Global and spatially varying B_0 drifts due to gradient system heating

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Introduction: In recent publications there is a trend to increase the resolution in fMRI and DTI imaging. This leads to longer readouts and larger line to line spacing in the EPI echo train which increases the sensitivity towards geometric distortions or a global shift of the image in phase encoding direction. Particularly, for acquisition schemes with varying phase encoding directions, such as PROPELLER-EPI [1], these shifts have to be well compensated. Static off-resonance effects can be corrected for by a multitude of methods [2, 3, 4]. A dynamic global shift of B_0 with increasing gradient coil temperatures [5] can be easily taken into account as a linear phase gradient in k-space. However, frequency shifts due to gradient heating can also exhibit a spatial dependency which is analyzed in this work.

Material and Methods: MR experiments were performed on a 1.5T whole-body scanner (Magnetom Avanto, Siemens Healthcare, Germany) using a 25 cm diameter spherical water phantom placed in the isocenter of the scanner. To stress and heat the gradients a PROPELLER-EPI DTI sequence was applied with Stejskal-Tanner gradient pulse pairs operating at the maximum supported gradient amplitude to achieve a b-value of 1000s/mm^2 for 15 directions and one b_0 image (TA=10.9min). In addition, slice selective spectroscopic acquisitions (first, center and last slice covering 2/3 of the sphere) using the same TR as the DTI acquisition were interleaved in this sequence. Prior to each DTI acquisition a 3D gradient echo FLASH sequence (TA=30s) was run to obtain phase data from which the spatial and temporal changes of B_0 were calculated. Furthermore, a single non-selective spectroscopic acquisition (TA=3s) was performed before each heating period. After heating the gradients with 9 repetitions of this GRE, spectroscopy and DTI group for a total acquisition time of 103 min, a non-selective spectroscopic sequence (TR=10 s, 64 repetitions) replaced the DTI sequence to allow the gradients to cool down. Except an initial shim and frequency adjustment there were no further adjustments throughout the latter experiment.

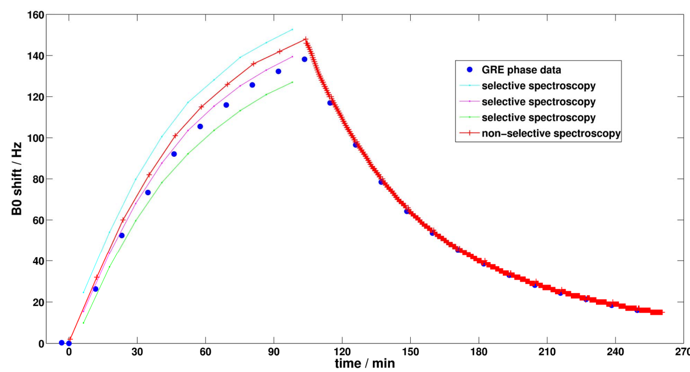

Fig 1: B_0 frequency drift measured in the phantom over time calculated from GRE phase data (average over whole phantom) and spectroscopic data. The curves acquired with slice selective spectroscopy clearly show a B_0 divergence for the three slices (~30Hz).

Results: Fig. 1 shows the evolution of B_0 (expressed as frequency shift) in the phantom. The frequency shift calculated from the mean phase shift of the GRE data (blue dots) is in good agreement with the non-selective spectroscopy (red curve) and the selective spectroscopy of the central slice (magenta curve). The overall frequency shift of approx. 150 Hz is surprisingly large but can be compensated in image reconstructions by applying appropriate linear phase gradients in *k*-space. However, the spectroscopic frequencies of the first (cyan curve) and last slice (green curve) deviate from the mean B_0 shift and a frequency difference of approx. 30Hz was measured after 100 min of gradient stress. Fig. 2 shows the spatial B_0 variations on a sphere's surface. After 20min of gradient activity a B_0 gradient occurred primarily along the z-axis and increased up to 30Hz frequency difference after 45min. After finishing the gradient activity (100 min) this spatial B_0 gradient vanishes after approx. 20 min while the global frequency shift takes much longer to reach the baseline (>150 min).

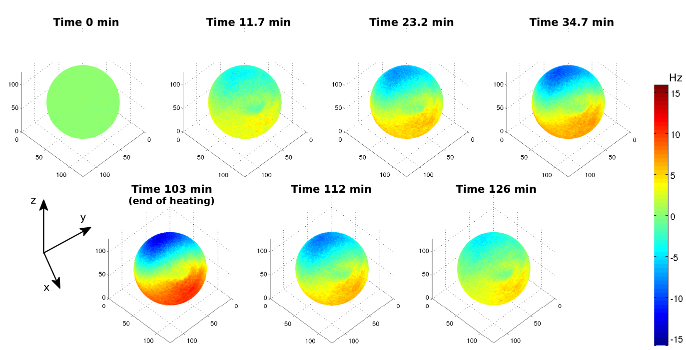

Fig 2: The B_0 distributions (in Hz) on a sphere 1 cm inside the phantom surface clearly show a gradient primarily along the z-axis during extended heavy gradient activity. To illustrate the spatial dependence the global frequency shift has been removed by subtracting the mean shift for each time point.

Discussion: The severe global shift of 150 Hz causes large geometric shifts in phase-encode direction for any EPI image. Even though the global shift can easily be compensated, a dynamically changing spatial B_0 gradient of 30 Hz will cause significant changes of geometric distortions throughout the object. Such a spatial gradient requires frequent updates of initially acquired field maps to compensate geometric distortions in addition to a frequency offsets for geometric shift compensation. Otherwise, severe reconstruction problems will occur for high resolution PROPELLER-EPI DTI measurements, because strong image blurring will result from the temporally changing geometric distortions. However, even for Cartesian sampled, single-shot EPI DTI or fMRI sequences a non-uniform change of B_0 will present problems if the later images are differently distorted than those obtained at the beginning of the measurement. Interleaving short slice selective spectroscopic acquisitions within the DTI sequence allows to acquire the actual mean frequency drifts during the DTI scan across the slice stack. Since the spatial distribution in Fig.2 has only slowly varying components, spatial changes in B_0 can be compensated by interleaving short low resolution field map scans with the DTI sequence. Data from the low resolution field maps can then be used to update an initial high resolution field map.

References: [1] Wang FN, et.al. MRM, 2005, [2] Man L-C, et.al., MRM, 1997, [3] Holland D, et.al., NeuroImage, 2010, [4] Zeng H, et.al., MRM 2004 [5] Förster BU, et al. MRM 2005.