AI for significantly lower dose and improved image quality

Overview

Philips Precise Image is a novel Philips approach that uses AI* for images with an appearance that more closely resembles that of typical filtered back projection while retaining the noise-reduction capabilities of advanced iterative reconstruction methods. This provides high-quality images with a familiar appearance, and at low dose.

* According to the definition of AI from the EU High-Level Expert Group.

Background

Filtered back projection (FBP) was the industry standard for CT image reconstruction for decades. While it is a very fast method, FBP is a suboptimal algorithm choice for poorly sampled data or for cases in which noise overwhelms the image signal, as is the case with low-dose or tube-power–limited acquisitions. Over time, incremental enhancements have been made to FBP to overcome some of its inherent limitations.

Philips previously introduced a hybrid approach (iDose^4) and a model-based approach (IMR) to iterative reconstruction to help personalize image quality based on individual patient needs at low dose. When used in combination with the advanced technologies of Philips CT systems, iterative reconstruction has provided a unique approach to managing important factors in patient care, such as enabling lower-dose imaging and improving image quality.

Philips CT 5300

Now AI has provided the advances that make possible the next level of dose-reduction technologies, combining low dose with a more familiar image appearance.

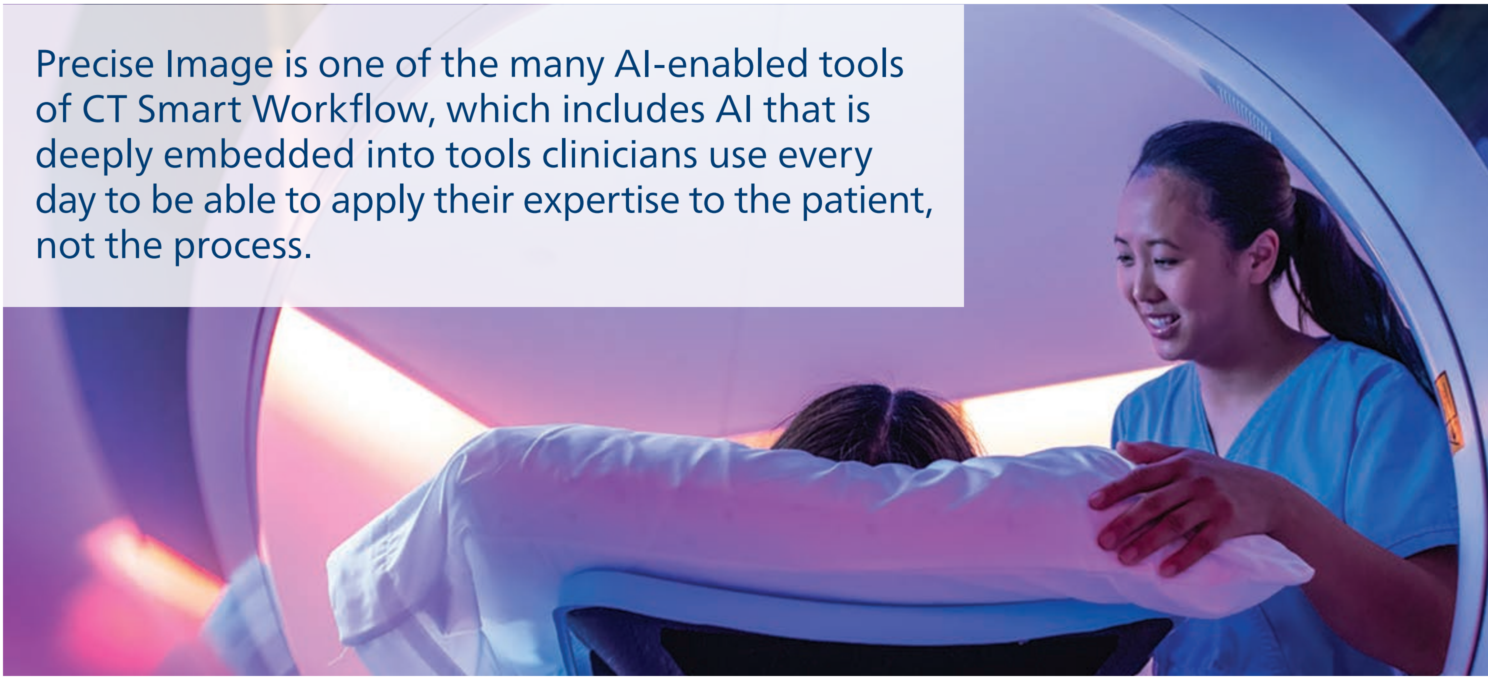
Traditional algorithms for iterative reconstruction typically penalize noisy images in some fashion, usually through a function of differences between neighboring voxels in the image. While effective in reducing noise, these penalty functions can produce an image appearance or noise texture that differs substantially from the appearance of traditional FBP images, which have been familiar to many radiologists over the years. This non-standard image appearance is a significant barrier to adoption of the technology for lowering dose across a range of clinical applications.

