CT / White paper

Empowering High-Quality Minimal Radiation Exposure CT Lung Scans with SilverBeam and Deep Learning Reconstruction

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Introduction

Canon Medical's SilverBeam introduces a novel X-ray filtration system specifically developed for computed tomography (CT) imaging. This innovative solution capitalizes on the physical properties of silver, leveraging its outstanding ability to optimally filter energy low-energy X-rays. Combined with Advanced intelligent Clear-IQ Engine (AiCE), a pioneering Deep Learning Reconstruction (DLR) algorithm for CT, SilverBeam elevates the potential for high-quality imaging with significant utility in scenarios that necessitate dose minimization. In particular, benefits are observed for larger patients and challenging anatomical regions in the context of lung cancer screening.

CT in Lung Cancer Screening

Lung cancer remains the leading cause of cancer-related deaths worldwide, responsible for over 270,000 deaths annually in Europe alone. Because of the high mortality rate, earlier detection through screening programs could significantly improve patient outcomes, such as survival rates, treatment options, and overall prognosis.

The U.S.-based National Lung Screening Trial (NLST) found that LDCT screening revealed a 20% reduction in lung cancer mortality compared to chest X-ray screening among over 50,000 current or former heavy smokers aged between 55 and 74 years, after a median follow-up of 6.5 years [1]. Based on these findings, the U.S. Preventive Services Task Force recommended annual LDCT screening for individuals aged 55 to 80 years with a smoking history of 30 or more pack-years, who currently smoke or quit smoking within the past 15 years.

The European medical community has been interested in using low-dose computed tomography (LDCT) for lung cancer screening for a long time. Recently, important data has come from the European Randomized Controlled Trial (NELSON). Both the NLST and early NELSON trials highlight the importance of effective nodule management. This underscores the association of LDCT with a marked reduction in lung cancer mortality, particularly within cohorts characterized as high-risk individuals [2] [3].

CT is widely used for its detailed, three-dimensional anatomical information. To address radiation risks, CT protocols, including ultra-low-dose CT (ULDCT), are evolving to minimize exposure while maintaining diagnostic accuracy. ULDCT has shown promise in applications such as pulmonary nodule assessment and lung cancer screening [1] [4]. Because lower radiation dose can lead to increased image noise, decreased image quality, and reduced sensitivity to pulmonary pathologies, it is critical to optimize the imaging chain to ensure both patient safety and diagnostic accuracy.

The efficacy of ULDCT protocols in detecting chest pathologies, with a radiation dose equivalent to that of chest X-ray radiography, was investigated in a study by Kroft et al. [5]. This study included 152 patients who underwent both chest radiography and ULDCT. The ULDCT protocol images were acquired with conventional filtering and reconstructed with Hybrid Iterative Reconstruction (HIR), Canon's Adaptive Iterative Dose Reduction Enhanced (AIDR 3D Enhanced). Results indicated that ULDCT with conventional filtering and HIR outperformed chest X-ray radiography in detecting certain chest pathologies. However, there remains potential for enhancing image quality and accuracy through advanced beam filtering techniques and DLR algorithms.

X-ray filtration

The X-rays generated by an X-ray tube exhibit a continuous range of bremsstrahlung photon energies with discrete lines of characteristic radiation overlaid. As these X-rays traverse the patient's body, varying degrees of absorption or attenuation occur, contingent on the patient's size and composition. Soft tissues, characterized by lower density and atomic number, absorb fewer X-rays than denser structures like bone.

The quality of radiation significantly impacts both image quality and radiation dose, determined by how X-ray photons of diverse energy levels interact with tissue. Within the energy range of approximately 1 to 30 keV, there is notable absorption of photons by the patient, leading to an elevation in entrance surface dose [6]. This signifies that a limited number of photons within this energy range will be transmitted through the patient to contribute to image formation [7].

In the realm of CT imaging, filtration is a crucial technique used to attenuate low-energy X-ray photons and shape beam intensity by filtering out undesirable X-rays with low energy before reaching the patient. Commonly, aluminum or copper filtration is employed, creating a "harder" beam [8] [9], which also reduces beam hardening artifacts from varied projections.

