Numerical RF Pulse Optimization to Reduce Peak B1 for Multi-spectral Imaging around Metal Implants

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Target Audience

Researchers seeking an improved RF pulse design for multi-spectral imaging around metal implants.

Purpose

Imaging around metal implants with traditional methods, such as Fast Spin Echo, leads to severe geometric distortions in the slice-select and frequency-encoding directions. 3D Multi-spectral acquisition techniques (3D-MSI) have been developed to image in the presence of large resonant frequency offsets surrounding metal implants[1-2]. Yet, limitations on B1 amplitude for the echo train refocusing pulses result in a tip angle that is less than ideal, causing reduced Signal-to-Noise Ratios (SNR). For example, the maximum achievable tip with the standard Gaussian refocusing pulse utilized in the commercial MAVRIC SL 3D-MSI technique[3] is 155 degrees at the hardware safety limit of 25uT for B1. In practice, the actual tip angle that can be achieved is usually lower (140 degrees, for example). As patient weight increases, the peak B1 is further reduced to meet safety constraints without stretching the scan time. Numerical optimization has been utilized for other RF pulse applications, such as small-tip-angle design[4]. In this work, we have redesigned the RF echo train refocusing pulses using numerical optimization with the goal of achieving a higher tip angle by lowering peak B1.

Methods

The original pulse to be optimized was a Gaussian pulse (2.25 kHz FWHM) with a 2.4ms pulse duration. The bandwidth and pulse-duration were held constant during the ensuing optimization. A nonlinear constrained minimization was coded in MATLAB (The Mathworks, Inc.) to optimize the original Gaussian refocusing pulse. The Bloch Equation Matlab Mex function provided online by Brian Hargreaves at Stanford University was utilized for this optimization to dynamically simulate the spectral response of the spin net magnetization[5]. The amplitude of the time domain pulse was constrained to yield a peak B1 of 15uT with a tip angle of 120 degrees. The target spectral response was the aforementioned Gaussian profile designed for multi-spectral image combination in the MAVRIC technique[1]. The cost function for the minimization algorithm computed the sum of the squared difference of the intermediate spectral response compared to the target spectral response, with an additional penalty term to minimize the integral of B1 squared, which is related to Specific Absorption Rate (SAR). We then modified the MAVRIC-SL pulse sequence to incorporate our customized refocusing pulses.

Results

Simulation results in Figure 1 show a reduction in peak B1 from 29.0uT (blue plot, original pulse) to 22.5uT (green plot) while achieving the same spectral response profile from the Bloch Simulation. Depicted in Figure 2 is the pulse sequence diagram for the Z-gradient and the RF pulses. A train of three numerically optimized (redesigned) refocusing pulses is shown following the excitation pulse. Images were acquired on a GE Healthcare MR750 (3T) scanner with a quadrature body transmit and receive coil. A simple phantom was constructed by inserting two titanium orthopedic fixation screws into an orange. Scan parameters included a 160x160 matrix, 6 spectral bins, Echo Train Length of 20, TE=6.7ms, TR=2.68s, and an input patient weight of 50kg. As patient weight is increased, the peak B1 and resultant tip angle is further scaled down. Figure 3 shows a central slice of the phantom acquired with the optimized (redesigned) pulse shown in Figure 1 and Figure 2. The image provides clear detail near the metal object as shown by the threads of the titanium screw.

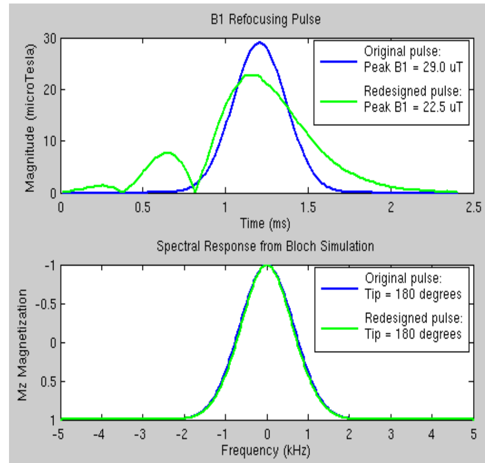

Figure 1: (Upper Panel) Peak B1 reduction for the redesigned pulse, allowing a tip angle increase from 140 to 180 degrees on the scanner. (Lower Panel) Simulation results from Bloch Simulator.

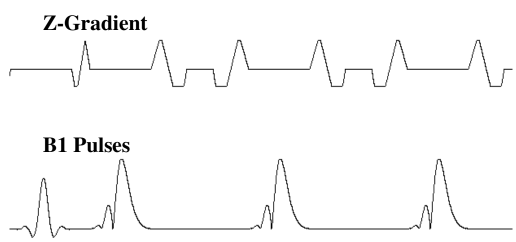

Figure 2: Pulse Sequence diagram showing the Z-gradient waveform paired with the 90 deg excitation pulse followed by a train of optimized 180 deg refocusing pulses.

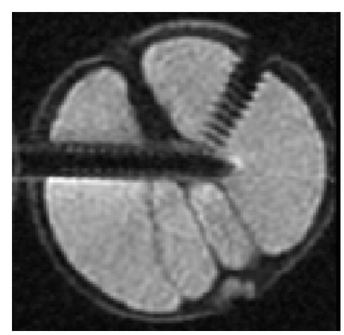

Figure 3: Image generated with the MAVRIC-SL pulse sequence modified to use our optimized refocusing pulses.

Discussion and Conclusion

An optimized refocusing pulse has been designed that yields lower peak B1 without compromising the spectral response for 3D-MSI imaging. This allowed the applied tip angle to be increased while keeping peak B1 within RF safety and hardware limits. To achieve a 180 degree tip, a peak B1 of 29.0uT would be required with the original Gaussian pulse. However, a B1 of 29.0uT is not achievable for clinical scanning due to hardware and safety limitations. Instead, 140 degrees was the maximum tip angle achievable on the scanner using the original MAVRIC Gaussian pulse before the RF safety limit was reached. After switching to our optimized (redesigned) pulse, we were able to increase the tip angle from 140 degrees to 180 degrees with the same scan prescription and remain within the RF safety and hardware limits. Based on the numerical optimization method described in this work, the peak B1 improvement may be leveraged to improve image quality to aid in diagnosis of complications surrounding metal implants.

References

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