While Philips IMR has addressed the computational burden of model-based reconstruction and its effects on reconstruction time, this has remained an issue for many manufacturers.

AI deep-learning reconstruction is trained to quickly yield low-noise images from low-dose scans by comparing them to conventional-dose images in a supervised AI learning process. This supervised learning allows for an image with a noise texture that more closely resembles a typical FBP image, while retaining the noise-reduction capabilities of iterative reconstruction methods.

Philips CT Smart Workflow

Precise Image is one of the many AI-enabled tools of CT Smart Workflow, which includes AI that is deeply embedded into tools clinicians use every day to be able to apply their expertise to the patient, not the process.



How Precise Image trains neural networks

Precise Image follows a supervised learning process to train a convolutional neural network (CNN) in a specified manner.

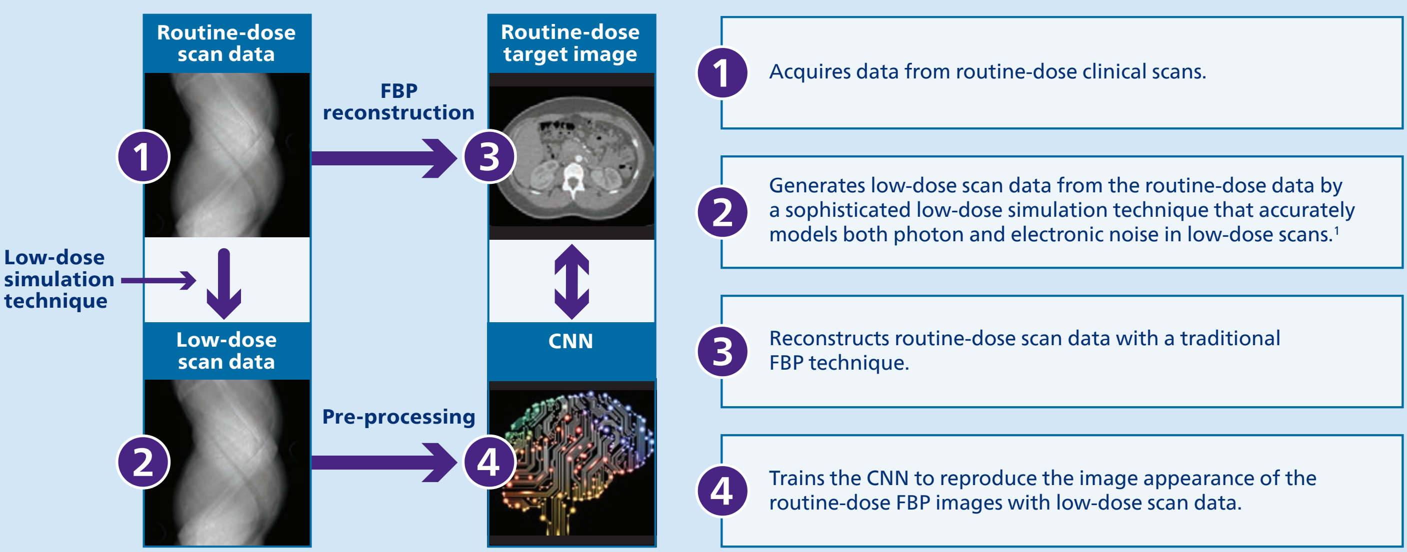


Figure 1 The training process for Precise Image AI reconstruction.

A closer look at deep learning

Deep learning is a subcategory of machine learning and AI. A convolutional neural network (CNN) is an artificial neural network with artificial neurons or nodes arranged in multiple layers between the input and output layers of mathematical manipulation. Complex CNNs, such as those of Precise Image, have many layers and the ability to model complex non-linear relationships. The design of a CNN acts as the foundation that will allow the network to achieve its optimization target in an efficient manner. With Precise Image, the networks were designed to address the specific challenges of image reconstruction and have optimized the number of nodes and layers within the network in a way that addresses the need for reduced latency and fast run-time while solving the complex optimization challenge.

