Elimination of Inflow Enhancement by Partial Pre-Saturation in RF Spoiled Imaging

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Introduction: For RF-spoiled gradient echo imaging (ie SPGR, FLASH, T1-FFE), the combination of spoiling gradients and quadratic phase cycling eliminates net transverse magnetization within a voxel [1-4] to enable pure T1 contrast. Generally, many RF excitations are required to attain steady state magnetization levels. Therefore, when unsaturated spins are flowing into the imaging volume, inflow enhancement [5] occurs at entry slices of the slab, which can affect quantitative imaging such as in calculation of the arterial input function. We hypothesize that partial saturation of an outer slab could provide the desired longitudinal magnetization to avoid inflow effects with minimal artifacts. To test this, we investigate the complex magnetization of partially saturated flowing spins in an RF-spoiled gradient echo sequence using simulations, phantom and *in vivo* experiments.

Method: A 3D SPGR sequence was modified by adding an outer slab saturation RF pulse (Fig. 1) to observe the effect of pre-saturation on flowing spins. The same minimum phase pulse with time x bandwidth = 20, 3.2 ms duration and 20° flip angle with a quadratic RF phase increment of 117° [1] was used for both the imaging slab excitation and outer slab partial saturation. For imaging parameters, TR/TE = 20/3 ms, 32 sections, each 0.4 cm thick, were used. The z-spoiler gradient generates 4 cycles of phase per section, and serves as both spoiler and dephaser for the 24-cm-thick saturated slab, located adjacent to the imaging slab.

First, the pulse sequence was simulated for stationary and flowing spins of 10 cm/s without and with the partial slab saturation, using T1/T2 = 1/0.2 s. We used the Bloch equations assuming 100 isochromats for each section. To simplify the flow of spins, we considered the net flow of isocromats per TR to occur at the end of each sequence repetition. Second, a flow phantom scan and neck scans from four volunteers were conducted with a GE 1.5T Excite Scanner, a standard head coil and a neurovascular 4-channel phased-array coil. For each scan, experiments without and with slab saturation were performed. For the flow phantom, the mean velocity of the water was set to 10 cm/s, and T1 of water was shortened to 1 s by dissolving Gd-DTPA to generate a T1 value close to that of blood. From the phantom and neck images, water and blood signal changes across the slab were quantified, respectively, using a manually-placed ROI along the vessel.

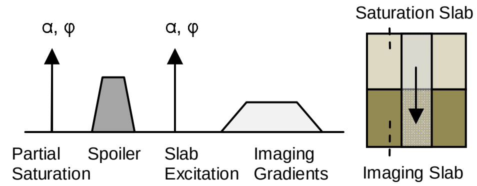
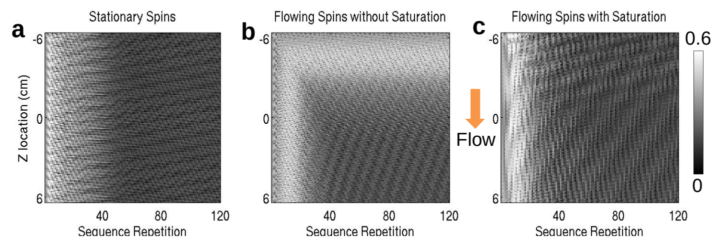


Fig. 1. Pulse sequence with partial slab saturation.



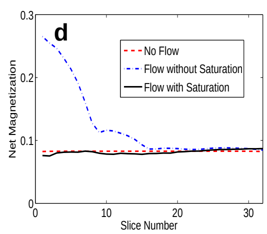


Fig. 2. Simulated evolution of transverse magnetization with sequence repetitions for stationary spins (a), flowing spins without (b) and with (c) incorporating partial slab saturation when spins flow from –z to +z. Only the magnetization within the imaging slab is shown. (d) shows signal profiles acquired by averaging over a section.

Results: The time evolution of transverse magnetization at TE is shown in Fig. 2 for stationary spins (a), flowing spins with 10cm/s without (b) and with (c) the partial saturation pulse. After 40-50 sequence repetitions, magnetization becomes periodic at each location for all three cases. The signal profiles of the slab, shown in (d), are calculated by averaging magnetization of 100 ischromats for each section (net magnetization). Even with the complicated magnetization profiles due to both RF and gradient spoilings, the net magnetization is smooth. With flowing spins, signal is greatly enhanced at entry slices but it decreases as spins become saturated as they penetrate the slab. By applying partial pre-saturation, flowing spins provide similar signal intensity to that of stationary spins. In Fig. 3, signal intensity changes through the slab in the ROIs of the phantom tube are shown, compared with those from stationary water and from full 90° pre-saturation [5]. In Fig. 4, the 16th neck slices from the entry of one subject and signal intensity changes within the right carotid artery are shown after compensating for coil sensitivity variation using reference body coil images. For both phantom and *in vivo* images, the partial pre-saturation provides uniform signal profiles within the imaging slab.

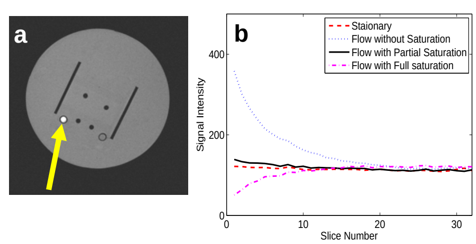


Fig. 3. (a) A phantom slice with the tube (shown by arrow) where water flows. (b) The signal intensity changes within the tube are shown for no flow, flow without saturation and flow with partial and full saturation.

Discussion: Partial pre-saturation can eliminate inflow enhancement efficiently with just adding one RF pulse to the sequence. For complete reduction, the saturation slab should be thick enough for spins to approximate the steady-state longitudinal magnetization. Compared to full saturation of flowing spins [6], which is commonly used to eliminate flow artifacts, partial saturation provides more homogeneous signal profiles and provides T1 contrast of both flowing and stationary spins for the spoiled gradient sequence. Thus, partial pre-saturation could be useful when measurement of an arterial input function and contrast concentration are required for contrast-enhanced MRI.

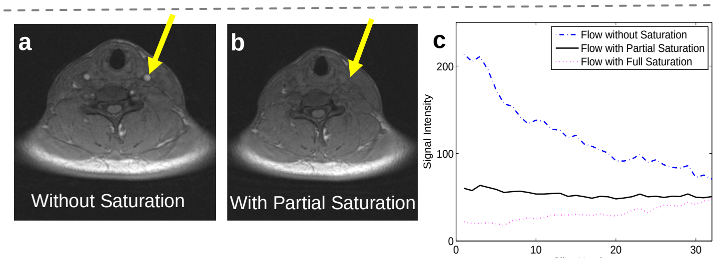


Fig. 4. (a-b) Axial neck images. Carotid arteries with enhanced blood are seen in the slice (a) when the pre-saturation is not used. (c) compares signal intensity changes within the right carotid artery (shown by arrow) without any saturation, with partial and full saturation.

References

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