Canon

CASE STUDY

Welcome Pack: a standardized brain MR examination with six sequences in less than 5 minutes

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Introduction

There is evidence that MRI has higher sensitivity and specificity compared to CT for brain imaging. However, MR is less cost-effective than CT because MR examinations are time consuming and not standardized.

Reducing scan time would allow completion of more cases, improved patient comfort, and/or inclusion of advanced sequences. Drawbacks of reduced scan time include decreased image quality with lower SNR (in part due to artifacts related to image acceleration), resolution and/or contrast.

An efficient and standardized protocol would assist radiologists who must choose among a variety of sequences [contrast (T1W, T2W, DWI, T2*W, …), 2D multi-slices versus 3D volume, and orientation plans], reduce incomplete exams, improve interscan reproducibility and allow more accurate remote reading.

To tackle the challenge of developing a fast and standardized protocol, we implemented on a commercial 3T MR "Vantage Galan 3T / ZGO" with strong gradients (100 mT/m peak amplitude at 200 T/m/s slew rate simultaneously) with dedicated 32ch head coil device (Canon Medical) a protocol (called *Welcome Pack*) which can be applied routinely to start the MRI exam for most brain diseases. The scan protocol includes 6 sequences and an auto localizer, which are all completed in less than 5 minutes (4'55''). This protocol includes a 3D FLAIR sequence of 100 seconds duration, using Artificial Intelligence (AI) via Deep Learning Reconstruction (DLR) from Canon Medical to reduce the noise of the image[1]. Such DLR strategy dramatically improves the image quality for all sequences but especially for the 3D FLAIR sequences that usually requires longer acquisition time.

Content of the *Welcome Pack* protocol

The optimized protocol includes 6 rapid sequences providing the main information commonly used for daily clinical examinations: axial 2D T1W (20 s), coronal 2D T2W with or without fat sat (33 s), 3D FLAIR (100 s), axial 2D T2*W (36 s), axial 2D DWI (28 s), and circle of Willis 3D TOF (59 s). The total scan time including localizer is 4 min 55 s.

The rationales for the sequences are as follows:

Axial T1W: This sequence identifies the presence of hemorrhages at the subacute phase (methemoglobin content), melanin content of metastases, fat of lipomas, high protein content of a cystic lesion. More generally, the sequence is used to study the tissue signal with and without gadolinium enhancement.

Coronal T2W with or without fat sat: This scan includes the orbits, the pituitary gland, the cavernous sinus and the posterior fossa and provides a good analysis of the skull base. In addition, it provides a T2 contrast that will complete the FLAIR sequence for the brain parenchyma analysis. Coronal T2W with fat sat is particularly useful in orbit imaging.

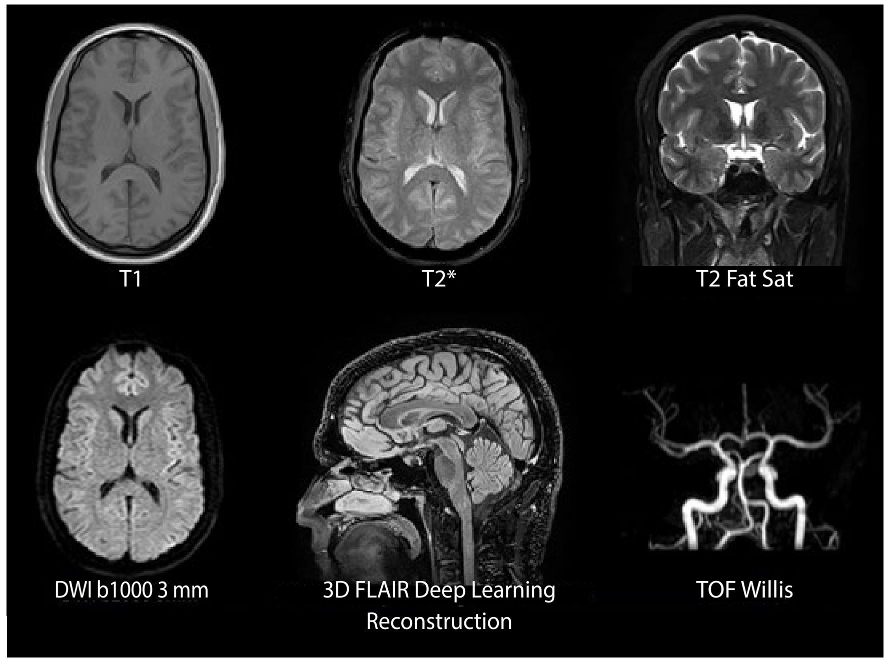
3D FLAIR: This sequence provides the most important contrast for brain MR imaging. Furthermore, 3D FLAIR is known to be more sensitive than 2D FLAIR to depict lesions within the brain stem and cerebellum[2-4]. In addition, 3D enables reconstruction in several planes. DLR was applied to identify and selectively remove noise in order to keep a high SNR despite the high resolution achieved in a limited time. DLR operates during MRI reconstruction so there was no time delay to obtain the corrected images.

