Journal of Neurology (2019) 266:431–439
https://doi.org/10.1007/s00415-018-9149-4

ORIGINAL COMMUNICATION

Clinical feasibility of 1-min ultrafast brain MRI compared with routine brain MRI using synthetic MRI: a single center pilot study

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Received: 15 September 2018 / Revised: 3 December 2018 / Accepted: 4 December 2018 / Published online: 7 December 2018

Abstract

Background Ultrafast brain MRI is required for uncooperative patients and time-critical diseases such as stroke because it reduces scan times and motion artifacts. This study investigated the clinical feasibility of a 1-min ultrafast brain MRI protocol for detecting intracranial abnormalities in restless and uncooperative patients.

Methods We retrospectively reviewed the records of 25 patients who underwent a 1-min ultrafast MRI protocol using T1-weighted image, T2-weighted image, echo-planar fluid-attenuated inversion recovery, diffusion-weighted image, and T2*-weighted image between March 2017 and May 2017. Simple methods were applied for ultrafast MRI protocol to reduce scan time as follows: parallel imaging techniques, multiband technique on diffusion sequence, and echo-planar fluid-attenuated inversion recovery. The images were compared with the routine brain MRI protocol using synthetic MRI, and quality was assessed by two independent readers. The Wilcoxon signed-rank test was used to compare the readers' ratings of the routine MRI protocol and ultrafast MRI protocol images.

Results Using a four-point assessment scale, overall image quality and anatomical delineation of ultrafast brain MRI images were lower than those of routine brain MRI images. However, the ultrafast protocol demonstrated sufficient overall image quality and anatomical delineation with an assessment rating greater than two points. The ultrafast protocol had fewer artifacts than the routine protocol using synthetic MRI.

Conclusions Although the overall image quality and anatomical delineation of the 1-min ultrafast MRI were inferior to those of the routine brain MRI protocol, the ultrafast protocol showed at least sufficient image quality. Therefore, this protocol may be an option in specific clinical situations involving non-cooperative, restless, or pediatric patients, or patients with time-critical disease such as stroke. Further study is required to validate our findings.

Keywords Ultrafast MRI · Synthetic MRI · Fast imaging · Brain · Image quality

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Introduction

MRI is widely used in the assessment of intracranial pathologies because it provides a high sensitivity with excellent soft tissue contrast [1], and has the advantage of lack of radiation. However, because of the relatively long scan time of brain MRI, it is limited in daily clinical practice for evaluating uncooperative patients, pediatric patients, and patients with time-critical diseases like stroke.

Recent advances in the design of head coils and imaging techniques such as parallel imaging, multiband imaging and synthetic MRI make it possible to shorten the imaging time while minimizing the reduction of the signal-to-noise ratio (SNR) [1–9]. Technically, parallel imaging works by acquiring a reduced amount of *k*-space data with an array of

receiver coils whereas multiband technique is a modification of regular pulse sequences in which RF pulses simultaneously excite multiple slices at the same time [2, 7, 10]. Recently, synthetic MRI has been introduced as a type of fast imaging, which can reduce the speed of brain MRI and rate of rescanning. Synthetic MRI is based on a quantitative approach to the absolute physical properties including longitudinal T1-relaxation time, transverse T2-relaxation time, and proton density, to produce multiple contrasts from a single scan. Quantification of T1 and T2 values and proton density can be used to calculate the signal intensity of a pixel by virtually setting any combination of echo time, repetition time, and inversion time to create T1-weighted image (T1WI), T2-weighted image (T2WI), and fluid-attenuated inversion recovery (FLAIR) [3, 8, 9]. These technical advances of MRI enable fast imaging with reduced motion-related artifacts and improved image quality, and a decreased need for sedation [2].

In previous studies, fast MR protocols, with scan times ranging from 3 to 10 min, showed a practical feasibility for use with patients intolerant to the examination, recent stroke patients, and pediatric patients [11–15]. In our institution, we use synthetic MRI as a routine brain MRI protocol based on previous studies that proved that synthetic images were as acceptable in clinical practice as conventional MRI for detecting a range of brain pathologies [1, 5, 6]. In addition to this neuroimaging protocol, we compared the ultrafast MRI protocol with a 1-min scan time to an 8-min (routine) protocol in restless and uncooperative patients without sedation.

To the best of our knowledge, there has been no study of a 1-min ultrafast MRI protocol in motion-prone patients. Moreover, there have been no previous studies comparing the different type of fast MRI protocols. We hypothesized that the ultrafast protocol would have sufficient image quality to interpret in the clinical setting and have fewer artifacts compared to those in synthetic MR images, and that it could be a useful option for evaluating patients intolerant to MRI or with time-critical diseases. Therefore, the purpose of this study was to evaluate the image quality and clinical feasibility of the 1-min ultrafast MRI protocol, compared with our routine MR protocol using synthetic MRI.

