Precision-Trained Deep Learning: Redefining Cardiac Imaging

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Introduction

Canon Medical's new Super Resolution Deep Learning Reconstruction (SR-DLR) algorithm is redefining diagnostic confidence by taking the power of whole-heart, single-rotation cardiac coverage on the 16cm Aquilion ONE / PRISM Edition CT scanner and enhancing it with Super Resolution benefits from the Ultra-High Resolution (UHR) Aquilion Precision CT scanner. Precise IQ Engine (PIQE) is a Super Resolution Deep Learning Reconstruction that brings together extraordinary spatial resolution, reduced noise, and single-rotation coverage for confident diagnosis of small vessels, plaques, and fine cardiac structures. The PIQE Deep Learning Reconstruction algorithm is trained using data acquired on the commercially-available Aquilion Precision CT system, which features UHR 0.25 mm detectors in routine clinical practice. Datasets reconstructed with PIQE empower the clinician with twice the high contrast signal definition, as well as reduce noise, in all three dimensions, relative to conventional hybrid iterative reconstruction. These benefits come with no loss of low contrast detectability and no additional radiation dose to the patient.

The PIQE reconstruction algorithm features a next generation, three-dimensional neural network trained to identify and preserve signal features, both in-plane and longitudinally, throughout the cardiac volume dataset. Trained on high quality cardiac cases acquired on clinically operating, Aquilion Precision systems, PIQE optimizes spatial resolution for the most clinically relevant tasks and realistic field-of-views. PIQE's three-dimensional learning also helps ensure continuity of small, longitudinally running vessels, which are often obscured by conventional reconstruction algorithms.

Ultra-High Resolution CT and Deep Learning Reconstruction

Aquilion ONE / PRISM Edition

The Aquilion ONE / PRISM Edition offers One Beat Cardiac imaging: covering the whole heart in a single rotation via 320 detector rows of 0.5 mm thickness. The ability to image the heart in one 0.275 second rotation prevents misregistration and excludes artifacts caused by stitching or beat-to-beat variation and ensures there are no contrast differences between the aortic root and apex of the heart.

PIQE builds off the foundation of Advanced intelligent Clear-IQ Engine (AiCE), the industry's first Deep Learning Reconstruction algorithm for CT, and enhances cardiac image quality by using Deep Learning to bring the benefits of the Aquilion Precision Ultra-High Resolution CT scanner to the Aquilion ONE / PRISM Edition.

Aquilion Precision

The Aquilion Precision CT system, introduced in 2017, was engineered from the ground up to create Ultra-High Resolution CT images. The system features 1792 detector elements per row, double the number of a conventional system, resulting in twice the intrinsic in-plane spatial resolution of a conventional CT detector. In addition, each of the 160 detector rows along the z-direction is 0.25 mm thick, half that of a standard CT detector. Proprietary cutting techniques allow for optically isolated detector elements and ultra-thin septa, resulting in a substantial increase in light-sensitive area relative to conventional CT. The Aquilion Precision detector is paired with an advanced X-ray tube design, utilizing reduced focal spot sizes, as small as 0.4 mm × 0.5 mm and rotating at 10,000 rpm to efficiently dissipate heat. Figure 1 demonstrates the spatial resolution in a cardiac case scanned with Aquilion Precision.

