The Origins of Bright Blood MPRAGE at 7 Tesla and a Simultaneous Method for T1 Imaging and Non-Contrast MRA

J. W. Grinstead[1], W. Rooney[2], and G. Laub[3]
[1]Siemens Healthcare, Portland, OR, United States, [2]Oregon Health and Science University, [3]Siemens Healthcare

Introduction

MPRAGE is a widely used pulse sequence for 3D T1-weighted anatomical imaging consisting of an inversion recovery (IR) pulse followed by a rapid gradient echo readout. Unlike at lower field strengths, it has been reported that the blood appears extremely bright in MPRAGE at 7 Tesla, and provides excellent vascular information [1,2]. However, the mechanism for this has not been completely explained. Others have optimized MPRAGE parameters to maximize the amount of blood inflow enhancement and background tissue suppression, at the expense of T1-weighted anatomical image quality [2]. The present work aims to explain the primary source of bright blood MPRAGE at 7 Tesla, and based on this understanding proposes a new technique providing simultaneous high-resolution T1 MPRAGE imaging and non-contrast angiography with excellent background suppression.

Methods

Simulations of the MPRAGE pulse sequence were performed to compare the signal levels of gray matter (GM), white matter (WM), CSF, and blood at 3T and 7T, both with and without the presence of IR pulses. The T1 values for the simulation were taken from the literature [3].

The adiabatic inversion pulse in MPRAGE is optimized to give uniform inversion in the presence of B1 inhomogeneity. Slab-selectivity is not required for good image quality, so it is common to use non-selective IR pulses. Slice-selective adiabatic IR pulses designed for 2D imaging (i.e. FLAIR) will not give good slab-selectivity if simply extended to a large 3D slab-thickness, because of the resulting extremely weak slab-selective gradient. So in practice, IR pulses in MPRAGE are usually effectively non-selective. However, if the reference gradient used in the design of the adiabatic IR pulse is increased, the slab-selectivity can be greatly improved. An MPRAGE pulse sequence was implemented using such an optimized slab-selective IR pulse.

Experiments were performed at 3 and 7 Tesla (Siemens Trio a Tim System and MAGNETOM 7T). Identical protocols were run on each system, as well as protocols using the TI/TR/FA that provide optimal MPRAGE anatomical image quality. The RF coils used were: 3T CP birdcage transmit-receive (Tx-Rx) head coil, 3T 12-channel phased array Rx-only head coil (Siemens), 7T 8-channel phased array Tx-Rx head coil (Rapid).

A high quality MPRAGE protocol used for structural imaging (1mm isotropic voxels, 10 minute scan time) was modified to run in approximately half the time using iPAT=2. Two measurements were performed, one with a non-selective IR pulse and the other with the improved slab-selective IR pulse. The two measurements were then averaged to restore the SNR of the original longer scan without iPAT, so that it could still be used for high quality structural imaging. The two measurements were also subtracted to yield an image of only the inflowing blood with the stationary tissue suppressed.

Results and Discussion

An often proposed explanation for the increased blood brightness in MPRAGE at 7 Tesla is the longer blood T1 at higher field. However, this would actually have the opposite effect, because the longer the T1 the quicker the blood will saturate during the gradient echo readout, and the slower the longitudinal magnetization will recover for a given TR. The purpose of using gadolinium-based contrast agents for angiography is to decrease the T1 of blood so that it will not saturate as quickly to make blood brighter, which is contrary to the idea that a longer T1 at 7T explains bright blood MPRAGE.

A major difference between research 7T scanners and clinical 3T scanners is the lack of body RF transmit coils at 7T, while at 3T it is most common to use a body RF coil for transmit and a local receive-only head array coil for signal reception. At 3T, a non-selective IR pulse will be transmitted by the body coil and will invert blood far outside the imaging volume, including the neck, aorta, and even the heart. At 7T, a non-selective IR pulse will be transmitted by the head coil and will only be able to invert blood within reach of this local coil. Typically, 7T head coils do not reach inferior to the cerebellum. This means that with a Tx-Rx head coil a non-selective IR pulse is effectively a slab-selective IR pulse.

