Dephased Double Echo Imaging with Outer Volume Suppression for Accelerated White Marker Imaging in MR-guided Interventions

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Introduction

In MR-guided interventions the medical device and the surrounding anatomy need to be visualized with both high spatial and temporal resolution. Device localization can be achieved with active tracking using miniaturized RF coils, but this is technically demanding and can cause hazardous RF-induced heating. Passive tracking makes use of positive or negative MR marker materials, whose detection might be difficult especially in intravascular interventions due to image artifacts from moving tissue and blood flow. Recently, a passive double-echo (DE) technique [1] was proposed to depict an MRI-compatible guidewire with a positive contrast ("white marker", [2, 3]) by acquiring a conventional and a dephased image within a total acquisition time (*TA*) of about 1-2 s. As two signals are already collected within the same *TR* interval, reduction of *TR*, and thus *TA*, is limited. During intravascular interventions only the vessels in close proximity to the guidewire need to be visualized, so that a reduced FOV in phase-encoding (PE) direction can be applied to shorten *TA*. Unfortunately, this reduced FOV imaging leads to unwanted aliasing, which can be avoided using outer volume suppression (OVS) [4]. In this study, we combine OVS with DE imaging to visualize a passive guidewire during MR-guided interventions.

Materials and Methods

Para- or ferromagnetic materials cause characteristic magnetic field distortions leading to a faster decay of the MR signal. The additional phase angle φ due to local B_0-variations can be locally compensated by applying an additional gradient G_{deph}, whereas MR signal from outside these field alterations becomes dephased ("white marker", [1]).

In this work, we propose an MRI pulse sequence, which combines the DE gradient compensation technique [1] with an OVS technique [4] for accelerated image acquisition. The corresponding sequence diagram is illustrated in Fig. 1. The image acquisition is segmented, so that after N k-space lines (IMA) M additional *TR* intervals (SAT) are applied to suppress the MR signal outside the FOV of interest (in case of Fig. 1: $N = 5$, $M = 2$). To maintain the magnetization steady state, the RF-pulse (α) for slice selective (SL) excitation is applied in both SAT- and IMA-sections. Furthermore, gradient moments in all three directions are adjusted to the same 0^{th}-momenta in SAT- and IMA-sections (Fig. 1). The shaded gradient in PE-direction within the SAT-section balances the 0^{th}-momentum of the SL-gradient of SAT-RF-pulse (α_{SAT}) and the subsequent spoiler gradient. In the example of Fig. 1, the dephasing/compensating gradient G_{deph} is employed in readout (RO) direction (black). The 0^{th}-momentum of G_{deph} is also considered in the SAT-section (dark gray). To further reduce *TA*, the first echo time (TE_1) is shortened by generating an asymmetric echo. For SNR improvement during ADC 2, a lower RO-bandwidth could be chosen. The direction of G_{deph} was defined via the user interface together with a corresponding dephasing length (L_{deph}) for contrast optimization.

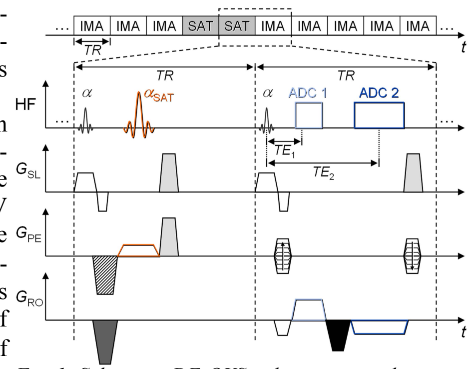

Fig. 1: Schematic DE-OVS pulse sequence diagram.