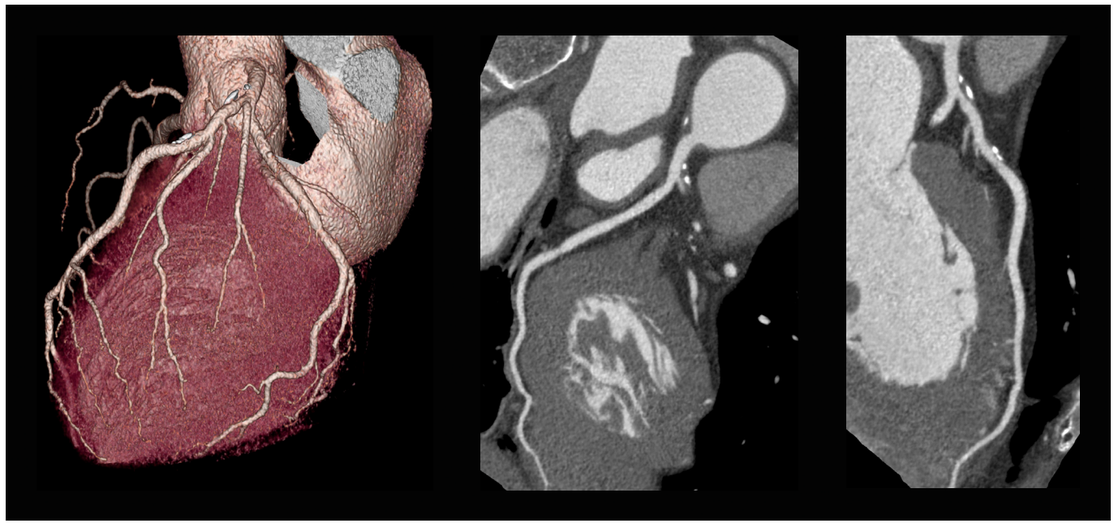

Figure 1: In this cardiac case performed on Aquilion Precision the sharp depiction of calcified and non-calcified plaques in the proximal LAD improves diagnostic confidence.

Deep Learning Reconstruction

AiCE Deep Learning Reconstruction, was developed in order to maintain the spatial resolution benefits of the Aquilion Precision while achieving dose neutrality* compared to conventional resolution CT. The ability of Deep Learning to improve spatial resolution and low contrast detectability while reducing noise is due to the power of machine learning, a form of Artificial Intelligence (AI).

Deep Learning is a type of machine learning that uses multi-layered neural networks to perform a task. Neural networks are comprised of thousands of "neurons," each of which perform a mathematical operation on the image data. The computational power behind thousands of neurons working together allows the network to generate more sophisticated rules for identifying signal features than is possible with conventionally programmed reconstruction. In the case of AiCE DLR, the task the network learns to perform is simply to distinguish signal features from noise. It identifies and enhances signal while removing noise, resulting in an industry-first low contrast specification of 1.5 mm at 3 HU and 22.6 mGy.

The key to a successful Deep Learning neural network lies in how it is trained, i.e. the process by which the neurons learn to perform the desired task. In order to learn, the network compares its output image to a gold standard reference image. The network adjusts the weights of its neurons until the error with respect to the gold standard is minimized. In the case of AiCE DLR, the gold standard clinical reference images are acquired with high tube current and reconstructed with a Model-Based Iterative Reconstruction (MBIR), that takes into account modelling of system optics, system physics, scanner statistical properties and human anatomy, and uses a greater number of iterations than could be otherwise used in a clinical setting due to time constraints.

Aquilion Precision's UHR mode reconstructed with AiCE DLR not only preserves higher contrast spatial resolution than traditional reconstruction, it also achieves dose neutrality compared to conventional resolution CT.

PIQE builds on the foundation of AiCE, the industry's first deep learning reconstruction algorithm for CT, and enhances cardiac image quality by using deep learning technology to bring the benefits of the Aquilion Precision Ultra High Resolution CT scanner to the Aquilion ONE / PRISM Edition.

PIQE Overview

PIQE is trained with Aquilion Precision data in order to maximize the inherent spatial resolution on the Aquilion ONE / PRISM Edition and then enhance it. This type of Deep Learning neural network is called a Super Resolution algorithm. With conventional reconstruction, there has long been a tradeoff between spatial resolution and noise that has forced CT systems to operate at much lower levels of spatial resolution than the detector and focal spot are capable of producing in order to maintain clinically acceptable dose levels. With Deep Learning, not only can this resolution be utilized, without increasing dose or noise, it can be enhanced further. As with all Deep Learning, the key to maximizing performance lies in the training process.

