CASE STUDY

3D Welcome Pack with Advanced intelligent Clear-IQ Engine (AiCE): a standardized 3D brain MR examination with 6 sequences in 6 minutes

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Introduction

Conversely to CT, MR examinations are time consuming and usually not standardized, with a sequence choice relative to the expected disease. An efficient and standardized protocol would assist radiologists in reducing incomplete exams, improving inter-scan reproducibility and increasing remote reading accuracy.

In a recent paper, we promoted the very short *Welcome Pack* protocol performing the six most useful sequences in less than five minutes[1] and which can be found on the latest commercial Canon MR systems. This protocol included an auto-localizer, 3D FLAIR, 2D T1W, 2D T2W, T2*W, diffusion and circle of Willis TOF. We also introduced the role of the Advanced intelligent Clear-IQ Engine (AiCE), a deep-learning denoising processing step, to increase the signal-to-noise ratio (SNR) of the 3D FLAIR scan. However, conventional 2D multi-slice T1W and T2W sequences have some limitations compared to 3D volumetric acquisitions, including image reformat in different planes, automated segmentation or volumetric quantification[2]. Thus, 3D acquisitions are providing much more information, but also request a significant increase in acquisition time, making its feasibility in clinical routine more difficult[3, 4].

In this study, we implemented and described a new comprehensive *3D Welcome Pack* protocol supported by AiCE, achieving a 3D standardized examination in a significantly shorter acquisition time compared to regular ones.

Method

We performed this *3D Welcome Pack* implementation on a commercial MR Vantage Galan 3T / ZGO* with strong gradients (100 mT/m peak amplitude at 200 T/m/s slew rate simultaneously), and we used a dedicated 32ch Head coil (Canon Medical).

The optimized protocol included the most commonly used sequences in daily clinical routine, such as 3D T1W (1 min 6 s), 3D T2W with or without fat saturation (1 min 13 s), 3D FLAIR (1 min 40 s), axial 2D T2*W (36 s), axial 2D DWI b-value=1000 s/mm^2 (28 s), and circle of Willis 3D TOF (59 s). The total scan time, including localizer, was 6 min 21 s compared to ~15 to 18 min for a standard 3D protocol without AiCE. Rationale for each selected sequence can be found in previous studies [1, 2-4, 7, 8].

AiCE technology, previously mentioned as *Deep Learning Reconstruction* (DLR), is the Canon Artificial Intelligence strategy to reduce the image noise[5, 6]. It has been used to denoise 3D acquisitions but also to improve image quality of 2D scans (T2*W and diffusion scans).

* Vantage Galan 3T / ZGO is not commercially available in all country.

This 3D AiCE protocol has been optimized on 10 volunteers. Images were reformatted in different planes and image quality was assessed by two experienced neuroradiologists (VD, TT) to ensure appropriate use for clinical conditions. Typical images are presented in figures 1-4.

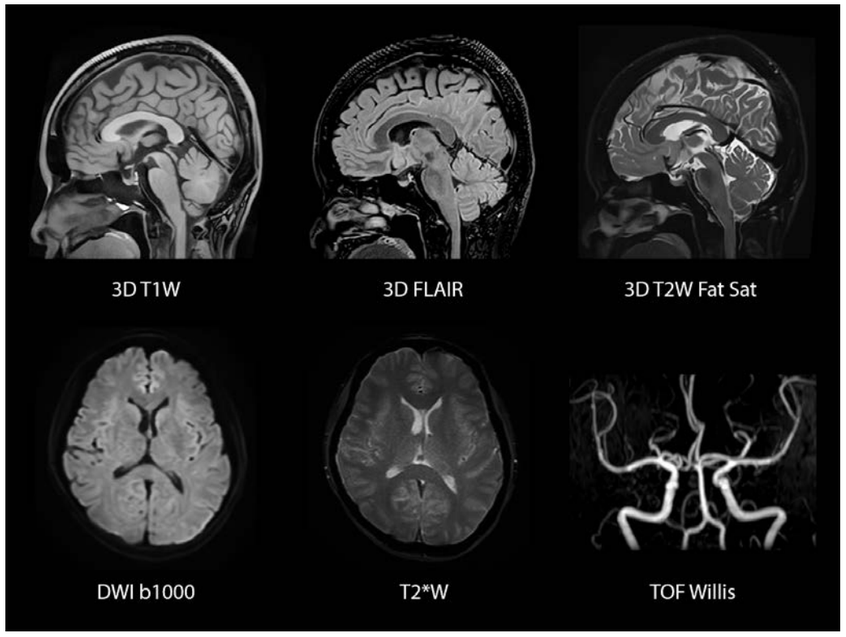

Figure 1 Typical *3D Welcome Pack* images on one volunteer. Total scan time: 6 min 21 s.

