GE Healthcare

Benefits of ASiR-V* Reconstruction for Reducing Patient Radiation Dose and Preserving Diagnostic Quality in CT Exams

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Abstract

A newly developed iterative reconstruction algorithm has potential to achieve significant reductions in patient radiation dose in CT exams while achieving image reconstruction speed similar to that of conventional analytical reconstruction using filtered back projection (FBP). The new method, ASiR-V, represents the next generation of Adaptive Statistical Iterative Reconstruction (ASiR*), which has been broadly adopted on CT systems worldwide for its ability to help reduce patient dose while maintaining image quality. It also has capability to improve imaging performance. Evidence for dose-reduction and image-quality benefits of ASiR-V was produced for low-contrast detectability in a large-scale model observer study, following the approach recommended by the MITA-FDA CT IQ Task Group, formed by the Medical Imaging & Technology Alliance (MITA) and the U.S. Food and Drug Administration. In this study, ASiR-V was shown to reduce dose by up to 82%† compared to standard filtered back projection (FBP) reconstruction at the same image quality. Dose-reduction benefits from ASiR-V were also observed in comparisons of actual clinical images from the same patients acquired using low-dose ASiR-V and high-dose FBP reconstruction. Image noise was significantly reduced in the ASiR-V images, and low-contrast objects were easier to distinguish when compared to the corresponding FBP reconstructions.

† In clinical practice, the use of ASiR-V may reduce CT patient dose depending on the clinical task, patient size, anatomical location, and clinical practice. 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. Low Contrast Detectability (LCD), Image Noise, Spatial Resolution and Artifact were assessed using reference factory protocols comparing ASiR-V and FBP. The LCD was measured in 0.625 mm slices and tested for both head and body modes using the MITA CT IQ Phantom (CCT183, The Phantom Laboratory), using model observer method.

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Background

In recent years, there has been increasing focus in the radiology community on reducing patients' X-ray radiation exposure. Correspondingly, one key focus of research and development among computed tomography (CT) system manufacturers has been on techniques to maintain or improve image quality and diagnostic efficacy while reducing patient radiation dose. This paper describes the next generation of the widely accepted Adaptive Statistical Iterative Reconstruction (ASiR) algorithm for enabling CT images with adequate image quality and diagnostic value at significantly lower radiation dose.

Challenge of Image Quality at Low Radiation Dose

CT imaging at low dose has always been challenging because the low-dose images are subject to contamination by image artifacts. In CT, patient images are generated (reconstructed) from detector measurements. For low-dose scanning, the noise properties of a CT detector play a critical role in image quality. In general, a detector signal contains two kinds of noise: X-ray photon noise and electronic noise in the data acquisition system. When the dose is low, the electronic noise could become the dominant noise factor and thus limit the low-dose performance of the CT system. The noise characteristics of the images themselves also need to be considered.

Approaches to Low-dose Image Reconstruction

A few years ago, conventional analytical reconstruction using filtered back-projection (FBP) was the primary reconstruction approach for the majority of commercial CT systems—it offered fast processing speed and robust image quality. However, for low-dose scans, FBP reconstruction suffers from noise and artifact contamination, which can reduce diagnostic confidence and accuracy. More recently, iterative reconstruction (IR) has been widely recognized as more effective than FBP in dealing with CT data acquired at lower radiation doses while preserving, or even enhancing, diagnostic accuracy and quality.

Adaptive Statistical Iterative Reconstruction (ASiR)[1] was the first commercially available reconstruction algorithm that provided significant dose benefit for CT imaging. ASiR has been accepted by numerous sites as the standard-of-care protocol for a variety of applications. As of March 2014, it has been installed on more than 4,200 CT systems, and it is the world's most-used iterative reconstruction (IR) method.

Latest Advance in High-quality, Low-dose Imaging

The latest enhancement to low-dose CT imaging is ASiR-V, the next generation of ASiR.

ASIR-V differs from the earlier Veo CT model-based iterative reconstruction,[2] in that it de-emphasizes the system optics modeling, enabling reconstruction speed similar to FBP. It is also designed to work for the majority of clinical modes on multiple CT products. Compared to ASiR, ASiR-V contains more advanced noise modeling and object modeling. ASiR-V has also added some physics modeling. ASiR-V reconstruction offers further promise toward the aim of acquiring low-dose CT exams at lower radiation dose to patients, while preserving or even enhancing diagnostic value. It is in use on several GE CT systems.

