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Gray Matter-White Matter Contrast on Spin-Echo T1-Weighted Images between 3T and 1.5T: A Quantitative Comparison Study.

Abstracts

Discrepancies exist in the literature regarding contrast between gray and white matter on spin-echo (SE) T1-weighted MR imaging at 3T. The present study quantitatively assessed differences in gray matter-white matter contrast on both single- and multi-slice SE T1-weighted imaging between 3T and 1.5T. SE T1-weighted sequences with the same parameters at both 3T and 1.5T were used. Contrast-to-noise ratio (CNR) between gray and white matter (CNR_{GM-WM}) was evaluated for both frontal lobes. To assess the effects of interslice gap, multi-slice images were obtained with both 0% and 25% interslice gap. Single-slice CNR_{GM-WM} was higher at 3T (17.66±2.68) than at 1.5T (13.09±2.35; $p<0.001$). No significant difference in CNR_{GM-WM} of multi-slice images with 0% gap was noted between 3T and 1.5T (3T, 8.61±2.55; 1.5T, 7.43±1.20; $p>0.05$). Multi-slice CNR_{GM-WM} with 25% gap was higher at 3T (12.47±3.31) than at 1.5T (9.73±1.37; $p<0.001$). CNR_{GM-WM} reduction rate of multi-slice images with 0% gap compared with single-slice images was higher at 3T (0.47±0.13) than at 1.5T (0.38±0.09; $p=0.02$). CNR_{GM-WM} on single-slice SE T1-weighted imaging and CNR_{GM-WM} on multi-slice images with 25% interslice gap were better at 3T than at 1.5T. The influence of multi-slice imaging on CNR_{GM-WM} was significantly larger at 3T than at 1.5T.

Introduction

Magnetic resonance (MR) imaging at 3T has gradually been introduced to clinical practice in addition to research fields. Signal-to-noise ratio (SNR) is better at 3T MR imaging than at 1.5T MR imaging [1-4]. This improved SNR at 3T MR imaging provides advantages in various applications [5-7]. Increased T1 relaxation time and improved SNR at 3T provides better visualization on MR angiography [8, 9].

Discrepancies exist in the literature regarding contrast between gray matter (GM) and white matter (WM) on spin-echo (SE) T1-weighted MR imaging at 3T. Nobauer-Huhmann et al. [10] reported that visual assessment of differentiation between GM and WM on SE T1-weighted sequences was significantly lower at 3T than at 1.5T. They noted that the repetition time (TR) optimized for 1.5T was too long to obtain sufficient contrast between GM and WM at 3T. A review by Scarabino et al. [11] stated that SE T1-weighted images show low contrast-to-noise ratio (CNR) between GM and WM (CNR_{GM-WM}), probably due to longer T1 relaxation time at 3T. Sasaki et al. [12] commented that delayed magnetization recovery due to longer T1 relaxation time reduces contrast between GM and WM on SE T1-weighted imaging at 3T. Ross [13] indicated in an editorial that quality of SE T1-weighted imaging is degraded by longer T1 relaxation time and chemical shift. Conversely, Lu et al. [14] recently published data

showing CNR_{GM-WM} increased by 20.7% on SE T1-weighted imaging at 3T compared with CNR_{GM-WM} at 1.5T by optimizing imaging parameters for each magnet. In addition, Schmitz et al. [15] demonstrated that SE T1-weighted imaging could display better CNR at 3T by adjusting flip angles.

To the best of our knowledge, no comparison studies featuring CNR_{GM-WM} of SE T1-weighted sequences with the same imaging parameters between 3T and 1.5T have been reported. Differences in CNR_{GM-WM} between single- and multi-slice SE T1-weighted sequences have also not been well studied between 3T and 1.5T.

The present study quantitatively examined differences in CNR_{GM-WM} for both single- and multi-slice SE T1-weighted images using the same imaging parameters between 3T and 1.5T.

Materials and methods

Subjects

Subjects comprised 10 healthy volunteers (7 males, 3 females, range 25 - 36 years, average 29 years). All subjects were neurologically examined by a neurologist (T. H.), and were considered neurologically healthy. The local ethical committee approved the study protocols and all subjects provided written informed consent before entering

the study.