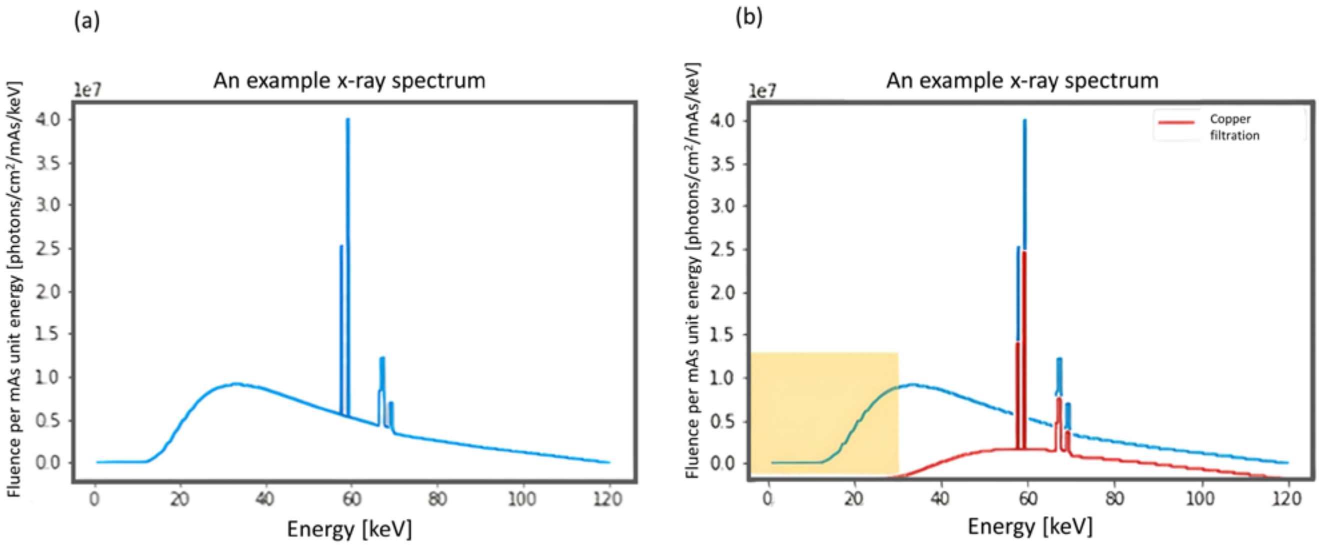

Figure 1 (a) A generic example of pre-patient spectra after the basic tube filtration and (b) after adding copper filtration. The yellow box highlights the low-energy X-rays, which are undesirable in imaging. (Figures are illustrative, and there might be slight differences from actual clinical system spectra)

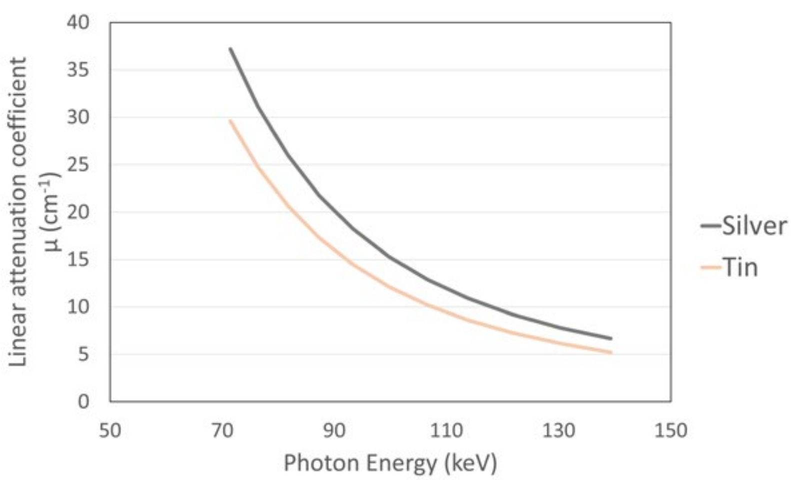

Figure 2 Comparison of the linear attenuation coefficients (μ) of silver and tin (Data from https://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html)

Figure 1 (a) provides a visual representation of pre-patient spectra after basic tube filtration and Figure 1 (b) demonstrates the impact of adding a thin sheet of copper filtration.