In general, a statistical iterative reconstruction obtains the final clinical image in an iterative manner as shown in Figure 1. At the beginning of the image reconstruction, an initial estimate of the imaged object is made. The estimate can be as simple as a constant value across the entire image, or an FBP reconstructed image. Then the initial estimate is updated based on actual measured projections, prior information, or characteristics that one knows about the imaging system and the imaged object. System optics and noise statistics, object and physics models are often incorporated in the iterative cycles to adjust the image reconstruction process.

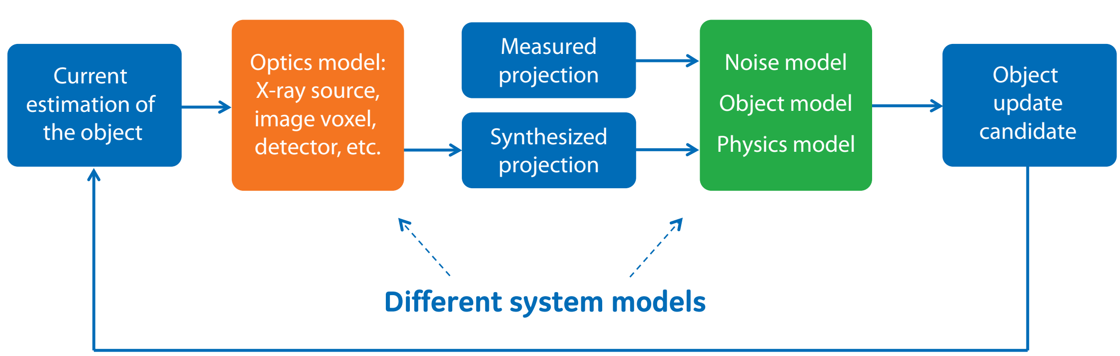

Figure 1: Flow diagram of iterative reconstruction process.

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The iterative reconstruction can be modeled as an optimization process that minimizes the following cost function:

$$\hat{x} = arg\min_{x}\{L(Ax,y)_w + \propto G(x)\},^1$$

Where:

$\hat{x}$ is a vector representing the next estimation of the reconstructed image vector x

A is the system matrix modeling the projection generation process

y is the measured projection vector

L is a data-matching function

G is a prior function governing the regularization process

w is a weighting function often related to the statistics estimation

$\propto$ is a parameter controlling the strength of the prior term.

The accurate modeling of the system optics (the orange box in Figure 1) is mainly responsible for the improvement in spatial resolution of the reconstructed images. The accurate modeling of the system noise statistics, object, and physics (the green box in Figure 1) contributes mainly to the reduction of noise, improvement of LCD, and reduction of artifacts in the reconstructed images. The ASiR-V algorithm focuses primarily on the modeling of the system noise statistics, objects, and physics and de-emphasizes the modeling of the system optics. The most time-consuming portion of the IR process is the modeling of the system optics. By excluding the most time-consuming component, system optics, and focusing on the other terms during the IR process, significant image quality improvement can be achieved without paying a large penalty in reconstruction speed.

ASiR-V reconstruction leverages an extensive system of statistical modeling that scientists and engineers have developed over the years. The advanced system noise model includes the modeling of the data acquisition system (photon noise and electronic noise) as well as noise characteristics of the reconstructed images. The photon noise model includes characterization of the photon statistics as it propagates through the imaging chain. The modeling of the reconstructed image noise includes characterization of the scanned object, using information obtained from extensive phantom and clinical data.

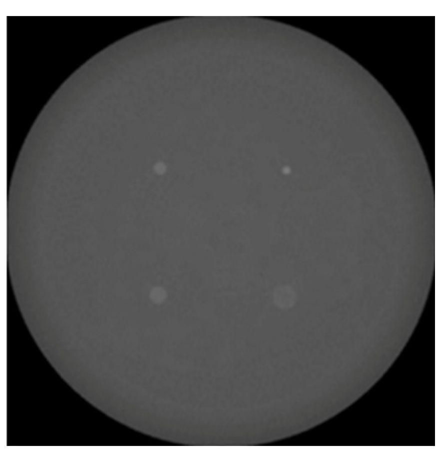

Figure 2: Left: A MITA LCD IQ phantom. Right: A CT image of four low-contrast objects in the MITA phantom.

