

"T1-enhanced" whole-brain black-blood RARE images using 3D MSDE-TSE with anti driven equilibrium

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INTRODUCTION:

Contrast-enhanced magnetic resonance imaging, using a 3D T1-weighted gradient echo sequence, is an established method for screening of brain metastasis [1-4]. However, since a contrast agent remains in both blood and tumor parenchyma, differentiation of (enhanced) vessels and tumor may be difficult [5]. To overcome this problem, "black-blood" T1-weighted 3D rapid acquisition with relaxation enhancement (RARE) (e.g., turbo spin-echo (TSE)) imaging has come into use recently [6,7]. This method uses a so called "motion sensitized driven equilibrium (MSDE)" pre-pulse [8,9], which comprises (1) a series of RF pulses with $90^\circ/180^\circ/90^\circ$ flip angles (i.e., T2-prep. pulse) and (2) motion sensitization gradients that are placed symmetrically around the 180° pulse. Although a MSDE prepared TSE (MSDE-TSE) sequence can produce excellent black-blood images, it potentially suffers from decreased T1 contrast due to "T2 contamination" because MSDE is based on a T2-prep pulse. This causes poor differentiation between gray matter and white matter, and may hamper accurate anatomical localization of certain brain lesions. To improve the T1 contrast of 3D MSDE-TSE sequences, we focused on the anti driven equilibrium (ADE) post-pulse [10], which applies the $+90^\circ$ pulse at the end of the echo-train. Park et al. have used a "restore" pulses scheme, which is similar to the ADE, for T1 contrast improvement in a saturation-recovery prepared 3D TSE sequence [11]. The $+90^\circ$ RF pulse brings the residual transverse magnetization to the negative longitudinal axis. Therefore, the pulse rebuilds the longitudinal magnetization, namely differences in T1 relaxation. Hence, we hypothesized that the ADE pulse can offset the T2-contamination. In this study, we introduced T1-enhanced whole-brain black-blood RARE imaging, using MSDE-TSE with an ADE pulse, for contrast-enhanced brain tumor screening at 3.0 Tesla, and compared this technique to conventional methods.

METHODS:

A total of 6 healthy volunteers and 3 patients were examined with a 3.0-Tesla whole-body clinical imager (Achieva, Philips Healthcare, Best, the Netherlands). The study was approved by the local-IRB, and written informed consent was obtained from all subjects.

Pulse sequence: The MSDE-TSE-ADE sequence is based on 3D low-refocusing flip-angle TSE to acquire contrast-efficient T1-weighted black-blood images [12]. The MSDE pulse in this study used so called "improved" MSDE (iMSDE) [9] for better suppression of the enhanced blood signals. The ADE pulse is applied at the last part of the sequence, which consists of an inverse refocusing sweep at the end of the echo train followed by a $+90^\circ$ RF pulse on the last echo top [13,14], to improve the T1 contrast. **Fig.1** shows the sequence diagram of MSDE-TSE-ADE.

Image comparison: A total of 6 healthy volunteers were examined. Each volunteer underwent three sequences; TSE, MSDE-TSE, and MSDE-TSE-ADE.

To evaluate improvement/deterioration of T1 contrast with MSDE-TSE and MSDE-TSE-ADE, we calculated relative contrast ratio (rCR) of white matter to gray matter (rCR_{WM-GM}) compared to TSE (as 1.00). Also, rCR of WM/CSF (rCR_{WM-CSF}) was measured. Relative signal-to-noise-ratio (rSNR) of these images was also measured. Qualitative and quantitative analyses were done in a blinded manner. The CR and SNR were assessed by using repeated-measures analysis of variance (ANOVA).

The imaging parameters common to all methods were: FOV = 240mm, resolution = 1.0mm^2 , 192 slices, slice thickness = 1.0mm, TR / TE_{eff} / ETL = 400 / 13.8ms / 17, FA = 90° , RFA = 40° with " $90^\circ+a/2$ " pseudo steady-state preparation [15], and acquisition time = 4min. In addition, iMSDE pre-pulse (duration = 17ms, gradient strength (b-value) = 10.57s/mm^2) was applied in MSDE-TSE / MSDE-TSE-ADE.

Feasibility evaluation: An initial evaluation of the MSDE-TSE-ADE sequence for contrast-enhanced brain tumor screening was performed in 3 patients with brain tumors (including metastasis and meningioma). All patients underwent three sequences for comparison; TSE, MSDE-TSE, and MSDE-TSE-ADE.