Furthermore, recent advancements in X-ray filtration have integrated other heavier metals, such as silver, for specific purposes in CT imaging.

SilverBeam Filter

Silver filtration is a technique for filtering X-rays in CT scans and hardening the X-ray spectrum. Silver's X-ray attenuation properties, including a K-edge of 25.5 keV, high atomic number (Z=47), high atomic weight (107.87 u), and high density (10.49 g/cm^3), harden the beam more than other commonly used materials like aluminum (Z=13, 26.98 u, 2.7 g/cm^3) and copper (Z=29, 63.54 u, 8.96 g/cm^3).

Additionally, as demonstrated in Figure 2 silver has a higher linear attenuation coefficient (μ) than other metals such as tin in the diagnostic X-ray keV range.

Silver filtering in X-rays, or SilverBeam Filter, selectively eliminates low-energy photons from a polychromatic X-ray beam. The outcome of this process is the generation of an energy spectrum that exhibits a shift towards higher energies, as depicted in Figure 3. As a result, the X-ray tube spectrum becomes narrower, featuring a reduced number of quanta at lower energies, thereby leading to an overall increase in the mean energy. This energy increase can help improve signal-to-noise ratio (SNR) in challenging, high-attenuation scenarios such as larger patients and the shoulder region of all patients and is therefore especially useful for examinations like reduced-dose lung cancer screening.

Phantom CT Scans and measurements

To measure the benefits of SilverBeam filtration in combination with AiCE reconstruction, an anthropomorphic phantom (CTU-41, Kyoto Kagaku CT) was scanned at various dose levels and reconstructed with two reconstruction methods, HIR and DLR. The anthropomorphic phantom contains anatomical structures cast on synthetic materials that mimic the attenuation of tissue in the human body, such as bone, lungs with pulmonary vessels, and internal organs.

The phantom was scanned at 120 kV with a 0.5 mm x 80 collimation, 0.5 s rotation time on the Aquilion Serve CT system with both fixed mA and with varying mA values - using automatic exposure control (AEC), SUREExposure. Scanning with fixed mA values means without using any planning CT, i.e. scanogram. In cases where SUREExposure was used for the phantom acquisitions, three different configurations were evaluated: a single anterior-posterior (AP) scanogram, a dual scanogram (AP and lateral), and the 3D Landmark Scan. The latter uses a helical scan with high pitch and SilverBeam Filter.