Methods

Patients

A review of the database of our institution identified 25 consecutive patients who underwent diagnostic brain MRI including ultrafast and routine protocols with 5 basic sequences in a single examination session from March 2017 to May 2017. These two sets of MR protocols were acquired for the clinical evaluation of motion-prone patients. The included patients were comprised of 15 men and 10 women (age range, 11–83 years; mean age, 56 years). The reasons for the MRI examinations were headache (9/25, 36%), dizziness or vertigo (6/25, 24%), syncope (2/25, 8%), parkinsonism (3/25, 12%), weakness of the extremity (1/25, 4%), sensory change (1/25, 4%), hemianopsia (1/25, 4%), brain metastasis work-up (1/25, 4%), and memory impairment (1/25, 4%).

Retrospective data collection and analysis were performed according to our institutional review board guidelines. The institutional review board approved the study and determined that patient approval and informed consent were not required for reviewing images and records.

Imaging acquisition

MR imaging was performed using a 3T system (Signa™ Architect; GE Healthcare, Milwaukee, Wisconsin) with a 48-channel head coil. Both ultrafast and routine MRI protocols included axial T1WI, axial T2WI, axial FLAIR, diffusion-weighted image (DWI) and T2*-weighted images (T2*WI).

Routine imaging protocol

A T1, T2, and FLAIR images were acquired using multi-echo multi delay (MDME) sequence. The synthetic MRI generates images using given repetition time (TR), echo time (TE) and inversion time (TI) based on the fitted data such as T1, T2, and proton-density values of each voxel.

DWI and 3D multi-echo gradient echo sequence (susceptibility weighted angiography, SWAN) for T2*WI were also acquired. The net acquisition time was 8 min and 29 s and total scan time was 9 min 12 s. Technical details for routine MRI protocol are given in Table 1. For synthetic reconstruction, a MDME sequence was performed, using a TR 4000 ms, TE 16.8 ms and 92.4 ms, echo train length 16 ms, and bandwidth 35.71 kHz with scan time of 4 min 32 s. The MDME data were reconstructed outside the clinical care environment using MAGnetic resonance image Compilation (MAGiC) software on a 64-bit Advantage Workstation (GE Healthcare, Milwaukee, WI, USA). No errors were logged during processing, and the average processing time was approximately 2 min per case. Imaging parameters (TR, TE, and TI) for each contrast image were selected to provide similar visual image contrast to conventional images acquired at our institution. Synthetic T1WIs were generated with a TR of 2500 ms and TE of 10 ms. Synthetic T2WIs were generated with a TR of 6000 ms and TE of 110 ms. Synthetic FLAIR was generated with a TR of 10,000 ms, TE of 85 ms, and TI of 2400 ms.

Table 1 Routine MRI and ultrafast MRI acquisition parameters

Imaging parameter	Routine MRI			Ultrafast MRI				
	Synthetic MRI (MDME)	Routine DWI	SWAN	Ultrafast T1-weighted	Ultrafast T2-weighted	Ultrafast EPI-FLAIR	Ultrafast DWI	Ultrafast T2*-weighted
FOV (cm)	22	22	22	24	24	24	24	24
Phase FOV (mm)	19.36	22	19.8	0.75	1	0.9	0.9	1
Section thickness (mm)	5	5	2.4	5	5	5	5	5
TR (ms)	4000	5436	33.1	167.7	392.7	10,000	2511 (auto)	1600
TI (ms)	–					2200		
TE (ms)	16.8, 92.4	71.2	23.2	2.6	102	100	74.9	22.2
ETL (ms)	16							
Frequency matrix	320	128	288	260	320	128	128	128
Phase matrix	288	192	260	190	320	256	128	320
Flip angle (°)	90	90	15	60	90	90	90	25
Bandwidth (kHz)	35.71	250	41.67	31.25	83.33	250	250	250
Parallel imaging acceleration factor	ASSET/2	ASSET/2.5	ASSET/2	ARC/2	ASSET/3	ARC/2	ARC/2	ASSET/3
Net scan time (min:s)	4:32	1:27	2:30	0:15	0:08	0:25	0:13	0:06
Total scan time (min:s)	4:44	1:50	2:38	0:31	0:26	0:55	0:29	0:26

ARC autocalibrating reconstruction for Cartesian imaging, *ASSET* array spatial sensitivity encoding, *DWI* diffusion-weighted imaging, *EPI-FLAIR* echo-planar imaging-fluid-attenuated inversion recovery, *ETL* echo train length, *FOV* field of view, *MDME* multiple-dynamic multiple-echo, *SWAN* susceptibility weighted angiography, *TE* echo time, *TI* inversion time, *TR* repetition time

