White Paper

Practical application of Iterative Reconstruction in Radiotherapy

To improve image quality for Radiotherapy CT Planning in 4DCT and Bariatric Cases

siemens-healthineers.com/ct-for-rt

SIEMENS Healthineers

White Paper

George Noid, PhD, Medical College of Wisconsin Department of Radiation Oncology

Nilesh Mistry, PhD, Siemens Healthineers

X. Allen Li, PhD, Medical College of Wisconsin Department of Radiation Oncology

Practical application of Iterative Reconstruction in Radiotherapy to improve image quality for Radiotherapy CT Planning in 4DCT and Bariatric Cases

Introduction

Excellent CT image quality is essential for radiation therapy planning with external beam and stereotactic treatment strategies. High soft tissue contrast, high spatial resolution, and sharper images with low image noise enable conformal therapy plans; that in-turn helps achieve the desired dose coverage while sparing adjacent organs at risk. Image quality often comes at the cost of higher imaging dose to the patients. However, it is desirable to reduce the imaging dose to the patient in order to mitigate the risk of inducing secondary malignancies, especially in the era where repeat imaging is often performed to determine the need for treatment adaptation. This is also true with early detection that may increase the number of patients being treated with radiotherapy at relatively young age with anticipated long term survival. Improving image quality while reducing or maintaining imaging dose can be achieved by applying Iterative Reconstructions (IR) such as the Sinogram Affirmed Iterative Reconstructions (SAFIRE*). SAFIRE reduces image noise while preserving contrast and spatial resolution, thereby ensuring that the data remains appropriate for planning.

Here, we demonstrate an application of SAFIRE in two situations: a) respiration correlated 4-dimensional CT (4DCT) and, b) CT for patients with high body mass index (BMI). Both of these situations often lead to images that are noisy thus limiting their usefulness in treatment planning. SAFIRE offers the possibility to improve image quality as measured by contrast and noise metrics, in these typical use cases while maintaining acceptable imaging dose.

Sinogram Affirmed Iterative Reconstruction

IR is an increasingly common alternative to traditional Filtered Back Projection (FBP) reconstructions of CT data. By iterating through image reconstruction cycles, one can generate optimal low noise, high contrast images (1). The theory behind IR has been around since at least the 1960s but advances in computational power over the past decade have unlocked the potential of the image quality enhancing algorithms (2). Traditional IR techniques start by reconstructing an initial image from the raw data (original sinogram) that is then used to "forward" project an estimate of the raw data (estimated sinogram). While in theory the

** SAFIRE may be optional on certain SOMATOM CT scanners. 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 consolation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.*
‡16 images/sec on and up to 20 images/sec with FAST IRS option (available on specific models).

original and estimated raw data should be identical, in reality this is not the case, and the differences between them can be used to generate a corrected image. For all subsequent iterations, the previous iteration's corrected image is used to generate a new estimated sinogram which in turn is the source of the next corrected image. However, the forward projection generated at each step is time-consuming especially when one has to precisely account for the system geometry, and can significantly slow down the reconstruction.

In comparison to other IR methods, Siemens' SAFIRE* reduces the complexity of the process by performing noise reduction in the image space and reducing artifacts in the raw data space by simplifying the model of projection rays (3) as shown in Figure 1. As a consequence, image quality enhancement is available at the scanner without interrupting clinical work flow. SAFIRE provides the user with control over the degree to which a study set is de-noised via its strength parameter from 1-5 which is related to the number of iterations it performs. Noise reduction is proportional to the SAFIRE strength, as is the additional time necessary for the reconstruction to be completed. A typical abdominal study set can be reconstructed in 9 seconds whereas the same study set requires almost 16 seconds at SAFIRE strength #5, a measureable but not clinically significant delay.

