Multi-coil Composite Pulses for Whole-Brain Homogeneity Improved over RF Shimming Alone

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INTRODUCTION: In recent years a number of methods for improving image homogeneity in high field MRI have been proposed, some of them relying on separate control of RF coils in a transmit array (1, 2). Here we combine accurate RF field calculations with accurate representations of the Bloch equation to demonstrate that by using multiple individually-optimized pulses, more homogeneous distributions in available signal intensity over the entire brain volume can be achieved at 300 MHz than when using a single optimized (or RF shimmed) pulse with the same transmit array. As simulated here it will be slightly more difficult to implement the multi-coil composite pulse experimentally than RF shimming of a single-pulse excitation, but (depending on method of implementation) could require no *a priori* knowledge of the RF coil field distributions, as is required for design of some multi-coil tailored pulse approaches, such as transmit-SENSE (2).

METHODS: The FDTD method was used to calculate the field distribution of each of 16 stripline elements in an array (3) with an elliptical arrangement about the head (Fig. 1) in the presence of the others, but assuming no coupling (no current at the terminals except for the driven coil for each of 16 calculations). The pertinent circularly-polarized component from all calculations in the entire brain were then combined and varied in magnitude and phase to produce available signal intensity distributions similar to that after i) a single pulse with a typical volume coil, ii) a single pulse with an RF shimmed transmit array, and iii) a two-pulse composite pulse with a transmit array where current magnitudes and phases from all elements in both pulses are shimmed individually. A net spin magnetization vector (with a magnitude of 1 in brain for simplicity and initially oriented with B_0) was defined and tracked throughout the brain and through all pulses using the calculated field distributions and the Bloch equation. The starting point (before optimization) for case iii above was the result of case ii above in a 90x-90y composite pulse configuration. Because the available signal intensity distribution was calculated immediately after the excitation pulse(s), the relaxation terms of the Bloch equation were considered irrelevant. The available signal intensity was calculated as the magnitude of the transverse component of the net spin magnetization vector.

RESULTS: A representation of the head model in the 16-element array is given in Figure 1. Figure 2 shows the available signal intensity distribution throughout the brain calculated using each of the methods described. While both optimized (or “shimmed”) cases demonstrate much greater whole-brain homogeneity in available signal than the original volume coil-like excitation, the two-pulse composite excitation (bottom row) is clearly superior to the single-pulse excitation.

DISCUSSION: From a simple perspective, using multiple sequential pulses with a transmit array increases the number of variables that can be adjusted to produce a homogeneous distribution in flip angle or available signal intensity. While for small flip angles the advantages of such a multi-coil composite pulse are limited (4), for larger flip angles the advantages are clear (Figure 2). Implementation of this approach would require consideration of more degrees of freedom (potentially as many as the number of pulses times the number of coils times 2, for driving magnitude and phase) in a “shimming” stage, but could still require no field measurements depending on the method of implementation.

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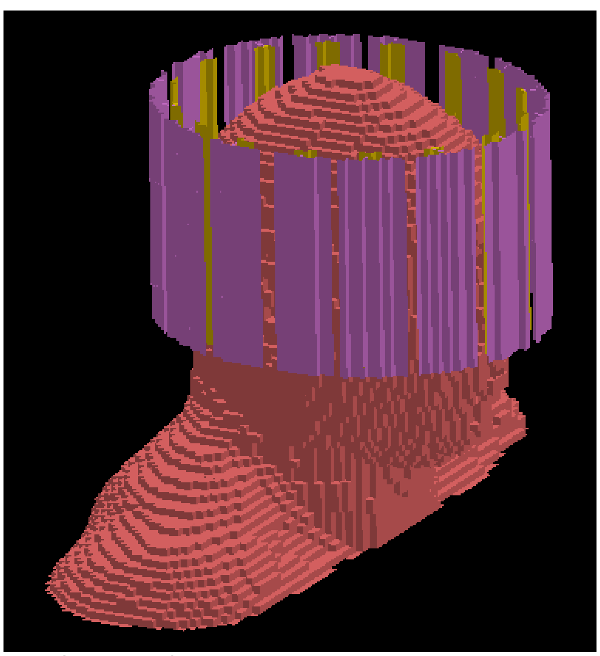

Figure 1: Geometry of human head model in 16-element transmit array. Inner and outer conductors are colored gold and purple, respectively.

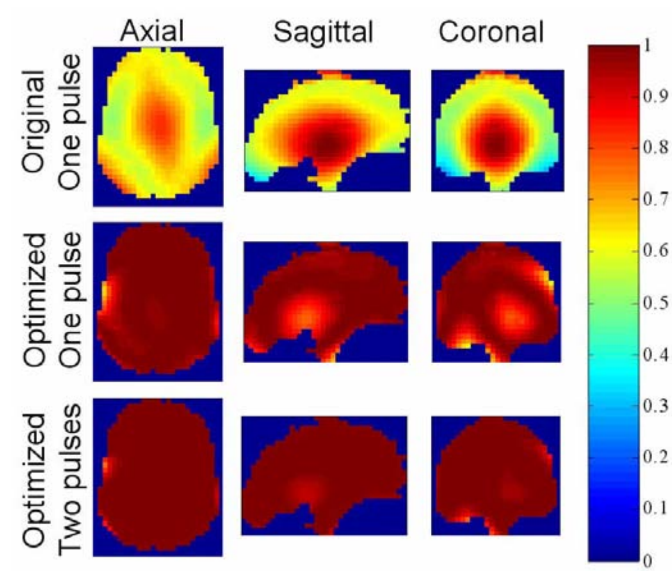

Figure 2: Available signal intensity distribution through the brain at 300MHz for *top*: current distribution similar to that in a standard volume coil, *middle*: a single pulse with currents “shimmed” to produce a homogeneous whole-brain, and *bottom*: a multi-coil composite pulse with currents “shimmed” individually in each of two consecutive pulses so that the end result is homogeneous throughout the brain.