Fig. 1 shows a numerical simulation of signal values over the MPRAGE gradient echo readout for typical T1 values at 3 Tesla. The blood signal brightness will be between CSF (dark on T1 weighted images) and gray-matter. However, if the blood does not experience an IR pulse, it will be much brighter for most of the readout. It can also be seen that the blood signal saturates slightly faster at 7T, as expected because of the longer T1.

It was found that for all protocols at 3T, the blood was much brighter throughout the head when using a Tx-Rx head coil. The bright blood did not persist as far superiorly in the brain compared to 7T, because the 3T Tx-Rx coil had a larger RF coverage compared to 7T and was still inverting blood beyond the imaging volume when using an effectively non-selective IR pulse. Only when using the optimized slab-selective IR pulse did the blood vessels become as bright at 3T as on 7T, regardless of the coil used at 3T.

Fig. 2 depicts an axial slice near the midbrain using the 3T Rx-only head coil, using the non-selective and the improved slab-selective IR pulses. The average of the two images is shown, demonstrating a high SNR anatomical image. The difference images are shown in **Fig. 3** as sagittal, coronal, and axial minimum intensity projections with excellent vessel enhancement and background suppression. There is no blood signal loss in the vertebral arteries as often seen in traditional time-of-flight scans, because here vessel enhancement is due primarily to inflow of un-inverted blood signal.

In conclusion, the primary source of bright blood MPRAGE at 7T has been explained, and a new method yielding simultaneous high-quality T1 images and non-contrast angiography has been demonstrated at 3T.

References [1] Maderwald, MAGMA 2008 21:159-67. [2] Zwanenburg, JMRI 28:1519-1526 (2008). [3] Rooney, MRM 57:308-318 (2007).

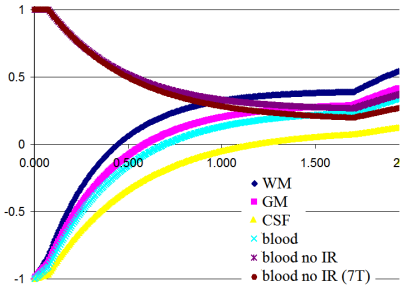

Fig 1. Simulation results of 3T tissues, as well as blood at 7T.

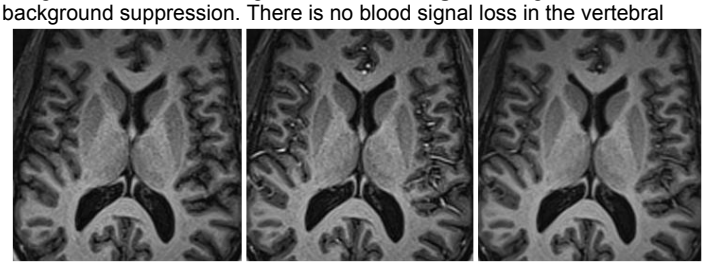

Fig 2. Zoomed axial slice at midbrain level at 3T. IR non-selective (left), slab-selective (middle), and the mean of both (right).

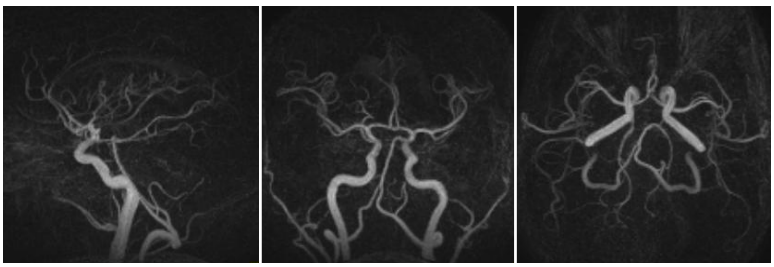

Fig 3. MIP images of the subtracted data set, sagittal (left), coronal (middle), and axial (right).