Imaging Protocols

All subjects underwent both 3T and 1.5T imaging on the same day in random order, using a 3T MR scanner (Magnetom Trio, Siemens, Erlangen, Germany), and a 1.5T MR scanner (Magnetom Symphony, Siemens, Erlangen, Germany). The interval between imagings was <30 min. The body coil was not standard equipment at 3T, therefore, the head coil was used as a transmission coil. The standard setup of body coil transmission was used at 1.5T. The image center was shared between both MR units by posting markers on the face of each subject. A circular polarized head coil was used and the head was firmly fixed using foam pads. Subjects were instructed not to move during MR imaging. Imaging slices were positioned parallel to the anterior commissure-posterior commissure line at the level of the basal ganglia.

Imaging Parameters

SE T1-weighted sequence that was routinely used at 1.5T was applied for both 3T and 1.5T imaging: TR, 600 ms; echo time (TE), 20 ms; slice thickness, 5 mm; number of averages,1; matrix, 256 × 256; flip angle, 90°; bandwidth, 90 Hz; scan time,

2 min 38 s. Within each subject, this sequence was repeated with the image center fixed for the single slice, multi-slice with 0% gap (gapless) and multi-slice with 25% interslice gap (1.25-mm interslice gap) (Fig. 1). The number of multi-slice images was set as 7 due to high systemic absorption rate (SAR) at 3T.

Analysis of regions of interest

GM and WM of frontal lobes and background were selected as regions of interest (ROI) on the center slice of each SE T1-weighted image (Fig. 2). In each subject, the same ROIs were applied for all images. $CNR_{GM\text{-}WM}$ was defined as the difference between intensities of GM and WM divided by the standard deviation of the background [16]. ROIs were drawn using ImageJ software (National Institutes of Health, Bethesda, MD, USA).

Statistical analysis

Two-sided paired t-test was applied using JMP 5.1 (SAS Institute Inc., North Carolina, USA). Values of $p<0.05$ were considered statistically different.

Results

Single-slice CNR_{GM-WM} was significantly higher at 3T (17.66 ±2.68) than at 1.5T (13.09 ±2.35) ($p<0.001$) (Fig. 3). A 1.37 ±0.23-fold gain in CNR_{GM-WM} was seen for single slice at 3T compared with 1.5T.

No significant difference in multi-slice CNR_{GM-WM} was noted with 0% gap (3T: 8.61 ±2.55; 1.5T: 7.43 ±1.20; $p>0.05$) between 3T and 1.5T. Multi-slice CNR_{GM-WM} with 25% gap was higher at 3T (12.47 ±3.31) than at 1.5T (9.73 ±1.37; $p<0.001$) (Fig. 3).

CNR_{GM-WM} reduction rate for multi-slice with 0% gap from single-slice was higher at 3T (0.47 ±0.13) than at 1.5T (0.38 ±0.09; $p=0.02$) (Fig. 4). No significant difference in CNR_{GM-WM} reduction rate was seen for multi-slice with 25% gap from single slice (3T: 0.29 ±0.16; 1.5T: 0.28 ±0.10; $p>0.05$) between 3T and 1.5T (Fig. 4).

Discussion

Single-slice SE T1-weighted imaging produced better CNR_{GM-WM} at 3T than at 1.5T in this study. Under the same imaging parameters for both magnetic fields, CNR_{GM-WM} increased 1.37 ±0.23-fold at 3T compared at 1.5T. Lu et al. [14] reported a 20.7% increase in CNR_{GM-WM} on SE T1-weighted imaging at 3T compared with at 1.5T in 5 volunteers, however, imaging parameters for SE T1-weighted imaging were

optimized for each magnet in their study. In this study, the same imaging parameters were applied for SE T1-weighted imaging at both 3T and 1.5T, and better CNR_{GM-WM} was seen at 3T compared with at 1.5T. To the best of our knowledge, this is the first comparison study featuring differences in CNR_{GM-WM} on SE T1-weighted imaging using the same imaging parameters between 3T and 1.5T.

CNR_{GM-WM} was decreased in multi-slice imaging with 0% gap for both magnetic fields when compared to single-slice imaging, and a larger CNR_{GM-WM} reduction rate for multi-slices with 0% gap from single slice was observed at 3T than at 1.5T. This might be due to crosstalk effect and/or magnetization transfer (MT) effect, both of which may reduce CNR with multi-slice imaging [17]. MT effect is reportedly higher at 3T than at 1.5T [18, 19], partially supporting our results.