Ultrafast imaging protocol

The ultrafast MRI protocol included T1WI and T2WI using spoiled gradient recalled echo (SPGR), echo-planar fluid-attenuated inversion recovery (EPI-FLAIR), DWI, and T2*WI. The net acquisition time was 1 min and 7 s and total scan time was 2 min 47 s. We incorporated parallel imaging, such as the array spatial sensitivity encoding technique (ASSET) and autocalibrating reconstruction for Cartesian imaging (ARC) with higher acceleration factors, and the Hyperband technique with optimized acquisition parameters into the ultrafast protocol to reduce scan time on the diffusion sequence. Technical details for the ultrafast MRI sequences are given in Table 1. The decision to acquire the ultrafast protocol images during examination was made by the supervising technologist at the workstation. Indications for image acquisition using both brain MRI protocols were patients with altered mental status or restless appearance with high likelihood of movement during the scan.

Radiologic assessment

All data sets were anonymized with randomization, and two readers reviewed all images using the picture archiving and communication system, blinded to patient information, acquisition parameters and protocol assignments. Two attending neuroradiologists with 7 and 2 years of experience performed an independent analysis of all sequences of both brain MRI protocols to evaluate the image quality of ultrafast MRI from a clinical feasibility perspective. The ultrafast MRI and routine MRI were assessed separately with a random order to minimize bias because of the results of the other images. For the interpretation, each reader was provided the ultrafast MRI, and they analyzed all images twice with an interval of 2 weeks between each analysis. After a 4-week memory washout period, the readers were provided the routine MRI of the enrolled patients. They also analyzed all of these images twice, using the same interval as in the ultrafast MRI interpretation. After their independent analyses, the same neuroradiologists performed image analysis in consensus to resolve disagreements. The evaluation included assessments of overall image quality, visualization of several anatomic structures, and severity of motion artifact [1, 6]. For assessment of each of these categories, a four-point assessment scale was used [16]. The criteria that were assessed are described in detail in Table 2.

Statistical analysis

The image quality assessments were assigned numerical values. Although the mean values of the readers' ratings were not directly statistically compared because these values were not strictly continuous variables, we decided to present a summary of the readers' ratings for each MRI sequence, expressed as the mean ± standard deviation. The Wilcoxon signed-rank test was also used to compare the reader's

Table 2 Radiologic assessment

Sequences	Criteria assessed	Four-point assessment scale
Synthetic T1, T2, FLAIR, Ultrafast T1, T2, FLAIR	(1) Overall image quality (2) Differentiation of gray-white matter at the level of the lateral ventricles (3) Demarcation of basal ganglia (4) Demarcation of the sulci	(1) Inadequate (not acceptable for diagnostic use) (2) Sufficient (acceptable for diagnostic use but with minor issues) (3) Good (acceptable for diagnostic use) (4) Excellent (acceptable for diagnostic use)
	(5) Motion artifact	(1) Images contain severe artifacts (not acceptable for diagnostic use) (2) Images contain moderate artifacts (sufficient for diagnostic use with minor issues) (3) Images contain mild artifacts (acceptable for diagnostic use) (4) Images do not contain visible artifacts (acceptable for diagnostic use)
Routine DWI, Ultrafast DWI, SWAN, Ultrafast T2*	(1) Overall image quality	(1) Inadequate (2) Sufficient (3) Good (4) Excellent
	(2) Susceptibility artifact (3) Motion artifact	(1) Images contain severe artifacts (2) Images contain moderate artifacts (3) Images contain mild artifacts (4) Images do not contain visible artifacts

DWI diffusion-weighted imaging, *FLAIR* fluid-attenuated inversion recovery, *SWAN* susceptibility weighted angiography, *T1* T1-weighted image, *T2* T2-weighted image, *T2** T2*weighted image

consensus ratings of routine and ultrafast MRI protocols. Interobserver reliability between two readers was calculated as percent agreement. All statistical analyses were performed with statistical software (SPSS, version 24.0; IBM Corp., Armonk, NY, USA), and *P* values less than 0.05 were considered statistically significant.

Results

Study population

Of 25 patients, 12 (48%) had abnormal MRI findings and 13 (52%) had findings that were considered normal. The range of diagnoses was as follows: focal encephalomalacia (6/25, 24%), acute or subacute infarction (2/25, 8%), subdural hygroma (2/25, 8%), small vessel disease (1/25, 4%), and cortical dysplasia (1/25, 4%).

