

SAFIRE: Sinogram Affirmed Iterative Reconstruction

White Paper

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Recent interest in iterative reconstruction techniques has skyrocketed due to increased focus on CT dose reduction over the past couple of years. Iterative Reconstruction (IR) is an alternative to the more common/traditional Filtered Back Projection (FBP) approach to image creation. IR is a well-understood technique that, in theory, can provide optimal low noise, high contrast images by looping “iteratively” through image reconstruction cycles. While traditional IR is a very robust technique, it is also impractical for clinical scenarios due to high computational hardware and processing time requirements for raw data reconstruction loops. Reconstruction times on the order of hours cannot easily be implemented into routine workflows without affecting patient care. Therefore, an alternative to traditional IR is very desirable.

Description of Iterative Reconstruction

Interestingly, there are two key outcomes of applying IR techniques: noise reduction and artifact reduction, with noise reduction being of key interest since it allows for lower dose imaging.

In traditional IR, once an image is reconstructed from the measured projections (raw data), a “forward” projection, which follows the original reconstruction rays in reverse, back through the original image, is performed to re-create an estimate of the raw data. This forward projection models the CT measurement process, but now, the image serves as the measured object in place of the patient. If the original image reconstruction was perfect, the measured and simulated (forward) projections would be identical.

In reality, they are not identical, and the differences between these two sets of projections are used to reconstruct a corrected image, which in turn, is used to update the original image. In each update cycle, non-linear processing (“regularization”) of the updated image is performed to ensure the stability of the reconstruction (convergence) and to selectively

reduce image noise in more homogeneous areas. After the correction/regularization, the cycle is repeated, thereby improving the image with each iteration (containing less noise) and, therefore, a better contrast-to-noise ratio.¹

As mentioned previously, the forward projection process in traditional IR is extremely time-consuming, particularly if you have to model the system precisely in order to account for the true detector and focal spot geometry. However, due to the linear nature of CT image reconstruction, it can be mathematically shown that noise reduction also can be accomplished equally in image space. Thus, the real benefit of raw data space iterations comes in the form of artifact reduction and increased spatial resolution beyond the classical limit. This key mathematical proof greatly reduces the computational time necessary for IR, since only a rough modeling of the projection rays are necessary and are only used for artifact reduction.²⁻⁴ Furthermore, an over-sampling during data acquisition utilizing a flying focal spot also allows for increased spatial resolution equivalent to traditional IR by simply adapting FBP to over-sampled projection data, thus enabling a fast and efficient method to achieve higher spatial resolution without time-consuming iterations.