Evidence of ASiR-V Dose Benefit and Image Quality Improvement

ASiR-V reduces dose up to 82% relative to FBP at the same image quality.‡

Quantifying dose reduction for IR methods can be complicated due to the inherent non-linear nature of the process. Various techniques have been used in the past to evaluate dose reduction, but many are not task-based and fail to guide clinical practice. Recognizing this problem, the Medical Imaging & Technology Alliance (MITA) and the U.S. Food and Drug Administration (FDA) have formed a joint MITA-FDA CT IQ Task Group to address it. The MITA LCD IQ phantom (Figure 2), which contains several low-contrast objects, was recommended for use to assess the dose-saving capability of IR algorithms through model or human observer studies.

Model observer studies have been applied extensively in quantifying nuclear medicine imaging and are now becoming more popular in quantifying CT imaging. LCD performance, which is directly affected by X-ray radiation dose used in imaging procedures, can be evaluated using mathematical model observers. A mathematical model observer for the CT detection task is a mathematical function that reads a CT image, analyzes its statistical properties, and quantifies the signal (low-contrast object, i.e., lesions) and background (quantum noise, electronic noise, and patient anatomical noise) characteristics. The output of this function is a scalar test statistic that is compared to a threshold to make a decision on whether the signal is present or absent. Model observers are consistent and objective, and some have been demonstrated to correlate well with human observer results for clinically relevant scenarios.[3] To determine the dose-reduction capability of ASiR-V,

‡ Image quality as defined by low contrast detectability. In clinical practice, the use of ASiR-V may reduce CT patient dose depending on the clinical task, patient size, anatomical location, and clinical practice. 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.

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hundreds of samples of the MITA LCD IQ phantom at various dose levels were acquired and processed through the selected model observer. The model observer evaluated the low-contrast objects in the phantom and determined the metric of detectability, which is the area under the receiver operating characteristics curve (AUC). The greater the AUC value, the easier it is to detect the object. By demonstrating that a lower-dose acquisition reconstructed with ASiR-V provides an AUC value not less than that of a high-dose scan reconstructed with FBP, one can quantify the dose-reduction capability from ASiR-V for this detection task.

In a large-scale model observer study, ASiR-V was shown to reduce dose up to 82% by following the recommended approach from the MITA-FDA Task Group. Figure 3 shows an example AUC comparison for four different low-contrast objects between high-dose FBP reconstruction, low-dose FBP reconstruction, and low-dose ASiR-V reconstruction. For each of the four contrast objects, which vary in size and intensity, it is clear that the AUC values for ASiR-V at low dose are significantly higher than the AUC values of FBP at low dose, and are equal to or greater than the AUC values of the high-dose FBP reconstruction.

The dose-reduction benefit from ASiR-V can also be seen on clinical images shown in Figure 4. In this figure, two patient cases are presented, each case containing a high-dose scan and a low-dose scan from the same patient. It is clear that the low-dose ASiR-V reconstruction provides similar image quality to the high-dose FBP reconstruction. Image noise is largely reduced in the ASiR-V images, and low-contrast objects are easier to distinguish when compared to the corresponding FBP reconstructions.