Image quality assessment

A representative example of both brain MRI protocol images is shown in Fig. 1. Each of the 2 attending neuroradiologists reviewed all 25 acquired image sets of the 2 different MRI protocols and had no difficulty in detecting intracranial abnormalities. Table 3 displays the mean assessment score for each category and reader, and the interobserver percent agreement. For the imaging review of both protocols, the interobserver percent agreement ranged from 60 to 100% in all items, except for gray matter–white matter differentiation on the ultrafast EPI-FLAIR. The items regarding the ultrafast T2WI demonstrated good-to-excellent results by both readers. On synthetic FLAIR images of the routine protocol, there was a distinct and granulated hyperintensity along the CSF boundaries to a different degree and extent in each patient, resulting in a decrease in overall image quality. However, the readers easily distinguished this characteristic synthetic FLAIR artifact from pathologic conditions without any significant effect on decision-making.

Table 3 displays the results showing a comparison of the readers' consensus ratings of routine and ultrafast MRI protocols for the five commonly used sequences, including T1WI, T2WI, FLAIR, DWI, and T2*WI or SWAN. Although the overall image quality and several anatomic delineations on all sequences of the ultrafast protocol were significantly lower than those of the routine protocol using synthetic MRI, they showed sufficient-to-excellent overall image quality and anatomic delineation with a greater-than-two-point average assessment rating (Figs. 2, 3). The motion artifact of ultrafast T1WI, T2WI, and FLAIR was none-to-mild; the ultrafast protocol had a tendency to reveal less motion artifact than synthetic sequences.

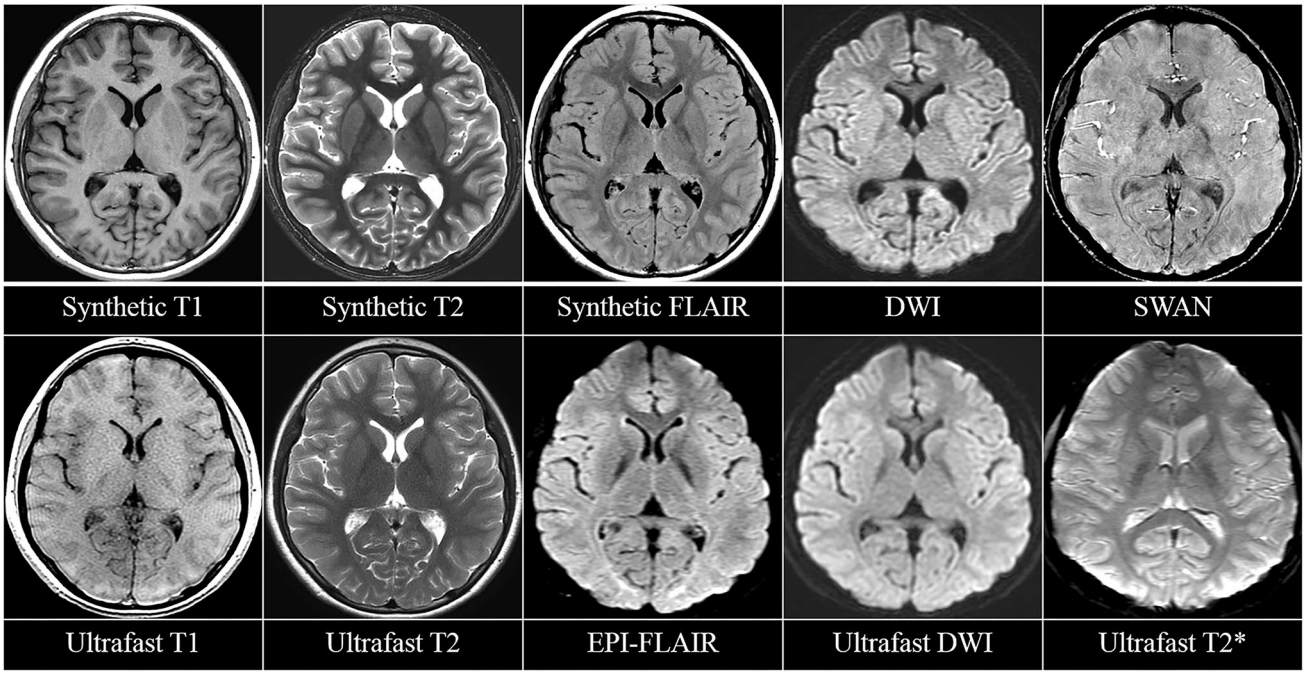

Fig. 1 Axial ultrafast and routine MRI of a normal brain. Ultrafast (lower row) image sets exhibit comparable legibility and quality to the routine (upper row) image sets. *EPI-FLAIR* echo-planar fluid-attenuated inversion recovery, *FLAIR* axial fluid-attenuated inversion recovery, *SWAN* susceptibility weighted angiography

Discussion

To the best of our knowledge, this is the first study that compares an ultrafast MRI protocol, which takes about 1 min, with a synthetic MRI protocol. In the current study, we found that the ultrafast protocol had a possibility as a viable option for the clinical use in patients who cannot tolerate long scan times or those with time-critical diseases because the ultrafast protocol produced at least sufficient overall image quality and conspicuity of anatomical details for clinical use.