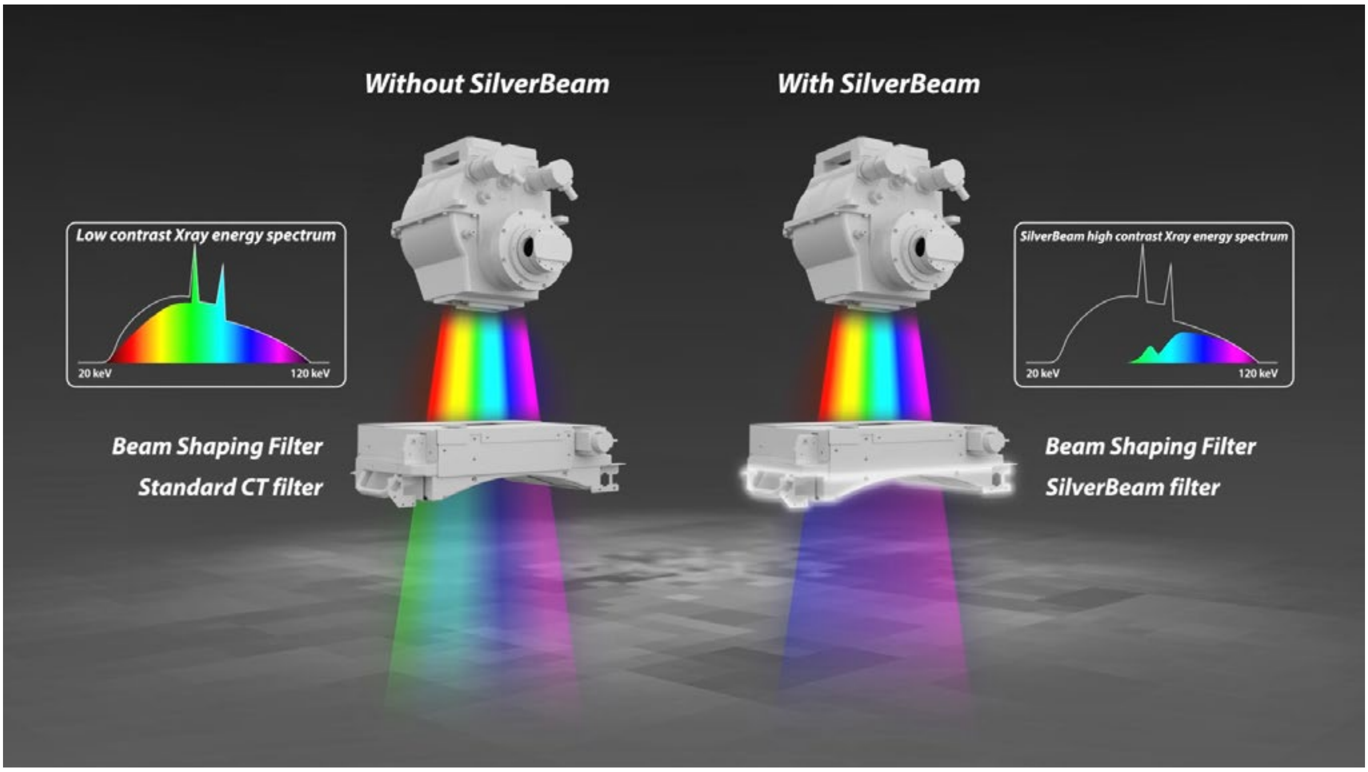

Figure 3 SilverBeam Filter is an energy filter that utilizes the photo-attenuation characteristics of silver to selectively eliminate low-energy photons from a polychromatic X-ray beam. This process results in the formation of an energy spectrum shifted toward higher energies.

Images were reconstructed using the HIR method, AIDR 3D Enhanced [10], and AiCE lung reconstruction [11]. AiCE is a fast, DLR reconstruction algorithm that includes both raw data and image domain components to reduce artifacts and improve the SNR. Research has shown that AiCE provides a better high-resolution CT image with improved quality compared to HIR for evaluating lung nodules, with significantly reduced objective image noise and subjective improvements in noise, artifacts, depiction of small structures and nodule rims, and overall image quality [12].

The images were reconstructed with a 1 mm slice thickness, and circular regions of interest (ROIs) with a 32.5-pixel diameter were placed to calculate Hounsfield units (HU), standard deviation (SD), and SNR values.

$SNR = ROI_{(soft\ tissue)}/SD_{(noise)}$,

Where $ROI_{(soft\ tissue)}$ is the mean CT number of the ROI in the heart-like structure of the phantom, and $SD_{(noise)}$ is the SD of the CT number in an ROI placed in the air part inside the phantom (Figure 4 and Figure 5).