* Applies to AiCE Body only

PIQE Training

The neural network behind PIQE is trained using high quality cardiac cases acquired on the Aquilion Precision. These cases are acquired with the Aquilion Precision's Super High Resolution (SHR) mode that yields Ultra-High Resolution in-plane and 0.25 mm nominal slice width. The SHR data is reconstructed with AiCE DLR which implicitly contains all the advanced models of MBIR. In addition to UHR mode, the Aquilion Precision also has Normal Resolution (NR) mode that combines detector channels to generate conventional resolution images in-plane and 0.5 mm nominal slice width equivalent to Aquilion ONE / PRISM Edition. Raw data acquired in UHR mode can be reconstructed through a downsampling algorithm to yield simulated Normal Resolution images, that have been demonstrated to be equivalent to true Normal Resolution images.[1] With this approach, both UHR and NR images can be produced from a single acquisition. As a result, pairs of UHR and simulated NR images have perfect spatial alignment, ideal for training a neural network. Simulated NR images are input to the neutral network and the corresponding UHR images are used as the gold standard target images. The neural network learns to maximize the inherent resolution possible with NR images and even enhance resolution further, while decreasing noise (Figure 2).

The neural network behind PIQE does not learn features solely in the axial plane but rather in three dimensions, meaning signal features are identified and preserved in all three planes. This makes PIQE well-suited for cardiac exams, which are usually reviewed in MPR and curved planes.

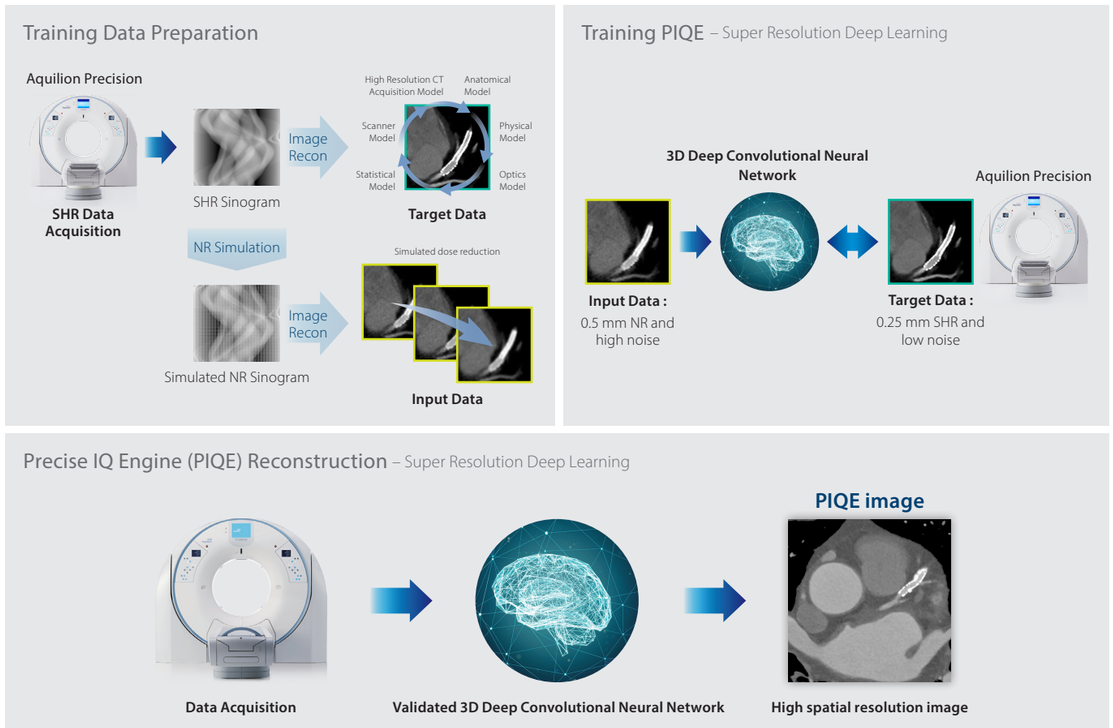

Figure 2: Training of PIQE network. Training data is prepared by down-sampling Precision UHR data. The network is trained using UHR data paired with down sampled, simulated NR data and actual UHR data. Once trained the network is validated and applied to the Aquilion ONE / PRISM Edition Scanner where it does not continue to learn.