Previous clinical study of fast brain MRI protocols also showed comparable image quality and high diagnostic concordance to conventional MRI [11]. However, the ultrafast MRI protocol of previous studies had a broad diversity of scan times, ranging from 3 to 10 min, which was much longer than our 1-min ultrafast MRI protocol [11, 13, 14]. In the present study, the ultrafast protocol included all of the five essential MRI sequences, similar to the previous studies [11, 13, 14], and we revealed the possibility of clinical application of 1-min ultrafast MRI protocol in motion-prone patients. In terms of short scan times with sufficient image quality for diagnostic use, the contributing elements of the ultrafast protocols in this study were the 48-channel head coil, parallel imaging techniques with appropriate acceleration factors, multiband technique on diffusion sequence, using EPI for the FLAIR image and acquisitions with optimized parameters. The 48-channel head coil allowed the use of more parallel imaging factors and compressed sensing techniques with less signal loss to maintain comparable image quality during the ultrafast protocol. The parallel imaging techniques such as ASSET and ARC, which obtain reconstructed images from undersampled raw data using multichannel coils. These parallel imaging can reduce scan time by the acceleration factor, however, the SNR decreases when the acceleration factor increases. In this study, we adjusted the acceleration factors to maximize reduction of scan time while minimizing SNR loss for the individual sequences of the ultrafast protocol when applying the parallel imaging technique as described in Table 1. In addition, HyperBand technique as a multiband technique enabled the acquisition of more slices or diffusion directions within a typical scan, allowing a significant reduction of scan time to obtain DWI with combined EPI. Therefore, the ultrafast protocol had a tendency to have less motion artifact than the routine protocol using synthetic MRI. The ultrafast protocol has also the advantage of less motion artifact because patient motion during examination affects only one sequence, whereas synthetic MRI can be affected by patient motion through all the derived sequences.

In a recent study, Skare et al. introduced a 1-min multicontrast EPI sequence (EPImix) that varying the magnetization and pushing EPI, which provides a very fast acquisition that is robust against motion [17]. The greatest benefit

Table 3 Assessment of synthetic an ultrafast MR image using a four-point assessment scale and comparison of ultrafast MRI with synthetic MRI

	Synthetic MRI				Ultrafast MRI				*P* value
	R1 (mean ± SD)	R2 (mean ± SD)	Mean value of two readers (mean ± SD)	Agreement (%)	R1 (mean ± SD)	R2 (mean ± SD)	Mean value of two readers (mean ± SD)	Agreement (%)	
T1									
STN	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	2.2 ± 0.4	2.1 ± 0.3	2.1 ± 0.3	20/25 (80)	< 0.001
GM–WM	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	2.5 ± 0.5	2.0 ± 0.2	2.3 ± 0.4	13/25 (52)	< 0.001
BG	3.9 ± 0.4	3.9 ± 0.3	3.9 ± 0.4	23/25 (92)	2.0 ± 0.2	2.0 ± 0.2	3.0 ± 0.2	24/25 (96)	< 0.001
Sulci	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	3.8 ± 0.4	3.6 ± 0.5	3.7 ± 0.5	20/25 (80)	< 0.001
Motion	3.6 ± 0.5	3.3 ± 0.5	3.5 ± 0.5	17/25 (68)	3.4 ± 0.5	3.1 ± 0.3	3.3 ± 0.4	15/25 (60)	0.004
T2									
STN	4.0 ± 0.2	4.0 ± 0.0	4.0 ± 0.1	24/25 (96)	3.4 ± 0.4	3.1 ± 0.3	3.2 ± 0.4	19/25 (76)	< 0.001
GM–WM	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	3.4 ± 0.5	3.1 ± 0.4	3.3 ± 0.5	17/25 (68)	< 0.001
BG	3.6 ± 0.6	4.0 ± 0.0	3.8 ± 0.5	16/25 (64)	3.0 ± 0.6	3.2 ± 0.6	3.1 ± 0.6	16/25 (64)	< 0.001
Sulci	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	1.00
Motion	3.6 ± 0.5	3.3 ± 0.5	3.4 ± 0.5	17/25 (68)	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	< 0.001
FLAIR									
STN	3.7 ± 0.6	3.6 ± 0.5	3.6 ± 0.5	14/25 (56)	2.5 ± 0.5	2.2 ± 0.4	2.4 ± 0.5	15/25 (60)	< 0.001
GM–WM	3.6 ± 0.6	3.7 ± 0.5	3.7 ± 0.5	22/25 (88)	2.9 ± 0.3	2.0 ± 0.2	2.5 ± 0.5	4/25 (16)	< 0.001
BG	3.6 ± 0.8	4.0 ± 0.0	3.8 ± 0.6	19/25 (76)	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	0.023
Sulci	4.0 ± 0.0	3.9 ± 0.3	4.0 ± 0.2	23/25 (92)	3.6 ± 0.5	3.3 ± 0.5	3.5 ± 0.5	17/25 (68)	< 0.001
Motion	3.5 ± 0.5	3.0 ± 0.2	3.3 ± 0.4	13/25 (52)	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	< 0.001
DWI									
STN	4.0 ± 0.0	4.0 ± 0.2	4.0 ± 0.1	24/25 (96)	3.6 ± 0.5	3.8 ± 0.4	3.7 ± 0.5	16/25 (64)	< 0.001
Susceptibility	3.0 ± 0.0	2.9 ± 0.3	3.0 ± 0.2	23/25 (92)	2.9 ± 0.3	2.9 ± 0.3	2.9 ± 0.3	25/25 (100)	0.157
Motion	3.9 ± 0.4	3.9 ± 0.3	3.9 ± 0.4	23/25 (92)	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	0.158
SWAN, Ultrafast T2*									
STN	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	3.0 ± 0.2	3.0 ± 0.0	3.0 ± 0.1	24/25 (96)	< 0.001
Susceptibility	3.2 ± 0.5	3.1 ± 0.4	3.0 ± 0.0	22/25 (88)	3.0 ± 0.0	2.9 ± 0.3	2.9 ± 0.3	23/25 (92)	0.257
Motion	3.9 ± 0.4	3.9 ± 0.3	3.9 ± 0.3	23/25 (92)	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	25/25 (100)	0.264