In this study, both multi-slice and gapless imaging exacerbated CNR_{GM-WM} on SE T1-weighted sequences and the degree of CNR_{GM-WM} reduction was larger at 3T than at 1.5T. Attention must therefore be paid to the interslice gap in applying SE T1-weighted sequences at 3T. The best CNR_{GM-WM} at 3T was obtained using single-slice imaging in this study, which of course will not likely be applicable in routine practice. However, radiologists need to know that CNR_{GM-WM} on SE T1-weighted sequences is better at 3T than at 1.5T without the influences of multi-slice imaging. 3D gradient

sequences such as magnetization prepared rapid acquisition with gradient echo (MPRAGE) or fast spoiled gradient echo (FSPGR) sequences are often used as substitutes for SE T1-weighted sequences at 3T [10, 12], but SE T1-weighted imaging may be applicable at 3T if sufficient interslice gap is applied and if SAR issue is cleared.

Relatively lower contrast between GM and WM at 3T has been reported by various authors [10-13], but these reports have mainly been based on visual assessment. In the present study, differences in $CNR_{GM\text{-}WM}$ on SE T1-weighted imaging between at 1.5T and 3T were quantitatively evaluated for the first time. Since the intensity of the center part of images on SE T1-weighted sequences at 3T is higher than the peripheral parts, probably due to B1 homogeniety [20, 21], display window-width might be set wider so that the center of images may not be whited-out, which might prevent radiologists from noticing the true contrast between GM and WM at 3T. Schmitz et al. [15] revealed that SE T1-weighted imaging with lower flip angles contribute to better CNR at 3T probably because of more uniform signal intensity distribution. They achieved SE T1-weighted imaging with lower SAR at 3T by decreasing flip angles. They also commented that there might be other factors which decrease CNR, such as magnetization transfer or shielding effects [15]. Lu et al. [14] reported that TR had a

more influence on CNR_{GM-WM} of SE T1-weighted images at 3T than TE. They optimized SE T1-weighted images at 3T by plotting CNR of T1-weighted images with various TR and TE, which showed better CNR_{GM-WM} than that at 1.5T [14].

The present study displays some limitations. Identical imaging parameters were applied for 3T SE T1-weighted sequence as 1.5T, which is routinely used in clinical practice, and a whole brain was not covered and total imaging slices were limited to match SAR limitations at 3T. Future studies need to optimize SE T1-weighted sequences at 3T to obtain more imaging slices with suitable CNR_{GM-WM}, so that SE T1-weighted sequences can be routinely used at 3T. According to the result of the present study, a 2 package of interleaved SE T1-weighted imaging with 100% interslice gap which will cover the whole brain might show better CNR_{GM-WM} at 3T. In clinical practices, SE T1-weighted imaging with reduced interslice gaps or with lower flip angles might show better CNR_{GM-WM} at 3T, however, further investigation should be done in future studies.

One possible reason for the differences in CNR_{GM-WM} on SE T1-weighted imaging between at 1.5T and 3T is that a body coil was used for transmitting at 1.5T, whereas at 3T a head coil was used, which is known to have poorer transmission efficiency and B1 homogeneity than a body coil.

In conclusion, $CNR_{GM\text{-}WM}$ on single-slice SE T1-weighted imaging and $CNR_{GM\text{-}WM}$ on multi-slice imaging with 25% interslice gap are better at 3T than at 1.5T. The influence of multi-slice imaging on $CNR_{GM\text{-}WM}$ is significantly larger at 3T than at 1.5T.

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Figure legends

Figure 1

SE T1-weighted imaging at 3T (upper row) and 1.5T (lower row). From left to right, total imaging slices are 1 (single slice), multi-slices with 0% interslice gap and multi-slices with 25% interslice gap. Contrast between GM and WM at 3T and 1.5T is more conspicuous in a single slice than in multi-slices. Contrast between GM and WM of a single slice is obviously better at 3T than at 1.5T. Contrast between GM and WM for multi-slices with 25% interslice gap is better at 3T than at 1.5T.

Figure 2

A representative image of ROI on SE T1-weighted image. GM and WM of frontal lobes are selected as ROI.

