Dynamic Shim Updating (DSU) for Multi-Slice Signal Acquisition

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Abstract A novel approach to optimal, extended volume (e.g whole head) shimming is presented. The method relies on dynamically updating an optimal shim setting for each individual slice in a multi-slice dataset. The optimal shims are obtained with a rapid, automated and user-independent phase mapping technique. T_2* and frequency distribution maps and spectroscopic images obtained from rat brain *in vivo* are presented to demonstrate the superior performance of DSU over global shimming for multi-slice signal acquisition.

Introduction The optimization of the main magnetic field homogeneity (i.e. shimming) is important for all NMR applications, but represents a crucial step for NMR spectroscopy and spectroscopic imaging and T_2*-based imaging. In the last decade several important advances in shimming methods and technology have been described [1-3]. The traditional, iterative shimming methods, which are often time-consuming and biased towards local optima, can be made quantitative and user-independent by using quantitative phase mapping methods (e.g. [1, 3]). These non-iterative methods are most often used to optimize the magnetic field homogeneity in a single (cubic) volume for NMR spectroscopy [1] or over a single slice for (spectroscopic) imaging [3]. When it is required to optimize the magnetic field homogeneity over more extended volumes (e.g. whole head), the performance of the single volume methods is fundamentally limited by the higher-order magnetic field inhomogeneities. Blamire *et al.* [2] presented a novel approach for extended volume shimming by dynamically updating an optimal (first-order) shim setting for each individual slice during the acquisition of a multi-slice dataset. Here we present an extension of dynamic shim updating (DSU) to include all first- and second-order shims. A novel, non-iterative, multi-slice, 1D phase mapping method is presented to obtain the optimal shim settings for each slice with minimal user interaction.

Methods All experiments were performed on a 4.7 T Bruker magnet interfaced to a Bruker Avance spectrometer. A 6.0 cm diameter volume coil was used for RF transmission, while NMR signal reception was achieved with an actively-decoupled 1.6 cm diameter surface coil. The NMR sequence to acquire 1D phase maps is shown in Fig. 1. The sequence is based on the previously described FASTMAP method [1], but extended to include multi-slice signal acquisition and DSU. The sequence is executed with adiabatic RF pulses to minimize user interaction. The dynamic shimming interface (DSI) consists of a custom designed circuit, placed within the Bruker shim controller that emulates standard Bruker shimming in addition to implementing DSU. The DSI is designed to store 16 optimal shims for 127 slices, which can be updated in less than 10 µs per slice, thereby allowing for real-time updating of optimal shim settings. The optimal shim settings were calculated in Matlab 5.0, after which home-written Visual Basic software was used to transfer the shim values to the DSI unit.
The *in vivo* performance of DSU was evaluated on the brain of male Wistar rats (180-220 grams, n = 4). The optimal global shim setting was obtained with a standard, single-volume FASTMAP experiment [1] from a $7 \times 7 \times 7$ mm^3 voxel placed in the middle of the brain. The optimal local shims were obtained with the sequence of Fig. 1, allowing for off-center shimming in all three directions. The in-slice shims for coronal slices were determined from an elliptical region-of-interest (10×7 mm^2).

Results The three spin-echo images of Fig. 2A, extracted from a five-slice dataset, show a typical slice coverage (+/- 3 mm relative to bregma) used in the presented studies. 2D multi-slice phase images were obtained from the identical slice positions with and without DSU. From the 2D phase maps, using an elliptical area positioned in the brain (10×7 mm^2) while avoiding edges of the brain by ~ 0.5 mm, frequency distributions were created. The frequency distribution of the slices acquired with (solid line) and without (dashed line) DSU are shown in Fig. 2B. As expected, the homogeneity of the middle slice does not improve significantly with DSU, since the global shim settings are close to optimal in the isocenter. However, DSU significantly improves the homogeneity of the outer slices, even at modest slice offsets of +/- 3 mm. With DSU, the homogeneity of all five slices is approximately identical, in sharp contrast to the global shim where only the middle slice has an acceptable homogeneity for many applications (e.g. spectroscopic imaging).

Conclusions Here we have presented a novel approach to optimal, extended volume shimming. The DSU method is based on preliminary work of Blamire *et al.* [2], but has been extended to include all first- and second order shims, which can be quantitatively determined with a novel, fast and user-independent, multi-slice FASTMAP routine. The high magnetic field homogeneity over multiple slices should be particularly useful for (1) water suppression and automated processing in multi-slice spectroscopic imaging and (2) T_2*-based functional and anatomical imaging.

References
[1] R. Gruetter, Magn. Reson. Med. 29: 804 (1993)
[2] A. M. Blamire et al, Magn. Reson. Med. 36:159 (1996)
[3] J. Shen et al, Magn. Reson. Med. 42:1082 (1999)

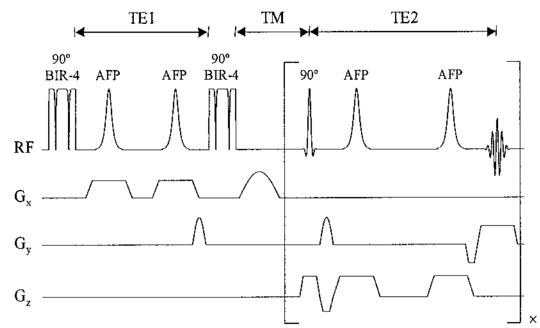

Figure 1 : Multi-slice phase mapping NMR sequence. The DSI increments the stored shims to the next slice prior to the selective 90° pulse and resets it to a global shim setting prior to the first RF pulse. During phase mapping the trapezoidal gradients change orientation to map along the x, y, xy and yx directions (for a coronal slice).

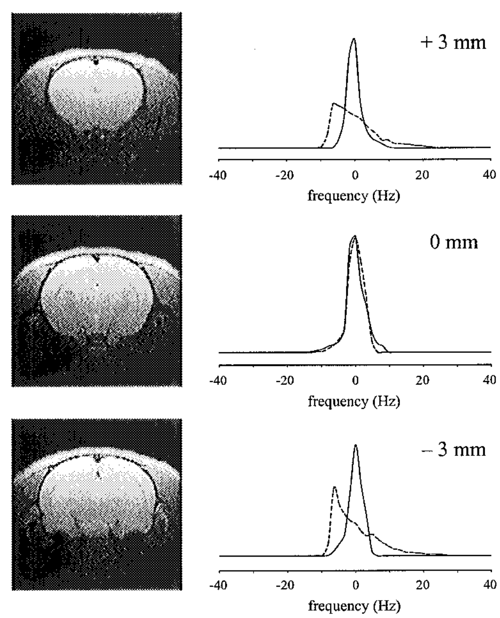

Figure 2 : Coronal images (left) extracted from a five-slice dataset, covering 6 mm in the z-direction. Frequency distributions (right) from the indicated slice with (solid line) and without (dotted line) dynamic shim updating (DSU).