Advanced intelligent Clear-IQ Engine (AiCE) Deep Learning Reconstruction: Effectively Removes Noise while Maintaining MR Signal

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Canon Medical has introduced Advanced intelligent Clear-IQ Engine (AiCE) Deep Learning Reconstruction (DLR)[1,2], which utilizes Deep Convolutional Neural Network (DCNN) with consideration of MR physics and signal processing principles. The synergy between MR physics, signal processing, and DCNN allows AiCE to effectively remove noise while maintaining MR signal thereby preserving anatomical and pathological structures.

It is well-known in the signal processing literature that image denoising and compression are much more efficient when performed in the transformed domain. For example, wavelet transform has been used widely in denoising[3] and Discrete Cosine Transform (DCT) is the basis of a popular JPEG compression standard, which is indispensable for transmitting digital images and photos across the Internet[4]. In AiCE's implementation, input noisy image is first DCT-transformed resulting in a low-frequency component and high-frequency components. Then, the AiCE's "adaptive" DCNN-based noise removal technique is performed only on the high-frequency components while leaving the low-frequency component unaltered via the use of skip connection. The rationale for such network architecture design is two-fold. Firstly, thermal noise is typically high-frequency and may only reside in the high frequency components of the DCT transform. Secondly, the low-frequency component in essence is a low-pass filtered version of the input image that contains its basic contrast. The utilization of the skip connection, in which the low-frequency component is bypassed by the convolutional layers, allows AiCE to preserve image's contrast and overall image content.

AiCE is designed to only remove Gaussian noise that presents in the MR image. That goal is achieved by the combination of training data preparation and the choice of the activation function in the DCNN, which allows AiCE to robustly remove noise while maintaining the MR signal. Keys features of the AiCE are described below:

- The training data was prepared by acquiring MR images with multiple averages. That results in high Signal-to-Noise Ratio (SNR) target images.

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- Noisy input images were simulated by adding Gaussian noise to the high SNR target images. To ensure clinical applicability, a wide range of clinically relevant noise levels were added to produce training data. That allows AiCE to be robust to different noise levels of the input images at deployment.
- AiCE employs an "adaptive" soft-shrinkage activation function instead of the rectified linear unit (ReLU) activation[5,6], which is commonly used in computer vision applications. Motivation of using soft-shrinkage activation in AiCE is that soft-shrinkage has been widely used and proven to be effective in signal processing literature for image denoising[3] and compressed sensing MR