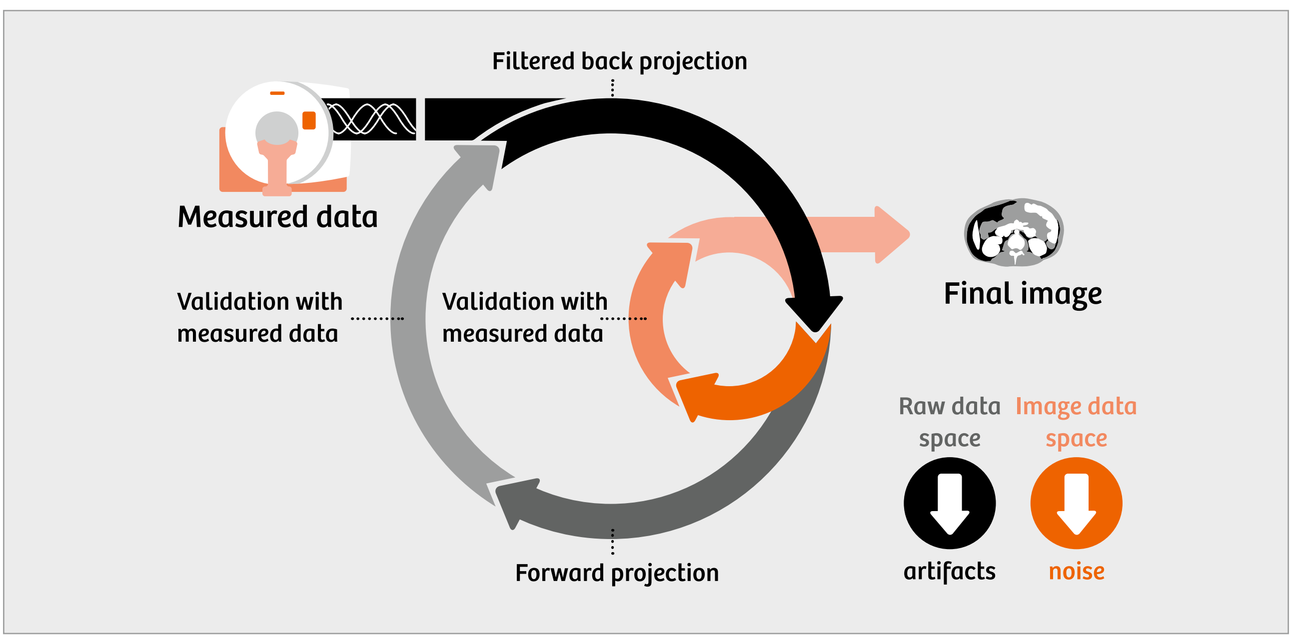

Figure 1: Data-flow used in SAFIRE

*SAFIRE may be optional on certain SOMATOM CT scanners. 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 consolation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.
‡16 images/sec on and up to 20 images/sec with FAST IRS option (available on specific models).

SAFIRE* can be used for all CT acquisitions to improve the image quality, however the advantage is easily demonstrated when using low dose imaging. IR can enable large dose reduction (4) which is of great benefit in diagnostic radiology where the mandate is to reduce the imaging dose to the patient. However, this is less essential in radiation oncology where patients are prescribed x100 more therapeutic radiation per fraction (~2 Gy) than that of a typical abdominal CT (~2 cGy). However, there are situations in Radiation Oncology, where the image quality with standard dose acquisition is degraded due to noise. Here we demonstrate the advantages of SAFIRE in Radiation Oncology in the two common classes of CT studies which are degraded by imaging noise and thus can be meaningfully enhanced using this technique: time sorted 4DCT and scans of patients with high BMI.

Time sorted 4DCT can quantify breathing related target motion for RT planning; this is essential for many thoracic and abdominal tumors (5). On current line of Siemens scanners, a time sorted 4DCT is acquired by scanning the patient with a low pitch (0.09) which facilitates multiple acquisitions of the same axial slice separated in time. By design, the number of acquisitions per axial slice is more than the number of phases of the breathing cycle into which the study set will be sorted. Thus it is possible to sort the images relative to the patient's breathing pattern which is simultaneously acquired using surface markers (optical reflectors) or respiratory bellows. The total imaging dose for such a scan can be 2X to 4X higher than a typical 3DCT (6, 7). However, to create the 4D images the data are then individually binned using either time, phase, or amplitude sorting (available on current line of Siemens CT scanners) and individually reconstructed to create a series of ~10 images; and these individual images are much noisier than a traditional 3DCT as the dose of an individual phase is 1/10th the total imaging dose. SAFIRE is designed to reduce noise without reducing contrast or spatial resolution and thus is an ideal solution for image reconstruction in these noise impaired time sorted 4DCT scans.

