

# The Influence of CT Reconstruction Methods on the Accuracy of Monitoring Lung Nodule Diameters at Different Dose Levels

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## Abstract

**Purpose:** This study aims to investigate the effect of filtered back projection (FBP) and sinogram-affirmed iterative reconstruction (SAFIRE) on the accuracy of lung nodule diameter measurements at different dose levels.

**Method:** 48 CT images were acquired (at tube-current time product of 10, 20, 30 and 40 mAs) using an anthropomorphic phantom Lungman N1 ©, containing simulated spherical lung nodules of +100 Hounsfield Units of 5, 8 and 12mm diameter. Images were reconstructed with FBP and SAFIRE strengths 1, 3, and 5. Twelve participants, with radiographic experience, performed nodule diameter measurements for all images. Nodule edge sharpness was calculated for all images by measuring the angle of profile edge slope. Contrast to Noise Ratio (CNR) values were obtained from pixel values in regions of interest (ROIs) in the lung nodule and background air. Measurement accuracy was assessed by calculating the absolute error percentage (AEP) between participant's measurements and actual nodule size.



**Results:** There is no significant difference in nodule diameter measurement between mAs values and reconstruction algorithms (p-value 0,009 - 0,969). AEP showed no significant difference (p-value 0,041-0,969) for any of the reconstruction algorithms.

**Discussion:** Previous research using SAFIRE suggests a decrease of mAs while maintaining image quality. Furthermore, SAFIRE has the ability to increase CNR and decrease image artefacts. However, the findings in this study suggest that accuracy of lung nodule measurement does not improve with an increase of CNR values nor the line profiles of edge sharpness.

**Conclusion:** Our study suggests that image dose levels can be reduced without compromising nodule diameter measurement accuracy, regardless of reconstruction method.

## Introduction

The use of computed tomography (CT) is increasing in medical imaging. UNSCEAR reported a substantial increase of more than 40% from 1997-2007 when compared to the previous decade. A consequence of this is an increased population risk of developing malignant tumours, due to possible DNA damage, caused by exposure to ionizing radiation (1) its use has increased rapidly. It is estimated that more than 62 million CT scans per year are currently obtained in the United States, including at least 4 million for children. By its nature, CT involves larger radiation doses than the more common, conventional x-ray imaging procedures (Table 1. For this reason, limiting the use of radiation in medical imaging, as well as justification and optimization of image quality

and dose levels is essential for every examination. Optimization of image noise and spatial resolution is paramount for accurate radiological assessment (2).

Lung nodule measurements in CT are routinely done for tumour treatment response evaluation, detection of lung nodules, or as follow-ups from previous findings (3) For nodule follow-up the development and size will be assessed with sequential scans. According to the guidelines published by the Fleischner Society, the largest diameter the nodule is measured on axial slices in order to evaluate the development with repeated scans (4). This monitoring will result in an accumulated dose over time, and to a general increased risk of developing a radiation induced cancer(1). An acknowledged dose reduction

method, for a simple and predictable result, is altering the tube current, although the consequence of this method is an increase of noise and image artefacts(5).

Iterative reconstruction (IR) techniques have been developed to reduce dose, whilst maintaining or improving objective image quality, by reducing noise and consequently improving Signal-to-Noise Ratio (SNR) (6–9) independent readers measured image noise; two readers assessed image quality of normal anatomic lung structures on a five-point scale. Radiation dose parameters were recorded. RESULTS: Image noise in datasets reconstructed with FBP (57.4  $\pm$  15.9. Sinogram-Affirmed Iterative Reconstruction (SAFIRE) is an advanced IR technique developed by Siemens© that uses both filtered back projection (FBP) and raw data-based iterations. Previous studies have shown promising results in the dose-reduction potential of SAFIRE while maintaining image quality, where image quality was assessed by objective measures (i.e. SNR and CNR values) and visual criteria such as image noise (i.e. graininess), quality of contour delineation (i.e. sharpness) and general impression (i.e. overall image quality)(2,10–13) the Definition Flash and the Definition Edge (all from Siemens, Erlangen, Germany. A potential downside of IR techniques is the requirement of high computing power which makes them time consuming, limiting its clinical application (14).

