is combined. Common SENSE is a new single-shot method to segment the EPI readout into two half length readouts. However, the data is combined in image space, avoiding the problems associated with previous single-shot segmented EPI methods.

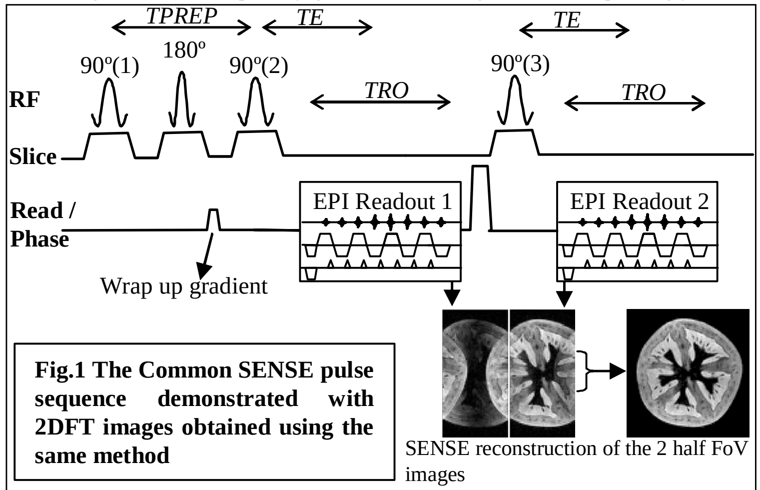

Fig.1 The Common SENSE pulse sequence demonstrated with 2DFT images obtained using the same method

Theory Two images with spatially varying sensitivity profiles and near identical contrast are produced in rapid succession by the Common SENSE pulse sequence (similar to TRAIL[2]). The two images are then acquired with a reduced Field of View (FoV) and combined as if they were multiple images from separate coils in a SENSE[3] experiment. A linear phase shift is imposed on the transverse magnetisation with a 'wrap up' gradient after the first 90° RF-pulse (see the pulse sequence in Fig.1 and corresponding magnetisation development in Fig.2). This creates two components of magnetisation M_x and M_y that are modulated by a cosine and sine respectively in the direction of the applied gradient. The second 90° RF-pulse then rotates a portion of the magnetisation (M_y) onto the z-axis where it is stored. The magnetisation that remains in the transverse plane is used to acquire an image. A third 90° RF-pulse recalls the magnetisation previously stored along z (affected by a small amount of T1 relaxation) and a second image is acquired. B_0 inhomogeneities are refocused at the second 90° RF-pulse by the 180° RF-pulse. Any magnetisation in the transverse plane after the first readout is spoiled to avoid any interference with the second readout. The 'wrap up' gradient used imposed a π radian linear phase shift is across the FoV. This produces images containing a sinusoidal modulation of ½ wavelength across the FoV, with a $\pi/2$ phase difference between each component. A full FoV image reconstructed from two half FoV images with these sensitivity functions has an SNR penalty of uniformly $1/\sqrt{2}$ compared to a conventional image; the minimum from sampling with half density.

