Contrast-Enhanced Three-Dimensional Whole-Brain Black-Blood Imaging for Efficient Detection of Small Metastases

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Introduction: Contrast-enhanced three-dimensional (3D) T_1-weighted MR imaging based on magnetization-prepared-rapid-gradient-recalled-echo (MP-RAGE), has been shown to be sensitive for the detection of small brain metastases due to the T_1-shortening effect of contrast agent (1). However, since contrast agent remains in blood and tumors, and thus increases signal intensity in both parts, it is challenging to accurately detect the brain tumors using the conventional method. The purpose of this work was to develop a novel contrast-enhanced 3D whole-brain black-blood imaging method which enhances the signal intensity of brain tumor while selectively suppressing that of blood, and thus enhance the accuracy of diagnosis for small brain metastases.

Pulse Sequence Design: Since the conventional MP-RAGE pulse sequence is inappropriate for black-blood imaging due to a fast recovery of the longitudinal magnetization of contrast agent, the proposed method is based on a single-slab 3D turbo/fast spin echo (SE) sequence optimized for T_1-weighted contrast (2). A timing diagram of the proposed pulse sequence is shown in Fig. 1. The whole brain was selected by volume excitation. Refocusing flip angles were varied to yield constant signal evolution for gray matter, maintaining reasonable T_1-weighted contrast along the echo train. At the end of the refocusing pulse train, composite restore pulses that consist of three hard pulses were applied, wherein the first two pulses refocus remnant transverse magnetization while the last pulse transfers the magnetization into the negative longitudinal axis, preparing a partial inversion recovery for optimal T_1-weighted contrast. A look at the readout direction in the pulse sequence illustrated in (2) for flowing spins, blood, suggests that SE signals are rephased every other echo, while stimulated echo (STE) signals keep dephased every echo. Thus, to suppress blood signals, magnetizations that produce SE/STE need to be dephased, and remain incoherent along the entire echo train. To increase the incoherence of STE signals, variable low refocusing flip angles were employed, and the gradient amplitude of spoilers along the readout direction was increased. Additionally, to prevent the SE signals from being rephased, motion-sensitizing matching crushers on either side of the first refocusing pulse were applied along all the three axes. Due to the additional crushers and thus elongated first echo spacing (ESP) compared with regular ESP in the remainder of echo train, the first refocusing flip angle was forced to 180° to prevent undesired signals from being refocused during data sampling periods.

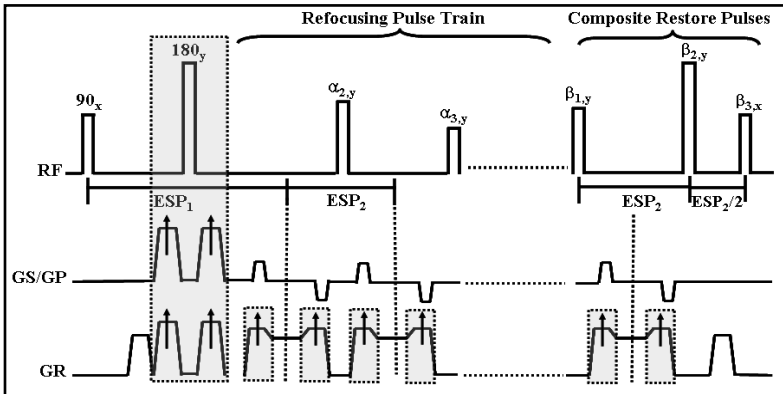

Fig. 1. Timing diagram of the proposed pulse sequence for enhancing tumor signals while suppressing blood signals (ESP: echo spacing).

