Evaluation of T1-weighted MRI Methods for Clinical Brain Imaging at 3.0 Tesla

C. Lin[1], A. Kalnin[1], K. Mosier[1], A. Johnson[2], L. Friggle[3], and A. Flammang[4]

[1]Department of Radiology, Indiana University School of Medicine, Indianapolis, IN, United States, [2]Department of Radiology, Wake Forest University School of Medicine, Winston Salem, NC, United States, [3]Department of Radiology, Clarian Health Partners, Indianapolis, IN, United States, [4]Siemens Medical Solutions USA, Inc., Malvern, PA, United States

Introduction

Magnetic resonance imaging (MRI) with T1-weighted (T1w) contrast provides important information for clinical diagnosis. Because of longer T1 relaxation times and higher specific absorption rates (SAR), it becomes difficult to produce images with desired T1 contrast with the conventional SE method at 3T [1]. Several competing methods have been introduced to circumvent this problem [2-6]. Although these methods have been used in routine clinical imaging, to our knowledge, a consistent comparison of all of them on the same subjects has not been made.

The purpose of this prospective study is to compare the image quality and tissue contrast characteristics of five T1-weighted imaging methods at 3T and thus provide the basis for optimal selection of methods and protocols for non-contrast enhanced clinical brain imaging at 3.0T as well as for selecting candidates for follow-up studies of lesion enhancement.

Methods

Following IRB approval, eleven healthy volunteers (6M/5F, age 25-52) were scanned with 2D conventional SE of 60^{o} excitation flip angle (SE 60) [2], 2D T1 FLAIR [3], 2D and 3D spoiled fast gradient echo (2D FLASH and 3D FLASH) [4-5] as well as 3D MP-RAGE [6] in a single session on a 3.0T scanner (Siemens TIM Trio) using a 12 channel head coil. For 2D methods, axial slices of 4mm thick, 1mm gap, 256mm FOV and 81.3% Phase FOV were acquired with 1mm in plane resolution in both directions. For 3D methods, axial slices of the same thickness and resolution were generated by reformatting 3D data set of 1mm isotropic resolution. A medium receiver bandwidth (rBW) of 250Hz/pixel was used in all methods to keep the chemical shift artifact the same. For SE 60, TR/TE = 700/8.5. For T1 FLAIR, TR/TE/TI/ETL = 2100/9.5/900/3 and the flip angle (FA) for the refocusing RF pulse was 150^{o} to reduce the SAR. For 2D FLASH, TR/TE/FA = 255/3.16/70^{o}. For 3D FLASH, TR/TE/FA =14/3.16/25^{o}. For MP-RAGE, TR/TE/TI/FA = 2250/1.86/1100/12^{o}. Low SAR RF pulses were used to minimize the SAR for SE 60 and T1 FLAIR. In some 2D methods, additional average or phase over-sampling was applied to match the scan time. For 3D methods, parallel imaging with acceleration factor of 2 was applied to achieve similar scan time of 2D methods so that all scan times are between 4:51 and 4:58.

The SNR and CNR of caudate nucleus (CN), cortical gray matter (GM) and white matter (WM) were measured based on the mean signal intensities in the corresponding ROIs and the standard deviation of noise in the background region. The images were also blindly reviewed and scored for perceived SNR (p SNR), perceived contrast between GM and WM (p G/W), definition of GM and WM boundary (G/W Def), distinction of fatty tissues from non-fatty soft tissues (Fat Def), artifacts and overall image quality (IQ) by three neuro-radiologists on 7-point Likert scales of 1(poor) to 7(excellent).

Results

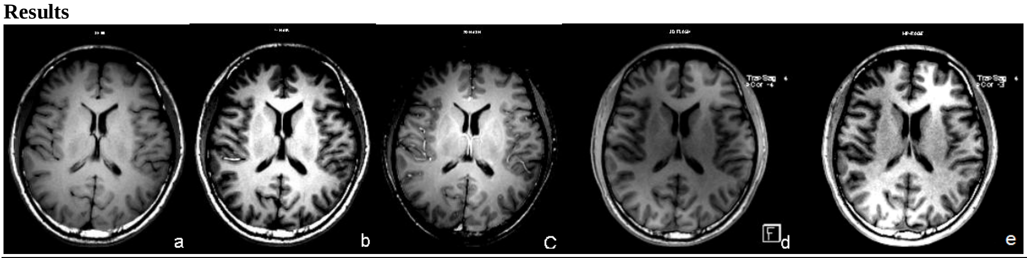

Figure 1 (left). Images acquired with a) SE 60, b) T1 FLAIR, c) 2D FLASH, d) 3D FLASH and e) MP-RAGE methods from one of the subjects.