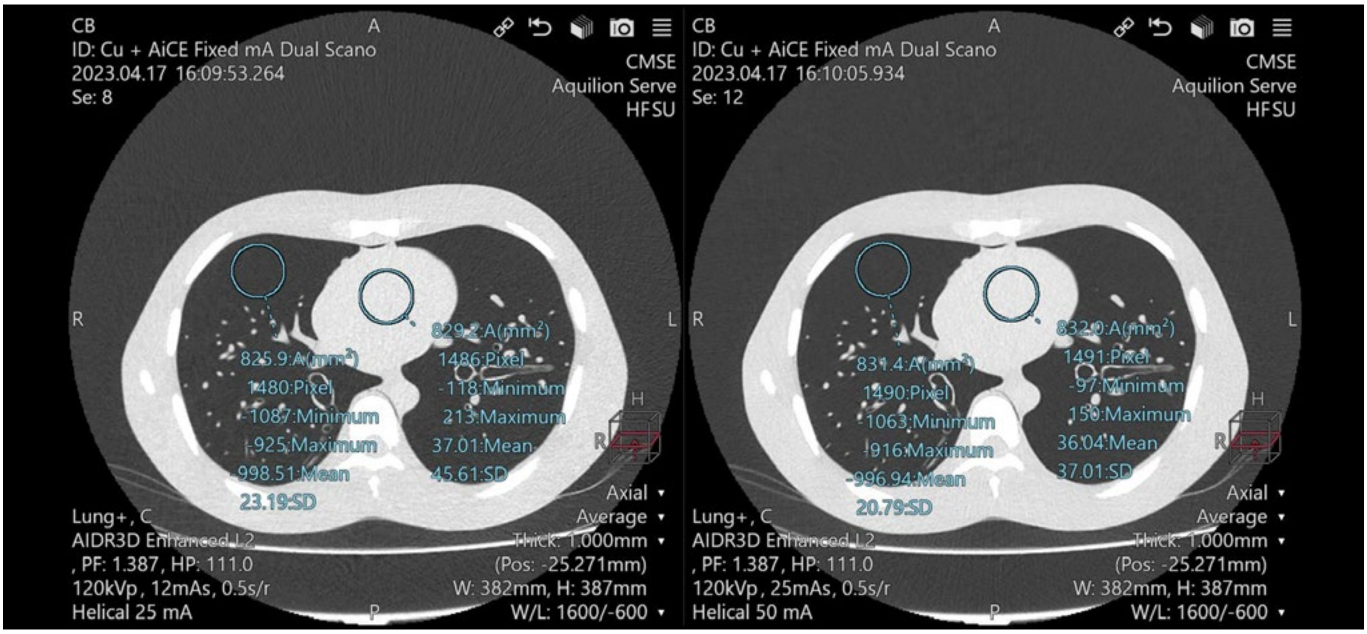

Figure 4 Example of the ROIs placed in the phantom to measure, mean HU, SD, and SNR. Images acquired with copper filtration and fixed mA of 25 and 50 and reconstructed with AIDR 3D.