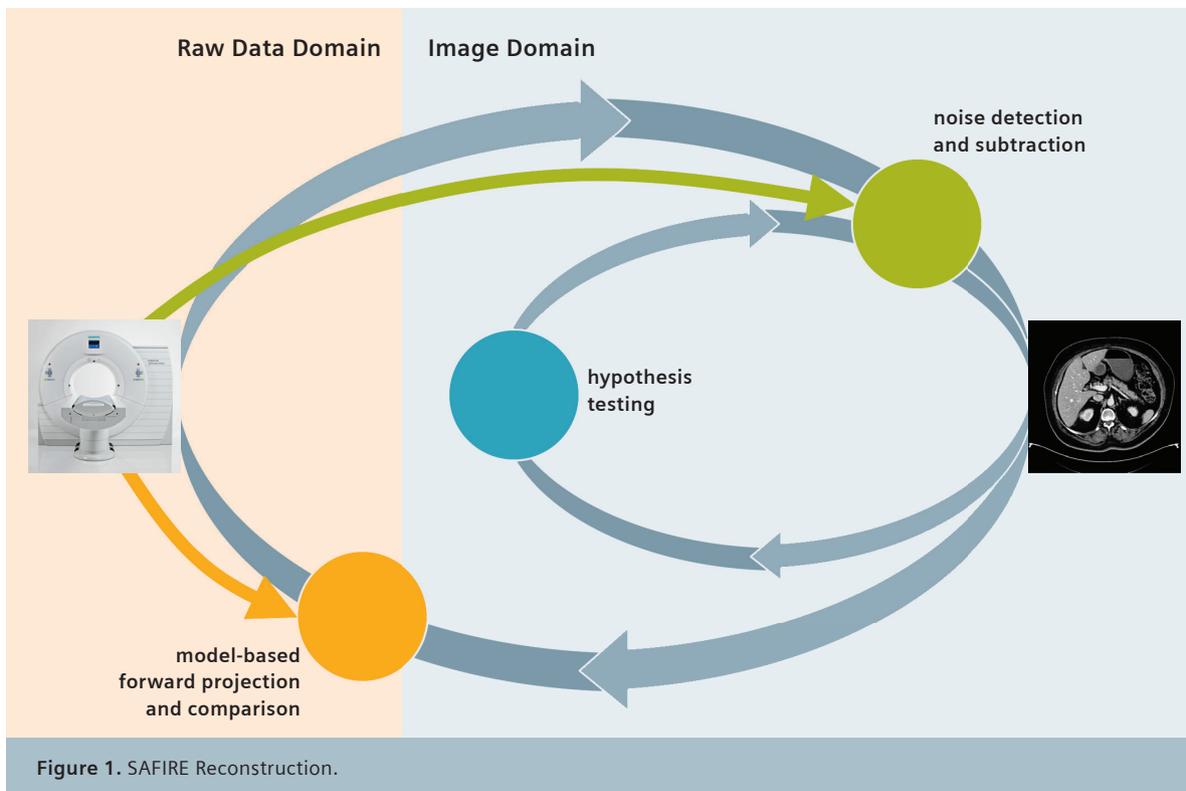
Siemens has taken advantage of these mathematical details and in 2010 introduced Sinogram Affirmed Iterative Reconstruction—SAFIRE. SAFIRE is an advanced IR technique that utilizes both projection space (raw) data and image space data, with the number of iterations in each “space” dependent on the needs of a specific scan. In contrast to other pure raw-data-based IR algorithms, SAFIRE is available right on the scanner and can reconstruct up to 20 images per second. Therefore, SAFIRE can easily be used in routine clinical workflow, with well-established reconstruction kernels, providing up to 60% reduction in dose.[†]

SAFIRE Reconstruction

Similar to traditional IR, SAFIRE performs an initial reconstruction using a weighted FBP, following which, two different correction loops are introduced into the reconstruction process. (Figure 1) The first loop, where data is re-projected into the raw data space (sinogram data), is utilized to correct imperfections in the original reconstruction and remove any artifacts from the data. This allows for additional validation of the images with the measurement data. The detected deviations are again reconstructed using the weighted FBP, yielding an updated image. This loop is then

repeated a number of times depending on the exam type. Within each iteration, a dynamic raw-data-based noise model is applied, allowing for reduction of image noise without noticeable loss of sharpness.

The second correction loop occurs in image space, where noise is removed from the image through a statistical optimization process. However, the regularization is still based on the knowledge of how noise in the projection (raw) data propagates into image space. The corrected image is compared to the original, and the process is repeated a number of times depending on the exam type.⁵



Motivated by variability in reader preference and image quality requirements for different exam types, five different “strengths,” defining parameters of the underlying noise model/regularization, are offered with SAFIRE. SAFIRE strengths 1–5 can be previewed for each reconstruction, with the default strength set at 3.

The level of noise reduction and noise texture will change depending on the strength that the user chooses for each reconstruction, with strength 1 being noisier and strength 5 being smoother. The strengths are NOT an indication of the number of iterations and will NOT affect reconstruction time. (Figure 2)

