Lowering the B_1 Threshold for BEAR B_1 Mapping

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PURPOSE: The recently proposed BEAR method[1] is a phase-based B_1 mapping method, with linear phase sensitivity to variations in B_1. The method relies on two hyperbolic secant (HS1) pulses operating in their adiabatic regime used for refocusing, which limits the range of B_1 that can be measured due to the adiabatic threshold of the pulses. Here, we redesign the BEAR method to use HSn pulses, which have lower adiabatic thresholds[2]. By optimizing the HSn pulse parameters, we can reliably acquire B_1 maps for lower nominal peak B_1 ($B_{1,nom}$) than with the original BEAR method. We validate the performance of BEAR with HSn pulses via simulation and in vivo at 3T.

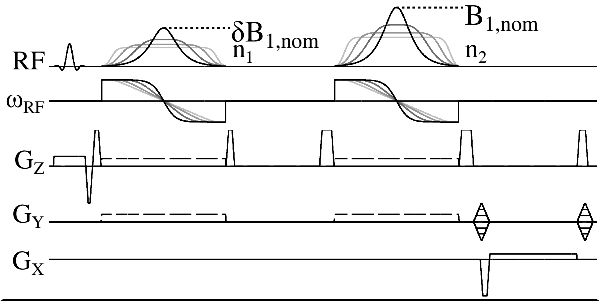

Figure 1: BEAR pulse sequence using HSn pulses: $n_1=n_2=1,2,4,8$ for lighter gray lines. $B_{1,A}$ for each HSn pulse is [0.091, 0.064, 0.052, 0.045] G respectively.

METHODS: Fig. 1 shows the BEAR sequence with HSn pulses[2], where n_1 and n_2 determine the shape of the magnitude sweep for each pulse, sech($\beta\tau^n$), and can be non-integer. The adiabatic threshold $B_{1,A}$ (the minimum B_1 that ensures refocusing of 90% $|M_{XY}|$) decreases with increasing n. Thus, increasing n reduces the sequence adiabatic threshold ($\sim B_{1,A}/\delta$, where δ is the ratio of the two pulse magnitudes), allowing for use of a lower $B_{1,nom}$.

The BEAR method using HS1 pulses has a flat phase response with respect to off-resonance frequency. BEAR with HSn pulses has a moderate quadratic variation in phase with respect to off-resonance frequency. This quadratic phase variation can be largely canceled by choosing appropriate values of n_1/n_2. Specifically, given an n_1, we choose n_2 to cancel any phase variation over the slice profile within a range of expected B_1 variation, for a given $B_{1,nom}$. n_2 is chosen by minimizing the maximum percent off-resonance phase difference from the on-resonance phase, over the expected B_1 range and slice profile. The expected variation in B_1 depends on the transmit coil used, so we have optimized the method with different n_1's for different B_1 ranges.

The adiabatic pulse parameters[1,2] were T/β/μ=12 ms/5.3 rad/5.5 and δ=0.9. A 40° tip angle, TE/TR=49/200 ms, was used for a single 2DFT acquisition on a GE 3T scanner. To eliminate unwanted sources of phase variation, phase-difference images were made with the second acquisition reversing the order of the two adiabatic pulses.

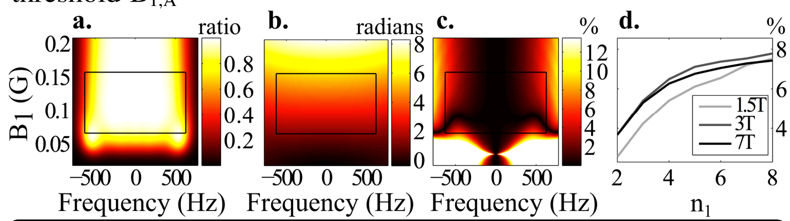

Figure 2: BEAR simulation results for HSn pulse optimization. Slice profiles for **a:** magnitude, **b:** phase and **c:** percent phase difference from 0 Hz for n_1/n_2= 4/4.153. Black boxes show the expected B_1 range at 3T, B_1 = 1±0.4*$B_{1,nom}$, $B_{1,nom}$=0.114 G. **d:** Maximum percent phase difference from 0 Hz over the range shown in (c) as a function of n_1 and main-field strength. B_1 variations were 20/30/50% for 1.5/3/7T.

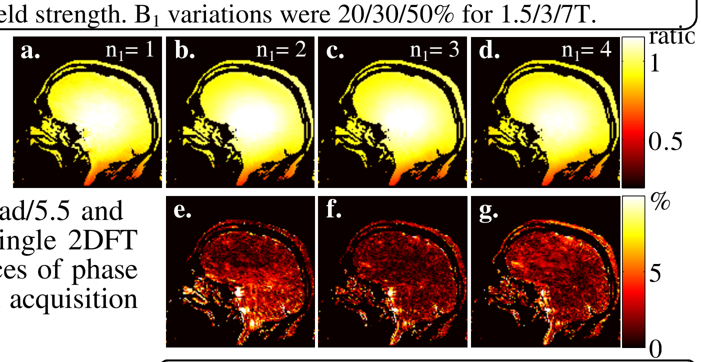

Figure 3: **a-d:** BEAR scan results for varying n_1 normalized by $B_{1,nom}$= [0.211, 0.142, 0.114, 0.102] G. **e-f:** % error for n_1=2,4,8 compared to n_1=1, with average errors = [2.68, 1.93, 2.50] %.

RESTULTS: Fig. 2a-c show Bloch simulation results for BEAR using a set of optimized HSn pulses (n_1/n_2=4/4.153). The magnitude and phase of the refocused M_{XY} as a function of B_1 and off-resonance frequency (Fig. 2a-b) show its insensitivity to off-resonance over the given B_1 range. Fig. 2c illustrates that the percent phase difference due to off-resonance is minimized for the given B_1 range and slice profile. Fig. 2d shows the maximum percent phase difference for varying n_1 and field strength, indicating less than 10% error for all optimizations. Fig. 3a-d show that the in vivo BEAR B_1 maps for n_1=1,2,4,8 are all closely matched. $B_{1,nom}$ was chosen to keep the total SAR the same for each image. Fig. 3e-g show percent differences with n_1=1 as the reference.

DISCUSSION/CONCLUSION: The BEAR method has been redesigned to use HSn pulses, reducing the peak RF amplitude required for accurate B_1 measurement, while maintaining its insensitivity to off-resonance frequency, and linear phase sensitivity to B_1 variations. The method minimizes the B_1 map error seen within a B_1 range by selecting a particular n_2. Optimizations of a few B_1 ranges were made since different amounts of variation are expected, depending on the transmit coil (e.g., the 50% variation in B_1 is typical for a head transmit coil at 7T). Scan results showed the method's accurate B_1 mapping ability even for low $B_{1,nom}$. We expect this method to be useful for acquiring B_1 maps at lower $B_{1,nom}$.

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References: [1] Jordanova *et al.*, Proceedings of ISMRM, Salt Lake City, p. 370, 2013. [2] Tannus *et al.*, NMR in Biomed, 10:423-434, 1997.