PIQE Performance

CT is a well-established tool for the non-invasive detection and rule-out of coronary artery disease, currently the number one cause of death worldwide. PIQE is optimized for routine clinical use, which means maximizing resolution in realistic, typical field of views. The limiting resolution of an image is often dictated by the display field of view, i.e., the larger the pixel size the less the maximum resolution that can be displayed. Therefore, PIQE resolution improvements manifest in two ways. First, PIQE increases the limiting resolution, increasing the maximum lp/cm in a typical field of view by 5 lp/cm. Furthermore, PIQE doubles signal definition, also known as the percent contrast preserved, relative to conventional hybrid iterative reconstruction (AIDR 3D). The CNR with PIQE is increased in all three dimensions as well, further improving image quality in all planes for multiplanar and curved reformats. The improvement in spatial resolution is achieved with no loss in low contrast detectability (Figure 3).

This means objects are better defined and easier to visualize than ever before (Figure 4). PIQE improves detectability of all high contrast objects, large and small.

These advancements in spatial resolution foster improved visualization of small vessels, stents and in-stent structure with no dose penalty. Furthermore, the three-dimensional neural network helps promote continuity of vessels in all planes.

PIQE not only increases spatial resolution but reduces noise by 45% and yields identical low contrast compared to conventional hybrid iterative reconstruction (Figure 5 and 6). Soft, lower contrast plaque is often the most clinically relevant for patient care. Note the noise texture is not impaired by PIQE and is equivalent to conventional hybrid iterative reconstruction (Figure 5).

PIQE improves CT Number Accuracy for fine structure

The spatial resolution abilities of PIQE help mitigate partial volume effects that can distort CT number accuracy on small, fine structures. PIQE demonstrates better strut delineation and HU values that are accurate vs conventional hybrid iterative reconstruction (Figure 4).

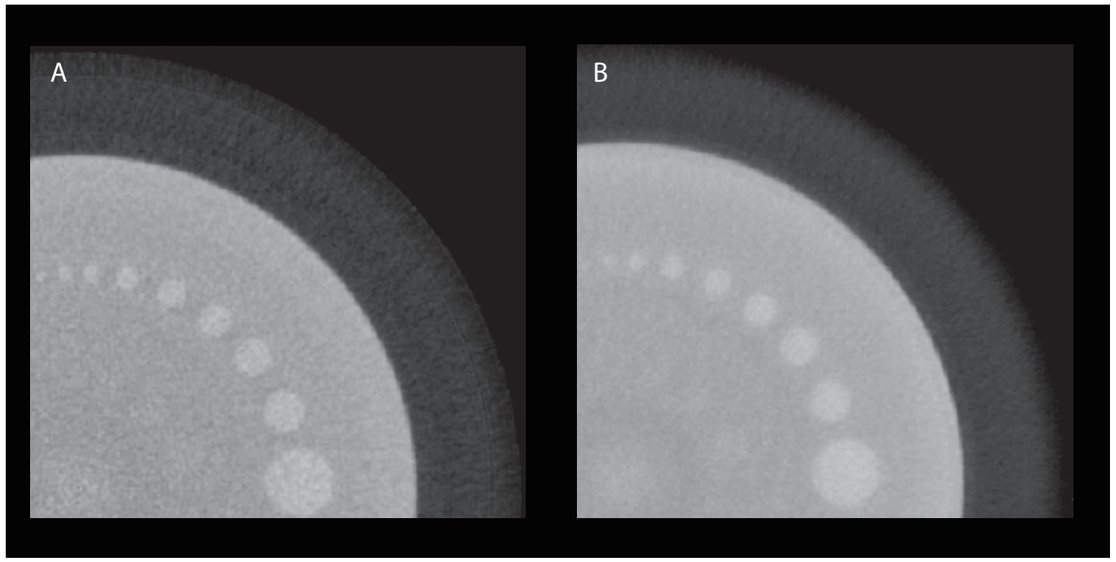

Figure 3: Catphan® phantom demonstrating equivalent low contrast detectability AIDR 3D Enhanced (A) compared with PIQE (B)