RESULTS and DISCUSSION:

A comparison of rCR_{WM-GM} , rCR_{WM-CSF} , and $rSNR_{WM}$, is shown in **Fig. 2**. Both rCR_{WM-GM} and rCR_{WM-CSF} of MSDE-TSE (as an indicator of T1 contrast) were lower than those of TSE. On the other hand, both rCR_{WM-GM} and rCR_{WM-CSF} of MSDE-TSE-ADE were significantly higher than those of TSE and MSDE-TSE. The rCR_{WM-CSF} of MSDE-TSE-ADE was increased substantially, especially compared to that of MSDE-TSE. That is, the ADE worked effectively to suppress long T2 value tissues such as CSF. Consequently, the ADE pulse could clearly improve the T1 contrast. However, the $rSNR_{WM}$ of MSDE-TSE-ADE was decreased most among the investigated sequences, and this should be noted as a drawback.

Representative non contrast-enhanced and contrast-enhanced T1-weighted sagittal brain images in patients with brain tumors by use of TSE, MSDE-TSE, and MSDE-TSE-ADE imaging at 3.0 Tesla are shown in **Fig. 3**. The MSDE-TSE-ADE sequence could provide a good T1 contrast comparable to that of TSE, and could also, simultaneously, provide black-blood images similar to those of MSDE-TSE.

CONCLUSION:

This study demonstrated a new scheme of the T1-enhanced whole-brain black-blood 3D RARE pulse sequence. This sequence can be used for 3D volumetric T1-weighted black-blood imaging, and it is effective in detecting small brain metastases by selectively enhancing tumor signals while suppressing blood signals. Further clinical investigations are needed.

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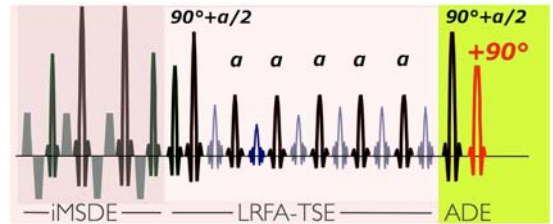


Fig.1 Scheme of MSDE-TSE-ADE pulse sequence. The MSDE-TSE consists of iMSDE prepulse and low refocusing flip angle TSE. The ADE consists of an " $90^\circ+a/2$ " extra-refocusing pulse and a $+90^\circ$ pulse.

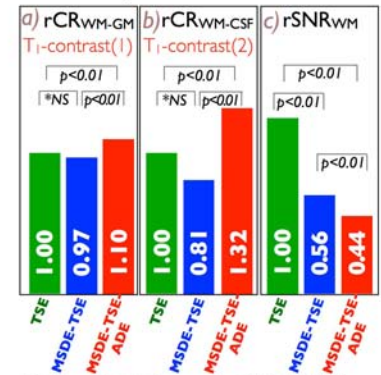


Fig.2 Comparison of relative(r)-CR_{WM-GM} [a], rCR_{WM-CSF} [b], and rSNR_{WM} [c], in volunteers (n=6). rCR_{WM-GM} and rCR_{WM-CSF} of MSDE-TSE was lower than that of TSE, but MSDE-TSE-ADE was significantly higher than that of TSE. Meanwhile, rSNR_{WM} of MSDE-TSE-ADE was decreased most substantially.

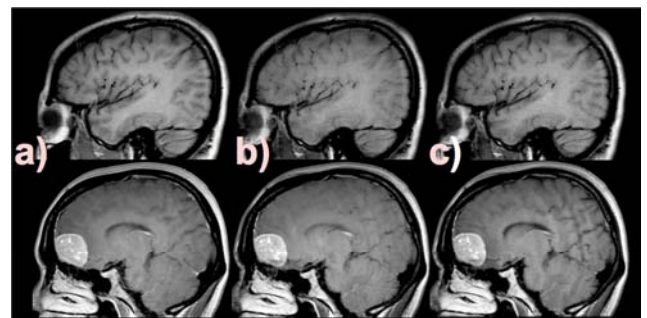


Fig.3 Representative non contrast-enhanced and contrast-enhanced images of TSE[a], MSDE-TSE[b], and MSDE-TSE-ADE[c].