This study aims to investigate the influence of FBP and SAFIRE on the accuracy of lung nodule diameter measurements at different dose levels.

## Methods

### Image Acquisition

Images were acquired using a clinically based and calibrated high frequency Siemens Healthcare©, Somatom Definition AS 64 slice CT scanner and Syngo software CT VA48A.

The images were acquired using helical scanning parameters with CareDose. Slice thickness of 0.6mm, pixel spacing of 0.69mm  $\times$  0.69mm and a pitch factor of 1.2 was used. Six consecutive scans were performed with a fixed kVp of 120 and mAs levels of 40, 30, 20 and 10. All other parameters were kept constant. Each scan resulted in a total of 560 images.

An anthropomorphic Lungman© phantom (No 1, Kyoto Kagaku Co.) was scanned in supine position (head first). According to the manufacturers website, the Lungman© phantom consists of material comparable to human tissue density. To simulate tumours of different sizes, spherical nodules were placed at different locations within the lung parenchyma. The nodules all had a HU (Hounsfield Unit) of +100. The nodules selected for this study had diameters of 5, 8 and 12 mm.

### Image reconstruction & dosage

Images were reconstructed using a smoothing kernel (B31f) for the FBP and SAFIRE strengths of 1, 3 and 5 with a medium smooth kernel (I31f). Three slices containing either 5, 8 or 12 mm nodules, from each scan parameter and reconstruction algorithm were selected. Each selected slice represented the nodule at its largest diameter, which was selected based on visual analysis. Three image sets were duplicated to assess intra-observer validity. In total there were 57 images included within a total of 19 image sets. All image sets were anonymised and presented in random order.

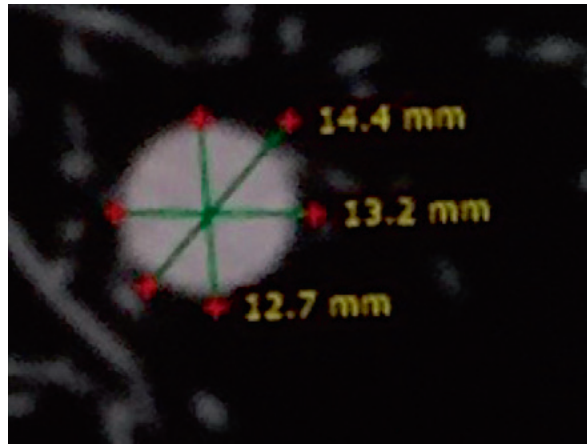
### Image display and viewing conditions

Images were displayed on a diagnostic level monitor, 24,11" EizoRadiForce MX2424W, with a resolution

of 1920x1200 pixels. A DICOM greyscale calibration standard was undertaken before data collection commenced. Viewing conditions of low ambient lighting remained constant for all participants.

### Population & data collection

Nodule diameter measurements were performed by 12 participants, consisting of student radiographers, experienced radiographers and a medical physicist. The observers were supervised, undertaking several test measurements before actual data collection commenced. Three measurements were taken for each nodule, in vertical, horizontal and diagonal planes (Figure 1). Nodule diameter was obtained using the line measurement tool within RadiAntDicom Viewer 1.9.16. This resulted in a total of 171 measurements being performed by each observer.