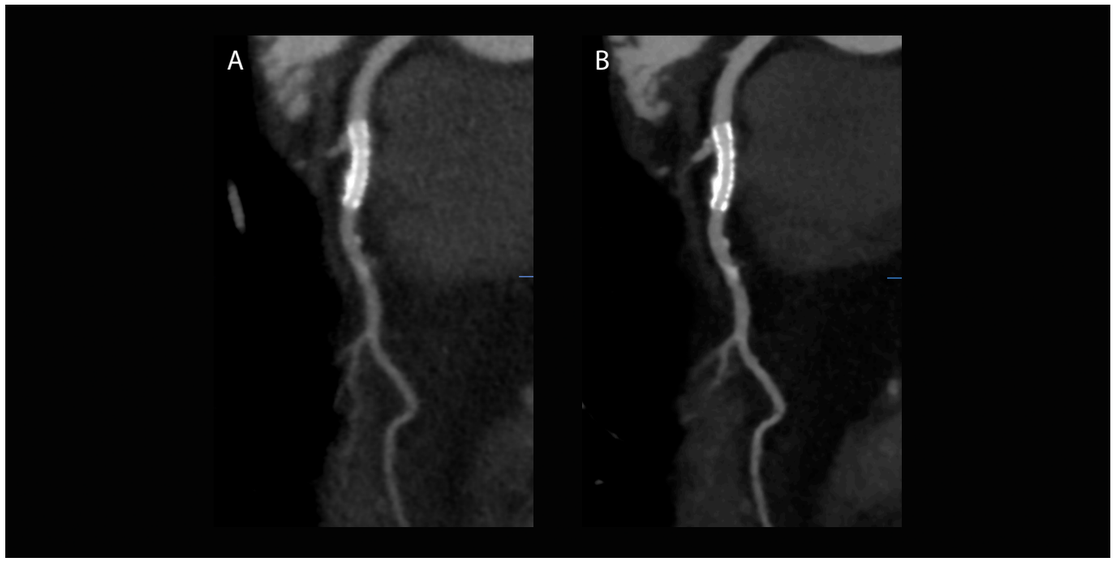

Figure 4: Visualization of a stent placed in the LAD using either AIDR 3D Enhanced (A) and PIQE (B). The stent as well as the intra-stent lumen are well defined on the PIQE images.

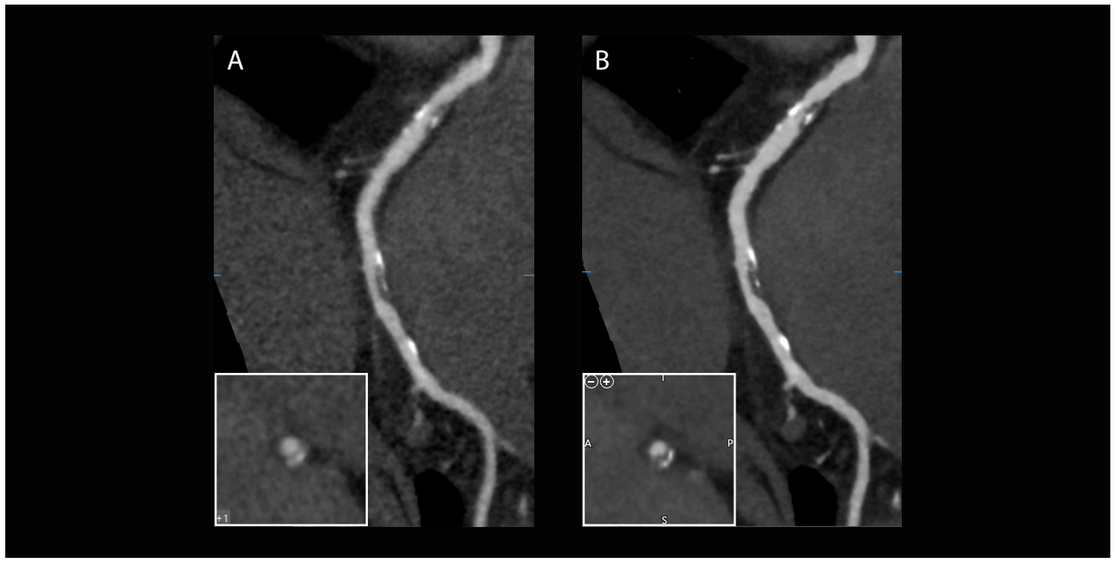

Figure 5: Multiple lesions are seen in the RCA. The various lesions and their different plaque components are clearly delineated in the PIQE images. AIDR 3D Enhanced (A), PIQE (B).