The DE-OVS-sequence was implemented on a clinical 1.5 T MR system (Siemens MAGNETOM Symphony, Erlangen, Germany). All phantom experiments were performed with a novel, MR-safe guidewire (MaRVis Technologies GmbH, Aachen, Germany). The guidewire is constructed from multiple glass fiber/epoxy rods of which the three peripheral ones are continuously doped with iron micro particles (< 150 µm, concentration: 1/10). These rods are embedded in a polymeric envelope. The guidewire sample had a length of about 40 cm and was tested in an *ex vivo* porcine aorta placed in a plastic container (Fig. 2a) filled with NaCl-solution (0.9 % NaCl, Gd-DTPA/H_2O: 1/1000). The guidewire was introduced through a standard 11 F-catheter sheath and placed in the branch of the left carotid (black arrow). The following sequence parameters were used: coronal plane: $TR/TE_1/TE_2$ = 8.8/1.55/5.07 ms, α = 8°, FOV: 256×105 mm^2, thickness: 12 mm, matrix: 256×48, partial Fourier: 7/8, RO-bandwidth (ADC 1/2): 720/270 Hz/px, phase resolution: 50 %. During the experiments G_{deph} was alternated between RO- and SL-direction (L_{deph} = 2.4/6.7 mm). Two sagittal SAT-bands (α_{SAT} = 120°, width: 90 mm) were used (Fig. 2b), and SAT-sections were applied after each 5^{th} k-space line ($N = 5$). Finally, the PE-FOV could be reduced to 37.5 % of the RO-FOV yielding a total *TA* of about 450 ms.

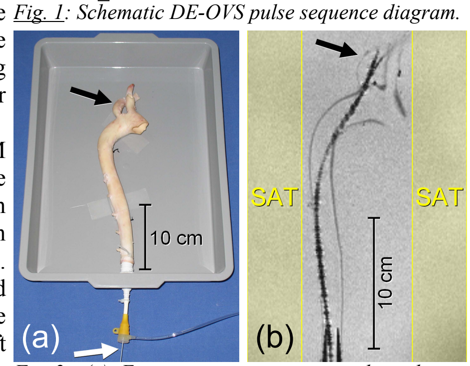

Fig. 2: (a) Ex vivo porcine aorta and guidewire (white arrow). (b) GRE image with SAT-bands.

Results and Discussion/Conlusion

In Fig. 3a, the rephased FLASH image acquired at ADC 1 is shown with the guidewire in dark. Figures 3b and c present images acquired with G_{deph} applied in RO- and SL-direction respectively. In both images, the passive guidewire is visible over its full length with positive contrast. The mean marker (guidewire) to background signal ratio amounts to 3.5/3.1 (G_{deph} in RO-/SL-direction). By applying SAT-sections after each 5^{th} IMA-section, a suppression ratio of the outer volume signals of about 15 (mean outer volume signal divided by mean image signal) was achieved which is consistent with [4]. In Fig. 3d, the dephased image (with G_{deph} in SL-direction, Fig. 3c) is overlaid onto the FLASH image after median filtering and thresholding (threshold value = 2×mean noise level). The overlay perfectly agrees with the guidewire artifact.

Depending on the DE-OVS-sequence parameters (width of the SAT-bands, reduced PE-FOV, asymmetry of first echo, etc.), a total acquisition time of less than 0.5 s is feasible. With the specified imaging parameters, the image update rate could be increased by a factor of 4 compared to the conventional DE technique [1]. Using simple image post-processing, the dephased image provides nearly a binary device contrast which might be used to further facilitate the device localization.

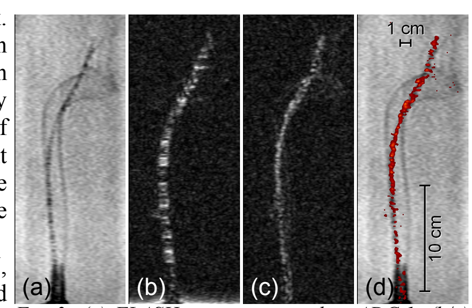

Fig. 3: (a) FLASH image acquired at ADC 1. (b/c) Dephased images with G_{deph} in RO-/SL-direction. (d) Dephased image (c) overlaid to FLASH image (a).

References
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