Agreement percent agreement (%), *BG* demarcation of the basal ganglia, *DWI* diffusion-weighted image, *FLAIR* fluid-attenuated inversion recovery, *GM–WM* differentiation of gray matter–white matter, *Motion* motion artifact, *R1* reader 1, *R2* reader 2, *SD* standard deviation, *STN* signal-to-noise ratio, *Sulci* demarcation of the sulci, *Susceptibility* susceptibility artifact, *SWAN* 3D multi-echo gradient echo sequence, *T1* T1-weighted image, *T2* T2-weighted image, *T2** T2*-weighted image

of multicontrast EPI is that the time between contrasts is removed, so the sequences only need a single prescan at the start of the MRI examination. From this advantage, the total scan time of EPImix is shorter than that of our ultrafast protocol. However, overall quality of T2WI from EPImix is relatively inferior than those of other image contrasts because a T2WI is essentially a $b = 0$ image. In addition, EPImix has a well-known limitation regarding an unavoidable susceptibility artifact in all sequences that it is not suitable for patients undergoing stereotactic surgery or radiation therapy etc. [17]. For the clinical perspective, EPImix is difficult to apply because it is a non-commercialized sequence under technical development. In contrast to EPImix, we used simple methods with the optimized commercialized sequences to reduce scan time for our 1-min ultrafast MRI, such as parallel imaging and multiband technique, which can be applied to different MR machines.

In this study, overall image quality and conspicuity of anatomical details were acceptable for diagnostic use with a greater-than-two-point assessment rating on all sequences of the ultrafast protocol. Notably, ultrafast T2WI showed good-to-excellent image quality with a greater-than-three-point assessment rating. However, the ratings of most items for the ultrafast protocol were significantly lower than those of the routine protocol using synthetic MRI. For the ultrafast protocol, the overall image quality is inevitably degraded even