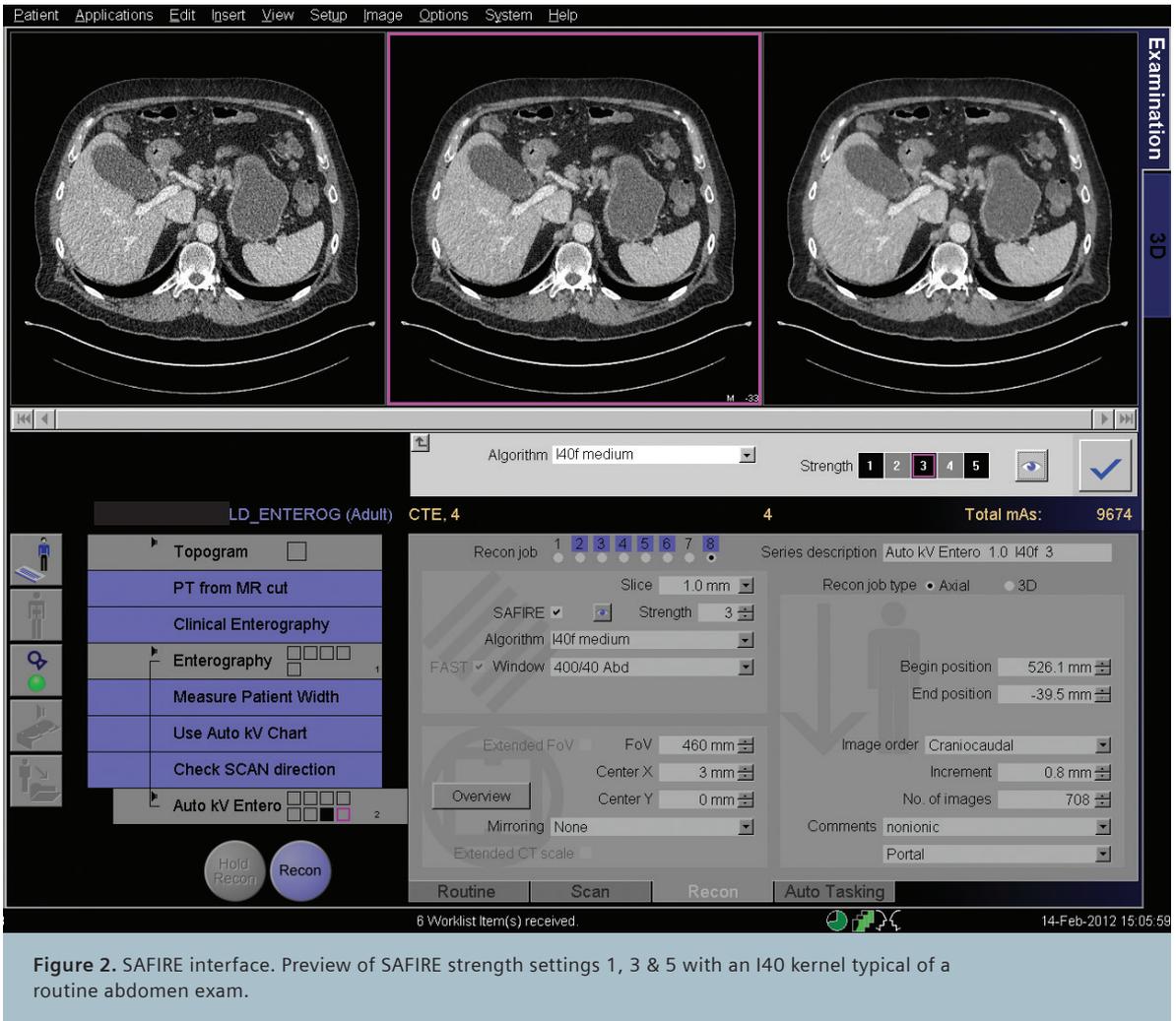
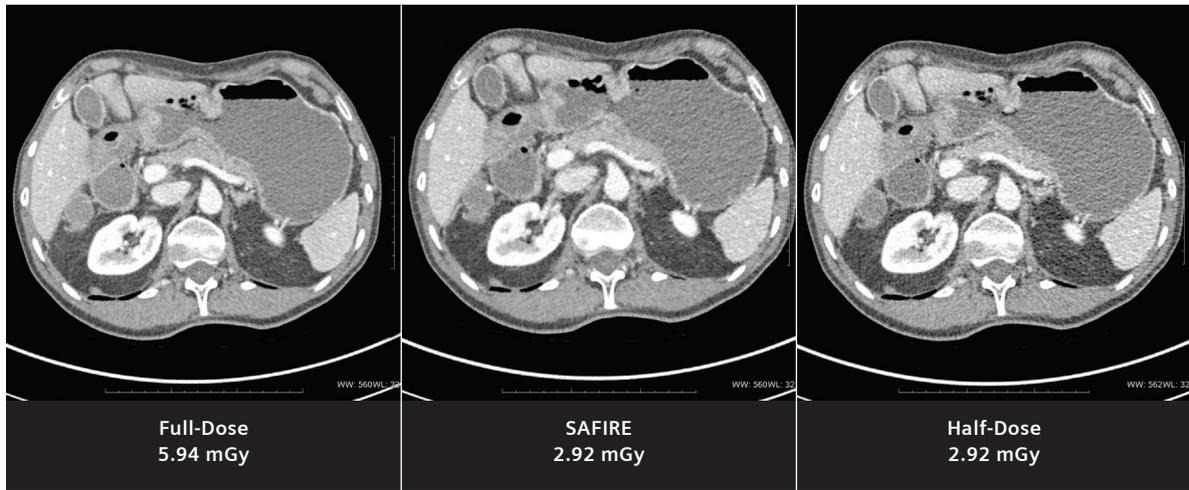


Figure 2. SAFIRE interface. Preview of SAFIRE strength settings 1, 3 & 5 with an I40 kernel typical of a routine abdomen exam.

