SEMINAR REPORT

Next-Generation Clinical Images Acquired Using ZGO in the Field of Orthopedics

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Introduction

Vantage Galan 3T / ZGO*, a next-generation high-resolution 3T MRI system manufactured by Canon Medical Systems, has been in operation at our hospital since August 2019. In this lecture, to illustrate some of the applications of the ZGO system in the field of orthopedics, I would like to discuss the clinical usefulness and future potential of Deep Learning Reconstruction (DLR), a noise reduction reconstruction technology employing AI that is available as a product called Advanced intelligent Clear-IQ Engine (AiCE), Compressed SPEEDER, a compressed sensing (CS) technology, and ultrashort TE (UTE) Multi Echo, an ultrashort echo time technology.

High-resolution imaging with DLR

In the field of orthopedics, it can be difficult to detect or evaluate lesions such as rotator cuff tears or labral tears using conventional MRI due to its limited resolution. In addition, high-resolution imaging is necessary to obtain a clear understanding of the extent of injury and the precise location of lesions. Although high-resolution images with a high signal-to-noise ratio (SNR) can be obtained by increasing the resolution and the number of imaging acquisition (NAQ), this results in a long scan time. High-resolution images can also be obtained using a surface coil, but the FOV is restricted in this case. It would therefore be ideal to have the ability to scan a wider range with a level of resolution equivalent to or higher than that of a surface coil.

AiCE is a noise reduction reconstruction technology that is based on the deep learning method. This method involves training a neural network to computationally generate images that are as close as possible to high-quality training images from input images that contain a significant amount of noise, resulting in the creation of a deep convolutional neural network (DCNN). By installing the DCNN in a diagnostic imaging system, low-SNR images acquired by the system can be denoised and converted to high-SNR images. Compared to a low-SNR image acquired with NAQ1 (Figure 1a), the SNR is improved in an image acquired with NAQ10 (Figure 1b), but the scan time is significantly longer. However, when AiCE is applied to an image acquired with NAQ1, an SNR equivalent to that of an image acquired with NAQ10 can be obtained with no increase in the scan time (Figure 1c).

When a standard smoothing filter is used to reduce noise, the values of adjacent pixels/voxels are averaged and detailed information concerning the contours of the bones may be lost, resulting in blurred images. On the other hand, with AiCE, which is trained to identify only noise that contains high-frequency components, noise can be selectively eliminated without affecting the contrast or signal values.

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

Figure 2 shows fat-suppressed proton density-weighted (PD-weighted) images. Compared to a 3 mm slice image (a), a 1 mm slice image with AiCE (b) depicts a partial tear of the supraspinatus tendon at the articular surface of the greater tubercle (circled area) more clearly due not only to a higher SNR but also to reduced partial volume effects in the thinner slice. In addition, the denoising performance of AiCE does not depend on the image type, because it has learned to identify only noise. Finally, AiCE can be applied not only to 2D images but also to 3D images.

Shorter examination times and higher resolution with Compressed SPEEDER

1. Technical features and clinical usefulness

Because scanning at a higher resolution generally requires a longer scan time, fast scan technologies are extremely important. Compressed SPEEDER is a fast scan technology which combines compressed sensing (CS) and parallel imaging (PI). The use of Multi-sensitivity Maps in PI increases the accuracy of unfolding images by creating two or more sets of sensitivity maps per coil channel. Using these maps for interative calculation in CS further increases the accuracy of unfolding images and thus provides clearer images. In addition, Compressed SPEEDER does not cause aliasing artifacts, which is a problem in conventional PI (SPEEDER) even when the encoding direction is set to the long axis. These characteristics are very well suited to imaging in the field of orthopedics. Figure 3 shows PD-weighted images. Extrusion and a horizontal tear of the medial meniscus (arrow) seen in images acquired with a SPEEDER factor of 1.5 (scan time: 3:02) (a) are depicted with comparable clarity in images acquired with a Compressed SPEEDER factor of 3 (scan time: 1:36) (b).

Compressed SPEEDER can be used for 2D fast spin echo (FSE), helping to reduce the total scan time in orthopedic MRI, in which 2D imaging is frequently employed. Taking advantage of the shorter scan time, it is also possible to select scan conditions that provide higher resolution. As shown in Figure 4, noise may be increased when Compressed SPEEDER is used for a low-SNR image (b, left). However, when AiCE is applied to the image, the labral tear (arrow) is visualized more clearly (b, right) with a shorter scan time than a SPEEDER image (a) while maintaining a high SNR.

