Dynamic Shim Updating (DSU) for Multi-Slice Imaging of the Human Brain

K. M. Koch[1], S. McIntyre[1], D. L. Rothman[1], T. Nixon[1], R. A. de Graaf[1]

[1]Magnetic Resonance Research Center, Yale University, New Haven, CT, United States

Introduction

The shimming of susceptibility-induced inhomogeneities continues to pose a significant challenge to researchers at the frontier of medical NMR. Many recent improvements have been made in shimming technology [1-4]. However, the ability to sufficiently homogenize a large region of interest, or globally shim a sample has remained elusive. This is largely do to the presence of inhomogeneities which cannot globally be compensated by first, second, or third order spherical harmonic shims. A number of different approaches to this problem have been examined, including, but not limited to local ferroshimming [1], local electro-shimming, and dynamic shim updating (DSU) [2,3]. DSU allows one to set optimal shim values for each slice within a multi-slice volume acquisition. The key benefit of this technique is the ability to compensate out locally manageable inhomogeneities in a global fashion. Here we present the application of first and second order DSU on the human brain. Significant in-vivo homogeneity differences were observed when comparing global and multi-slice shim settings.

Methods

Experiments were performed on a 4.0 T Bruker Magnet interfaced to a Bruker Avance Spectrometer with Magnex gradients and shims. RF reception and transmission was carried out by a birdcage volume coil.

The global shim was optimized using the 1D FASTMAP linear projection technique [4]. Local slice shim currents were determined from multi-slice 2D homogeneity maps acquired through a standard gradient echo mapping sequence. The maps were fit to spherical harmonics using custom-written software based on MINPACK [5] provided Levenberg-Marquardt optimization routines. These fits were made over per-slice selected regions of interest (ROIs).

A home-built dynamic shim interface (DSI) was placed between the shim amplifiers and the spectrometer to update the shims for each slice within the acquisition. The interface consists of a Bruker-compatible microprocessor designed to store 16 optimal shims for up to 128 slices. Slice updating occurs within milliseconds, allowing for real-time shim updating within the acquisition. Custom-written Visual Basic software provides the transfer of per-slice optimized shim currents to the DSI.

In-vivo images were collected on a human brain centered in the magnet's isocenter. Five transverse slices of thickness 0.25cm were centered at z = {-3.0 , -1.5 , 0 , 1.5 , 3.0 cm}. The multi-slice imaging sequence used a TR of 800ms and TE = {8.0, 8.25, 8.5, 9.0, 10.0, 13.0}ms. To demonstrate the effectiveness of the technique, only first and second order shims were updated. For quantitative homogeneity comparisons, frequency offset histograms were collected from manually selected regions of interest within the homogeneity maps.

Results

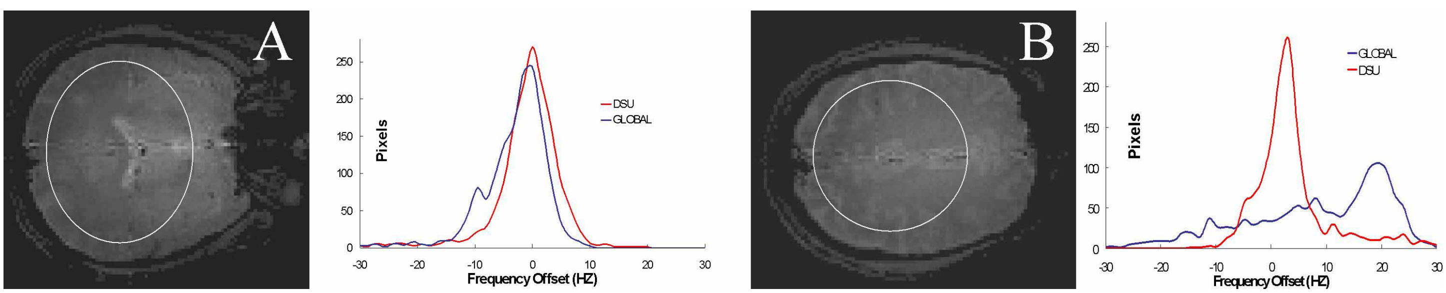

FIGURE 1. Anatomical images (128x128 data matrix over FOV = 20x20cm) from (A) z = 0 (center of brain) and (B) z = 3.5cm (top of brain) slices, together with frequency offset histograms with and without DSU, extracted from the indicated ROIs.

For slice (A), located in the center of the brain, the frequency offset histogram shows little difference between the global shim and dynamic shim settings. This is to be expected because the global shim is centered in this slice and its setting is locally optimal. It is in (B), as we move to the outer regions of the brain that the optimal global shim begins to deviate from locally encountered field inhomogeneities. Using DSU, inhomogeneities in the outer slices are compensated with a locally optimal shim setting. Therefore, with a global shim setting, only the middle slice has an optimal homogeneity. DSU allows all slices to be shimmed optimally, creating a uniform static field homogeneity over all slices, and hence over a large, global region.

Discussion

Our results demonstrate that significant improvements in global homogeneity within the human brain can be accomplished by using local optimization of shim values. What has been demonstrated here is only a proof of principle. This technique can easily be rendered more effective by taking through-slice inhomogeneities into account. The method can also be extended to third order spherical harmonic shims as well.

One of the limiting factors in DSU technology is eddy fields induced with rapid shim changes. We have tested all first, second, and third order shims and measured induced eddy fields which couple to lower order shims and/or the static field. Second order shims only showed coupling to the static field and thus, do not have a significant effect on image quality. However, the inclusion of third order shims or acquisition of spectroscopic data requires the implementation of pre-emphasis circuitry.

Finally, it must be noted that DSU is fundamentally limited by spherical harmonic shim technology. Spherical harmonic shims cannot adequately locally compensate inhomogeneities in the locality of either the sinus or auditory cavities. In the face of these obstacles, local non-spherical harmonic shim technology will need to be used in conjunction with DSU to achieve truly optimal global homogeneity [1].

Acknowledgements This work is funded by NIH grants NIBIB EB002097 and BRP NS31815.

[1] J.L. Wilson et al, Magn. Reson. Med. 48: 906 (2002)
[2] R.A. de Graaf et al, Magn. Reson. Med. 49: 409 (2003)
[3] A.M. Blamire et al, Magn. Reson. Med. 36: 159 (1996)
[4] R. Gruetter, Magn. Reson. Med. 29: 804 (1993)
[5] J.J. More et al, Argonne Natl. Lab. Report ANL-80-74 (1980)