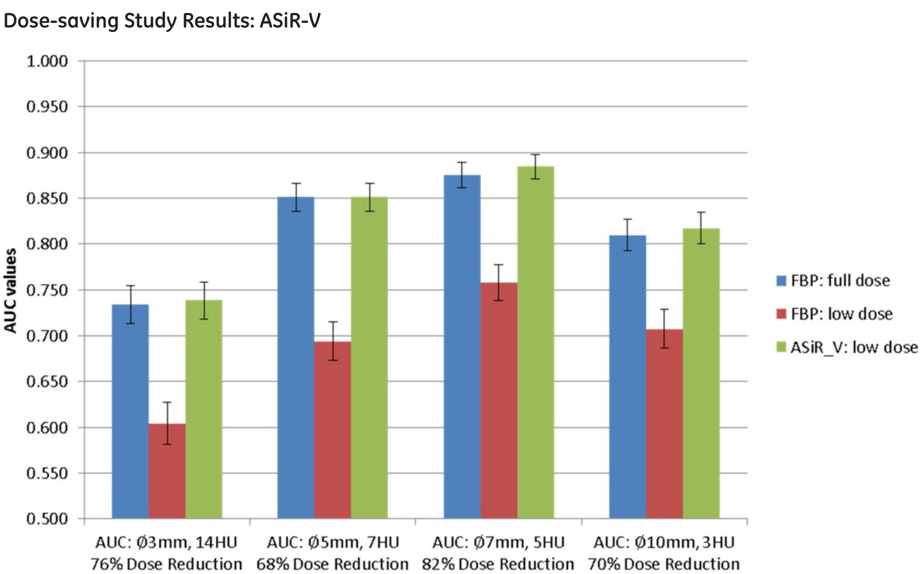

Figure 3: AUC values for high-dose FBP, low-dose FBP, and low-dose ASiR-V for four different low-contrast objects. The AUC values were calculated using the MITA-FDA recommended method. High-dose FBP and low-dose ASiR-V give similar AUC values while low-dose FBP has a significantly lower AUC value. Up to 82% dose reduction is observed with ASiR-V in this study. The variances of estimated AUC values were estimated via the one-shot method.[4]

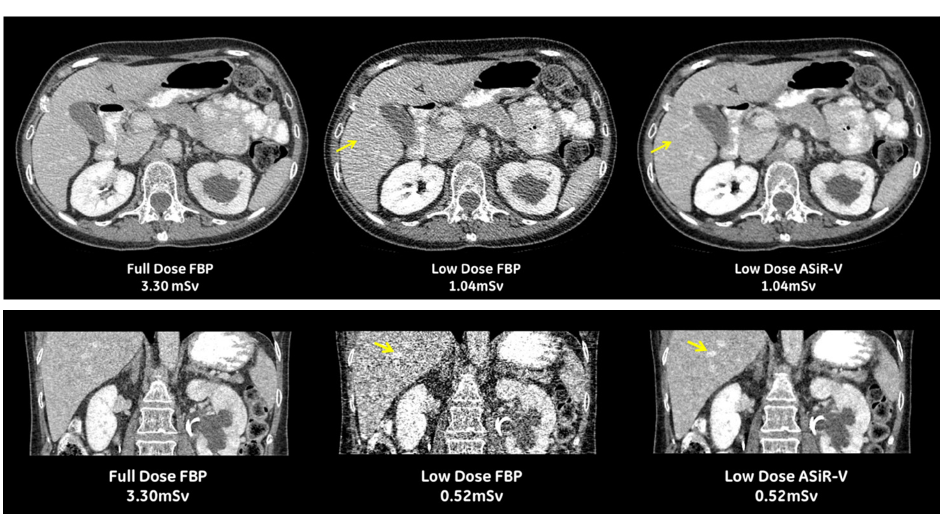

Figure 4: Two clinical cases of dose reduction. The low-dose ASiR-V reconstruction gives image quality similar to the full-dose FBP reconstruction. The top and bottom cases show two different lower-body abdomen acquisitions with a scan length of 135 mm. The top case indicates more than 3X dose reduction, and the bottom case indicates more than 5X dose reduction. Improvements in noise, low-signal streak artifacts, and LCD are demonstrated (as indicated by the arrows in the bottom case for noise and LCD and in the top case for streaks). The dose information for the corresponding scans is provided in the figure.

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LCD Improvement Study Results: ASiR-V