Figure 3

CNR_{GM-WM} for single slice, multi-slice with 0% gap and multi-slice with 25% gap at 3T (dark gray bar) and 1.5T (light gray bar). Error bars represent standard deviation. Single-slice CNR_{GM-WM} was higher at 3T (17.66 ±2.68) than at 1.5T (13.09 ±2.35; $p<0.001$). Multi-slice CNR_{GM-WM} with 25% gap is higher at 3T (12.47 ±3.31) than at

1.5T (9.73 ±1.37; $p<0.001$). No significant difference in multi-slice CNR_{GM-WM} with 0% gap is noted between 3T and 1.5T (3T: 8.61 ±2.55; 1.5T: 7.43 ±1.20; $p>0.05$).

Figure 4

CNR_{GM-WM} reduction rate for multi-slice imaging with 0% gap from single-slice imaging at 3T (dark gray bar) and 1.5T (light gray bar). Error bars represent standard deviation. CNR_{GM-WM} reduction rate is significantly larger at 3T (0.47 ±0.13) than at 1.5T (0.38 ±0.09; $p=0.02$). CNR_{GM-WM} reduction rates for multi-slices with 25% gap from single-slice imaging at 3T (dark gray bar) and 1.5T (light gray bar) are shown. No significant difference in CNR_{GM-WM} reduction rate is noted (3T: 0.29 ±0.16; 1.5T: 0.28 ±0.10; $p>0.05$.