**Image 1** Example of a training image

### Objective measurements of Image Quality

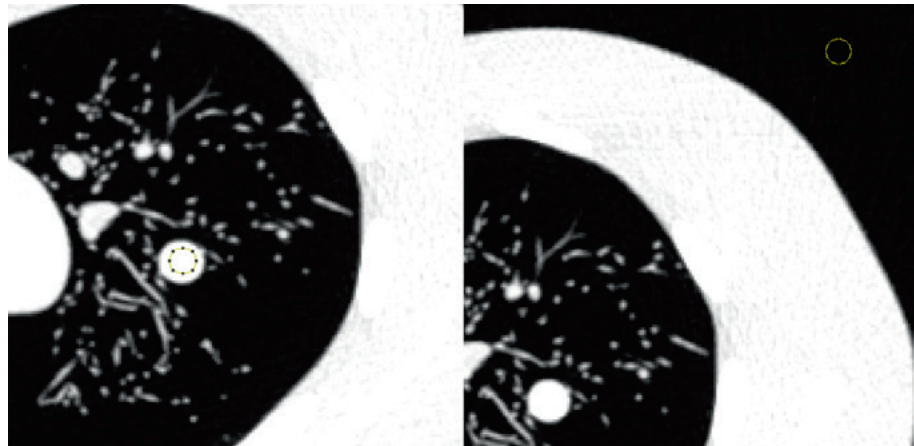
Measurements of objective image quality were performed using ImageJ©. CNR was calculated by using two identical regions of interest (ROIs), one in the centre of the nodule and one in air surrounding the phantom, to measure the attenuation values. ROIs differed for each nodule size and were selected to fit easily within the boundaries of the nodule and as close to 50% of the nodules actual size as the software allowed (Image 1). Calculations of CNR were performed in Microsoft Excel©, using the equation

where  $\mu_x$  is the mean signal value in ROI x, and  $\sigma_x$  the variance in ROI x, respectively.

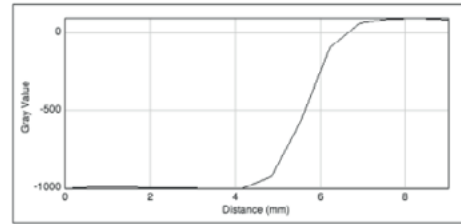
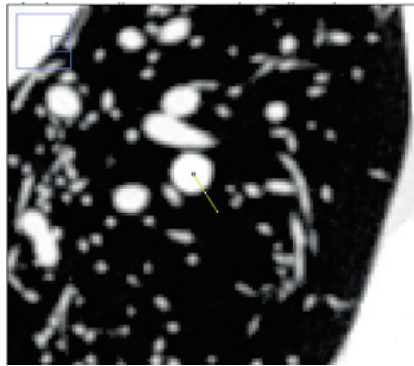
Edge profile assessment was inspired by a method described by Manning, 2004(15). Edges were identified by visual inspection, and subsequently a line profile was drawn perpendicular to the nodule edge in ImageJ© as shown in Image 2. Edge sharpness was assessed by calculating the angle of the profile edge slope, in Microsoft Excel©.

First, a trend line was produced to assess the steepness of the line profile.  $R^2$ -values of the trend lines varied from 0,93 to 0,98 indicating good correlation. The slopes of the trend lines were then converted to angles (in degrees).

**Image 1** Defined ROIs for objective image quality calculation



**Image 2** Nodule line placement with the resulting line profile



### Statistical analysis

Differences in mean nodule diameter measurement between reconstruction algorithms were analysed with a Mann-Whitney Wilcoxon test. Due to multiple testing, alpha was adjusted using a Bonferroni correction resulting in a level of significance of 0.0083.

Observer performance was assessed by calculating the absolute error percentage (AEP) for mean nodule diameter measurements with the following formula:

$$AEP =$$

where indicates the mean nodule diameter measurement and AS indicates actual nodule size. Differences in AEP were analysed with a Mann-Whitney Wilcoxon test with a level of significance of 0.083.

### Results

With an increase of reconstruction algorithm complexity the objective image quality, as defined by CNR, and nodule edge sharpness, increases.

Table 1 shows an improvement of CNR for increasing dose levels and reconstruction algorithm complexity.