Philips Incisive CT

Training the neural network

While a well-designed CNN presents a great deal of promise in solving complex optimization problems, it is important to realize that it is only as good as the training with which it has been provided. Correctly done, a supervised training strategy involves assembling a set of inputs and outputs that provide a sufficient sampling of the problem space to be solved. A well-reasoned and thorough approach at this point is critical for achieving robustness of the network. To train Precise Image neural networks, we begin with routine-dose scans with a clinically desired image appearance. From there, low-dose scan data is simulated in a way that accurately models both photon and electronic noise.

The network is then given the task of replicating the image appearance of the routine-dose images from the low-dose input. By training the networks in this way, they are more robust to the variety inherent in CT from factors such as applied radiation dose, patient size and patient anatomy.

Validating the neural network

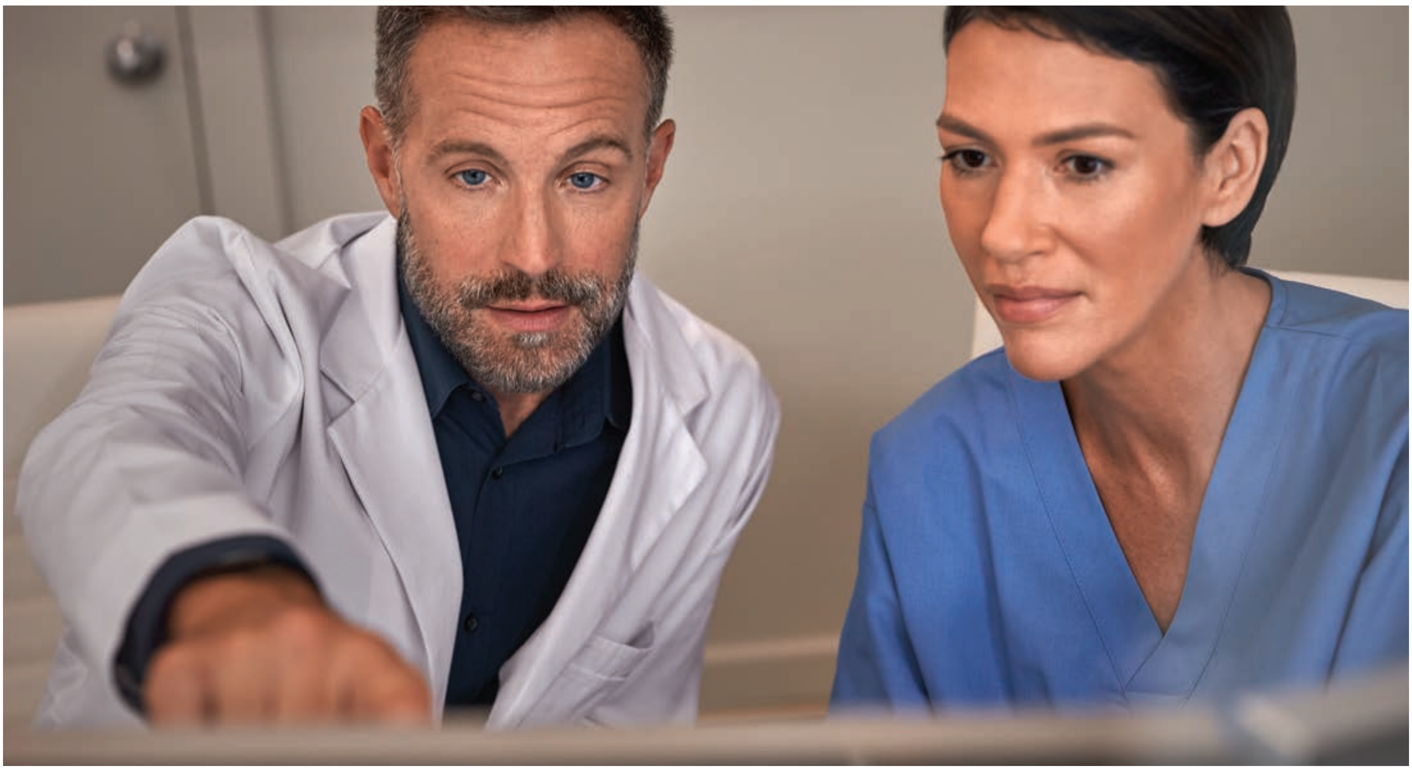
Trained Precise Image neural networks are validated using patient data obtained with a variety of scan parameters from a diverse population. Philips begins by providing low-dose data simulated from routine-dose scans as input to the neural networks. The resulting low-dose images of Precise Image are compared to routine-dose images reconstructed using standard methods. When image quality of low-dose images of Precise Image meets or exceeds routine-dose standard reconstructions, sufficient training of the neural network is confirmed.