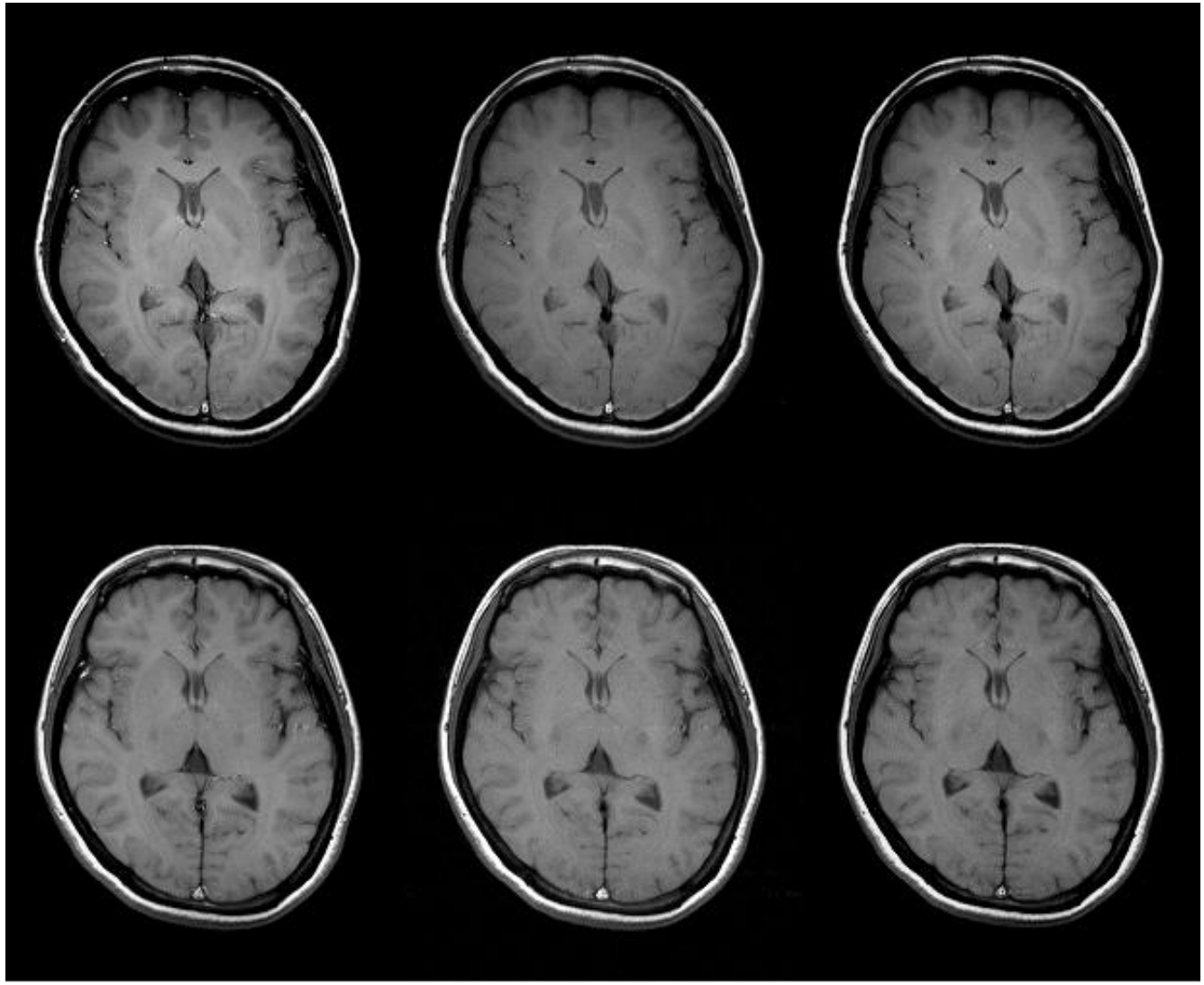
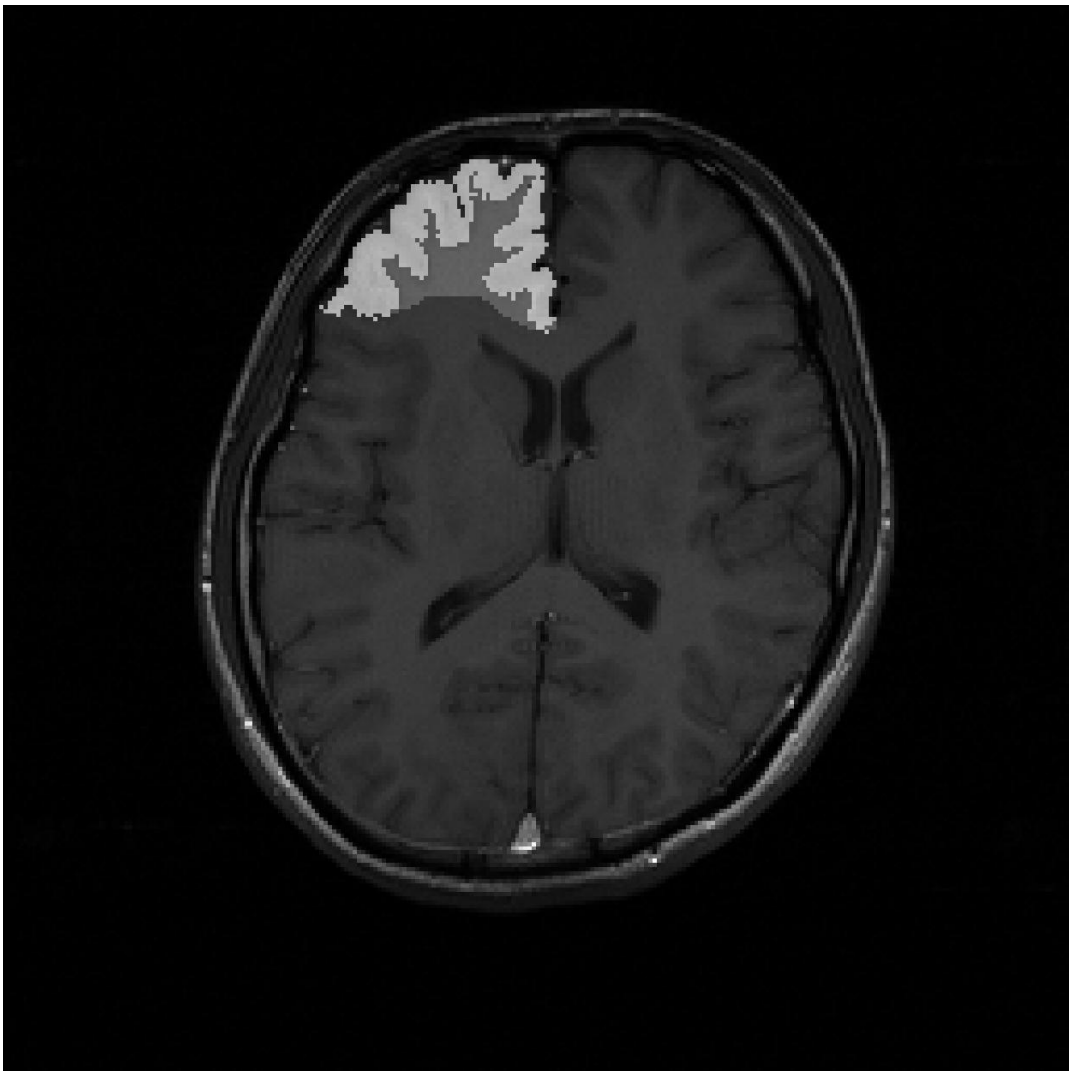