Another class of CT images in RT that can be substantially enhanced with the use of SAFIRE is those of patients with high BMI. Obesity is defined by the National Institute of Health in terms of the Body Mass Index. Patients with high BMI typically have a much wider mid-section. A person with a BMI 20% higher than the recommended range of 25 to 29.9 is considered obese. Currently 1 in 3 adults in the United States is obese (8). The noise in an axial slice of a CT is roughly proportional to the diameter of the subject in that axial slice if x-ray tube voltage (energy) and imaging dose are fixed. Hence as a patient's BMI increases the noise in their CT images will also increase. In extreme cases, image quality can be severely degraded as a consequence of increased imaging noise and photon starvation. While increasing the x-ray energy can mitigate the effect, this will also reduce the soft tissue contrast. SAFIRE can be used in such cases to reduce the impact of imaging noise while preserving contrast without increasing the imaging dose.

** SAFIRE may be optional on certain SOMATOM CT scanners. 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 consolation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.*
‡16 images/sec on and up to 20 images/sec with FAST IRS option (available on specific models).

Example cases

4DCT is typically acquired in thoracic or abdominal cases, and we demonstrate the value of using SAFIRE* in a thoracic case in Figure 2. The effect of increasing the SAFIRE strength on a time sorted 4DCT is shown in figure 2. The four images are from an axial slice of a 4DCT set at the 0% expiration phase (end of exhale) during respiration. The study set was acquired on a Siemens CT-on-rails (SOMATOM Definition AS Open) at 120 kVp with a pitch of 0.09, a rotation time of 0.5 s and a CTDIvol of 29.2 mGy. The reconstruction kernel was 30f (medium-smooth kernel) for both the FBP (Figure 2A, B) and SAFIRE images (Figure 2C, D). The noise plotted in Figure 2E is defined as the standard deviation of the voxels in the target ROI (magenta contour) in figure 2A–D. SAFIRE strength 0 in Figure 2E means the image was reconstructed using the standard FBP.

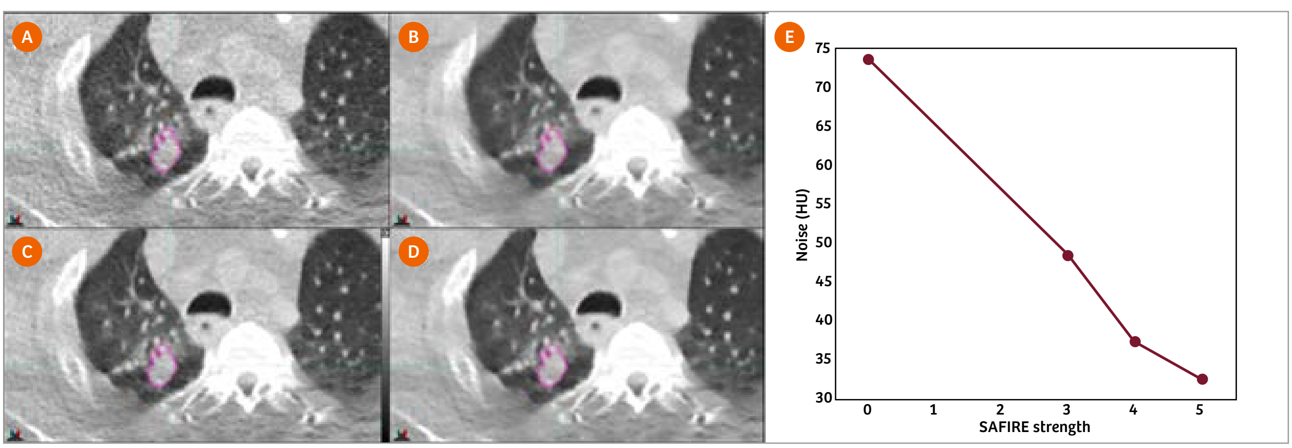

Figure 2: (A-D) axial slices from 4 reconstructions of the same 4DCT dataset time-sorted to the 0% expiration phase. The reconstruction kernel used is 30f (medium-smooth), CTDIvol of 29.2 mGy and a tube voltage of 120 kVp. (A) is the FBP image while the remaining images (B-D) are SAFIRE reconstructions from strength 3 to 5. (E) shows the STD of noise calculated from the region of interest in 6 adjacent slices (not shown in Figure). SAFIRE strength 0 indicates a FBP reconstruction as seen in (A).