Inference allows for fast clinical workflows

Once networks have been trained, the weights of the nodes and layers of the CNN are fixed. This means new inputs in the form of patient data can be rapidly processed to support high-throughput clinical workflows with the improved diagnostic confidence delivered by Precise Image. With the smart design of the network as the foundation and the robust training complete, Precise Image delivers the fastest AI-based reconstruction in the industry.

AI reconstruction must be fast if it is to be integrated into the daily routine

Philips Precise Image is an AI-based reconstruction technique that uses the power of a deep-learning neural network for improved clinical confidence and provides an image appearance that closely resembles FBP. All reference protocols can be reconstructed in under one minute.



Average reconstruction times for common protocols

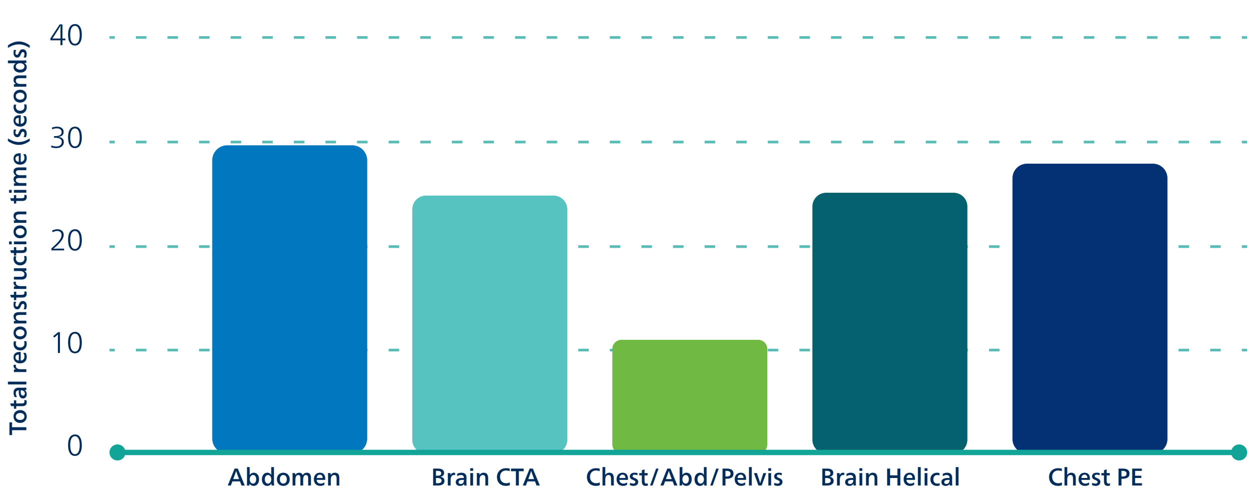


Figure 2 Precise Image allows for average reconstruction times of 30 seconds or less for common protocols.

Technical and clinical performance

Philips Precise Image has been extensively tested on both phantom and clinical data. Many general image quality metrics are computed using phantom images. However, Precise Image uses primarily clinical images in the training procedure, rather than phantom images, to ensure that networks are not trained to simply give good results on performance phantoms, but to provide improved clinical images. Nevertheless, these clinical benefits can also be measured on traditional phantoms with excellent results, as shown in the following sections.

Noise-power spectrum

A common complaint with iterative reconstruction images is that the noise texture differs significantly from FBP images. Precise Image is trained to reproduce the noise texture of FBP, while at the same time delivering significant noise reductions. An established metric for quantifying noise texture is the noise-power spectrum (NPS). For this measurement, a 30 cm water phantom was scanned at 300 mAs, and again at 100 mAs. Images for Precise Image were generated from the 100 mAs scan with increasing noise reduction to create images with high image quality and reduced noise. A series of normalized NPS values were then computed for each of the images for Precise Image, as well as for the high-dose FBP image. A representative comparison is shown demonstrating the similar NPS profile of a low-dose Precise Image reconstruction and a high-dose FBP reconstruction **(Figure 3)**.