In an improvement compared to other commercially available IR solutions, SAFIRE images have noise texture nearly equivalent to standard images. In blinded studies, readers could not differentiate between full-dose images with standard reconstruction and half-dose images reconstructed with SAFIRE.⁶⁻⁷ (Example 1)

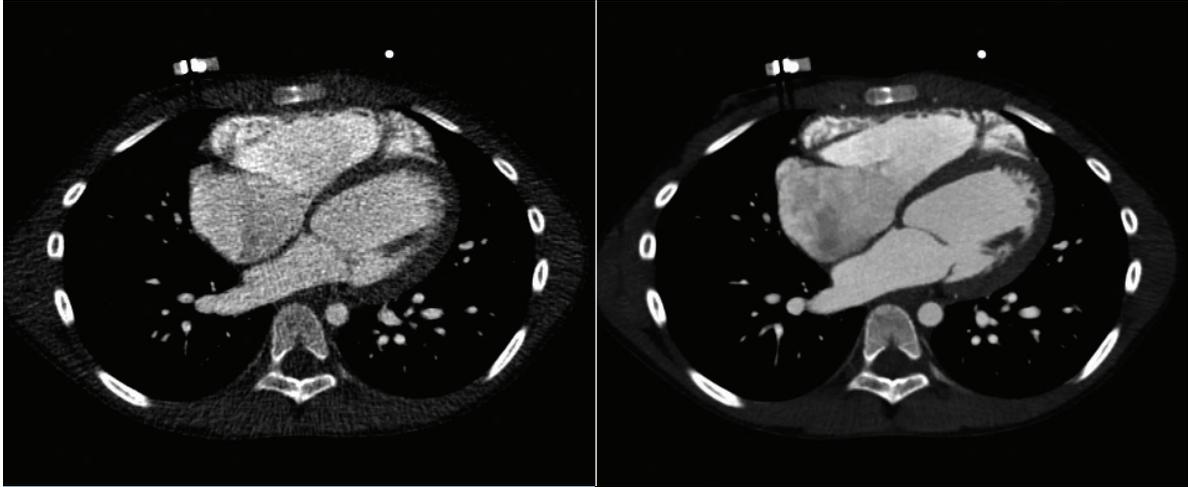
In this clinical study conducted at the Mayo Clinic⁶, researchers found that images reconstructed with SAFIRE at half the routine dose (2.92 mGy) were of equivalent image quality to standard (wFBP) images at full dose (5.94 mGy), and that inter-reader variability played the largest role in diagnostic accuracy.



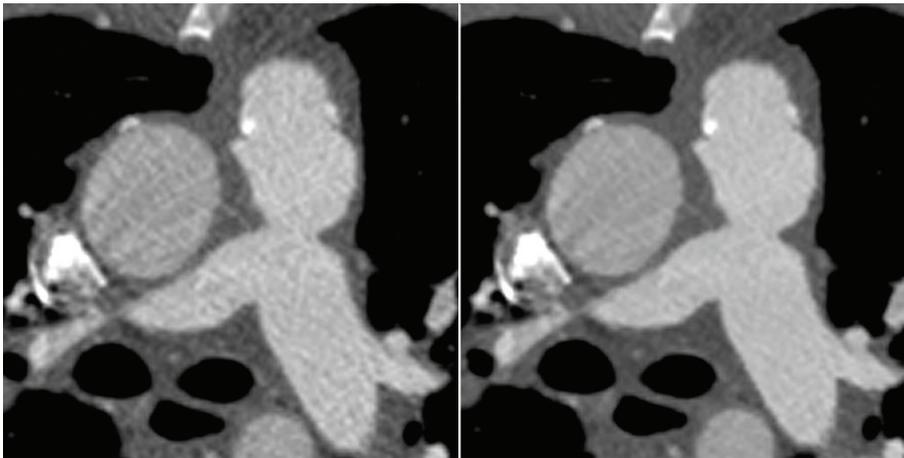
Example 1: CT enterography at 80 kV. Images were reconstructed at 2-mm slices using the B40 kernel for the full-dose and half-dose exam. The corresponding I40 kernel was utilized for reconstructing the half-dose SAFIRE images. Images Copyright 2011, Mayo Foundation for Medical Education and Research.