Axial T2*W: This susceptibility-weighted sequence detects hemorrhages at the chronic or acute phase and/or calcification within brain parenchyma and meninges. It can also provide information on the iron content of the brain nuclei.

Axial DWI: This is one of the key sequence of MR brain imaging. Its role is to capture the microscopic motion of water that is modified in many neurological disorders especially vascular conditions and also inflammatory conditions or tumors.

Circle of Willis TOF: This sequence is useful for the large spectrum of vascular diseases and for patients suffering headache. In addition, considering the high prevalence of brain aneurysm in the general population, a routinely obtained Circle of Willis TOF image could aid detection prior to bleeding[5-6].

This protocol has been optimized in 20 healthy volunteers and 5 patients with various diseases. Image quality was reviewed by two experienced neuroradiologists (VD, TT) to ensure appropriate use for clinical conditions.



6 sequences including 3D FLAIR and TOF

Technical comments

Parameters of sequences

	3D Localizer	Ax T1W	Co T2W Fat Sat	3D FLAIR[1]	Ax T2*W	3D TOF[2]	Ax DWI[3] b1000
Slice thickness (mm)	5	5	5	1.2	5	1.9	3
FOV PExRO[4] (cm)	32 × 32	23 × 25	20 × 20	23 × 23	23 × 25	20 × 20	24 × 24
Resolution interpolated (mm) PExRO[4]	2.5 × 2.5	0.5 × 0.5	0.3 × 0.3	0.5 × 0.5	0.5 × 0.5	0.4 × 0.4	0.8 × 0.8
Acceleration Factor SPEEDER[5]		2	2.5	2 × 3	3	3	3
DLR[6]	No	No	No	Yes	No	No	No
Time (s)	19	20	33	100	36	59	28

Notes :

[1] To reduce the acquisition time, 3D FLAIR was acquired 1 × 1 × 1.2 mm with a 1 x 1 x 1.2 mm resolution, reconstructed as 0.5 x 0.5 x 0.6 mm
[2] 3D TOF was acquired with a 1.9 mm slice thickness, interpolated at 0.95 mm
[3] DWI acquiring with a 3 mm slice thickness is optimal to detect small infarct
[4] PExRO : Phase Encoding direction by Readout direction
[5] Parallel Imaging Factor
[6] Deep Learning Reconstruction

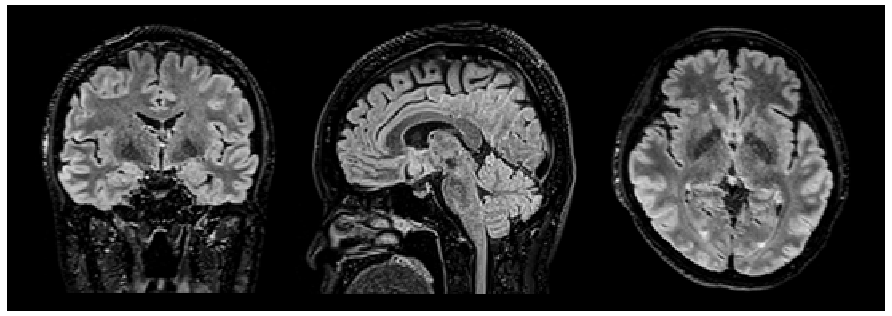
How was the short scan time achieved ?