**Table 1** CNR values vs. reconstruction algorithms and mAs (8mm nodule)

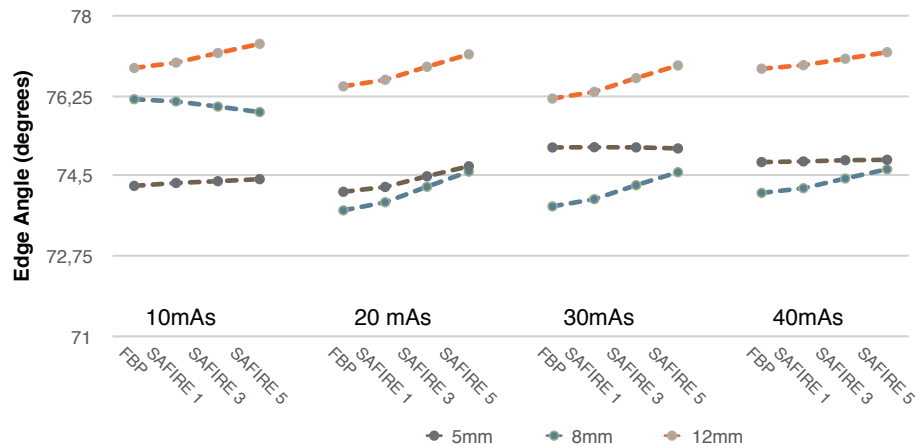
DOSE (mAs)	FBP	SAFIRE 1	SAFIRE 3	SAFIRE 5
10	24,34	27,38	36,70	55,39
20	31,06	34,99	47,58	74,95
30	36,85	41,25	54,48	84,59
40	54,03	60,69	85,43	141,77

Nodule edge sharpness improves with increasing reconstruction algorithm complexity. Furthermore, edge sharpness differs for each nodule size with the largest nodule having the sharpest edge (Figure 1). For the 5mm nodule at both 30 and 40 mAs, and the 8mm nodule, at 10mAs; SAFIRE 5 produced the least sharp nodule edge and are an exception to this trend. There is, however, no defined relationship between dose and edge sharpness for the three nodule sizes.

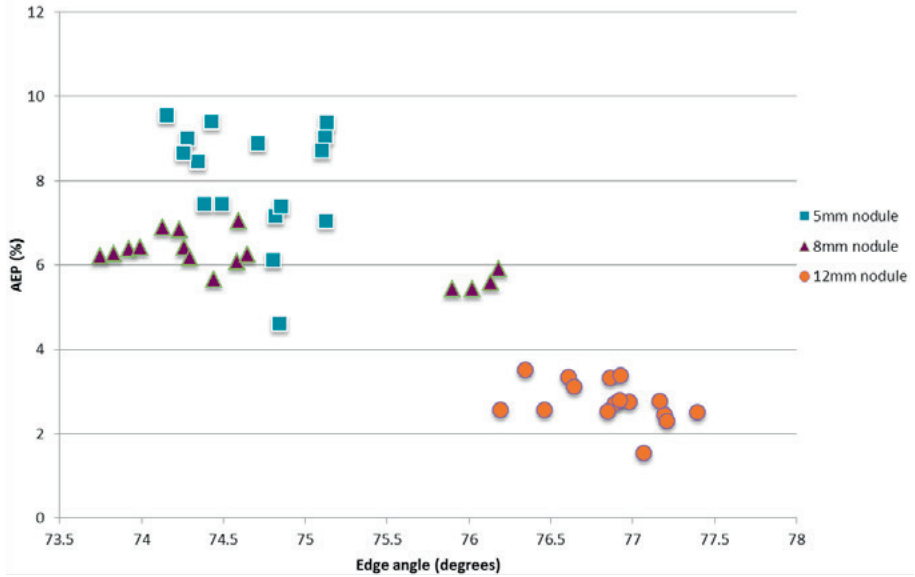
Absolute error percentage in observer diameter measurement decreases with an increase of nodule edge sharpness. (Figure 2). However, it appears that the accuracy of nodule diameter measurements improves as nodule size increases (Figure 3).

The AEP measurement accuracy also increases as nodule diameter increases (Figure 2). For 12mm nodules, mean absolute error values are all below 3.4%. Mean AEP values for 8mm nodules range from 5.4% to 7%, 5mm nodules showing AEP values from 4.6% to 9.6% respectively.