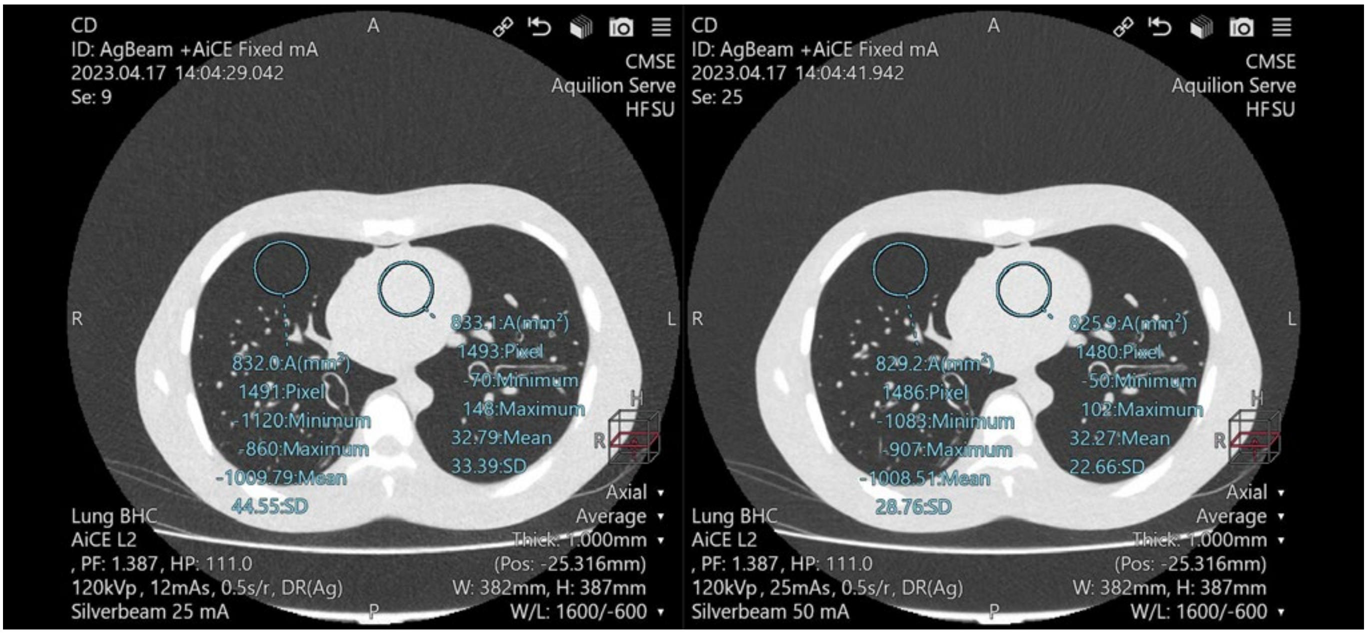

Figure 5 Example of the ROIs placed in the phantom to measure, mean HU, SD, and SNR. Images acquired with SilverBeam and fixed mA of 25 and 50 and reconstructed with AiCE.

SilverBeam and AiCE: reduced Dose, Superior SNR

The reduced dose scanning method – SilverBeam and AiCE, results in an improvement of image quality and reduction in noise, ultimately resulting in superior SNR values compared to the conventional filtration and reconstruction approach. Our findings are based on measurements obtained using an anthropomorphic phantom at matched CDTIvol values ranging from 0.1-1.5 mGy, representing minimized dose CT scans.

The improvement in SNR values is up to 70% compared to the conventional filtration and reconstruction method (Figure 6).

Clinical Examples

A clinical example of the SNR properties is provided in Figure 7, which shows a small lung nodule well-demonstrated in the upper right lung using reduced dose, at a CTDIvol of 0.9 mGy, chest CT combining SilverBeam with DLR.

The dose-length product (DLP) was 38.7 mGy·cm. With a conversion factor (k) of 0.014 mSv·mGy^{-1}·cm^{-1}, the effective dose (E) equals 0.54 mSv.

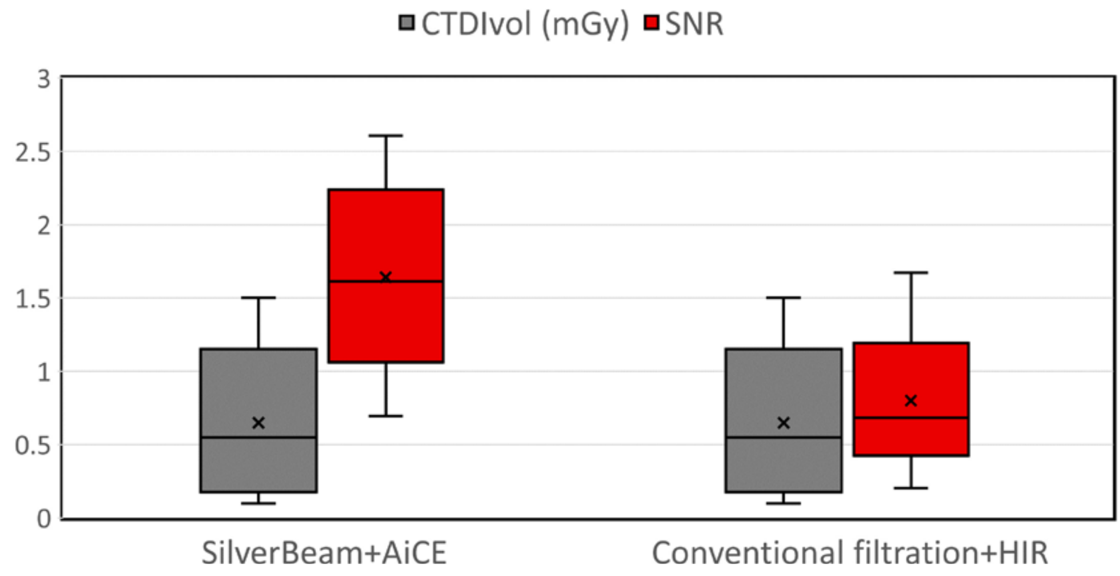

Figure 6 Results of the evaluation of SNR on anthropomorphic phantom comparing SilverBeam and conventional filtration with the AEC and different scanograms. Black lines = median. The use of Silver filtration (SilverBeam) results in a 13-70% increase in SNR at matched dose.