In order to fit within a five minutes duration, all possible technical choices were combined to adapt TR/TE, matrix and speeder (parallel imaging factors) to keep a high resolution, contrast and SNR.

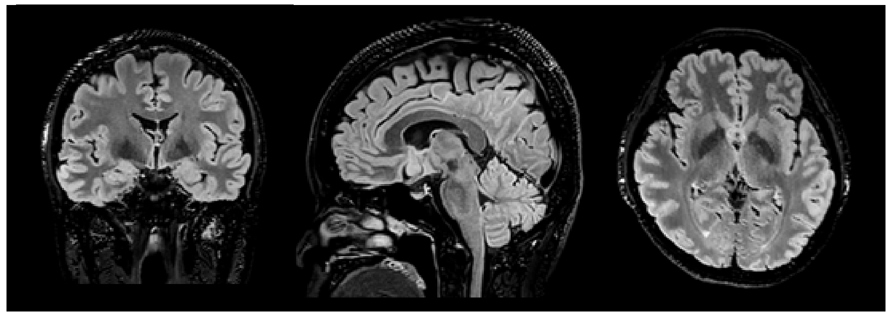
All sequences benefited from the use of a 32 channels coil giving a higher SNR and higher parallel imaging SPEEDER factors.

DWI also benefited from the 100 mT/m allowing a better quality of diffusion with lower TR/TE.

Concerning the very short 3D FLAIR scan time, acceleration was achieved by combining multiple techniques. This FLAIR is based upon our 3D mVox (variable-refocusing-flip-angle 3D FSE) sequence with parallel imaging (SPEEDER) factor 2 in the phase encoding direction and 3 in the slice encoding direction. We used also partial Fourier in the slice encoding direction (SE AFI 70%) and the new fast 3D mode thus reducing the acquisition time by 2. A short TR is set for a short scan time, and a T2prep pulse is used to increase CNR (Contrast-to-Noise Ratio) and keep an optimal contrast between grey and white matter. There was no artifact related to acceleration, so DLR can be used to denoise and improve then the SNR.



3D FLAIR raw image



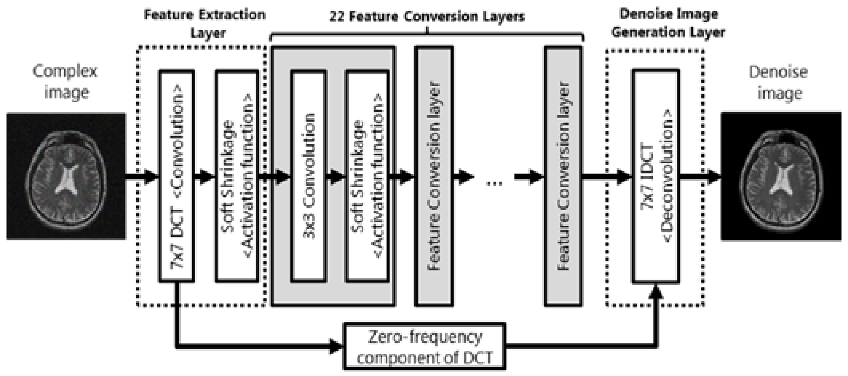
3D FLAIR with DLR

How DLR improved 3D FLAIR images?

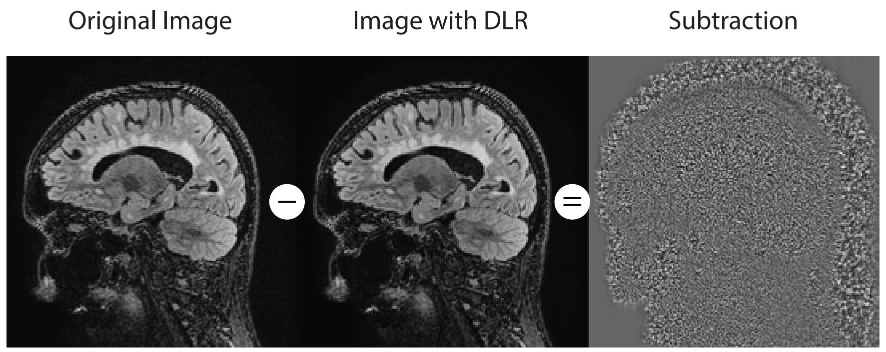
The 3D FLAIR acquired in 100 seconds had a good contrast but low SNR.