Table 1 (below). Average measured SNR, CNR and median image quality scores from the blinded review by three neuro-radiologists.

	CN SNR	GM SNR	WM SNR	C/W CNR	G/W CNR	p SNR	p G/W	G/W Def	Fat Def	Artifacts	Overall IQ
SE 60	150±15	109±14	140±15	10±5	31±11	5.0	4.0	4.0	**7.0**	4.0	4.0
T1 FLAIR	113±12	75±12	124±13	11±4	**49±4**	**7.0**	**7.0**	**6.0**	**7.0**	**5.0**	**6.0**
2D FLASH	**338±32**	**282±33**	**323±33**	15±7	41±21	6.0	4.0	6.0	2.0	4.0	4.0
3D FLASH	91±4	94±10	128±10	**37±7**	34±5	5.0	6.0	4.0	6.5	4.5	5.0
MP-RAGE	71±5	70±9	96±7	24±5	26±6	2.0	6.0	5.0	**7.0**	**5.0**	5.0

Fig. 1 shows the typical T1w images acquired with five different methods. The average of measured SNR and CNR are listed in table 1 as well as the median scores by radiologists. Quantitative measurement shows 2D FLASH has the highest SNR and, while 3D FLASH provides the highest CNR for CN/WM (ANOVA, $p<0.001$), T1 FLAIR offers the highest CNR for GM/WM (ANOVA, $p<0.001$). T1 FLAIR was also rated the best for the overall image quality with equal weighting in each category (Kruskal-Wallis Test, $p<0.005$).

Discussion

Optimizing the protocols while maintaining consistency to allow reasonable comparisons among sequences was challenging. The gradient echo based methods would benefit from higher rBW and smaller voxels to compensate for susceptibility effects and fat/water dephasing. The high SNR of 2D FLASH can potentially be traded off to improve other aspects of image quality. The perceived limitations in contrast between GM and WM with 2D FLASH were a substantial contributor to its overall poor neuro-radiologist rating. 3D acquisition with isotropic resolution provides the possibility of reconstructing images in any orientation. This could be an important advantage in clinical imaging, but it is not reflected in the image quality measurement or scoring, with particularly poor perceived SNR with 3D techniques. The type of artifacts varys among the methods and will be subject to further analysis.

T1 FLAIR was rated the best among the five methods for image quality. However, the anatomical coverage with T1 FLAIR is limited by the inherently high SAR. For 3 out of 11 subjects, the number of slices with T1 FLAIR was limited to less than 20 which did not allow for whole brain coverage in one acquisition with the given TR. Further reduction of RF deposition would be helpful to make this method more practical.

References

1. DeLano MC, Fisher C. 3T MR imaging of the brain. Magn Reson Imaging Clin N Am. 2006 Feb;14(1):77-88
2. Schmitz BL, Grön G, Brausewetter F, Hoffmann MH, Aschoff AJ. Enhancing gray-to-white matter contrast in 3T T1 spin-echo brain scans by optimizing flip angle. AJNR Am J Neuroradiol. 2005 Sep;26(8):2000-4
3. Stehling C, Niederstadt T, Krämer S, Kugel H, Schwindt W, Heindel W, Bachmann R. Comparison of a T1-weighted inversion-recovery-, gradient-echo- and spin-echo sequence for imaging of the brain at 3.0 Tesla. Rofo. 2005 Apr;177(4):536-42
4. Runge VM, Patel MC, Baumann SS, Simonetta AB, Ponzo JA, Lesley WS, Calderwood GW, Naul LG. T1-weighted imaging of the brain at 3 tesla using a 2-dimensional spoiled gradient echo technique. Invest Radiol. 2006 Feb;41(2):68-75
5. Yamashita E, Iwata N, Kinoshita T, Ogawa T, Hirata Y. Evaluation of three-dimensional fast spoiled gradient recalled acquisition in the steady state (FSPGR) using ultra magnetic field 3-Tesla MRI for optimal pulse sequences of T1-weighted imaging. Nippon Hoshasen Gijutsu Gakkai Zasshi. 2006 Feb 20;62(2):297-304
6. Lin C, Watson RE, Ward HA, Rydberg CH, Witte RJ, Bernstein MA. MP-RAGE compared to 3D IR-SPGR for Optimal T1 Contrast and Image Quality in the Brain at 3T. 14th Scientific Meeting of International Society for Magnetic Resonance in Medicine, Seattle, Washington, May 2006