Hyperbolic secant parameter optimization for non-selective inversion at 7 T

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Purpose

As with other adiabatic pulses, an hyperbolic secant (HS) inversion pulse [1] requires sufficient RF amplitude and duration such that a spin lock of the magnetization is maintained throughout the duration of the pulse. Due to the limited RF power commonly available in commercial human scanners and the large B_1^+ (transmit RF) inhomogeneities that occur at high field, HS pulses designed for lower field strengths will not in general satisfy the adiabatic condition at all spatial locations in a sample imaged at high field, thereby corrupting the image with spatial varying signal intensity or contrast. The bandwidth (BW) of a HS pulse can be reduced in order to gain more robust insensitivity to B_1^+ variations; however, the ideal bandwidth and optimal amplitude and frequency modulation (AM/FM) functions for HS pulses in the human brain at 7 T have apparently not been reported in the MR literature. The objectives of this study are therefore to 1) use ΔB_0 and B_1^+ field measurements to identify the appropriate BW and necessary extent of B_1^+-insensitivity for HS pulses used for non-selective inversion in the human brain at 7 T and 2) improve the mean inversion efficiency of HS pulses via numerical optimization of the HS modulation functions given by $\mathrm{AM}(t) = A_0\mathrm{sech}(\beta t)$ and $\mathrm{FM}(t) = -\mu\beta\tanh(\beta t)$.

Methods

Using a Philips 7 T MR scanner with a volume T/R head coil, two informed and consenting subjects were scanned with a double-echo (ΔTE=0.5ms) 3D gradient echo sequence to map the static (ΔB_0) field and a 3D flip-angle mapping (AFM) sequence [2] to infer the spatial distributions of relative B_1^+ intensities (Fig. 1). All scans were performed in the presence of higher-order B_0 volume shimming. At the vast majority of locations in the brain of subject A, the static field varies by no more than ±200 Hz, while the ratio of B_1^+ to the nominal value ($B_{1,nom}^+$) falls in the range of 0.30-1.00. These ranges of field variation were used to construct a 15x41 grid of relevant B_1^+-ΔB_0 coordinates for the purpose of numerical optimization [3]. With a target flip angle (α^T) of 180° being prescribed at all points on this grid, the function

$$\delta_\alpha(A_0,\beta,\mu)=\frac{1}{m\,n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left|\frac{\alpha^S_{i,j}(A_0,\beta,\mu)-\alpha^T_{i,j}}{\alpha^T_{i,j}}\right|$$

(where m and n represent grid indices and α^S is the flip angle calculated via simulation of the Bloch equations) was minimized via a gradient descent algorithm to find optimal values of the HS parameters A_0, β, and μ (15 µT, 516 rad/s, and 3.89, respectively) given a fixed pulse duration of 15 ms and a maximum RF amplitude of 15 µT. Two other HS pulses were constructed in order to evaluate the performance of the optimized pulse: 1) a 15 ms pulse with the same total bandwidth as the optimized pulse (±317 Hz) but with μ =5.0 and β = 401 rad/s [1] and 2) a 15 ms, μ =5.0, β = 942 rad/s HS pulse with BW = ±750 Hz.

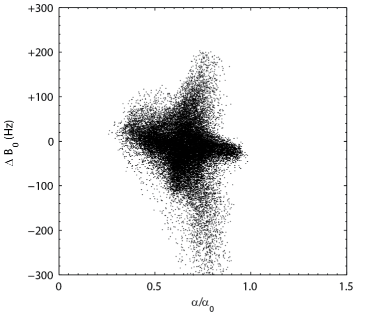

Fig. 1 The distribution of static field offsets (vertical axis) and relative RF intensities (horizontal axis, reported as the ratio of actual to nominal flip angle) as measured in the human brain at 7 T.