A nearly constant normalized NPS can be maintained with Precise Image – regardless of the magnitude of the noise reduction – that closely matches the NPS given by FBP reconstruction. Thus, image noise texture can be customized to closely match that of FBP images, even for low doses and strong levels of noise reduction.

Precise Image provides AI reconstruction that preserves the traditional FBP look and feel

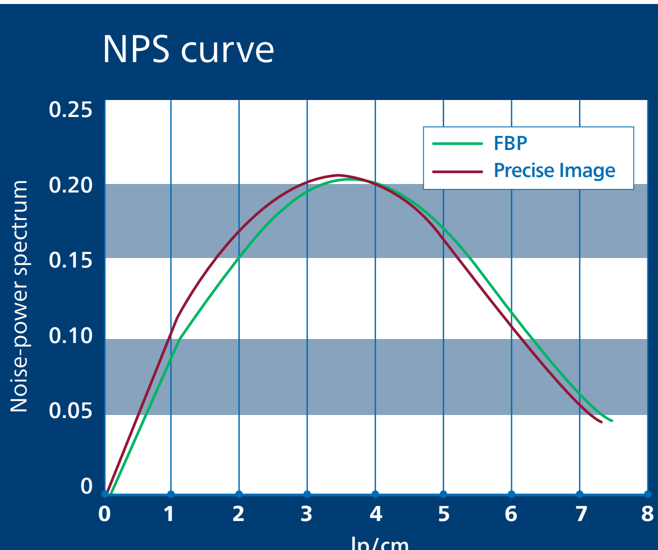
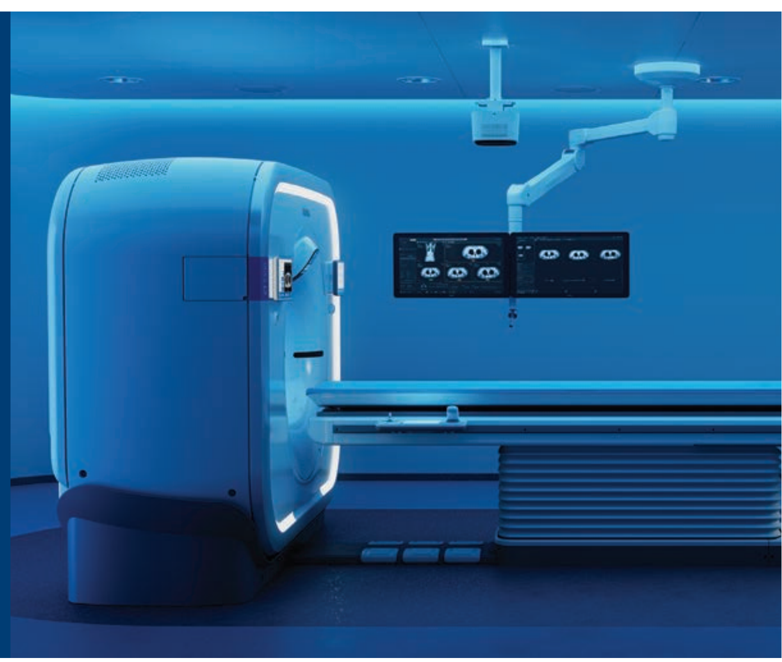


Figure 3 Normalized noise-power spectrum measurements from a 30 cm water phantom.



Low-contrast detectability

A low-contrast detectability (LCD) test is an established method for measuring the dose reduction capabilities of reconstruction algorithms. A human or model observer is presented with many different noisy images, some containing a known low-contrast object and some with no object present, and for each image the observer must decide if the object is present or not. Success at making the correct determination for each noisy image is measured, and these scores can be used to derive a detectability index (d') that reflects the statistical success of detecting the object with a given dose and reconstruction method. A d' = 0 corresponds to no better than random guessing, while a d' = 4.38 corresponds to nearly perfect detectability.