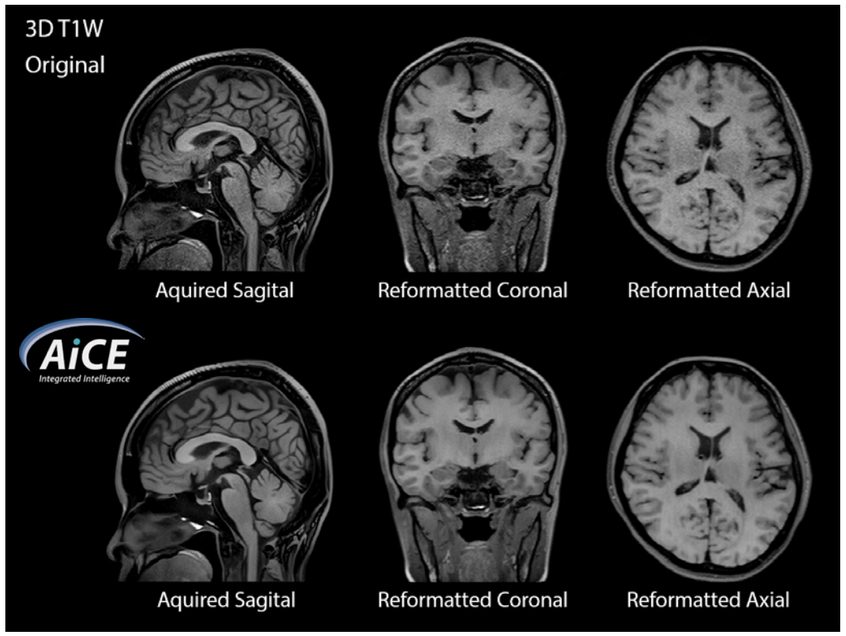

Figure 2 Typical 3D T1W images with and without AiCE denoising. Scan time: 1 min 6 s.

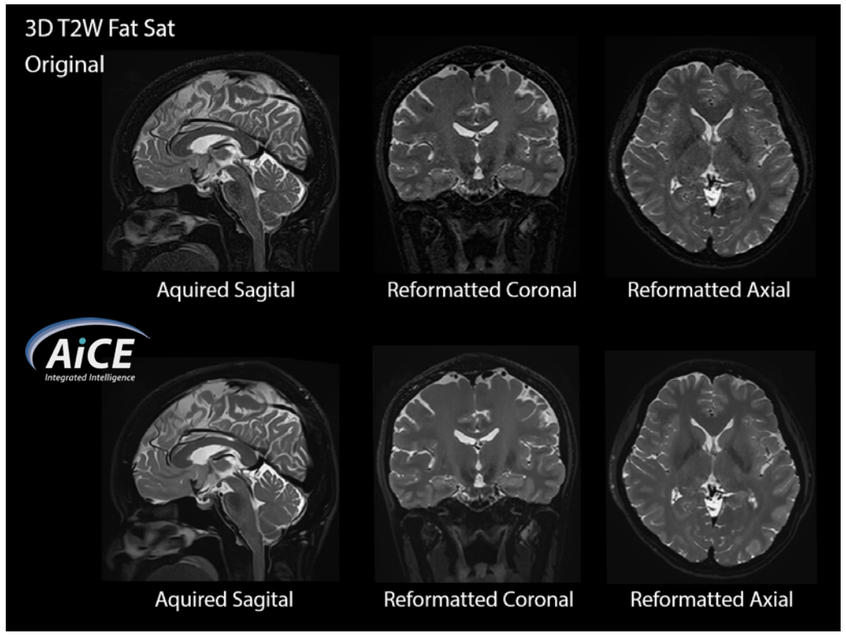

Figure 3 Typical 3D T2W Fat Saturation images with and without AiCE denoising. Scan time: 1 min 13 s.