Figure 7 Clinical images of low-dose Lung Cancer Screening CT scan acquired with SilverBeam and reconstructed with AiCE Lung. CTDIvol=0.9 mGy, DLP = 38.7 mGy·cm, E= 0.54 mSv (k=0.014·mSv·mGy^{-1}·cm^{-1}). The yellow circle indicates a lung nodule.

A clinical image featuring a 7.7 mm lung nodule, which was acquired using SilverBeam technology and reconstructed with AiCE Lung is shown in Figure 8. The exam CTDIvol was 0.7 mGy, DLP was 27.1 mGy·cm, and E was 0.38 mSv.

Figure 9 depicts a clinical image with signs of lung fibrosis that was acquired with SilverBeam technology and recreated with AiCE Lung. The CTDIvol of this ULDCT exam was 0.5 mGy, DLP was 17.1 mGy·cm, and E was 0.24 mSv.

These clinical reduced dose chest CT scans result in effective doses that are up to 22 and up to 33 times lower than the standard European (~5.5 mSv) [13] and U.S. (~8 mSv) effective doses [14].

Conclusion

SilverBeam Filter, Canon Medical's novel silver-based filtration for CT, selectively eliminates low-energy photons from a polychromatic X-ray beam, thus offering numerous advantages that position it as the preferred approach over other filtration materials for specific applications, like reduced-dose lung screening. When combined with AiCE technology, SilverBeam demonstrates the ability to produce CT images of high quality while minimizing patient radiation exposure.

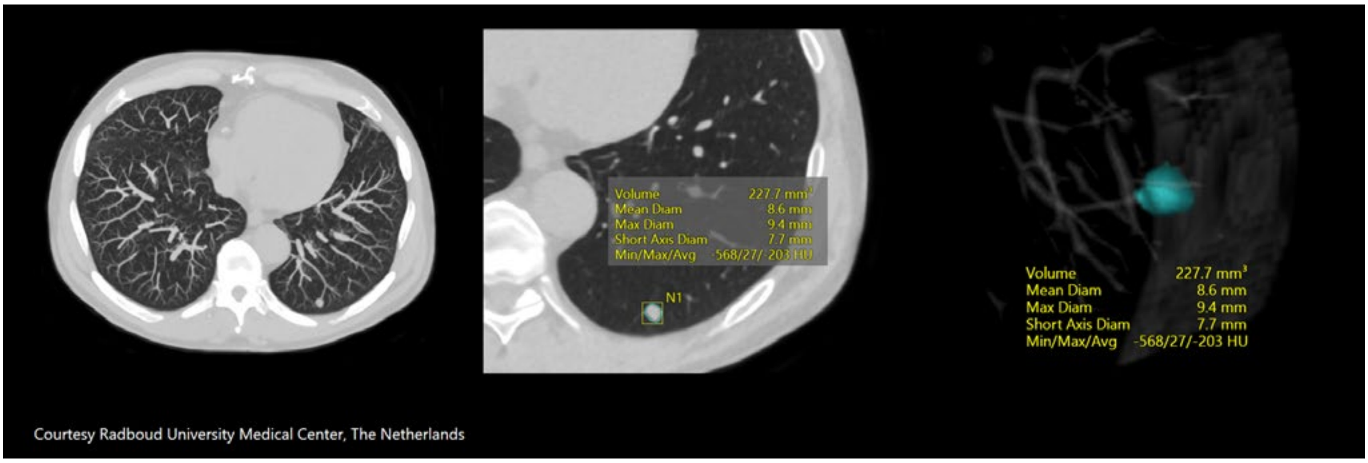

Figure 8 Clinical image with a small lung nodule, acquired with SilverBeam and reconstructed with AiCE Lung. CTDIvol=0.7 mGy, DLP = 27.1 mGy·cm. E=0.38 mSv ($k=0.014 \cdot mSv \cdot mGy^{-1} \cdot cm^{-1}$).

Figure 9 Clinical image of ultra low dose SilverBeam scan reconstructed with AiCE Lung. CTDIvol=0.5 mGy, DLP = 17.0 mGy·cm. E=0.24 mSv ($k=0.014 \cdot mSv \cdot mGy^{-1} \cdot cm^{-1}$). The lung apices demonstrate signs of lung fibrosis.

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