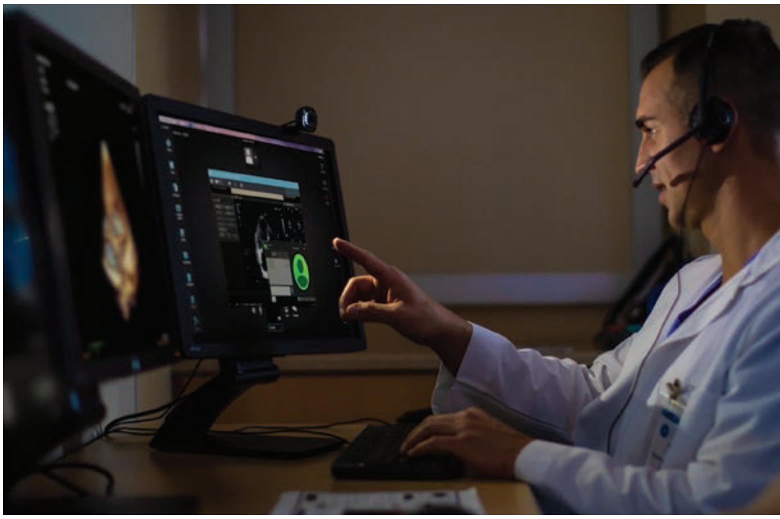
The LCD test for Precise Image uses the MITA low-contrast phantom CT 189 and focuses on the 10 mm diameter, 3 HU contrast pin. The model observer is a channelized Hotelling observer (CHO) with 3-DOG channels, as described in the IQmodelo tool.[2] We use 200 image pairs (object present, object absent), and compare the d' of FBP at a dose of 10 mGy to Precise Image at 2 mGy (80% dose reduction).

Results of the LCD test show detectability with Precise Image to be 60% better than FBP at 10 mGy. The measured noise of the Precise Image reconstructions was 85% lower than that of the FBP images. This test shows that with Precise Image, users can get both significant dose reduction (80%) and improved low-contrast imaging (60% better LCD and 85% lower noise), all while retaining a more traditional noise texture than with other reconstruction techniques.*

* In clinical practice, the use of Precise Image may reduce CT patient dose depending on the clinical task, patient size, and anatomical location. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task. Dose reduction assessments were performed using reference body protocols with 1.0 mm slices at the "Smoother" setting of Precise Image, and tested on the MITA CT IQ Phantom (CCT189, The Phantom Laboratory) assessing the 10 mm pin and compared to filtered-back projection. A range is seen across the four pins, using a channelized hoteling observer tool, that includes lower image noise by 85% and improved low-contrast detectability from 0% to 60% at 50% to 80% dose reduction. NPS curve shift is used to evaluate image appearance, as measured on a 20 cm water phantom in the center 50mm x 50 mm region of interest, with an average shift of 6% or less.

Clinician review

A team of experienced radiologists independently reviewed images of the chest, abdomen and pelvis from 40 patients using iDose[4] and Precise Image. Both image sets for each patient were rated for diagnostic confidence, sharpness, noise level, image texture and artifacts on a 5-point Likert scale, where 1 was the worst and 5 was the best. All scans were performed at routine dose levels, and iDose[4] images were reconstructed at the acquired dose. Images using Precise Image were reconstructed at 50% of the routine acquired dose using low-dose simulation techniques.



For each attribute assessed, ratings from the two image sets were compared using a two-sample Welch's t-test (α=5%) to check for statistically significant differences in the ratings. Results showed an improvement in each attribute with images from Precise Image reconstructed at 50% of the acquired dose **(Figure 4)**.