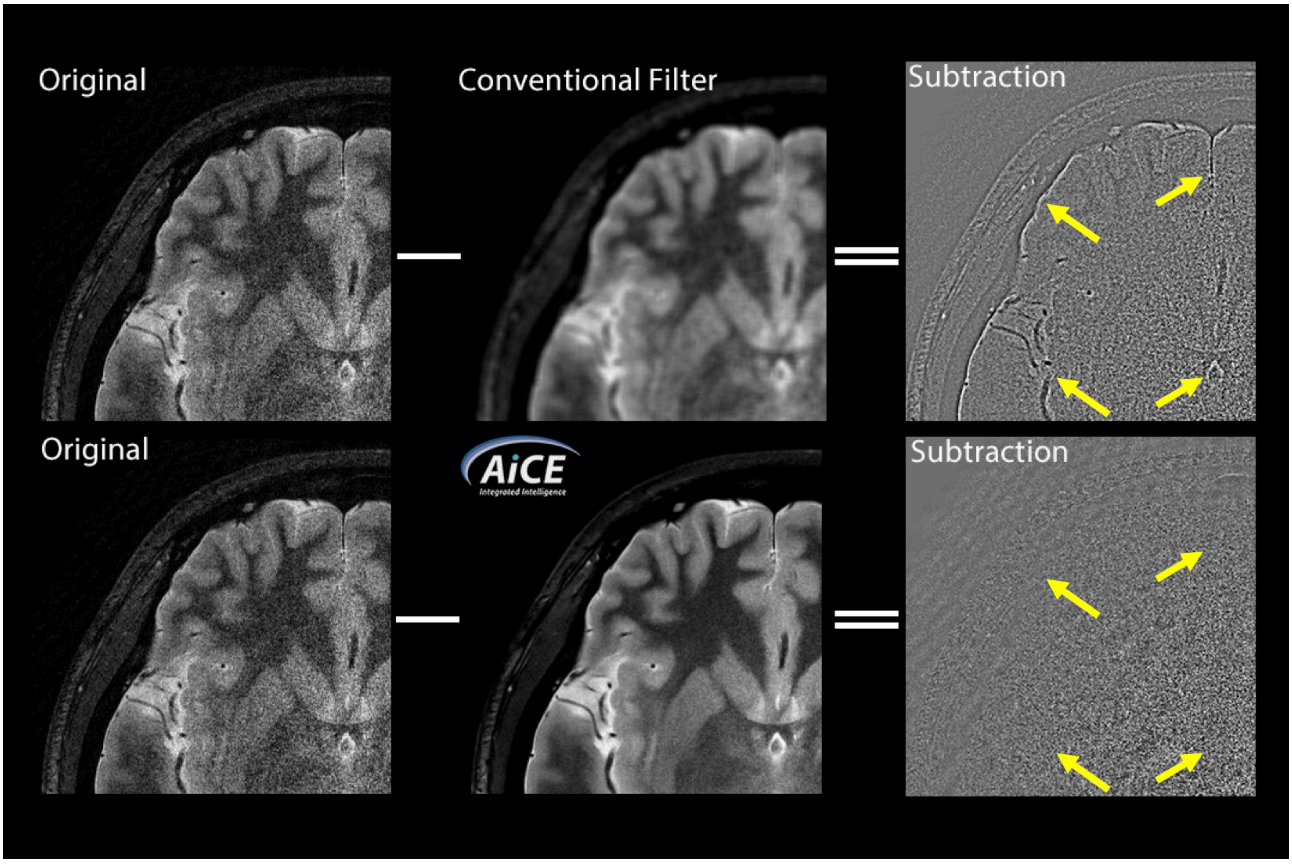

Figure 1. Subtraction images demonstrate that AiCE (bottom row) effectively removes noise while maintaining anatomical features.

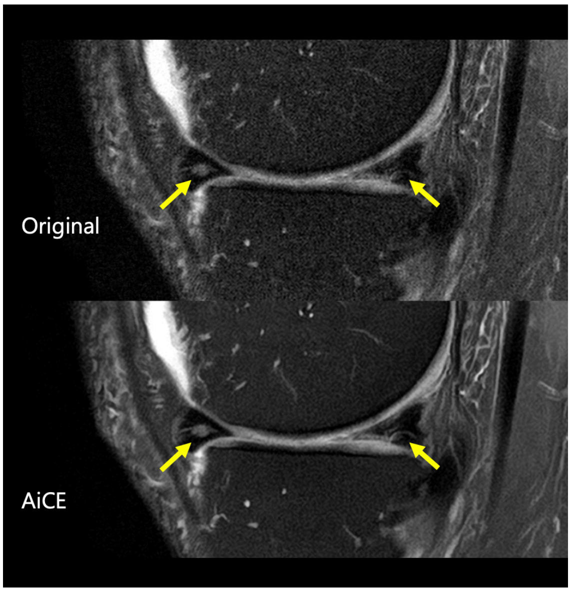

Figure 2. Meniscus tears (arrows) are preserved in the AiCE reconstructed image.

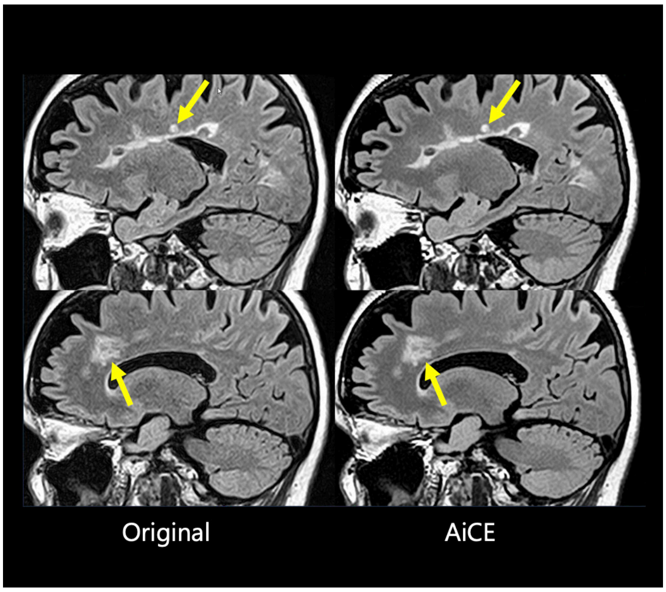

Figure 3. Multiple sclerosis (MS) lesions (arrows) are preserved in the AiCE reconstructed image.

image reconstruction.[7] Furthermore, the soft-shrinkage activation was designed to be adaptive by allowing the thresholding strength to be a learnable parameter, which is learned from training. That enable AiCE to be “adaptive” to a variety of noise levels observed at deployment.

• AiCE training data was prepared such that the DCNN only learn to reconstruct {clean image + noise} to {clean image}. That prevents the DCNN from adding new information into the images since the only difference between the input and target images is noise, the CNN learns to nominally remove only noise.

Figure 1 demonstrates that AiCE is trained to only remove noise while maintaining anatomical structures. **Figures 2 and 3** demonstrate that anatomical and pathological features are preserved in AiCE reconstructed images.

In summary, the synergy between MR physics, signal processing knowledge, and power of deep learning enables AiCE to effectively remove noise while maintaining MR signal. That results in exceptional image quality in various clinical protocols. The evidence of AiCE’s performance was demonstrated via non-clinical performance testing using model observer study and clinical performance testing using human observer study.

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