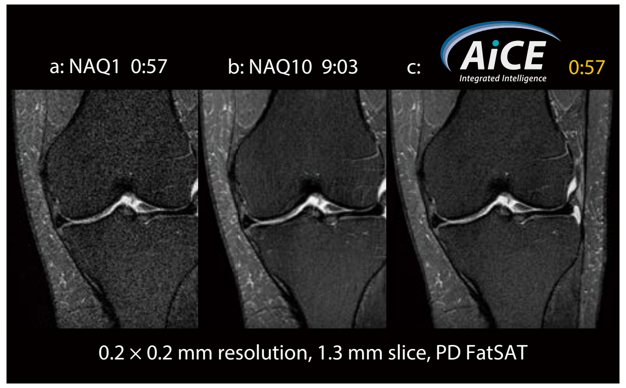

Figure 1 Denoising effect of AiCE.

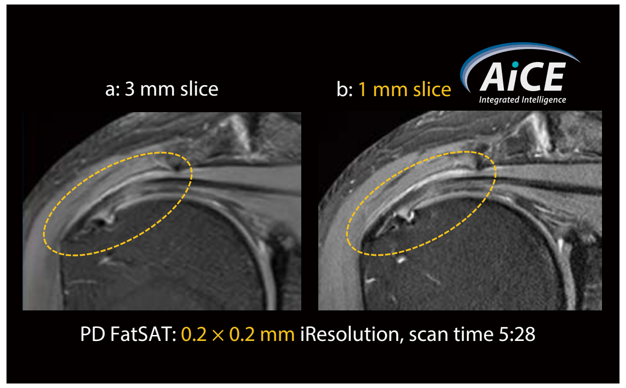

Figure 2 Application of AiCE to fat-suppressed PD-weighted images (partial tear of the supraspinatus tendon at the articular surface).

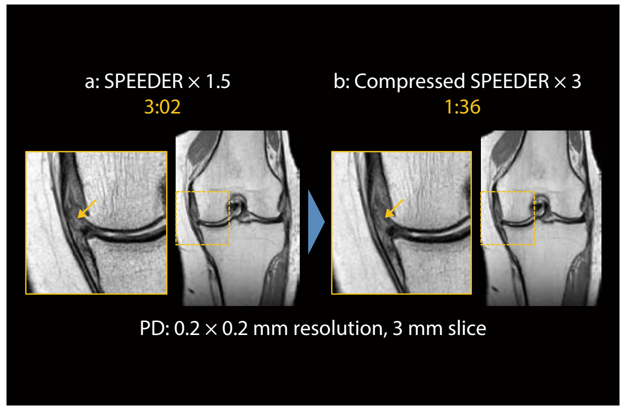

Figure 3 Comparison of PD-weighted images with SPEEDER (a) and PD-weighted images with Compressed SPEEDER (b) (extrusion and horizontal tear of the medial meniscus).

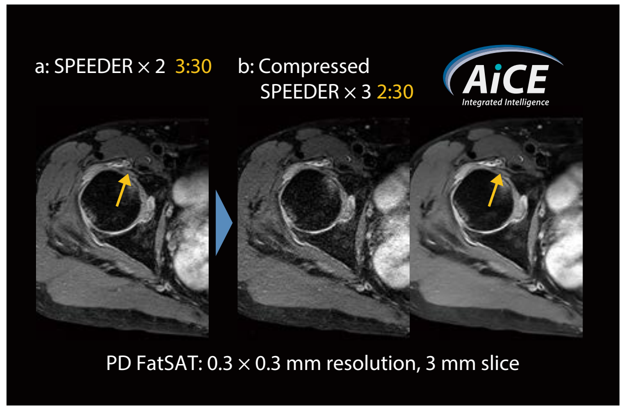

Figure 4 Fat-suppressed PD-weighted imaging with Compressed SPEEDER and AiCE employed in combination (labral tear).

2. Application to 3D imaging

Compressed SPEEDER can also be used for 3D imaging (WIP). For example, fast advanced spin echo (FASE) 3D T2-weighted images of the knee (0.5 mm isovoxels) can be acquired in a scan time as short as 3:48. Canon has developed a high-speed 3D scan technology known as "Fast 3D mode" which also achieves higher scan speeds while ensuring good image quality by adopting a unique k-space filling method and employing PI in combination.

On the other hand, some reports have described difficulties in visualizing medial meniscus injuries and posterior root tears of the lateral meniscus in 3D imaging.[1,2] This may be attributable to blurring due to a longer echo train spacing or low resolution.

3. Ideal MR images in the field of orthopedics

A broad outline of MR imaging can be summarized as follows. 2D imaging provides high in-plane resolution and is less affected by motion artifacts, but it is susceptible to partial volume effects due to the thicker slice thickness. 3D imaging allows thin-slice images to be acquired, and the acquired image data can be observed from any desired direction by multiplanar reconstruction (MPR), but it suffers from a number of disadvantages such as limited resolution, blurring, long scan times, and susceptibility to motion. Taking these basic characteristics into consideration, it can be said that ideal MR images in the field of orthopedics are high-resolution thin-slice 2D images that can be acquired in a short scan time. We have actually performed thin-slice 2D imaging with AiCE and have been able to obtain images that are sharper than 3D images in a shorter scan time.