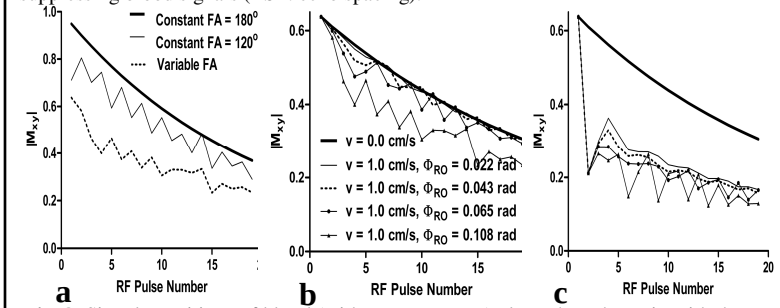

Fig. 2. Signal transitions of blood (with contrast agent) along the echo train with three different refocusing flip angle (FA) schemes (v , 5cm/s) (a), four different first-order readout gradient moments (φ_{RO}) with variable flip angle scheme (b), and additional motion-sensitizing diffusion gradients + the schemes shown in b (c). Note that blood signals rapidly decrease with variable flip angles, larger first-order readout gradient moments, and motion-sensitizing matching crushers (b-value, 5s/mm^2)

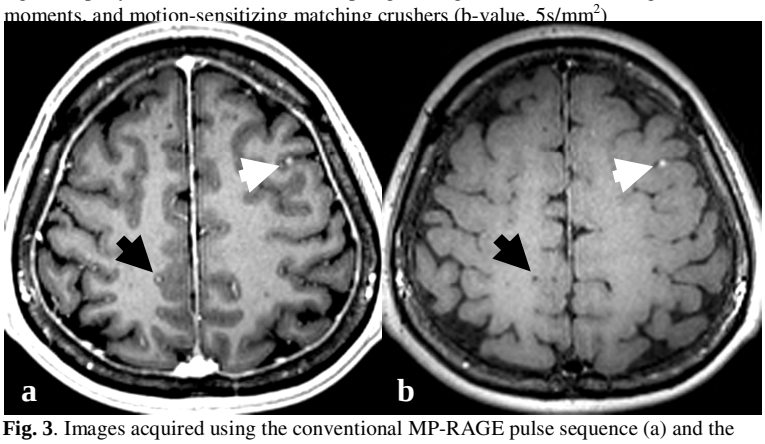

Fig. 3. Images acquired using the conventional MP-RAGE pulse sequence (a) and the proposed pulse sequence (φ_{RO}=0.108, b-value=5s/mm^2) (b). Note that both blood (black arrow) and metastatic tumor (white arrow) signals are enhanced in the brain parenchyma in (a) while only tumor signals appear to be bright in b.

Materials and Methods: To demonstrate the signal behavior of flowing spins, the Bloch-equation was numerically simulated along the readout direction for the following three different flip angle schemes (constant 180°, constant 120°, variable flip angles), assuming that all the gradients are rectangular (duration, 0.9 ms; GR, 20mT, velocity (v), 5 cm/s) and all RF pulses are very short (duration, negligible). Simulation was then performed for the variable flip angles and v = 1 cm/s as the first-order readout gradient moment increases with/without the matching crushers. Informed written consent was obtained prior to imaging. Imaging was then performed in 5 patients suspected of brain metastasis at 3T (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany) using the conventional MP-RAGE and the proposed sequence for comparison. Imaging parameters for the MP-RAGE were: TR/TE/TI, 2300/3/900 ms; FA, 9°, FOV, 256x256 mm^2; matrix, 256x256; partitions, 176; thickness, 1 mm. Those for the proposed method were: TR/TE, 630/11~16 ms; ETL, 23; ESP, 3~5 ms; (others, identical)

Results: Fig.2a shows that variable flip angle scheme is advantageous in suppressing blood signals compared with constant flip angle schemes. Signal intensity of slowly moving blood rapidly decreases with the increase of the first order readout gradient moment (Fig. 2b) and the additional matching crushers (Fig. 2c). In patient studies, the proposed method selectively enhances tumor signals with blood suppression (Fig. 3b) while the MP-RAGE increases signal intensity of both blood and tumors (Fig. 3a)

Discussion and Conclusion: We successfully demonstrated a novel contrast-enhanced 3D whole-brain black-blood imaging method and its clinical application for detecting small metastases. Although the proposed method yields lower contrast in gray-white matters than the MP-RAGE due to the increased ESP and TE resulting from the motion-sensitizing gradient schemes, high contrast of tumor-background with blood suppression would be a clear advantage in accurately diagnosing small brain metastases. **References:** 1.Singh et. al.,Radiology,2000,217:50;2.Park et.al.,MRM,2007,58:982