Similar to other IR techniques such as IRIS (Iterative Reconstruction in Image Space), SAFIRE is not for dose reduction alone; it can also be used to improve image quality, as in the case of very low dose pediatric imaging, or to reduce noise in obese patient scans. Example 2 shows a very low dose pediatric cardiac scan with a DLP of 12. In this case, SAFIRE reduced image noise by ~35% and improved

SNR and CNR (~50% each) while maintaining the contrast (HU values). Diagnostic confidence was unaffected. In a larger study on 55 pediatric cardiac patients, SAFIRE was found to significantly reduce image noise (by 35%) and improve qualitative assessment of image noise and noise texture. An additional pediatric example can be found in Example 3.⁸⁻⁹



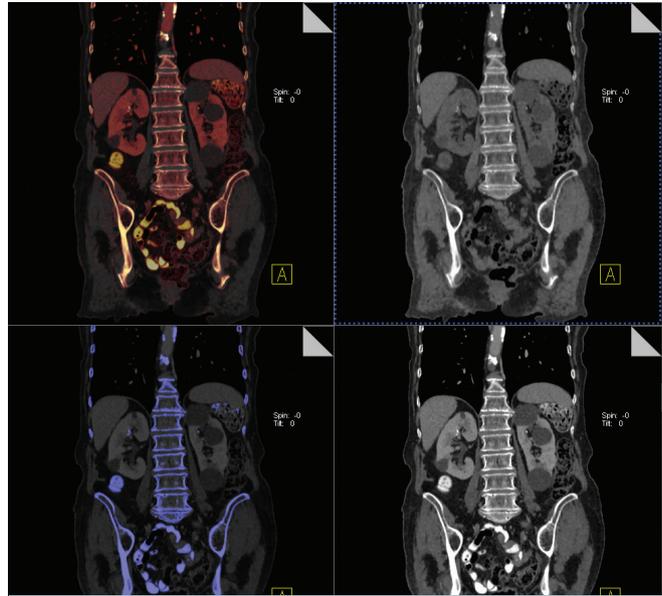
Example 2: Pediatric Congenital Heart Disease: RVOT conduit at 80 kV, DLP 12. Left: standard weighted FBP reconstruction (B36 kernel), Right: SAFIRE reconstruction (I36 kernel). Images Copyright 2011, Minneapolis Heart Institute Foundation.



Example 3: Pediatric Congenital Heart Disease, pulmonary artery conduit at 80 kV, DLP 41. Left: standard weighted FBP reconstruction (B36 kernel), Right: SAFIRE reconstruction (I36 kernel). Images Copyright 2011, Minneapolis Heart Institute Foundation.

Several other scientific and clinical studies have been conducted and published regarding the benefits of using SAFIRE.⁹⁻¹⁵ SAFIRE can also be used on Dual Energy images as seen in Example 4. While SAFIRE can reduce image noise by up to 60%†, and improve image quality in noisier exams, it is also easily integrated into routine workflow. In addition, it may provide some users the confidence needed to begin lowering routine dose levels.

In contrast to other “straightforward” implementations of traditional IR requiring extensive hardware in order to barely obtain reconstruction times in the order of hours, SAFIRE maintains the advantages of a general IR approach with routinely acceptable computation time. This is achieved by intelligently applying the respective mechanisms for noise reduction, increased spatial resolution, and artifact reduction in the data space where it can be accomplished most effectively.



Example 4: SAFIRE for dual energy imaging. Image descriptions clockwise from top left: color overlay, vnc, renal stone and monoenergetic E=78keV.

† In clinical practice, the use of SAFIRE 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. The following test method was used to determine a 54 to 60% dose reduction when using the SAFIRE reconstruction software. Noise, CT numbers, homogeneity, low contrast resolution, and high contrast resolution were assessed in a Gammex 438 phantom. Low dose data reconstructed with SAFIRE showed the same image quality compared to full dose data based on this test. Data on file.

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