Precise Image improves diagnostic confidence at half the dose

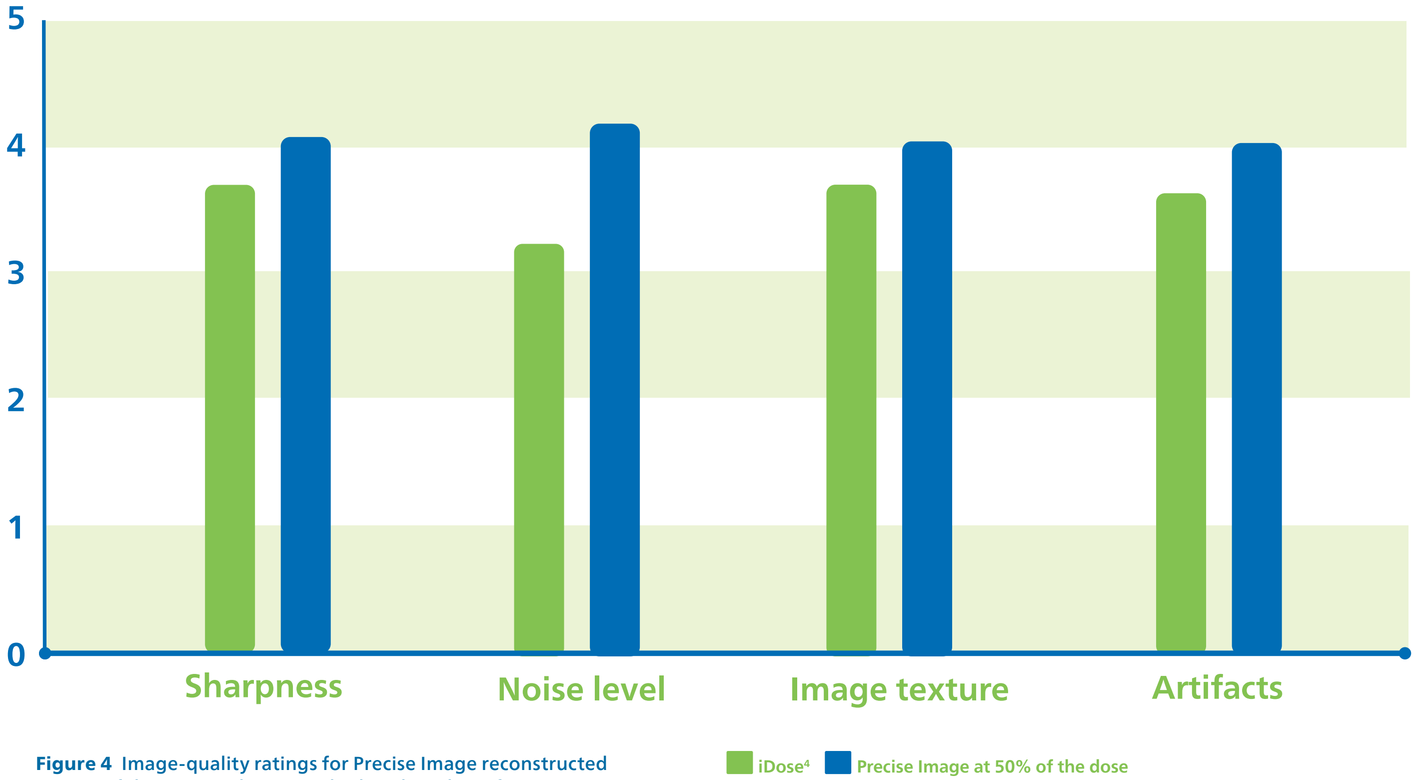


Figure 4 Image-quality ratings for Precise Image reconstructed at 50% of the routine dose were higher than those for iDose[4] images reconstructed at 100% of the routine dose.

Independent evaluation

Demonstration of dose reduction potential in standard geometric and anthropomorphic phantoms

Three peer-reviewed publications[3,4,5] evaluated the impact of Precise Image on image quality at reduced doses compared to iDose[4]. Each paper focused on a different body region and applied both a task-based and subjective image quality assessment to phantom scans performed at multiple dose levels. For task-based assessment, the defined task functions assessed with geometric phantoms were:

- Chest (5 mm lesions): Visualize low-contrast soft tissue nodule within mediastinum, ground glass opacity, and high-contrast pulmonary lesions
- Abdomen (10 mm lesions): Visualize liver metastasis in portal phase, HCC in portal phase, and HCC in arterial phase
- Lumbar spine (5 mm lesions): Visualize lytic and sclerotic bone lesions

Up to 94% dose reduction
while maintaining or improving detectablity

Key findings

Precise Image provided a significant improvement in task-based detectability (d') relative to iDose[4]. This enabled potential dose reduction of 46-94% across the anatomies while maintaining or improving detectability relative to iDose[4]. Subjective image quality assessment performed using anthropomorphic phantoms confirmed images were satisfactory for clinical use at these dose levels.

Demonstration of dose reduction potential in lifelike 3D-printed phantoms

Another study[6] used a novel 3D-printed lung phantom created from actual patient images demonstrating pathology to evaluate Precise Image performance at reduced doses. The 3D-printed phantom exhibits attenuation profiles, textures, and structures that are more representative of clinical scans than traditional phantoms. Scans performed across a wide range of dose levels with two body habitus configurations were reconstructed with FBP, iDose,[4] and Precise Image. Quantitative image quality metrics were compared across reconstructed images.