Figure 1



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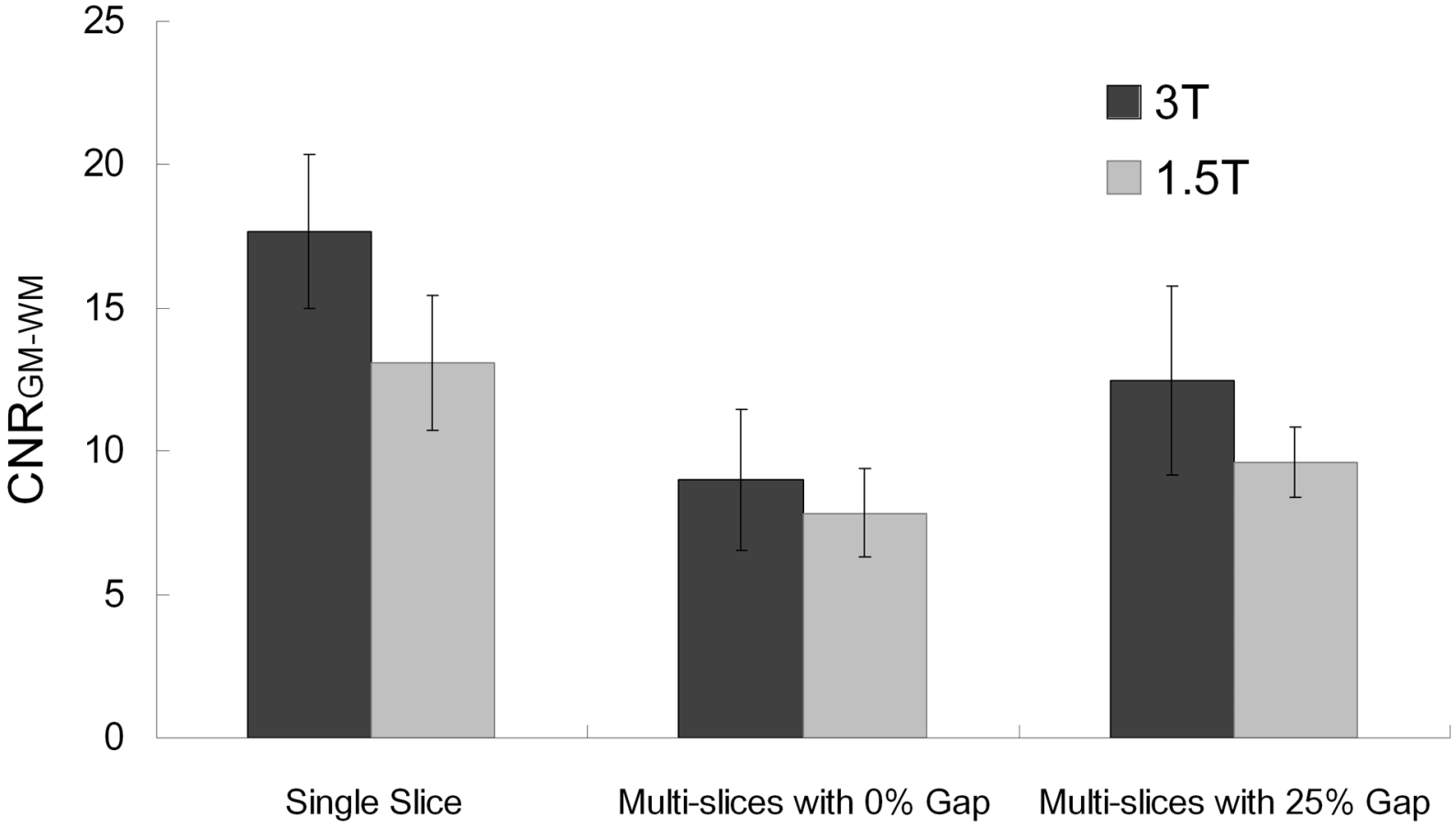
25
20
15
10
5
0
CNRGM-WM
3T
1.5T
Single Slice
Multi-slices with 0% Gap
Multi-slices with 25% Gap