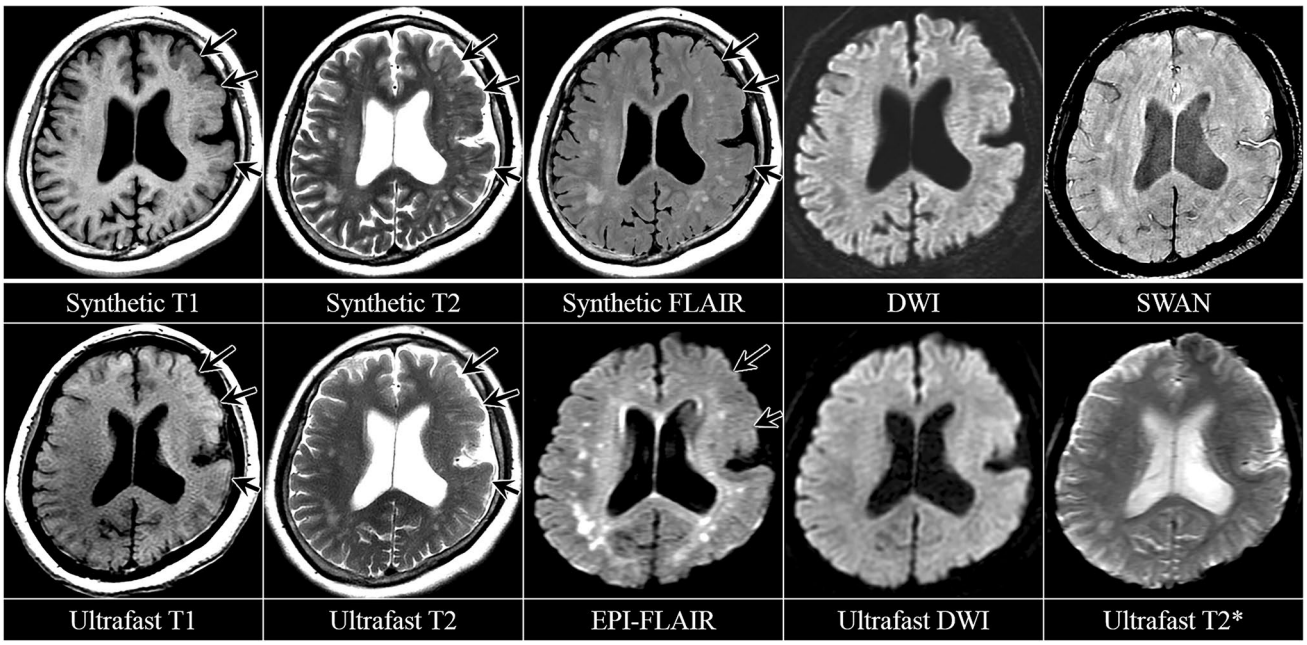

Fig. 2 Cortical dysplasia in the left frontotemporal lobes in a 55-year-old woman. The thickened and overfolded cortex with a bumpy appearance in the left frontotemporal lobes (arrows in upper row) suggesting polymicrogyria is visualized on the synthetic MRI (upper row). On the ultrafast MRI (lower row), the thickened cortex with a bumpy appearance (arrows in lower row) is also well-delineated (arrows in lower row). *EPI-FLAIR* echo-planar fluid-attenuated inversion recovery, *FLAIR* axial fluid-attenuated inversion recovery, *SWAN* susceptibility weighted angiography