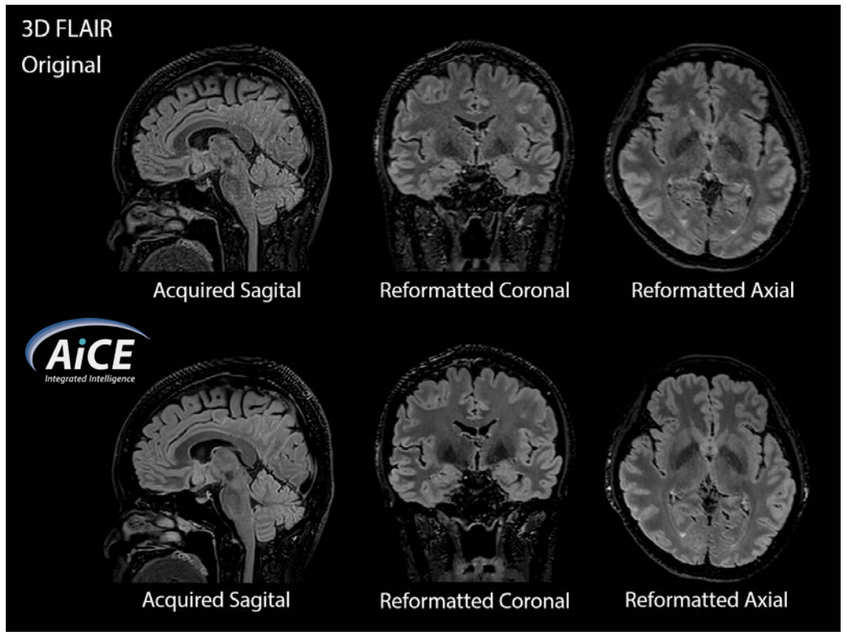

Figure 4 Typical 3D FLAIR images with and without AiCE denoising. Scan time: 1 min 40 s.

Table 1 *3D Welcome Pack* sequences parameters

	3D Localizer	3D T1W[1]	3D T2W[1] Fat Sat	3D FLAIR[1]	Ax T2*W	Ax DWI[3] b1000	3D TOF[2]
Slice thickness (mm)	5	1.2	1.2	1.2	5	3	1.9
FOV (cm)	32×32	23×23	23×23	23×23	23×25	24×24	20×20
Interpolated resolution (mm)	2.5×2.5	0.5×0.5	0.5×0.5	0.5×0.5	0.6×0.5	0.8×0.8	0.4×0.4
SPEEDER factor[4]		2×2	2×3	2×3	3	3	3
AiCE[5], [6]	–	+++	+++	+++	++	++	+
Acquisition time (min)	0:19	1:06	1:13	1:40	0:36	0:28	0:59

[1] 3D T1W/T2W/FLAIR were acquired with a 1×1×1.2 mm resolution and interpolated as 0.5×0.5×0.6 mm.
[2] 3D TOF was acquired with a 1.9 mm slice thickness and interpolated at 0.95 mm.
[3] DWI was acquired with a 3 mm slice thickness, optimal to detect small infarcts.
[4] Parallel Imaging Acceleration Factor (Phase encoding direction × Slice encoding direction).
[5] Advanced intelligent Clear-IQ Engine.
[6] AiCE improved image quality of all sequences and appeared even more critical for low SNR 3D sequences.

Technical comment

How was the short scan time achieved?

In this work, the acceleration of 3D scans was achieved by the combination of multiple techniques:

- All sequences benefited from the use of a 32-channel coil, giving high SNR and parallel imaging (SPEEDER) factors. These SPEEDER factors had to be optimized for each sequence, to balance acquisition time and SNR. For 3D T2W and 3D FLAIR, we obtained a 6x acceleration factor using SPEEDER factor 2 in the phase encoding direction and 3 in the slice direction. For 3D T1W, we chose the balance of an acceleration factor of 4 to ensure a better image quality.
- Partial Fourier in the slice direction was also used to further reduce the acquisition time. 3D T1W/T2W/FLAIR were all based on 3D mVox (Variable-Refocusing-Flip-Angle 3D FSE) sequences, using the "fast mode" and that reduced the acquisition time by a factor of 2. For 3D T1W and T2W scans, short repetition times (TR) were set to realize a short scan time while tissue contrasts were maintained with the use of T2 Plus and T1 Plus pulses. For 3D FLAIR, a T2 preparation pulse was used to increase the contrast-to-noise ratio between grey and white matter. No artifacts related to these accelerations were observed, allowing the use of AiCE to denoise and improve the SNR.

How did AiCE improve the *3D Welcome Pack?*

The main limitation to use 3D sequences with high resolution in the clinic is their low SNR at short scan times. As a strong denoising solution based on artificial intelligence, AiCE increases SNR by reducing the image noise level. For scan times around one minute, 3D sequences reconstructed with AiCE led to clinically relevant images with high SNR, whereas original data without denoising would suffer from a too low image quality (Figure 5).

One of the main advantages of AiCE is its ability to determine the image noise and automatically adjust the denoising level. This denoising process is only applied on the high frequency components, which next to image details also represent most of the noise. On the other hand, low frequency components, containing most of the contrast information, remain unchanged and are re-combined after denoising in order to keep the native contrast (Figure 6).

