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ORIGINAL ARTICLE /*Research and new developments*

T1-weighted parenchyma attenuated inversion recovery: A novel sequence that improves contrast ratio of enhancing brain lesions

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Contrast enhancement;
Contrast-to-noise ratio (CNR)

Abstract
Purpose: The purpose of this study was to develop and test a parenchyma attenuated T1-weighted inversion recovery MR sequence (PAIR) that increases the contrast between enhancing and non-enhancing tissues in the brain and to compare the contrast ratio of enhancing brain tumors on this sequence compared to spin echo magnetization transfer (SEMT).
Patients and methods: PAIR sequence parameters were developed to reduce signal from gray matter (GM), white matter (WM), and cerebrospinal fluid (CSF) in a healthy adult volunteer. Forty-one patients (17 men and 24 women) with a mean age of 55 ± 13 (SD) years (range: 21—78 years) with known or suspected brain tumors underwent PAIR and SEMT imaging after intravenous administration of gadobenate dimeglumine. In patients with confirmed tumors, PAIR and SEMT images were compared for contrast ratio of tumor-to-WM, tumor-to-GM, and tumor-to-CSF.
Results: A total of 23 enhancing neoplastic lesions were found in 14/41 patients. All tumors were visualized on both contrast enhanced PAIR and SEMT images. PAIR images showed a 2.5 fold increase in maximum tumor-to-GM contrast ratio ($P < 0.0001$), a 1.4 fold increase in maximum tumor-to-WM contrast ratio ($P = 0.0007$) and a 5-fold increase in maximum tumor-to-CSF contrast ratio ($P < 0.0001$).
Conclusion: PAIR provides improved lesion-to-background contrast ratio compared to SEMT and may be useful as an added sequence in tumor evaluation.

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Early detection of brain tumors and inflammatory lesions can change patient outcomes by expediting treatment. MR imaging has established itself as the mainstay of tumor detection and classification in the brain. Standard T1-weighted spin echo magnetic resonance (MR) imaging was originally used for detecting enhancing lesions. Fast spin echo soon replaced spin echo due to reduced imaging time and improved conspicuity of enhancing lesions [1]. To improve further upon this, various additional techniques were developed. Triple dose contrast regimens for example, have been shown to provide greater lesion detection and contrast ratio than standard doses [2]. However, the added value of these findings has yet to be established relative to the potential for increased complications from a higher dose of gadolinium chelate. Increasing the delay in imaging after contrast administration is another strategy that has been attempted but found to be ineffective in increasing lesion conspicuity [3].

Magnetization transfer sequences utilize a magnetization transfer pulse to suppress signal from background tissues. These sequences have allowed for increased contrast ratio of enhancing lesions, proving equally effective as triple dose gadolinium chelate with standard spin echo [4,5]. As a result, magnetization transfer has become the standard of care in many imaging centers [4]. Three dimensional gradient echo sequences have also proven to be superior to standard spin echo sequences, mainly due to higher resolution and thinner slices rather than improved contrast ratio [6—9].

Inversion recovery is another option that has not been widely used in clinical practice [10]. Inversion recovery allows for nulling of signal from a chosen tissue through the use of an inversion pulse. Numerous T2-weighted inversion recovery sequences have been allowed for improved detection of white matter lesions as well as improved differentiation of anatomic structures [11—13]. Compared with T2-weighted inversion recovery imaging, T1-weighted techniques, including T1 fluid attenuated inversion recovery (FLAIR) and T1 phase-sensitive inversion recovery (PSIR) are not as widely used in neuro-imaging [10,11,14—16]. T1-weighted FLAIR imaging can improve sensitivity and specificity for leptomeningeal and facial nerve enhancement due to a lack of confounding enhancement within surrounding slow flow vessels [14,16—18]. Despite its advantages in the leptomeninges, T1-weighted FLAIR imaging has shown inconsistent results in the brain parenchyma, with some studies actually showing decreased contrast to noise ratio of enhancing brain lesions, especially within avidly enhancing lesions [10,16,19—22]. To date, no T1-weighted inversion recovery sequence has specifically aimed at nulling signal from background gray mater (GM) and white matter (WM) to improve enhancing lesion contrast and conspicuity.

The purpose of this study was:

- to develop and test a parenchyma attenuated T1-weighted inversion recovery MR sequence (PAIR) that increases the contrast between enhancing and non-enhancing tissues in the brain;
- to compare the contrast ratio of enhancing brain tumors on this sequence compared to spin echo magnetization transfer (SEMT).

Materials and methods

Patients

Approval for this study was obtained from the Singer Research Institute-Allegheny Health Network Institutional Review Board. Informed consent was obtained from all patients. The PAIR sequence was designed to provide T1-weighting while minimizing signal from WM, GM, and cerebrospinal fluid (CSF). Multiple iterations of the sequence with varying inversion times (TI) and repetition times (TR) were tested on a healthy volunteer until visually sufficient T1-weighting and parenchyma attenuation were obtained with the sequence parameters outlined below.

All inpatients and outpatients above 18 years of age undergoing enhanced MR imaging of the brain for known or suspected brain tumor over a three-week span were approached to participate in the study. Informed written consent was obtained from 41 patients (17 men and 24 women) with a mean age of 55 ± 13 (standard deviation [SD]) years (range, 21—78 years). The study involved adding the single additional axial gadolinium chelate enhanced PAIR sequence to the normal brain MR imaging protocol, which included T2-weighted fast spin echo MR imaging in the transverse plane, T2-weighted FLAIR imaging in the transverse plane, gradient echo susceptibility weighted imaging in the transverse plane, T1-weighted MR images obtained before intravenous administration of gadolinium chelate in the sagittal and transverse planes, and T1-weighted SEMT MR images obtained after intravenous administration of gadolinium chelate in the transverse, coronal and sagittal planes.

MR imaging protocol

A Siemens Avanto® 1.5 T MR system (Siemens Healthineers, Munich, Germany) with standard circular polarized head coil was used. Axial PAIR was obtained with a fast spin echo inversion recovery sequence: 700/11/2 (TR/TEeff/excitations); TI, 300 ms; concatenations, 5; flip angle, 150; acquisition time, 4 minutes 38 seconds. SEMT was obtained with the following sequence:

- 445/17/1 (TR/TE/excitations);
- concatenations: 2;
- flip angle: 150;
- acquisition time: 2 minutes 35 seconds.

Both sequences used 23 sections, a 256×192 matrix, a 230 mm rectangular field of view (FOV) and 5 mm thick sections with a 1.5 mm gap. Concatenations were chosen to be higher for the PAIR sequence — five versus two — to improve overall signal to noise, which had decreased due to the inversion recovery technique. As signal from all tissues increased, contrast was not substantially affected from the difference in concatenations. Gadobenate dimeglumine (Multihance®; Bracco, Milan, Italy) was administered for contrast enhancement with the standard dose of 0.1 mmoL/kg of body weight. In order to minimize the effect of sequence order and sequence duration on gadolinium chelate enhancement, patients had an SEMT sequence performed both before and after the PAIR sequence. In order to randomize the analysis, the PAIR sequence was compared to the earlier SEMT

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