A Novel Backgound Suppression Method for Endovascular Therapy

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Introduction

In MR-guided endovascular therapy, robust visualization of catheters throughout the procedure is critical. Catheter conspicuity may be achieved using either active or passive catheter visualization techniques. Although active methods have the advantages of high spatial and temporal resolution, typically only a region at the tip is active and so it is not possible to determine catheter position at more than a few discrete points. Active catheters also have intravascular radio frequency (RF) heating risks.[1] In contrast, catheters filled with dilute solutions of MR contrast agents ensure passive visualization of the catheter length and have no heating risk. In practice, a thick slab of tissue including the catheter must be excited, leading to partial volume effects that make passive catheter visualization challenging. In order to overcome this limitation, background suppression methods[2,3] are proposed that reduce signal from tissue. Here, we propose using Hadamard (HD) RF slice profiles to better suppress background and improve the visualization of contrast-filled catheters. A simple heterogeneous tissue model was developed to compare Hadamard profiles with the more commonly used projection dephaser (PD) methods.[2,3]

Methods

For small-tip-angle RF excitation pulses, Pauly *et al.*[4] have shown that the RF-weighting function $W(k)$ and slice profile $M_{xy}(z)$ are a Fourier transform pair, where $W(k)$ is given by $B_1(t)/|\gamma G(t)|$. Using this approach, an RF pulse, $B_1(t)$, and gradient, $G(t)$, pair was designed to produce a Hadamard-like magnetization profile $M_{xy}(z)$ (Figs 1a-c). Conceptually, it can be seen that net magnetization from a homogeneous slab of tissue excited by Hadamard RF will be zero, thereby increasing the catheter conspicuity. PD acquisition was simulated using a rectangular slice profile and applying a phase twist of 2π rad across the excited slab. A heterogeneous tissue model was developed (Fig 1d) to mimic the features (both structured and noisy) seen in brain parenchyma. To estimate these features, we assessed anterior-posterior brain parenchymal signal variations from the middle slices of a 3D dataset. Considerable structure (spatial correlation) was observed and the standard deviation was found to be approximately 20% of the mean signal. In our simulations, the total background signal (S_b) was computed by multiplying the heterogeneous model with the respective slice profiles and then summing the signal in z. A similar process was used to find the total signal for a pixel containing catheter and background (S_c), except a contiguous segment of the heterogeneous tissue model was first replaced by a "catheter" with intensity 5 times the mean background signal. The catheter position was both fixed at $z = 2.5$ mm and also allowed to vary randomly. Catheter diameters normalized by the excited slice width (*i.e.*, D_c/D_z) ranged from 0.008 to 0.1. The simulation process was repeated 1000 times, and the mean and standard deviation of the signal difference ($\Delta S = |S_c| - |S_b|$) and the catheter contrast ($\Delta C = \Delta S/|S_b|$) were calculated.

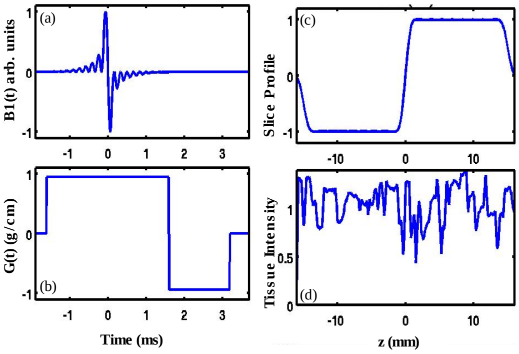

Fig 1. (a,b) RF excitation and gradient pulses resulting in (c) a Hadamard slice profile. (d) Tissue intensity along slice direction from the heterogeneous simulation model.

Results

For catheter diameters ranging from 0.25 to 3 mm placed at $z = 2.5$ mm in a 30 mm slice, the HD method had a consistently higher signal difference (Fig 2a) and catheter contrast (Fig 2b) than the PD method. The mean background signal (S_b) for the HD was close to zero. S_b for the PD was also small but at least an order of magnitude larger than the values obtained with the HD. Random placement of the catheter in the slice did not affect the PD measurements, but degraded the HD method performance. For a $D_c = 3$ mm catheter in a $D_z = 30$ mm slice (*i.e.*, $D_c/D_z = 0.1$), the performance of the PD and HD methods was equivalent with random catheter placement.

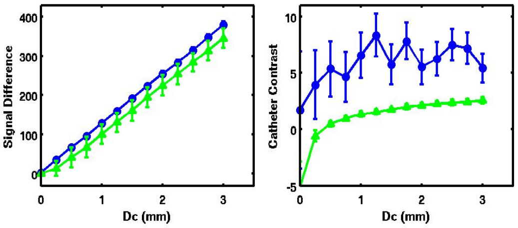

Fig 2. (a) Signal difference, ΔS, and (b) catheter contrast, ΔC, for fixed catheter position and catheter diameters ranging from 0.25 to 3 mm in a 30 mm excited slice. HD in blue (with circles), PD in green (with triangles). Error bars are standard errors.

Conclusion

In passive catheter visualization, HD RF pulses provide improved performance compared to more conventionally used PD methods. Since the mean S_b of HD method was close to zero, the observed catheter contrast fluctuations were due to noise in this measurement, even after 1000 iterations. Over a range of catheter sizes, the signal difference and catheter contrast were superior. The performance of HD degraded only with unrealistically large catheters (3 mm) were randomly placed in a 30 mm thick slice.

References

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