Figure 3 demonstrates how noise reduction from SAFIRE can improve auto-segmentation in an axial slice from a time sorted 4DCT. Scan parameters for Figure 3 were the same as for Figure 2 and the study set is time sorted to the 0% expiration phase. The cyan contour of the right lung in Figure 3(A) was generated by a standard auto-contouring algorithm using the region grow tool on the FBP reconstruction. The magenta contour of the right lung in Figure 3(B) was generated using the same tool but on the SAFIRE strength 5 reconstruction of the same time sorted 4DCT. It is evident that noise in the FBP reconstruction degraded the quality of the auto-segmentation.

*SAFIRE may be optional on certain SOMATOM CT scanners. 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 consolation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.
‡16 images/sec on and up to 20 images/sec with FAST IRS option (available on specific models).

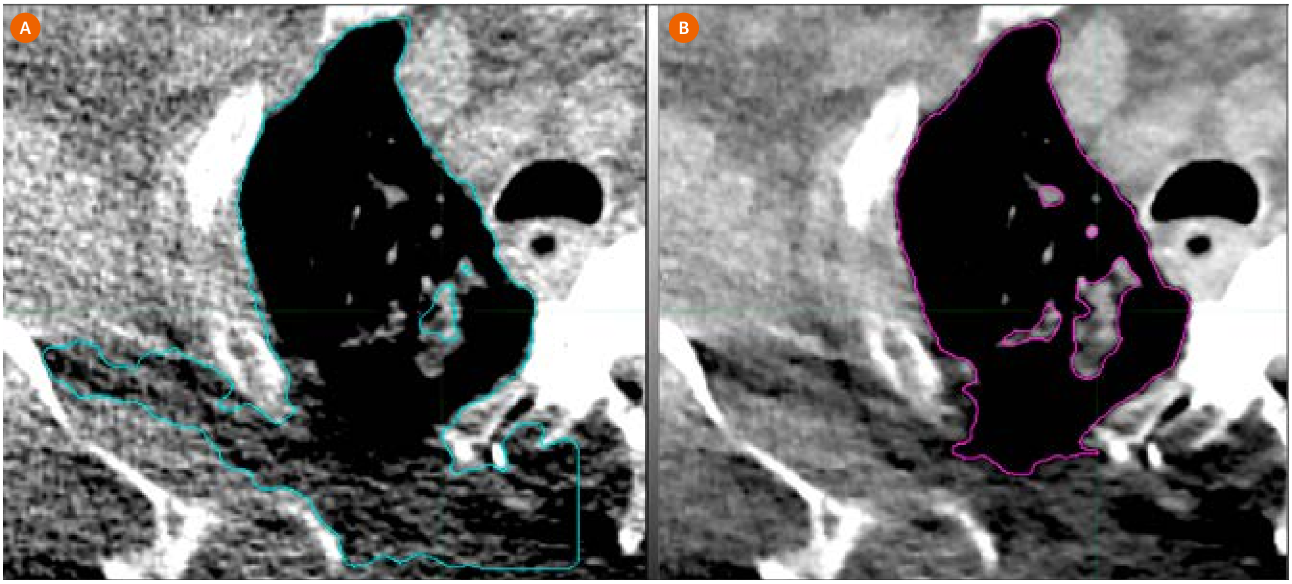

Figure 3: Axial slice from a 4DCT dataset time sorted to the 0% expiration phase in a lung cancer patient. Tube voltage was 120 kV, reconstruction kernel used is 30f (medium-smooth), with an imaging dose measured as CTDIvol of 29.2 mGy. (A) is the FBP reconstruction and (B) is SAFIRE strength 5. The contour in A and B were auto-generated using a standard auto-contouring engine.

Figure 4 illustrates the potential image dose saving using SAFIRE* for 4DCT. For this case two 120 kVp 4DCTs were acquired in the same liver cancer patient on different treatment days. The first utilized the standard protocol imaging dose of 29.2 mGy CTDIvol while the second used the dose level of a standard 3DCT, 17.5 mGy CTDIvol. Both were time sorted to the end of expiration phase and both were reconstructed with a FBP and SAFIRE using the 30f kernel.

Figure 4 A and B are axial slices from the FBP and SAFIRE standard dose acquisitions while C and D are axial slices from the FBP and SAFIRE low dose acquisitions. The two images were registered using a rigid registration tool and the GTV is identified by the magenta contour. The contrast between the GTV and a nearby ROI was used to calculate the contrast to noise ratio (figure 4E). It is noteworthy that the low dose SAFIRE strength 5 study set has a higher contrast to noise ratio than the standard dose FBP.