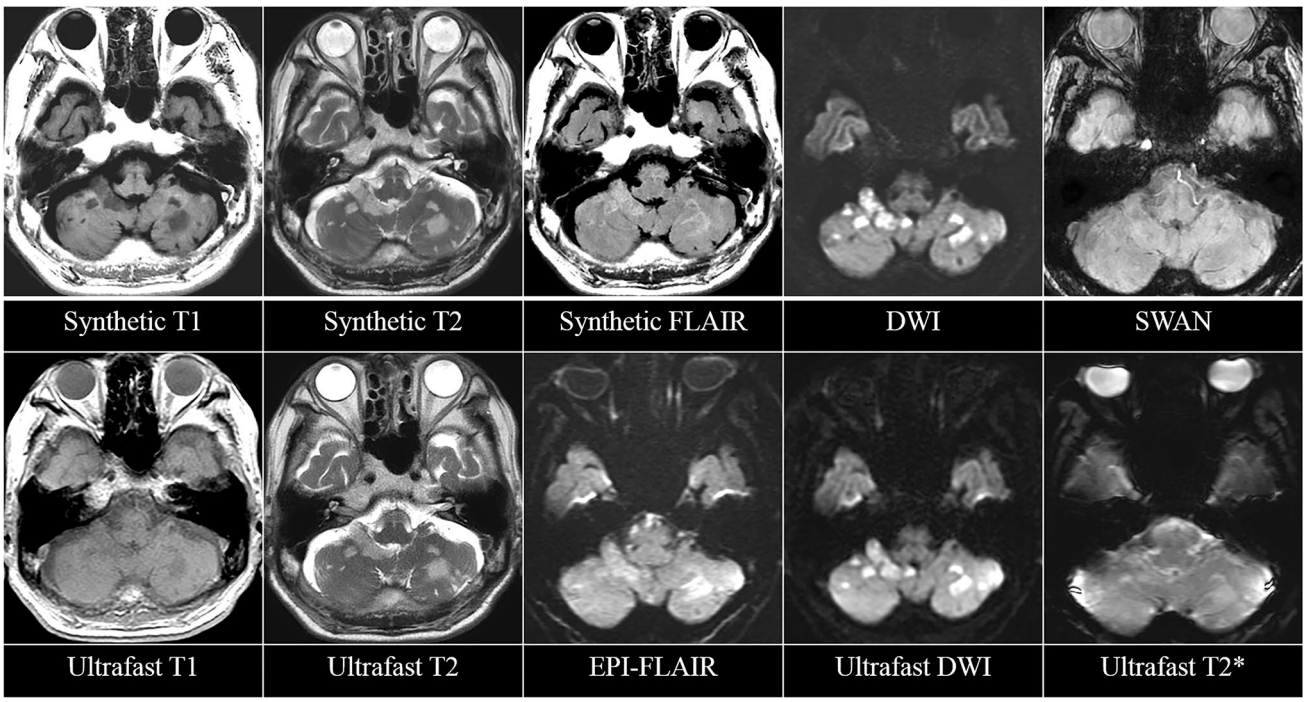

Fig. 3 Acute infarction in the bilateral cerebellar hemispheres in an 82-year-old man. Multifocal diffusion restrictions are apparent in the bilateral cerebellar hemispheres with T1 hypointensity, T2, and FLAIR hyperintensity. These lesions appear similar on routine (upper row) and ultrafast (lower row) image sets. *EPI-FLAIR* echo-planar fluid-attenuated inversion recovery, *FLAIR* axial fluid-attenuated inversion recovery, *SWAN* susceptibility weighted angiography

though we had taken steps to compensate for the deterioration of image quality as a result of reducing the scan time. Therefore, this issue can be argued that it was insufficient to have an advantage over the routine protocol using synthetic MRI. In addition, the results may be also affected by the radiologist's familiarity with the ultrafast protocol because we did not have an adaptation period. However, the significance of the current study is that a 1-min ultrafast protocol may be a viable option in motion-prone patients. We expect that further study, using an optimized protocol with adjusted parameters and faster acquisition techniques, is required to more comprehensively evaluate the diagnostic performance of the ultrafast MRI for the clinical use.

In contrast to a previous study [2], the ultrafast T1WI revealed the lowest image quality with anatomic delineations among the ultrafast sequences. Because this discrepancy may be related to scan parameters and the very short scan time, the image quality of the ultrafast T1WI can be improved by adjusting these factors. We also found that the ultrafast EPI-FLAIR had a lower image quality than synthetic FLAIR; however, it demonstrated overall sufficient image quality. Previous studies on the use of EPI-FLAIR sequences have revealed that the major limiting factor of EPI-FLAIR is susceptibility artifact, although lesion detection was comparable to conventional FLAIR [18, 19]. In this study, using parallel imaging, we mitigated the susceptibility artifacts and distortion to some extent on EPI-FLAIR [20, 21]. In addition, we also identified the characteristic hyperintense artifact of synthetic FLAIR, which has been well described in previous studies [4, 5]. In the present study, the hyperintense artifact appeared as a thin, granulated, and marginal hyperintensity along the brain surface with a wide range in degree and extent, resulting in a decrease in overall image quality. We ascertained that the artifact tended to appear in the temporo-occipital region and brainstem. However, this artifact did not have a significant impact on the diagnosis, similar to the result of the previous study [5].

There are several limitations in this study. First, this study was retrospectively designed, so there may be unavoidable selection bias. Second, the sample size was small. Additional studies with large sample sizes and more optimized patient selection will be necessary to validate our study. Third, we provided percent agreement to evaluate interobserver reliability instead of kappa statistics. This was done because kappa statistics provided paradoxically low values due to the imbalanced number of concordant and discordant pairs [22, 23]. Fourth, we did not perform quantitative analysis such as contrast-to-noise ratio (CNR) or SNR because fast imaging protocol inevitably leads to a decline in the overall image quality, and SNR cannot accurately be measured in synthetic MRI. Previous studies on fast MRI protocol also had a similar drawback likely to this study [11, 14]. In addition, there is a limitation to analyze and generalize the quantitative assessment due to small number of patients in the present study. Although the image quality analysis is limited by the reader's subjective judgement, the readers could intuitively perceive the effect of CNR and SNR in both ultrafast and routine brain MRI protocols during the image quality analysis. Fifth, we could not randomize the acquisition order of routine MRI and ultrafast MRI, because of the retrospective study design. Lastly, the 1-min ultrafast and 8-min routine protocols are optimized for use with a specific 3T MR machine and 48-channel coil to compensate for the issue of SNR reduction. Therefore, further study with different 3T MR machines and head coils is required to validate the clinical feasibility of the 1-min ultrafast MRI protocol.

Conclusions

In conclusion, the 1-min ultrafast brain MRI protocol demonstrates sufficient image quality for diagnostic use even though the overall image quality and anatomical delineation were inferior to those of routine brain MRI protocol. Our results suggest that the 1-min ultrafast protocol may be a possible option in patients unable to tolerate longer scan times due to the inherent benefit of its short scan time, decreasing the rate of rescanning or scanning failure and reducing the need for sedatives during examination. Further technological advances to improve the overall quality of the ultrafast MR images are required to expand the clinical use of the ultrafast MRI in evaluating intracranial abnormalities. We believe that the ultrafast brain MRI protocol may broaden the indications of brain MRI examination in non-cooperative, restless, and pediatric patients, as well as patients with time-critical disease such as acute stroke. Further studies with larger sample sizes and various MR scanners are essential to validate our results.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

Ethical standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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