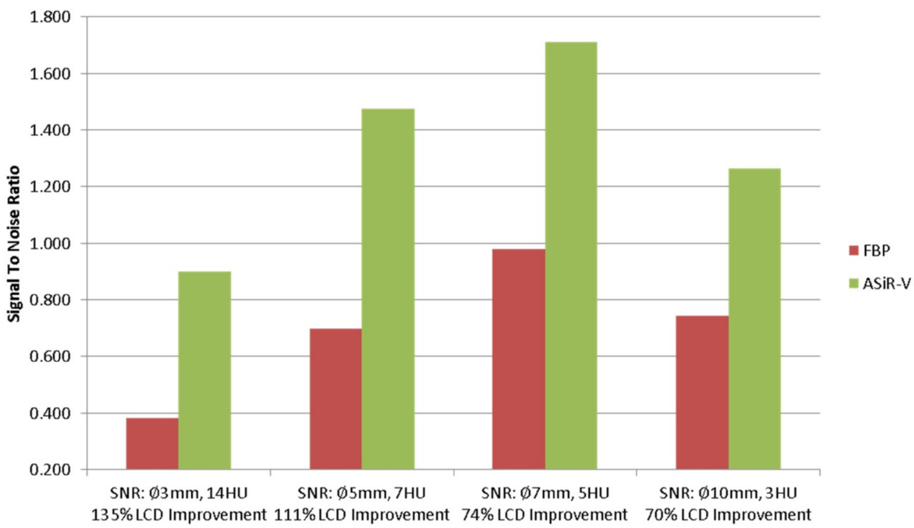

Figure 5: LCD Improvement of the low-contrast objects.

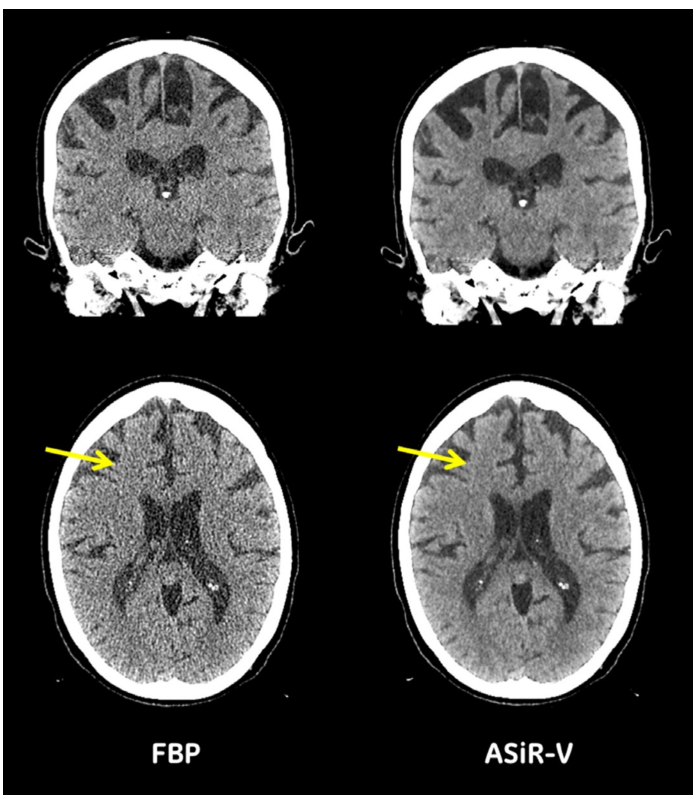

Figure 6: ASiR-V reduces noise in a neurology case and enables better gray/white matter differentiation, as indicated by the arrows.

ASiR-V improves low-contrast detectability relative to FBP up to 135% at the same dose.

The ability to detect low-contrast objects is a function of scan dose and image noise. The general trend in CT imaging is to reduce the dose of clinical scans, thereby reducing radiation exposure to the patient. However, a side effect of dose reduction is increased image noise, which limits the ability to detect low-contrast objects. ASiR-V increases the detectability of low-contrast objects, thus offering the capability to reduce patient dose. Again, the model observer approach can be used to demonstrate the LCD improvements that result from ASiR-V.

For a detection task, the degree of overlap between the probability density functions of the test statistics determines the detectability of a signal. The detectability index (signal-to-noise ratio, or SNR) has been widely used to quantify the ability to detect a signal.[3] This study also applied the detectability index to describe and compare the LCD performance of the FBP and ASiR-V reconstruction algorithms.

Study results demonstrated that ASiR-V improves LCD relative to FBP by up to 135% at the same dose, as shown in Figure 5. Figure 6 provides a clinical example of ASiR-V LCD improvement in a neurology case.

ASiR-V significantly reduces noise compared to FBP at the same dose.

A known consequence of dose reduction is an increase in image noise, typically defined as the standard deviation of the CT number in a region of interest of a uniform region. The magnitude of noise in the images can have a direct impact on diagnostic accuracy. As described previously, the ASiR-V algorithm enables dose reduction by intelligently reducing noise compared to FBP reconstruction. Alternatively, when the dose is kept the same, the ASiR-V algorithm improves image quality by reducing noise compared to FBP.