Figure 5 shows a case of tibial osteonecrosis and chondral defects of the femur and tibia. Compared to a FASE 3D fat-suppressed PD-weighted image (Figure 5a), a 1-mm-slice FSE 2D fat-suppressed PD-weighted image with AiCE (Figure 5b) more clearly depicts the morphological characteristics of the osteonecrosis and chondral defects (circled area).

Potential for quantitative evaluation using UTE Multi Echo (WIP)

In diagnostic imaging, in addition to diagnosis based on qualitative images, it may also be necessary to perform evaluation based on quantitative data. Quantitative analysis can make it possible to detect abnormalities that cannot be seen in qualitative images, to identify lesions more quickly and thus improve prognosis, and to observe changes in lesions over time that may not be discernible in qualitative images. UTE technology, which enables scanning with a short TE of 0.5 ms or less,[3] can be used for quantitative analysis. In the field of orthopedics, tissues with a short T2* such as ligaments and tendons, for which quantitative analysis is difficult using conventional sequences due to low signal values, can be visualized and quantitatively evaluated.

In the UTE sequence, radial sampling is performed from the center of the k-space and signals are acquired from immediately after the RF half pulse, thus significantly reducing the TE. UTE Multi Echo allows multi-TE data to be acquired in a single scan, permitting T2* maps and scatter plots to be obtained in a short scan time (Figure 6).

With regard to the clinical applications of UTE, it has been reported that measurement of signals from a ROI placed in the patellar tendon showed a slightly higher T2* value in a patient with patellar tendinopathy than in a patient with a normal patellar tendon.[4] With UTE Multi Echo, the signal values obtained from multi-TE data can be used to make an excellent fitting curve in the monoexponential decay model (a model that assumes a single type of T2* in each voxel) or the biexponential decay model (a model that assumes two types of T2* [short T2* and long T2*] in each voxel). It is also possible to derive short or long T2* values.[5]

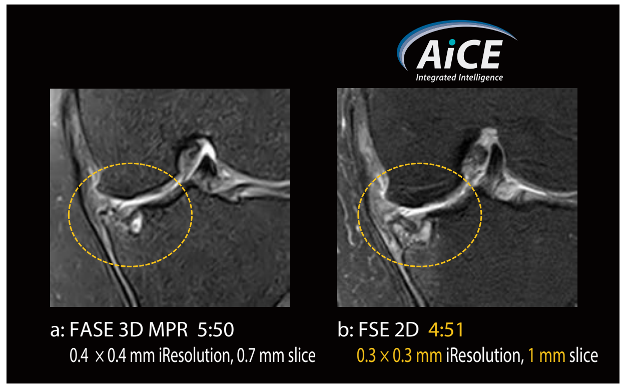

Figure 5 Evaluation of tibial osteonecrosis and chondral defects of the femur and tibia using a 2D thin-slice image obtained with AiCE.

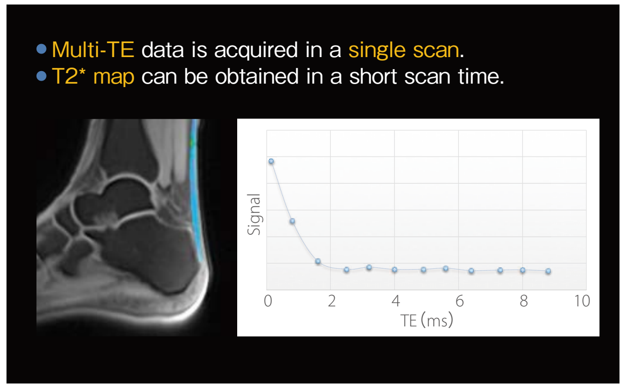

Figure 6 T2* map and graph obtained using UTE Multi Echo (WIP).

Conclusion

AiCE allows high-resolution imaging to be performed with a high SNR without prolonging the scan time. 2D images with a slice thickness of 1 mm (which are difficult to obtain using conventional techniques) can now be acquired with AiCE in a practical scan time, which substantially enhances diagnostic capabilities.

Compressed SPEEDER can reduce the scan time with no deterioration in image quality, permitting both shorter routine examination times and higher resolution. Both AiCE and Compressed SPEEDER can be employed for all types of images, 2D and 3D. Fast 3D mode is also useful as an option for high-speed scanning.

UTE Multi Echo enables quantitative evaluation of the tendons and ligaments and shows potential for the detection of abnormalities that cannot be visualized in qualitative images.

Acknowledgements

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