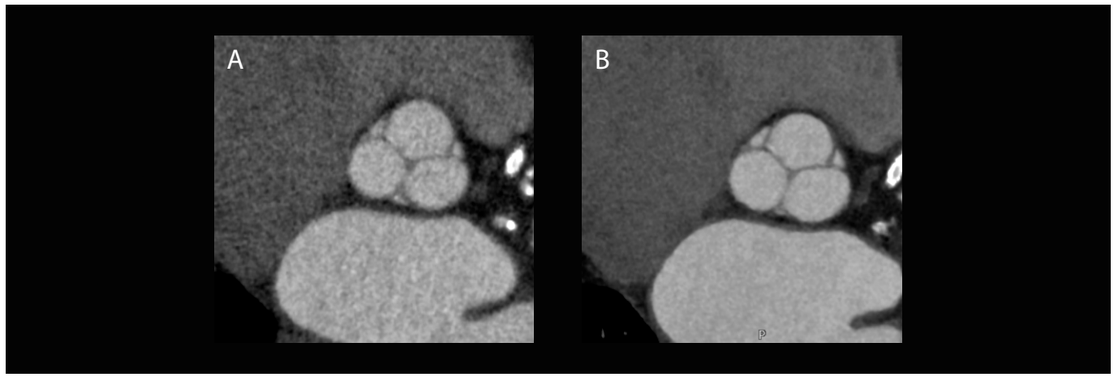

Figure 6: Aortic valve leaflets are clearly depicted in the PIQE reconstruction. AIDR 3D Enhanced (A), PIQE (B).

Cardiac Suite

PIQE* joins a suite of features available on the Aquilion ONE / PRISM Edition designed to optimize cardiac image quality and workflow.

High quality cardiac scans start with patient positioning. SURE Position automatically corrects both vertical and lateral patient position and then produces a new virtual scanogram, obviating the need for a repeat scanogram, saving time and dose.

SURE Cardio offers a number of tools that helps ensure consistency of image quality across patients of varying sizes and heart rates. Real Time Beat Control analyzes and predicts an individual patient's heartbeat in order to optimize ECG gated scanning. Real Time Beat Control also includes automatic Arrhythmia detection, which detects irregular heartbeats and adapts the scan protocol accordingly. PhaseXact detects the optimal cardiac phase with the least amount of motion for clinical evaluation.

SURE kV and Automatic Exposure Control for automatic kVp and mA selection can be used in combination with PIQE for maximum dose efficiency.

Canon Medical's ECG-gated Single Energy Metal Artifact Reduction (SEMAR) corrects metal artifacts created by implanted cardiac devices such as pacemakers and defibrillators, to optimize the readability of cardiac CTA images. SEMAR also helps reduces artifacts due to photon starvation and scatter. SEMAR can be preset in the scan protocol such that the application of SEMAR is fully automatic during reconstruction, requiring no additional input from the operator.

With a full volume reconstruction time of under two minutes, PIQE can be integrated into the standard workflow for all cardiac examinations.

*Pending FDA clearance

Conclusion

PIQE uses a 3D Deep Convolutional Neural Network to bring the power of Ultra-High Resolution CT to full coverage, single rotation cardiac examinations on the Aquilion ONE / PRISM Edition, with no increase in patient dose. PIQE doubles signal definition, lowers noise, and improves CNR, all with no loss in low contrast detectability relative to conventional hybrid iterative reconstruction. The combination of improved spatial resolution while maintaining LCD helps improve visualization of stents and coronary plaque, both calcified and non-calcified, providing a more confident diagnosis of coronary artery disease.

Reference:

1. Validation of synthesized normal-resolution image data generated from high-resolution acquisitions on a commercial CT scanner. Hernandez AM, Shin DW, Abbey CK, Seibert JA, Akino N, Goto T, Vaishnav JY, Boedeker KL, Boone JM. *Med Phys.* 2020 Oct;47(10):4775-4785

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