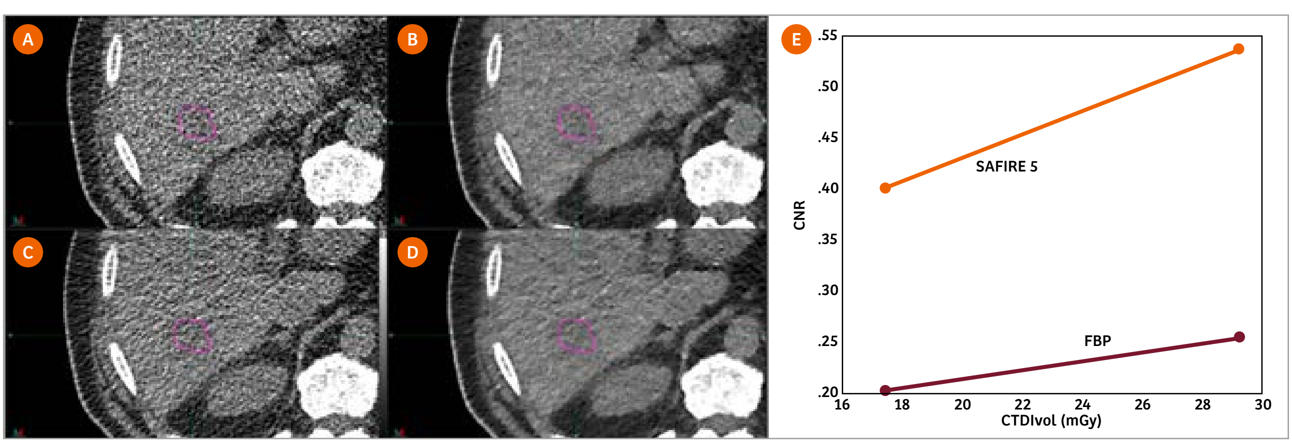

Figure 4: Axial slices of a 4DCT dataset time-sorted to the 0% expiration phase. Tube voltage was 120 kV and the reconstruction kernel used is 30f (medium-smooth). A and B are FBP and SAFIRE reconstructions respectively of the same low dose scan (17.5 mGy CTDIvol). C and D are FBP and SAFIRE reconstructions respectively of the same standard dose scan (29.2 mGY CTDIvol). Figure 4E shows contrast to noise (CNR) as a function of dose for both reconstructions as calculated from the magenta GTV.

** SAFIRE may be optional on certain SOMATOM CT scanners. 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 consolation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.*
‡16 images/sec on and up to 20 images/sec with FAST IRS option (available on specific models).

Figure 5 demonstrates the image quality enhancement on a brachytherapy patient (A,B) with a particularly high BMI (>40). In order to reduce the effect from photon starvation, imaging was done using a tube voltage of 140 kVp with a CTDIvol of 29.2 mGy. Despite using a higher tube voltage to mitigate the effect of patient size related noise in the reconstructed images, the FBP image shown in panel (A) has substantially degraded image quality. Figure 5C is a plot of the noise reduction after the application of SAFIRE* on 6 patients with a BMI > 24. The noise was calculated using the standard deviation in a cylindrical ROI of a uniform region of the patients and the noise reduction was defined as the difference in the noise between the FBP and the SAFIRE strength 5 reconstructions.