To improve it, we have applied the DLR algorithm, which is based on the Deep Convolutional Neural Network (DCNN). Image data was analyzed at pixel level in the image domain to recognize noise.

Training data sets have been built combining high SNR ground truth images (target) and low SNR noisy images (input). The difference between the ground truth and noisy images is the noise due to the acquisition chain. The training process iteratively optimizes the parameters in the neural network to reduce the difference between denoised images (output) and ground truth images.



DLR is implemented after converting k-space to real-space with inverse FFT (fast Fourier Transform). After DLR processing, the rest of the reconstruction process such as zero padding zooming, gradient distortion correction and so on is done to get a final reconstructed image.



Conversely to usual filters, and as evidenced on the image above obtained on a patient with Multiple Sclerosis, DLR provides a selective suppression of noise

Discussion

We provide here a rapid standardized MR protocol of shorter than 5 minutes including 6 sequences and an auto localizer.

Previous published works have demonstrated the feasibility of rapid protocols of around 5 minutes[7]. At comparable field strength and with a head 32 channel coil, GOBrain from Siemens proposes a five sequences protocol in 4 minutes and 59 seconds. However, while keeping within 5 minutes, our *Welcome Pack* offers an additional Circle of Willis TOF sequence, a 3D FLAIR sequence, a 3 mm slice thickness DWI and a fat saturated coronal orientated T2WI.

Circle of Willis TOF can be optional, thus making the *Welcome Pack* protocol shorter than 4 minutes without this option.

Instead of a simple 2D FLAIR, suggested by other vendors, we propose here a shorter protocol with a 3D FLAIR sequence. 3D FLAIR has been widely recognized to encompass the contrast of T2W and 2D FLAIR with a higher performance for diagnostic accuracy[2-4]. Reducing the scan time of the 3D FLAIR impacted the SNR and image quality but it's compensate here by the use of the DLR technology, 3D FLAIR recovered good signal (an increase of SNR by 94% after optimized DLR).

We found 3 mm slice thickness for DWI more suitable than 5 mm as it has been demonstrated that thin slices are superior for diagnosing small brain infarcts, such as lacunas and/or small strokes in the posterior fossa[8].

We also prefer the T2WI sequence acquired in the coronal orientation (rather than axial) with the possibility of a fat saturation mode. The coronal plane is a good complement to the axial images obtained with other sequences. In addition, the coronal plane allows a better analysis of the skull base, including the sinuses, the orbits, the hypophysis and cavernous sinuses and the foramen magnum.

It has bees previously demonstrated that adequate rapid protocols do not impact the diagnostic value of brain diseases[9]. The image quality of *Welcome Pack* was assessed by two experienced neuroradiologists who found anatomical landmarks and contrasts suitable for interpretation. DLR dramatically improved rapid 3D FLAIR image quality making it equal to the regular 3D FLAIR sequence which needs 4-5 min acquisition time on most current MRI scanners.

This study has been performed on a magnet coupled with high gradients and a 32 channels coil. We expect for the future to translate the *Welcome Pack* to a lower magnetic field, lower gradients and with the use of a lower channel count head coil, for an acceptable additional scan time. We are currently evaluating the performance of the same protocol with different systems and coils.

Shorter scan time may improve patient comfort and can enable the completion of more cases in a given time. It also allows to perform more complete examinations when needed, such as the use of gadolinium enhanced sequences or more specific and advanced sequences that are usually very time consuming. For example, after completing the *Welcome Pack* protocol we are using high resolution sequences for specific parts of the brain such as hippocampus, thalamus or cortex allowing segmentation and quantification, microstructure analysis with diffusion DTI or magnetization transfer, functional evaluation with perfusion-weighted images or fMRI, and metabolic analysis with spectroscopy, CEST or QSM.

Conclusion

A standardized protocol for routine brain MRI with six sequences in less than five minutes, including a 3D FLAIR improved by AI, is achievable and provides adequate information. This protocol allows us to increase throughput and/or add advanced sequences.

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MCSMR0001EA 2019-10 CMSC/ITP/Printed in Japan

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