Results and Conclusions

Flip-angles for all HS pulses were simulated over the B_1^+-ΔB_0 optimization grid (Fig. 2, column 1) and within an axial slice of the brain of subject B (Fig. 2, column 2). Frequency profiles at varying B_1^+ intensity are shown in column 3, and AM and FM functions appear in column 4. The BW = ±750 Hz pulse (Fig. 2, row 1), which may be suitable for 3 T applications (and which corresponds to a commercial implementation), clearly results in flip angles that are highly sensitive to the B_1^+ variations found at 7 T. The mean flip angle ± relative dispersion for the in vivo simulation is 148°±13%. The non-optimized BW = ±317 Hz pulse (row 2) demonstrates the gain in B_1^+-insensitivity that comes with a reduced bandwidth, as this pulse results in a mean flip angle of 170°±3%. The optimized pulse results in a modest improvement in flip-angle uniformity with a mean of 175°±2%.

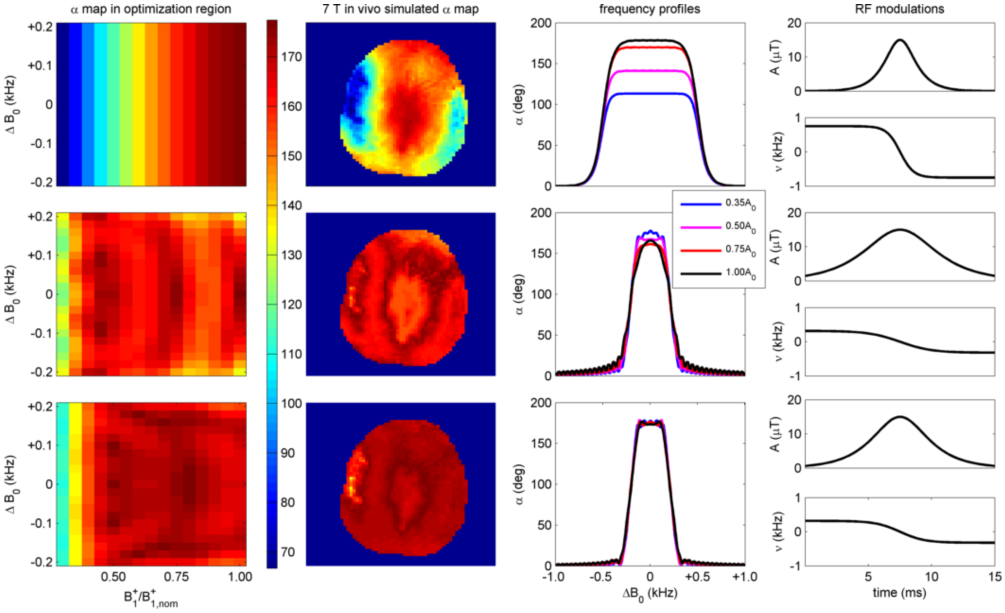

Fig. 2 Results for three HS pulses: a high bandwidth pulse (row 1), a reduced bandwidth pulse (row 2), and an optimized pulse with reduced bandwidth (row 3). Flip-angle maps are calculated on the grid of targeted static and RF field variations (column 1) and within an axial slice of the human brain (column 2). Frequency profiles for $B_1^+/B_{1,nom}^+$ intensities of 0.35, 0.50, 0.75, and 1.00 are shown in column 3 with AM and FM waveforms in column 4.

In summary, this study has demonstrated that an HS bandwidth of ±~300 Hz appears sufficiently low to accommodate the range of B_1^+ variations in the brain at 7 T while being large enough to encompass the spread of static field variations achievable with higher-order B_0 volume shimming. Furthermore, numerical optimization of HS parameters in the context of 7 T field variations has been shown to result in a noticeable improvement in inversion uniformity. These results should prove useful at high field for such non-selective inversion applications as arterial spin labeling and inversion preparation for T_1-weighting.

Acknowledgments: This work was supported by NIH grant number RO1EB000461.

References

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