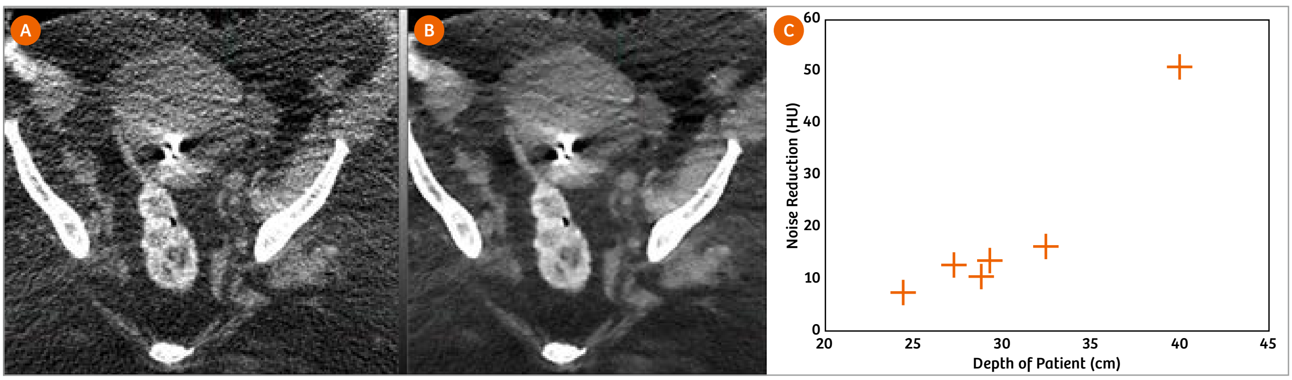

Figure 5: Axial slice of a CT scan of a uterine cancer brachytherapy patient with a BMI of 40 reconstructed with a FBP (A) and SAFIRE strength 5 (B). The pitch was 0.6, tube current was 140 kVp and imaging dose was 29.2 mGy CTDIvol. Reconstruction kernel used in both cases is 30f (medium smooth). Figure 5C shows the noise reduction (difference between STD of noise between FBP and SAFIRE reconstructions) when SAFIRE strength 5 is used in 6 different patients with high BMI (BMI>24).

Conclusion

Image guided radiation therapy planning and delivery guidance depends on high quality CT in order to provide the best possible treatment. In some cases, especially 4DCT or in patients with high BMI, image quality may be inadequate due to the reduction of photon flux and subsequently the increase in noise when compared to standard 3DCT imaging. If the noise level is too high, smaller targets with low contrast and certain organs at risk may be difficult to delineate from the surrounding tissue, thereby increasing uncertainty and thus requiring larger margins for planning (see Figure 4). Furthermore noisy CT images can often lead to increased error when using time-saving standard auto-segmentation tools (see Figure 3) thus interrupting clinical workflows. Siemens Healthineers' Iterative reconstruction technique "SAFIRE" can be applied in such situations to reduce the noise without increasing the imaging dose or compromising on the image quality as assessed by contrast and noise. SAFIRE iterative reconstruction is directly available on the scanner console and images can be reconstructed in a clinically relevant time-frame†.

*SAFIRE may be optional on certain SOMATOM CT scanners. 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 consolation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.
‡16 images/sec on and up to 20 images/sec with FAST IRS option (available on specific models).

References

[1]Kalra MK, Maher M, Toth T, et al. Strategies for CT Radiation Dose Optimization. Radiology. 2004 Mar; 230(3): 619-628. DOI 10.1148/radiol.2303021726

[2]Beister M, Kolditz D, Kalender WA. Iterative reconstruction methods in X-ray CT, Phys Med. 2012 Apr; 28(2):94-108. doi: 10.1016/j.ejmp.2012.01.003. Epub 2012 Feb 10.

[3]Grant K, Raupach R, "SAFIRE: Sinogram Affirmed Iterative Reconstruction." Siemens Medical Solutions White Paper A911IM-CT-121036-P1-4A00 2012

[4]Winklehner A, Karlo C, Puippe G, et al. Raw data-based iterative reconstruction in body CTA: evaluation of radiation dose saving potential. Eur Radiol. 21: 2521–2526. doi: 10.1007/s00330-011-2227-y

[5]Rietzel E, Pan TS, Chen GTY. Four-dimensional Computed Tomography: Image Formation and Clinical Protocol. Med. Phys. 2005 APR; 32(4): 875-889. DOI: 10.1118/1.1869852

[6]Mori S, Ko S, Ishii T, et al. Effective doses in four-dimensional computed tomography for lung radiotherapy planning. Med Dosim. 2009; 34:87–90.

[7]Hubbard P, Callahn J, Cramb J, Budd R, Kron T. Audit of radiation dose delivered in time-resolved four-dimensional computed tomography in a radiotherapy department. J Med. Imag. Radiat. Oncol. 2015; 59: 346-352. DOI: 10.1111/1754-9485.12284.

[8]https://www.niddk.nih.gov/health-information/health-statistics/Pages/overweight-obesity-statistics.aspx

Siemens Healthineers Headquarters
Siemens Healthcare GmbH
Henkestr. 127
91052 Erlangen, Germany
Phone: +49 9131 84-0
siemens-healthineers.com

Published by Siemens Healthcare GmbH · Order No. A91AT-24301-70C1-7600 · Printed in Germany · 6492 CIT12760 0818 ·