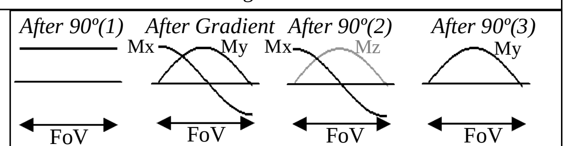

Fig. 2 Progression of magnetisation through the Common SENSE pulse sequence

Methods EPI experiments were performed on a SMIS MR5000, 4.7T/90cm system provided by Philips Medical Systems utilising a head gradient set (Magnex, UK) and a standard birdcage coil. Processing was performed offline using software developed in MatLab (Mathworks, Natick, MA). A blipped phase encoding / sinusoidal readout gradient EPI sequence was used (100x64 matrix re-gridded to a uniform 64x64 matrix). Acquisitions performed with read gradients of opposite polarity were used to eliminate ghosting[4]. Maps of the sensitivity profiles imposed by the Common SENSE pulse sequence were generated using full FoV Common SENSE images and a reference image (not shown). Images were taken using a single-shot, single segment 'standard' acquisition and a single-shot Common SENSE acquisition featuring two half length readouts. A healthy volunteer's head was imaged with UCLH ethics committee approval. The following parameters were used: TR=3500ms, TE=20ms (the approximate T_2* of grey matter at 4.7T), TPREP~10ms and TRO~13ms, FoV=20cm, 3mm slice thickness, for a 64x64matrix. The minimum total acquisition time at this TE for the Common SENSE image is ~63ms, for the equivalent standard image it is ~33ms. This should allow both methods to acquire at least 48 slices within the TR used here.

Results In Fig.3, a comparison of Common SENSE and standard GE-EPI images is shown. Fig. 3a shows a Common SENSE image reconstructed from half FoV data. Fig. 3b is a standard EPI image; both are obtained in one shot. A difference image (Fig. 3c) shows regions with a large percentage change (white or black pixels) on the edges of the brain and in the frontal sinus regions indicating a reduction in distortion. Blurring is also improved in the image by halving the effective readout time. The penalty is a $\sqrt{2}$ reduction in SNR when compared to the standard protocol.

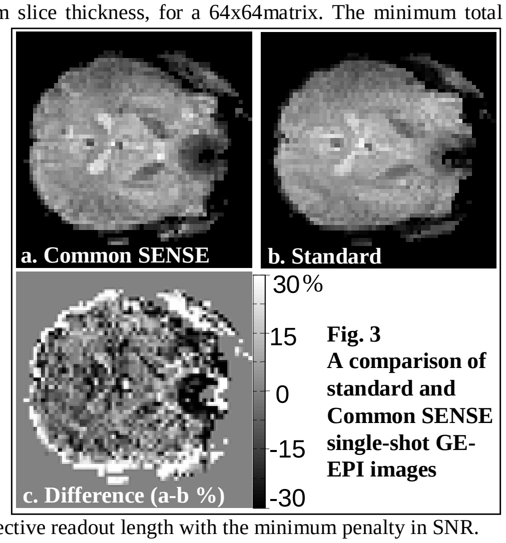

Fig. 3 A comparison of standard and Common SENSE single-shot GE-EPI images

Discussion Common SENSE has been used to perform segmented GE-EPI in a single-shot. This was achieved by producing two half FoV images in rapid succession, before using reconstruction methods from SENSE to obtain a full FoV image. The advantages of Common SENSE are that the EPI readout length is halved while the phase encoding bandwidth is doubled. The corresponding increase in image quality does not come with a penalty in temporal resolution like most multi-shot segmented EPI methods. The Common SENSE image requires a longer total time to obtain data for one slice. However, the total acquisition time for Common SENSE of ~63ms at 4.7T can allow sufficient volume coverage for fMRI experiments. Also, because the data is gained within a few tens of milliseconds and combined in image space, Common SENSE is not sensitive to mismatches in phase or amplitude between the data segments that can cause ghosting artefacts. Common SENSE is not an alternative to SENSE, but instead, is a new method for shortening the EPI readout that does not require additional hardware. For a significant increase in the resolution of GE-EPI images to be to be realised at high field strength, a combination of methods is likely to be necessary; together SENSE and Common SENSE could produce a maximum reduction in the effective readout length with the minimum penalty in SNR.

References **1** Rzedzian, R.R. 1987, *High speed, high resolution, spin echo imaging by mosaic scan and MESH*, Proc.6th Meeting of the SMRM, p. 51. **2.** Priest, A. N. et al. 2002, *TRAIL (Two Reduced Acquisitions InterLeaved)*, Proc.10th Meeting of the ISMRM, abs. 2381.**3.** Pruessmann et al. *SENSE: sensitivity encoding for fast MRI.* Magn Reson Med 1999;42:952–962. **4.** Thomas, D. L. et al, 2003, *Reducing motion-related artefacts caused by 2D phase correction in time course EPI..*, Proc.12th Annual Meeting of ISMRM, abs. 1026.

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