Multi-dimensional Susceptibility Conditioned RF Pulse (SCOPE) Design: A Spokes Approach

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TARGET AUDIENCE Researchers and clinicians seeking to study tissue susceptibility will benefit from this abstract.

PURPOSE Tissue susceptibility is an important property that has great potential in many clinical applications, especially neurovascular imaging and quantitative susceptibility mapping [1]. However, local field variations induced by bulk susceptibility can obscure or even null tissue signal in certain areas of the brain. An example would be signal loss due to dephasing in orbitofrontal area of the brain in susceptibility weighted imaging (SWI) [2]. In this work, we present a novel multi-dimensional RF pulse design method using a modified spokes approach [3] that is geared toward compensating for bulk tissue susceptibility induced phase variations.

METHODS Under the small-tip-angle (STA) regime, the excitation pattern and the RF and gradient waveforms in excitation k-space follows Fourier relationship [4]. This has been exploited in many cases, of which spokes pulse design is one great example. Conventional spokes design was primarily used to correct for B1 inhomogeneities in parallel transmit. The cost function can be written as: Eq. (1): $b_1 = \underset{b_1,\vec{k}}{\arg\min} \left\| d(\vec{x}) - [A(\vec{k})b_1](\vec{x}) \right\|^2_{\vec{x}\in \mathrm{FOE}} + \beta \left\| b_1 \right\|$, where d is the desired excitation magnitude, $\vec{x}$ is the evaluated spatial locations in the field of excitation (FOE), b_1 is the RF pulse, $A(\vec{k})$ is the Fourier encoding matrix and b is the Tikhonov regularization parameter. As can be seen in Eq. (1), the excitation magnitude difference in the FOE is minimized. The optimization problem is transformed to an equivalent cost function by adding an arbitrary phase term to the desired excitation pattern in order to avoid the non-linearity of the absolute value operator [5]. To modulate phase pattern, we have modified the cost function to:

$$b_1 = \underset{b_1,\vec{k},\varphi_{\bar{\Omega}}}{\arg\min} \left\| de^{i\varphi_{\Omega\cup\bar{\Omega}}(\vec{x})} - [A(k)b_1](\vec{x}) \right\|^2 + \beta \left\| b_1 \right\|^2$$

, where Ω is the ROI inside which phase is predetermined and outside which ($\bar{\Omega}$) phase values can be arbitrary. The desired phase in the ROI was calculated by scaling the field inhomogeneity with desired echo time. A greedy algorithm similar to that described in [3] was used to optimize the cost function. One-dimensional, 2D and 3D pulse designs were carried out numerically and the resultant pulses were validated through numerical Bloch simulation. Furthermore, these multi-dimensional pulses were incorporated into gradient recalled echo (GRE) sequences to evaluate the phase modulation experimentally. Experiments were performed on a 3T Siemens Verio scanner (Siemens Healthcare, Erlangen, Germany) equipped with a 12-channel phased array. One normal volunteer participated in the study after providing informed consent. All procedures were approved by the local Institutional Review Board.

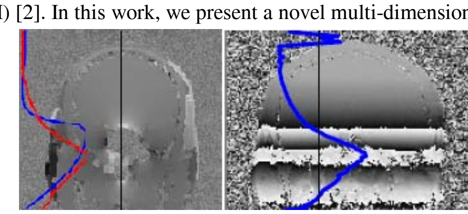

Fig 1. 1D SCOPE phase modulation. Left: unwrapped phase from calibration scan with a line profile (blue, along with its low-pass filtered version in red) used for pulse design. Right: excitation phase and a line profile (unwrapped).

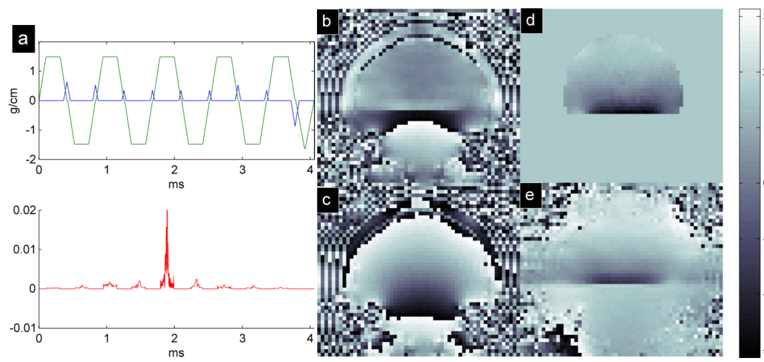

Fig.2. 2D SCOPE pulse design example. (a) gradient and RF waveforms using 9 spokes; phase images at echo time using SCOPE 2D pulse (b) and a regular sinc pulse (c); (d) shows the phase map used in designing the pulse in (a); and (e) shows the phase difference between (b) and (c).

RESULTS AND DISCUSSION Figure 1 shows a design example for 1D SCOPE pulse. It is seen that the modulated phase profile matches the design template quite well. In Figure 2, a 2D SCOPE pulse was designed and tested on the volunteer. Figure 2(d) and (e) clearly show that the excitation phase modulation matching the designed pattern. Figure 3 shows an example for 3D SCOPE design and the comparison between Bloch simulations and the design template. Again, good agreement between the two is observed. We would show 3D in vivo data once they are collected.

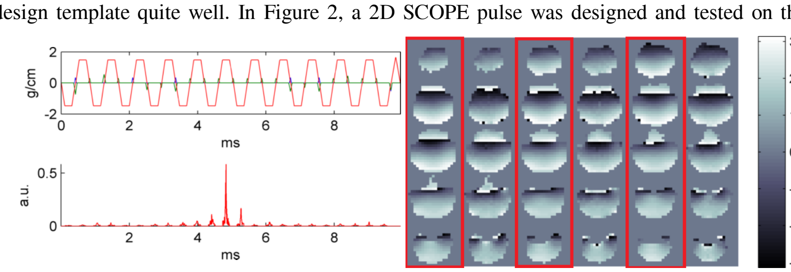

Fig.3. SCOPE 3D pulse design example. Left: spokes pulse with 23 spokes. Right: excitation phase through Bloch simulations (in red columns) compared to design template.

CONCLUSION We have presented a novel pulse design method for compensating susceptibility-induced phase. Numerical and volunteer experiments in vivo showed the validity of the proposed method.

REFERENCES

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