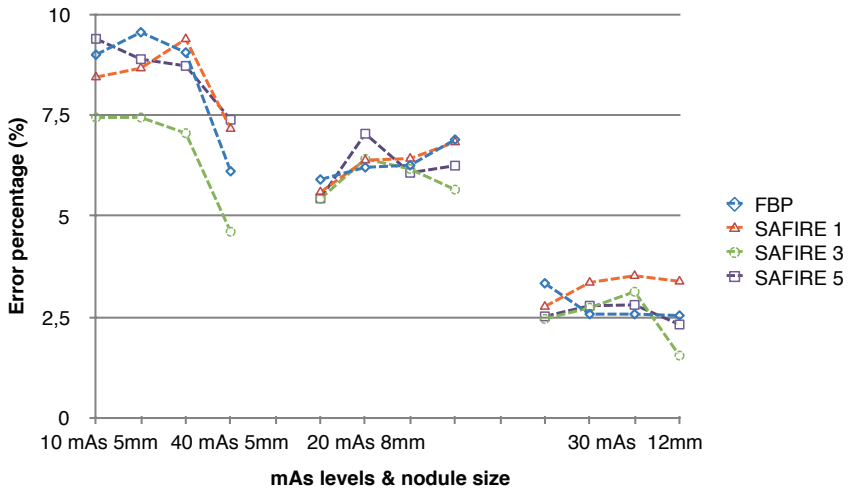
For 8mm and 5mm nodules, accuracy is decreasing with mean AEP of around 6.2% and 8%, respectively. For 8mm and 12mm nodules, dose levels seem to have no effect on measurement accuracy (Figure 3). An effect of mAs on measurement accuracy is visible for small nodules only where mean AEP values are 6.32% at 40 mAs, increasing to 8.6% at 10 mAs. Differences in mean AEP between reconstruction algorithms are greatest in the smallest nodule, depending on mAs level. For mAs values between



**Figure 1** Edge sharpness versus mAs and reconstruction method



**Figure 2** Mean absolute error percentage versus nodule edge angle



**Figure 3** Absolute nodule diameter error percentage versus mAs and reconstruction method



10 and 30, standard deviation is between 0.23% and 0.47%. At 40 mAs there is a greater spread in observer performance between reconstruction algorithms, with a standard deviation of 0.9%.

For medium and large nodules, observer performance seems independent of reconstruction algorithm. For 5mm nodules, SAFIRE3 seems to have the most effect on measurement accuracy, compared to the other reconstruction methods.

Results from the Mann Whitney Wilcoxon test on mean observer measurements showed no significant difference between reconstruction algorithms.

P-values ranged from 0.009 to 0.969. An overview of p-values is given in Table 2.

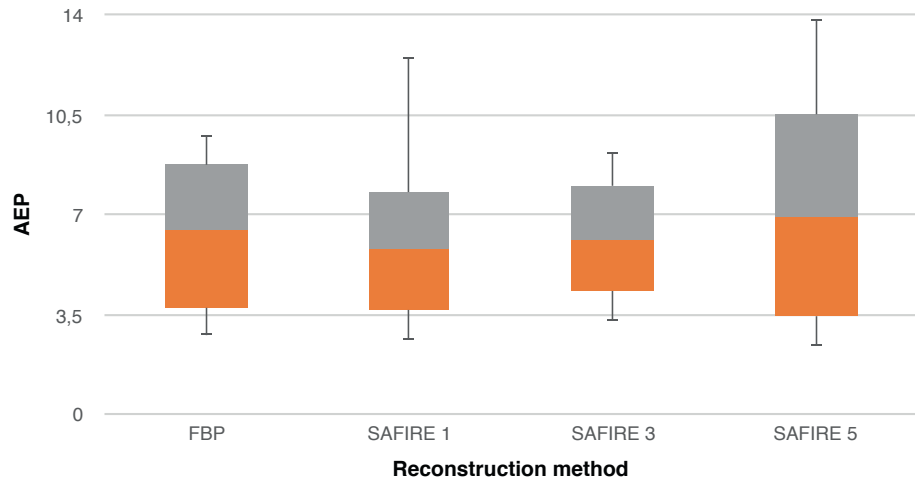
P-values calculated with the Mann Whitney Wilcoxon on observer measurement accuracy showed values between 0,041 and 0,969, showing no significant difference between reconstruction algorithms.

This is illustrated in Figure 4, where absolute error percentages show similar distribution for all reconstruction methods, with a large spread in the data.