Depending upon the scan technique and reconstruction parameters, the noise can be decreased significantly with ASiR-V. In Figure 7, one can observe noise reductions of 84% for a low-dose abdomen case and 74% for a low-dose pulmonary case.

ASiR-V has the capability to improve spatial resolution compared to FBP at the same image noise.

To decrease dose and maintain equivalent image quality, noise reduction is required in clinical images. However, noise reduction could result in loss of spatial resolution. ASiR-V preserves spatial resolution while decreasing dose, or reducing noise and improving the LCD—and it also has the capability to achieve higher spatial resolution when compared to FBP at the same image noise.

Figure 8 presents an ankle case where ASiR-V clearly improves the resolution of the cortical bone while maintaining a noise level similar to that of the FBP reconstruction.

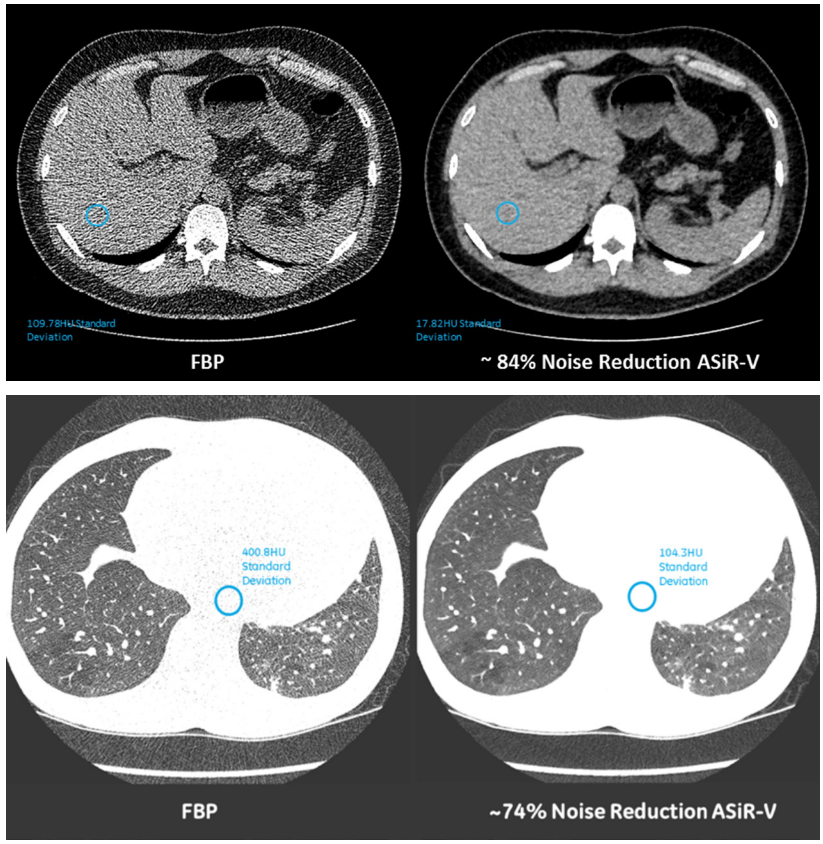

Figure 7: ASiR-V reduces streaks and noise in clinical images. The top row shows an ultra-low-dose abdomen scan where ASiR-V significantly reduced low-signal streaks and image noise. The bottom row shows a pulmonary clinical case where ASiR-V reduced image noise to help visualize lung structure and low-density variations.

