Spatial Localization with Pulsed Second-Order Shims

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Introduction – In the early 1990s Cho and coworkers (1-3) showed the spatial localization of a 2D circular volume with a single RF pulse using pulsed second-order magnetic fields. For their experiments they constructed a dedicated radial gradient coil, in addition to the regular linear gradient coils, that generated a field proportional to that obtained from a conventional Z^2 shim (i.e. $Z^2 - 0.5(X^2+Y^2)$). Unfortunately this technology was not further developed, presumably due to the need for specialized gradient coils. Here it is shown that identical results can be obtained by pulsing the existing second-order spherical harmonic shim coils using hardware previously developed for dynamic shim updating (4). Theoretical and experimental considerations involved with 2D spatial localization using pulsed shims will be presented.

Methods - All experiments were performed on a 4.0 T Magnex magnet (Magnex Scientific Ltd, Oxford, UK) interfaced to a Bruker Avance Spectrometer (Bruker Instruments, Billerica, MA) equipped with Magnex gradients capable of switching 36 mT/m in 2000 us. RF reception and transmission was carried out with a Bruker quadrature volume-coil. Switching of all first- and second-order shims was achieved with hardware identical to that described for dynamic shim updating (4), which included pre-emphasis of all second-order shims. In order to minimize amplifier oscillations following shim changes, a 5 ms constant-slope ramp was imposed on all second-order shims. 2D MR images (FOV = 25.6 cm, matrix 64 x 64) were acquired on a 3 L spherical water phantom with a spin-echo sequence. A linear gradient was applied during the SLR 90º excitation pulse (1 ms, 5.6 kHz) to select a conventional 1D slice, while pulsed shims were executed during the 180º sinc refocusing pulse (5.8 ms, 1.0 kHz) to select a 2D elliptical volume.

Results – Fig.1A shows the slice-selective MR image without in-plane volume selection (i.e. without pulsed shims). Fig. 1B shows the MRI in the presence of a pulsed Z^2 and X shims, which select a circular ROI shifted by $\Delta x = 2$ cm closely approximating the target ROI (dotted line). Fig. 1C shows the image in the presence of Z^2, X^2-Y^2 and XY shims. The X^2-Y^2 shims elongates, while the XY shim rotates the ROI. Changing the RF frequency offset under the conditions identical to those in Fig. 1B results in the selection of a ring. Different chemical shifts during spatial localization with linear gradients lead to a spatial displacement (‘shift’) of the ROI. During second-order shim localization, the ROI does not shift but dilates or contracts depending on the sign of the offset. However, for the same RF bandwidth and ROI size (width), the absolute displacement in the presence of a second-order shim field is significantly smaller than during regular slice selection.

Conclusions – It has been shown experimentally that a single selective RF pulse in the presence of a pulsed second-order shim field can select a complete 2D volume. The reduced number of RF pulses can lead to a reduction in echo-time and RF power deposition. The relatively low shim strengths currently available on most MR systems limits the localization to large volumes. However, since the elliptical volume closely approximates the human brain in the axial orientation, the technique is a natural candidate for volume pre-localization (Fig. 1C) or outer volume suppression (Fig. 1D) to achieve single-shot lipid suppression in MR spectroscopic imaging.

This research was supported by NIH grant R21 CA118503.

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