Up to 83% dose reduction
with no compromise to diagnostic image quality

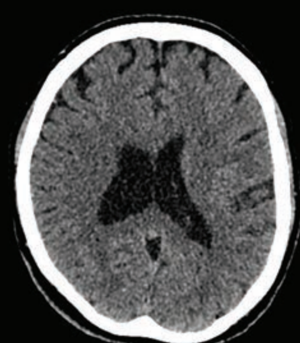
Key findings

Precise Image can reduce radiation dose compared to a diagnostic reference level (12 mGy FBP) by 25-83%, depending on the level of noise reduction prescribed without compromising diagnostic image quality, surpassing the dose reduction achieved through iDose[4].

Clinical image comparisons

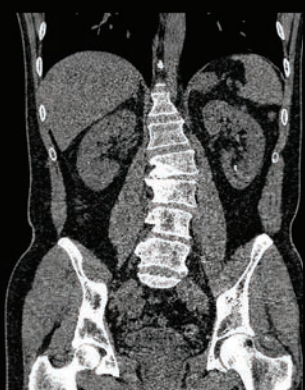
iDose^4

Precise Image



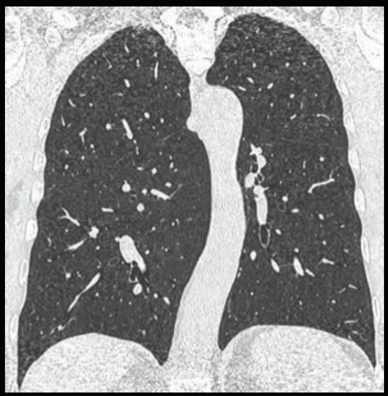
iDose^4

Precise Image

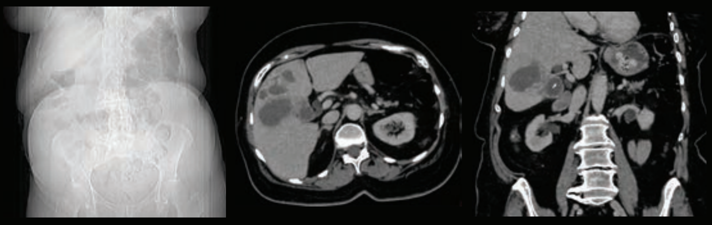


iDose^4, 1 mm slices

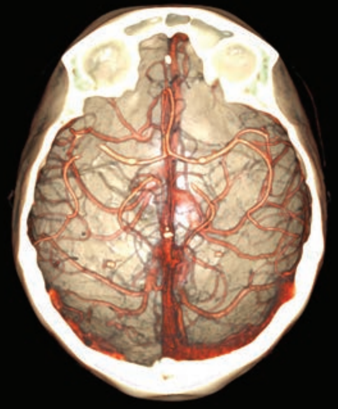
Precise Image, 1 mm slices



Precise Image, 1 mm slices
80 kVp, 35 mAs, $CTDI_{vol}$ 0.8 mGy, DLP 33 mGy*cm, effective dose 0.46 mSv (k= 0.014)



Precise Image, BMI 45, 1 mm slices

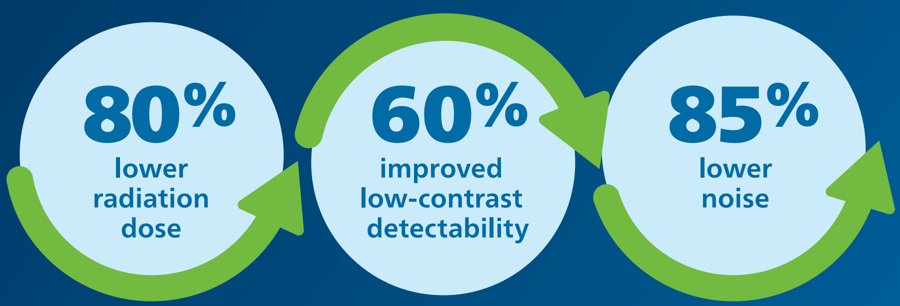


Precise Image, Photo Realistic Volume Rendering

Conclusion

Precise Image significantly lowers dose, while at the same time improving image quality with fast reconstruction time

Precise Image is an advanced AI-enabled reconstruction algorithm that has been shown to simultaneously provide 80% lower radiation dose and 85% lower noise and 60% improved low contrast detectability. It can be used in a wide range of clinical applications – from body to head to cardiac.* It offers an image appearance that closely resembles FBP and delivers results quickly, with all reference protocols reconstructed in less than a minute.



*Precise Image for cardiac scans is 510(k) pending – not available for sale in the USA.
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Printed in the Netherlands.
4522 991 85841 * APR 2024