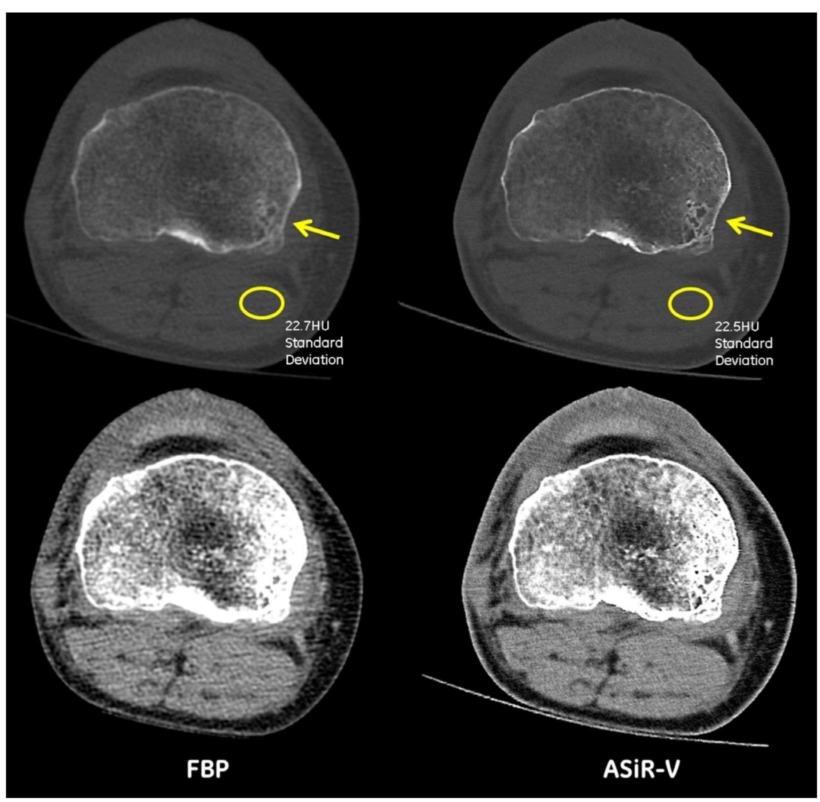

Figure 8: A clinical ankle case. The FBP reconstruction clearly has lower resolution than the ASiR-V reconstruction, as pointed out by the arrows. The ASiR-V reconstruction displays a noise level similar to the FBP reconstruction, as shown by the ROI measurements.

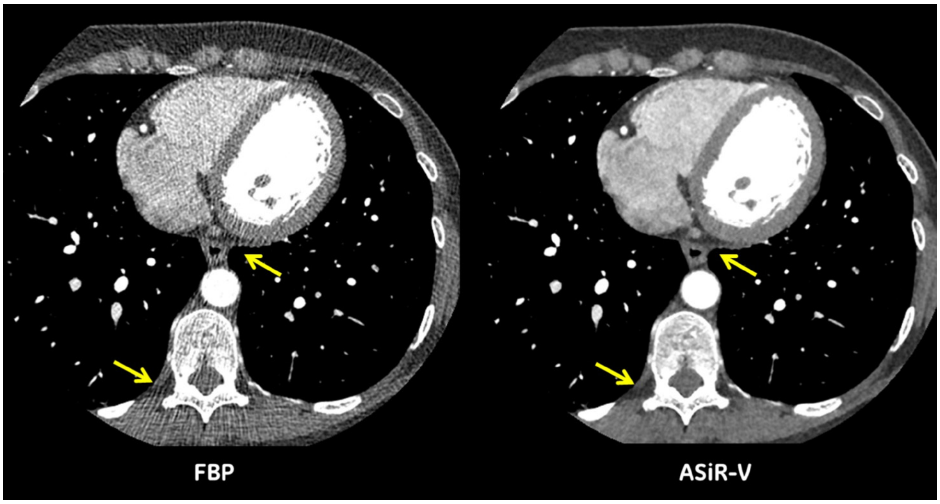

Figure 9: A 0.28s-per-rotation cardiac scan. Streaks can clearly be seen in the FBP reconstruction, as pointed out by the arrows. The streaks are almost completely removed from the ASiR-V reconstructed image.

ASiR-V has the capability to reduce low-signal artifact, such as streak artifact, compared to FBP.

When the dose is low during a clinical acquisition, photon starvation will cause low-signal artifacts (i.e., streaks) in the image. The presence of streaks may affect a diagnosis if the streaks interact with critical clinical information. ASiR-V has the capability to reduce low-signal artifact, such as streak artifacts, when compared to FBP.

Figure 9 shows a cardiac scan where ASiR-V almost completely removes the low-signal streaks that are clearly visible in the FBP reconstruction.

ASiR-V reconstruction offers further promise toward the aim of acquiring low-dose CT exams at lower radiation dose to patients, while preserving or even enhancing diagnostic value.

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imagination at work

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