Positive Iron Contrast by Flow Enhanced Off-Resonance-Saturation for Remote Detection of Iron Based Contrast Agents

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Introduction

Hypointense contrast originating from iron-loaded atherosclerotic plaques within a vessel wall have been observed in contrast-enhanced gradient echo based MRA images of vessel lumen [1], allowing a fast remote detection of iron-loaded plaques. We demonstrate here on a flow phantom how a more specific positive iron contrast [2,3] mechanism - flow enhanced off-resonance saturation (feORS) -, combined with MRA might facilitate the detection of iron based contrast agents confined within a small vessel wall volume. Spins within vessel lumen flowing in the vicinity of a susceptibility inhomogeneity induced by iron located in the vessel wall experience a transient but significant frequency shift (Figure 1). At this moment they can be saturated by Off Resonance Saturation (ORS) pulses. The saturated spins will then leave the off-resonant region, while new non-saturated spins arrive which can also be saturated by ORS pulses. The saturated volume will grow as a function of time and be revealed as a tail-like positive contrast by subtracting images with and without feORS. Initial results from phantom experiments show the feasibility of this method.

Materials and methods

Experiments were conducted using a vertical Bruker 17.6T MR tomograph on a flow phantom (Figure 1) consisting of a water filled 1.4mm inner diameter capillary (Best Medizintechnik, Nümbrecht, Germany) immersed into water and connected to a water pump. A 0.2mm drilled hole was filled with pure Resovist (Schering, Germany) to act as a local susceptibility perturber (400 ng Fe). A fieldmap in the absence of flow was calculated from the phase variations between two 3D 200x90x90 FLASH datasets (FOV=40x18x18 mm³) with echo times TE=4ms and TE=5ms respectively. Positive iron contrast images were calculated from the magnitude subtraction of two 2D 200x100 flow compensated FLASH images (FOV 40x15x1.6mm³, TR=50ms, FA=60°, TE=2.5ms) respectively without and with feORS. The feORS module consisted of a series of 90° SLR-pulses (pulse duration=6ms, BW=1kHz, Offset frequency=-600Hz) with an interpulse delay of 0.5ms and gradient spoiling after each pulse.

Results

Positive as well as negative off-resonance frequency shifts affect the spins located inside the capillary at the vicinity of the iron loaded hole (Figure 1). Non assessable frequency shifts within gray colored voxels are expected to present a majority of negative frequency shifts over 100Hz and spins in this region will mainly be saturated by the -600Hz ORS pulses. Positive iron contrast appears as a bright tail starting at the hole-position after 60ms of feORS saturation and for a flow velocity of 80cm/s (Figure 2, C). The length of the tail shortens with decreasing feORS duration (Figure 2, D-E) or decreasing flow velocity (Figure 2, H,G,F). A loss of contrast hence of saturation efficiency of the feORS module with increasing flow velocity is observed as well as false positive contrast from background signal, suggesting the need for more optimized feORS pulses. TOF-MRA enhances the contrast to noise of flowing spins while reducing background false positive signal.

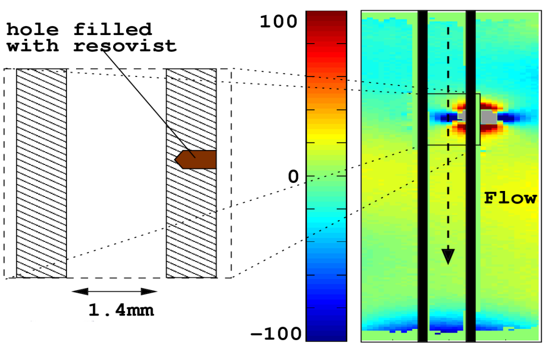

Figure 1: scheme of the capillary with hole filled with Resovist (left). Fieldmap [Hz] of phantom (right). Notice the frequency shifts inside the capillary caused by the iron allowing the cumulative ORS of spins flowing in the vicinity of the hole loaded with iron.

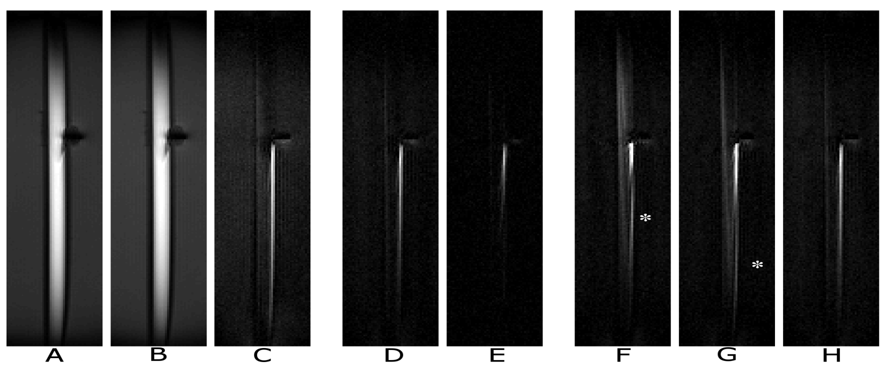

Figure 2: Image without (A) and with 60ms feORS (B). Corresponding positive iron contrast (C). Maximal flow velocity Vmax=80cm/s. D-E: same as (A), but feORS duration of 30ms (D) and 12ms (E). F-H: same as (D) but Vmax=20cm/s (F), 40cm/s (G), 80cm/s (H). Image intensity scaling: 0 to 5 (A-B), 0 to 1(C-H). Cropped FOV=40x9mm.
(*) Saturation contrast from previous TR cycle.

Discussion

A new positive iron contrast aiming at remotely detecting iron-loaded cells within the vessel wall by targeting flowing spins only and based on a flow enhanced ORS mechanism scaling with flow velocity and saturation time could be observed. Flow-enhanced ORS was successfully combined with TOF angiography for optimal CNR. feORS requires a good overall field homogeneity, short ORS pulse duration and sharp spectral selectivity. Those requirements can become a limit to the technique in presence of small amounts of iron contrast agent inside the vessel wall or at high magnetic field where macroscopic susceptibility artefacts become more severe. In vivo, an optimum flow velocity for maximum contrast will depend of the efficiency of the feORS module and voxel size.

Conclusion

We have demonstrated on phantom experiments that flow-enhanced off resonance saturation is a promising technique to generate positive iron contrast. It has been shown that the combination of flow and ORS augments the saturated volume multiple times. Combined with TOF angiography, the technique has the potential to ease the detection of iron-loaded atherosclerotic plaques where conventional angiography images only deliver a non specific hypointense contrast which cannot differentiate between iron load in a vessel wall, turbulent flow, local variation of lumen or stenosis.

References

[1] S. Ruehm et al., *Circulation 2001;103;415-422,* [2] JH Seppenwoolde et al., *proc ISMRM 2006, p360,* [3] O. Zurkiya et al., *Magn Reson Med 2006;56;726-732*