Dose level	FB vs. S1	FB vs. S3	FB vs. S5	S1 vs. S3	S1 vs. S5	S3 vs. S5
5 mm, 10 mAs	0,139	0,085	0,687	0,722	0,182	0,266
5 mm, 20 mAs	0,645	0,721	0,838	0,824	0,919	0,374
5 mm, 30 mAs	0,504	0,409	0,156	0,443	0,878	0,456
5 mm, 40 mAs	0,528	0,167	0,126	0,371	0,374	0,838
8 mm, 10 mAs	0,556	0,057	0,197	0,009	0,221	0,789
8 mm, 20 mAs	0,969	0,503	0,609	0,798	0,592	0,248
8 mm, 30 mAs	0,789	0,305	0,213	0,754	0,929	0,287
8 mm, 40 mAs	0,366	0,756	0,695	0,513	0,272	0,477
12 mm, 10 mAs	0,609	0,074	0,126	0,01	0,049	0,35
12 mm, 20 mAs	0,929	0,239	0,724	0,367	0,373	0,388
12 mm, 30 mAs	0,239	0,289	0,61	0,062	0,285	0,332
12 mm, 40 mAs	0,284	0,147	0,046	0,23	0,075	0,505

**Table 2** Results of the Mann Whitney Wilcoxon analysis for mean observer measurements

**Figure 4** Box-and-whiskers of mean AEP values vs. reconstruction algorithms for the 8mm nodule scanned with 20 mAs



Intra-observer reliability was good. Observer performance difference was not significant with a mean calculated p-value of 0,452.

### Discussion

Our study suggests that mAs, and therefore radiation dose, can be lowered equivalently when using FBP or SAFIRE, without compromising nodule measurement accuracy in a phantom. Previous research suggests that SAFIRE is an excellent algorithm for minimising undesirable effects of dose reduction by increasing SNR and CNR (8,10) the Definition Flash and the Definition Edge (all from Siemens, Erlangen, Germany). However, an increase of image CNR appears not to affect a correct subjective perception of the nodule edge. With an increase of

CNR levels, sharpness of the nodule edges appeared to increase. Nodule measurements however did not differ statistically between reconstruction algorithms. In addition, observer performance as indicated by AEP did not show any significant difference between reconstruction methods. This suggests that the accuracy of nodule measurements does not increase with an increase of CNR values. Objective image quality is not a valid predictor of observer measurement accuracy.

Table 1 indicates that when mAs increases CNR also increases; Figure 1 indicates that when mAs increases nodule edge sharpness also increases. Mathematically speaking, the increase in CNR and nodule edge angle suggests that the nodules

should become visually clearer. However, there is no significant difference between nodule diameter measurements made by the observers across all mAs values (Table 2). This can be explained because of the very high contrast and therefore high level of conspicuity of the lesions. This is confirmed in Figure 3.

### **Limitations and Recommendations**

Nodule diameter measurement is susceptible to error according to size. Real-life nodules are complex, their shape and distribution of attenuation will not be as well-defined as they are in a phantom. The nodules in this study possess a sharp edge separating it from surrounding tissue. In clinical practice this particular shape could represent a benign nodule, or a metastasis(16). Also, nodule size in the acquired slices might not be an accurate representation of the actual nodule size due to the slice thickness and voxel sizes, introducing an inherent error in observer measurements.

Although test-retest scores shows good intra-observer reliability, the overall observer experience was at novice level. However, since the diameter measurements can be considered a low order task, this might not pose such a limitation to the validity of the results. However, a further study should be undertaken using expert observers.

Other aspects to consider are the inherent human artefacts of respiratory and circulatory movements which are not factors in a phantom study. When eliminating these, the image might be presented in a slightly better quality. With this being a common bias when using a phantom, it raises a question regarding if this study could be considered for clinical research.

Each nodule edge angle in this study is only calculated once in one plane. For validity of measurements, multiple calculations on multiple planes are recommended by Manning's work (15). This is a limitation that needs consideration when evaluating the accuracy of the edge sharpness. Still, a trend can be seen, and highlights findings presented in Figure 1.

### **Conclusion**

The findings in this study suggest that accuracy of lung nodule diameter measurements do not increase with an increase of CNR values, but do suggest that image dose levels can be reduced without compromising measurement accuracy, regardless of reconstruction method.

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