Fast Structural Brain Imaging using an MDEFT Sequence with a FLASH-EPI Hybrid Readout

R. Deichmann[1]

[1]Wellcome Department of Imaging Neuroscience, Institute of Neurology, London, England, United Kingdom

Introduction: The Modified Driven Equilibrium Fourier Transform (MDEFT) sequence [1,2] is widely used for structural brain imaging. MDEFT provides good contrast between white matter (WM) and grey matter (GM), even at high field strengths [1]. Algorithms for optimising sequence parameters at different field strengths have been presented recently [3]. The sequence consists of segments comprising a magnetization preparation part followed by acquisition of several gradient echoes, in general based on three-dimensional (3D) FLASH imaging [4]. However, the long sequence duration may compromise its application to whole brain coverage with a high spatial resolution. Acquisition times can be reduced by using a FLASH-EPI hybrid readout, where several echoes with different phase encoding are acquired after each excitation pulse. This concept has been described in detail as Interleaved Gradient Echo Planar Imaging (IGEPI) [5]. It has been shown both theoretically [6] and experimentally [7] that hybrid sequences can yield higher signal-to-noise ratio (SNR) than either FLASH or EPI. Hybrid sequences have been used extensively for various purposes, e.g. for the fast acquisition of quantitative T1 maps [8]. In this work, we show how a hybrid readout with 2 echoes per excitation can be integrated into an MDEFT sequence for anatomical brain imaging with whole brain coverage and isotropic resolution of 1 mm. The total acquisition time is 8 min. It is shown experimentally that the resulting brain images have the same SNR and contrast-to-noise ratio (CNR) as images acquired with a considerably longer standard MDEFT sequence based on a FLASH readout.

Theory: The preparation part of MDEFT has the structure $90°–\tau1–180°–\tau2$ where $\tau1$ and $\tau2$ are optimised for maximum SNR and CNR [3]. For all experiments described in this work, the following matrix size and gradient directions were chosen: readout (superior/inferior): 256 pixels, 2D-phase (anterior/posterior): 224 pixels, 3D-phase (left/right): 176 pixels. In the hybrid MDEFT sequence, 176 excitation pulses with repetition time TR are sent after each preparation experiment, stepping through the different values of the 3D-phase encoding gradient. After each excitation pulse, two gradient echoes are acquired under read gradients of opposite polarity with the same degree of 3D-phase encoding but different degrees of 2D-phase encoding, differing by a constant value which corresponds to 50% of the total k-space coverage in 2D direction. This sequence segment is repeated 112 times with increasing degree of 2D-phase encoding to cover the full k-space. Problems may arise from the fact that the two echoes and thus different parts of k-space are sampled with different echo times (TE). To avoid artefacts, the concept of echo time shifting (ETS) is used [5,9] which consists in a successive TE increase in the outer loop, thus leading to a smooth TE variation across k-space. A further problem may be the fact that 50% of central k-space data are acquired early during the experiment (covered by the second echo), and the other 50% at the end of the experiment (covered by the first echo). Thus, subject movement at any time during the experiment will lead to phase discontinuities in central k-space and therefore cause strong artefacts. To avoid this problem, asymmetric k-space sampling was chosen in 2D direction, shifting coverage by 20 lines. In this way, central k-space is covered by the first echo only, and central k-space data arise from a limited number of subsequently acquired steps, covering a short time-span only. A further increase in data quality is achieved by acquiring 2 navigator echoes without any 2D or 3D phase encoding and performing a phase correction for the whole data set.

Methods and Materials: Experiments were performed on a 1.5T Sonata whole body scanner (Siemens Medical Systems, Erlangen, Germany) using a whole body transmit coil and an 8-element phased array head receive coil. The hybrid MDEFT sequence was tested on five healthy volunteers (three male, two female) aged between 29 and 41 years (mean: 36 years). The imaging parameters were $\tau1/\tau2$=256ms/384ms, TR/TE/FA/BW = 20.66ms/8.42ms/25°/46kHz, matrix size as described above, isotropic resolution 1 mm, total duration 8 min. (Note: due to ETS, each echo will have a different TE. The reported value of 8.42ms refers to the echo covering the centre of k-space). For each volunteer, the SNR in WM and GM was determined in regions of interest inside the corpus callosum and the caudate nucleus, respectively, as described in [3], and the CNR was calculated from the difference of the SNR values. For one of the volunteers, an MDEFT dataset with a standard FLASH readout was additionally acquired as described in [3], with the imaging parameters $\tau1/\tau2$=223ms/307ms, TR/TE/FA/BW = 12.24ms/3.56ms/23°/27kHz, matrix size as described above, isotropic resolution 1 mm, total duration 12 min.

Results: For the 8 min hybrid MDEFT sequence, the average SNR values were 40.9±1.3 (WM) and 26.5±1.2 (GM). The average CNR was 14.5±0.4. These values are similar to results reported for the 12 min standard MDEFT sequence [3]. Figure 1 shows zoomed areas from data sets acquired with the 8 min hybrid MDEFT sequence (left) and the 12 min standard MDEFT sequence (right). Clearly, the image quality is comparable. In some areas, the hybrid MDEFT sequence yields better contrast, e.g. for the optic radiation which is less visible in the standard sequence (left).

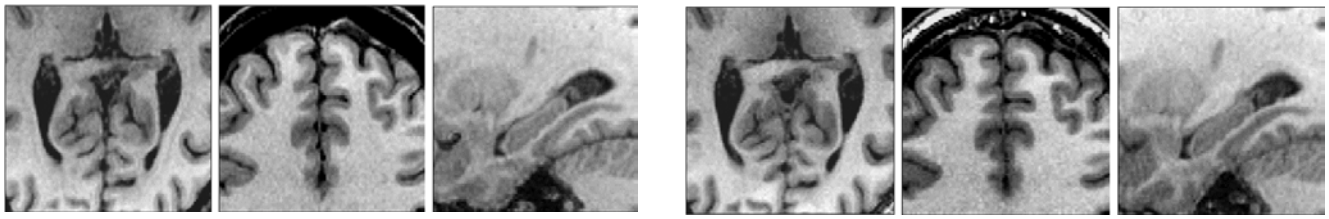

Fig. 1: *Zoomed areas from data sets acquired with the 8 min hybrid MDEFT sequence (left) and the 12 min standard MDEFT sequence (right).*

Conclusion and References: The method presented in this work allows for the fast acquisition of T1 weighted anatomical brain images by using a FLASH-EPI hybrid readout. A structural data set acquired with the hybrid MDEFT sequence with a total duration of 8 min displayed the same SNR and CNR as images acquired with a 12 min MDEFT sequence based on a standard FLASH readout.

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