Halting the Effects of Flow Enhancement With Effective Intermittent Zeugmatographic Encoding (HEFEWEIZEN) in SSFP

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Introduction: Atherosclerosis is a major cause of morbidity and mortality. Traditional bright blood angiography techniques depict the vascular lumen but do not detect the initial outward remodeling of the atherosclerotic plaque. While promising, previous dark blood (DB) techniques also had significant limitations. The commonly used dual inversion recovery (DIR) turbo spin echo (TSE) has long acquisition times and loss of spatial resolution (spatial blurring) due to extended echo trains. Previous attempts made to introduce DB contrast in TrueFISP either doubled the TR (1,2) or interrupted the steady state and were susceptible to motion-induced signal loss during flow suppressing diffusion gradients. Recently a new framework for magnetization preparation in SSFP was proposed and applied to fat suppression (3). In this work, the new SSFP framework is extended to DB magnetization preparation in TrueFISP. The ability to suppress blood flow and the effects on stationary tissue are characterized during high resolution vessel wall imaging in the carotid arteries.

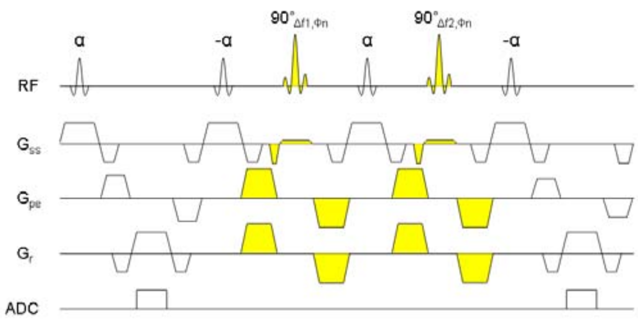

Fig. 1. HEFEWEIZEN sequence diagram. Additions to standard TrueFISP are shaded.

Methods: HEFEWEIZEN introduces spatial saturation in TrueFISP by periodically replacing the normal phase encoding and readout gradients with spatially selective excitation pulses to excite and spoil magnetization in saturation bands adjacent to the imaging slice (fig 1). The imaging slice magnetization experiences regularly spaced alpha pulses and zero net dephasing over each TR (SSFP conditions). Pairing of two adjacent TRs ensures cancellation of induced eddy currents (4). Experiments were performed on 2 asymptomatic volunteers and 2 patients with carotid artery stenosis on a 1.5 T scanner (Siemens Espree, Erlangen, Germany). The ability to selectively suppress blood flow based on direction of inflow (saturation above, below, above and below the imaging slice). The DB preparation parameters saturation slab thickness, the gap from the saturation slab to the imaging slice and the frequency of the magnetization preparation were characterized. The DB preparation was curtained to the central portion k-space to investigate a method of accelerating the HEFEWEIZEN acquisition. Multi-slice TrueFISP and DB TrueFISP, time-of flight MRA and DB TSE images were acquired centered of the carotid bifurcation in the patients.

Results: The ability to selectively suppress blood based on direction of inflow was demonstrated. Interestingly, the phenomenon of outflow suppression in TrueFISP, previously predicted in simulation, was verified (4). ROI analysis in the carotid arteries, jugular veins and muscle tissue demonstrated good flow suppression with low inter-slice variability and low disturbance to the imaging slice magnetization (table 1). Parameter optimization demonstrated maximal suppression with MP performed every 8-18 readouts. Reducing the saturation slab to imaging slice gap beyond 20 mm or increasing the thickness above 100 mm produced significant (>20%) stationary tissue suppression. High resolution images with control DB TSE images in a patient demonstrated the ability to detect low-grade stenosis using rapid DB TrueFISP, which was not possible with the bright blood equivalent (fig 2). Results in patient with a history of endarterectomy with re-stenosis demonstrated the ability to vialize the vessel wall in the common, internal and external arteries in patients with high grade stenosis.

Table 1. Average Suppression

Arterial	Venous	Stationary
88 ± 4%	85 ± 3%	11 ± 11%

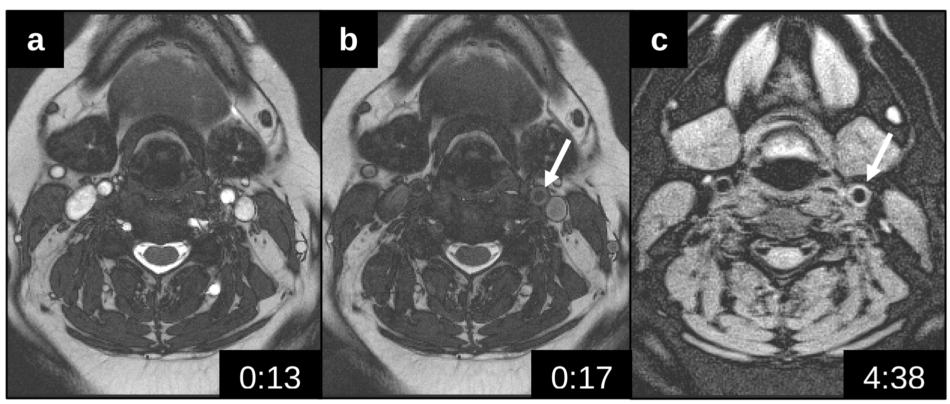

Fig. 2. High resolution images in a patient with low grade carotid artery stenosis. **(a)** Normal (bright blood) TrueFISP. **(b)** DB TrueFISP. **(c)** Control fat saturated DB TSE. Note the similarity of the depiction of stenosis in the DB TrueFISP and control TSE images (arrows) and the much faster DB TrueFISP acquisition. Acquistion times given in bottom right corner of images.

Discussion: A new fast DB TrueFISP pulse sequence has been developed and applied to high resolution carotid artery imaging. Good flow suppression (> 80%) was achieved with a minor increase in the overall acquisition time (13%). TrueFISP magnetization evolution is maintained in the imaging slice throughout the acquisition, resulting in a low stationary signal disturbance (~10%). Using HEFEWEIZEN, it was possible to visualize moderate and severe carotid artery stenosis on high resolution TrueFISP images with a short acquisition time (<17 s).

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