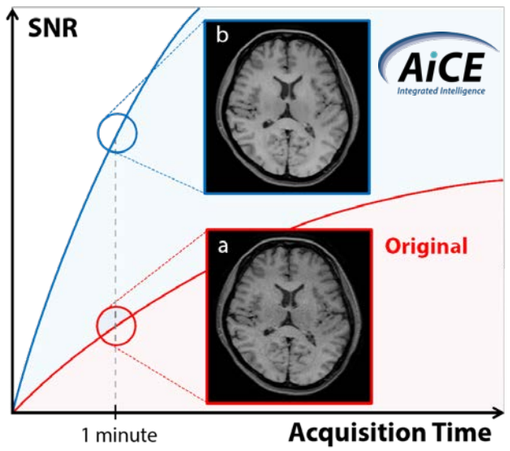

Figure 5 Relationship between SNR and acquisition time is depicted in this illustration with 3D high resolution T1W brain images. In case of a short acquisition time (one minute), these sequence parameters lead to images with low SNR (a), which can be regained thanks to the use of AiCE (b).

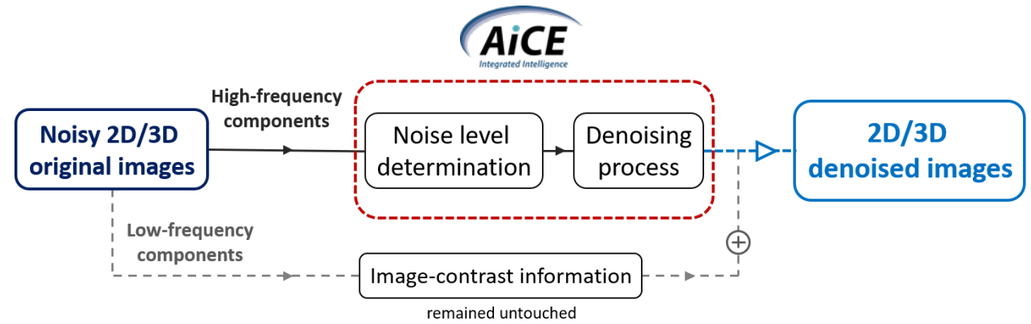

Figure 6 AiCE process on 2D or 3D datasets including: noise estimation, denoising on image components with edge and detail information, preservation of native contrast information.

Discussion

Our previous *Welcome Pack*, which included 3D FLAIR, was designed to propose a rapid and standardized MR protocol, offering a full range of basic sequences and suitable contrasts for diagnosis of most brain diseases. We refer to reference 1 concerning the justification of our sequence choice. Our *3D Welcome Pack* now includes a localizer, 3D FLAIR, 3D T1W, 3D T2W, 2D T2*W, 2D diffusion and 3D circle of Willis TOF, with a very short total acquisition time of only 6 min and 21 s. The major improvement can be found in replacing 2D T1W and T2W sequences by 3D sequences. The 3D acquisitions improve spatial resolution by reducing the slice thickness from 5 mm to 1.2 mm and interpolated to 0.6 mm, leading to an almost isotropic voxel [0.5×0.5×0.6], appropriate for multiplanar reformatting. Furthermore, 3D T1W can be used for volumetric analyses[2] and, when combined with 3D FLAIR, to automatically detect white matter lesions with dedicated software[9].

AiCE technology can process 3D or 2D data with the same efficiency. On 3D FLAIR, 3D T1W and 3D T2W sequences it creates a significant increase in SNR while keeping the scanning time as low as possible. Compared to original images, SNR increased by 94% for 3D FLAIR, 59% for 3D T2W and 51% for 3D T1W. AiCE improved the image quality of all sequences and appeared more critical for sequences with low SNR such as fast 3D scans. However, denoising reconstruction times are expected to be a bit longer for 3D than for 2D data.

We proposed in this study a new 3D version of the protocol, implemented on a 3T system with high gradients and using a 32-channel coil, optimal for high acceleration factors. However, it can easily be adapted to different field strengths, different gradients and head coils with a different number of channels, while still achieving strongly reduced scan times.

Reducing the scan time of the protocol while maintaining its diagnostic value may improve patient comfort and can significantly increase the throughput. This gain in time also allow to perform extended examinations when needed, such as gadolinium-enhanced imaging or more specific and advanced sequences such as high resolution, microstructure characterization or functional analysis (diffusion, DTI, magnetization transfer, perfusion, fMRI, spectroscopy, CEST, QSM, etc.).

Conclusion

In this work, we described a standardized 6 minutes protocol for routine brain MR exploration, with 3D acquisitions and a high SNR that was dramatically improved by AiCE technology.

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