Figure 3

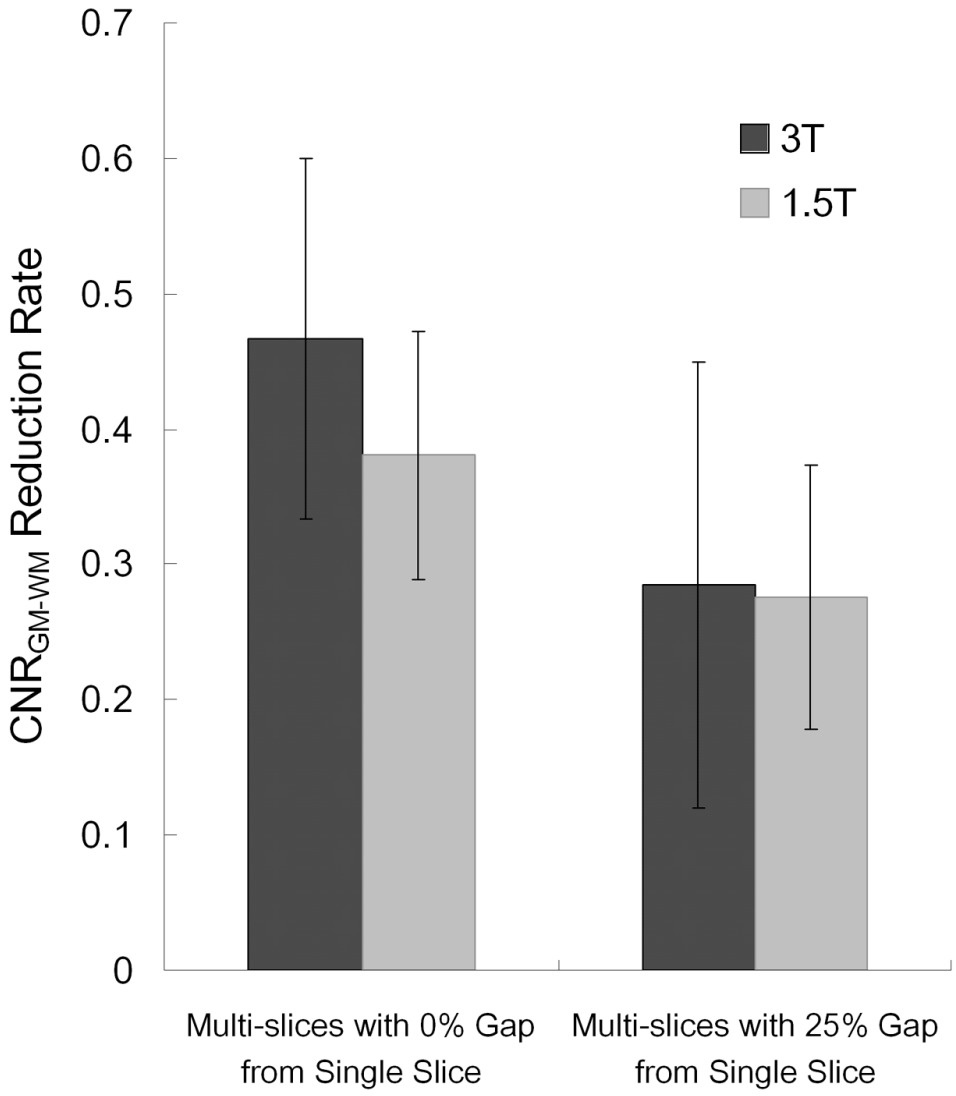
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CNR GM-WM Reduction Rate
3T
1.5T
Multi-slices with 0% Gap from Single Slice
Multi-slices with 25% Gap from Single Slice

Figure 4