Dose-Time-Quality Relationships in Spectral Photon Counting CT in Energy Bins

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Introduction

Spectral photon-counting computed tomography (SPCCT) is an emerging imaging modality that directly converts individual X-ray photons into electrical signals while simultaneously measuring their energy, enabling spectral imaging.

It also provides improved spatial resolution, and enhanced dose efficiency through improved electric noise suppression

Compared with conventional computed tomography (CT), SPCCT enabling quantitative multi-material decomposition, including high-Z elements, with improved sensitivity and specificity [1,2]

Radiation dose is governed by acquisition parameters, including tube voltage, tube current, beam filtration, and number of projections (Np). Previous studies in conventional CT have shown that increasing Np enhances image quality, with diminishing improvements beyond moderate sampling levels[3,4]

Increasing Np also increases radiation dose and acquisition time, highlighting the need to optimize acquisition protocols that balance dose, image quality, and scan efficiency.

Aim

This study aimed to optimize the number of projections (Np) in spectral photon-counting CT (SPCCT) by evaluating its impact on radiation dose, acquisition time, and image quality.

Methods and Materials

Phantoms scans were acquired at 115kVp and 40µA using four projection settings (Np = 373-1440). Radiation dose, acquisition time, and image quality were evaluated as explained below:

Radiation dose with acquisition time:
Radiation dose was assessed using Monte Carlo simulations (OpenGATE) and experimental measurements performed under identical acquisition conditions (Table 1). Acquisition time was recorded experimentally for each projection setting (Np).

The MARS scanner is shown in Figure 1a. The geometry of the cylindrical phantom (CTDI) in Figure 1b.

A normalization factor (NF), defined as the ratio of the experimental to simulated dose, was calculated and applied to calibrate the simulated dose values. The calibrated doses were then validated against the experimental measurements

Image quality:
Image quality was assessed by comparing undersampled reconstructions with the highest-dose reference images for each projection setting (Np).

Analysis was performed within a homogeneous ROI of a QRM phantom, and image quality was quantified using the peak signal-to-noise ratio (PSNR), root mean square error (RMSE), and structural similarity index (SSIM).

Tablet 1. Acquisition protocol for simulation and experimental measurements.

Parameter	Value
Tube voltage (kV)	120
Tube current-time product (µAs)	6.4
Field of view	13X13 mm
Pitch	0.7
Number of projections (Np)	373, 727, 981 and 1440

Figure 1a. MARS SPCCT

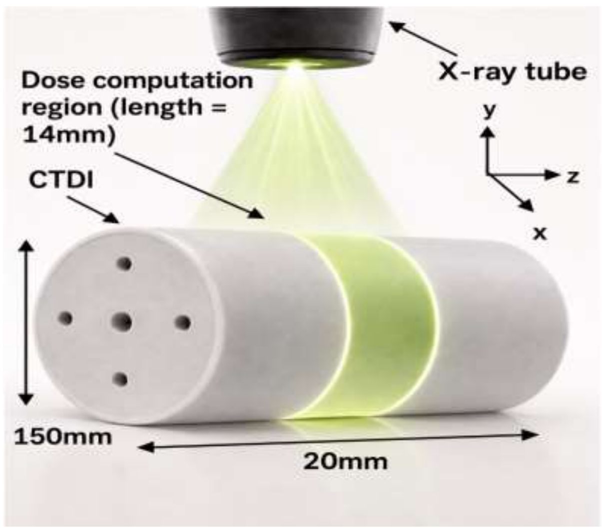

Figure 1b. Schematic side view of side CTDI Phantom and scanner's geometry.

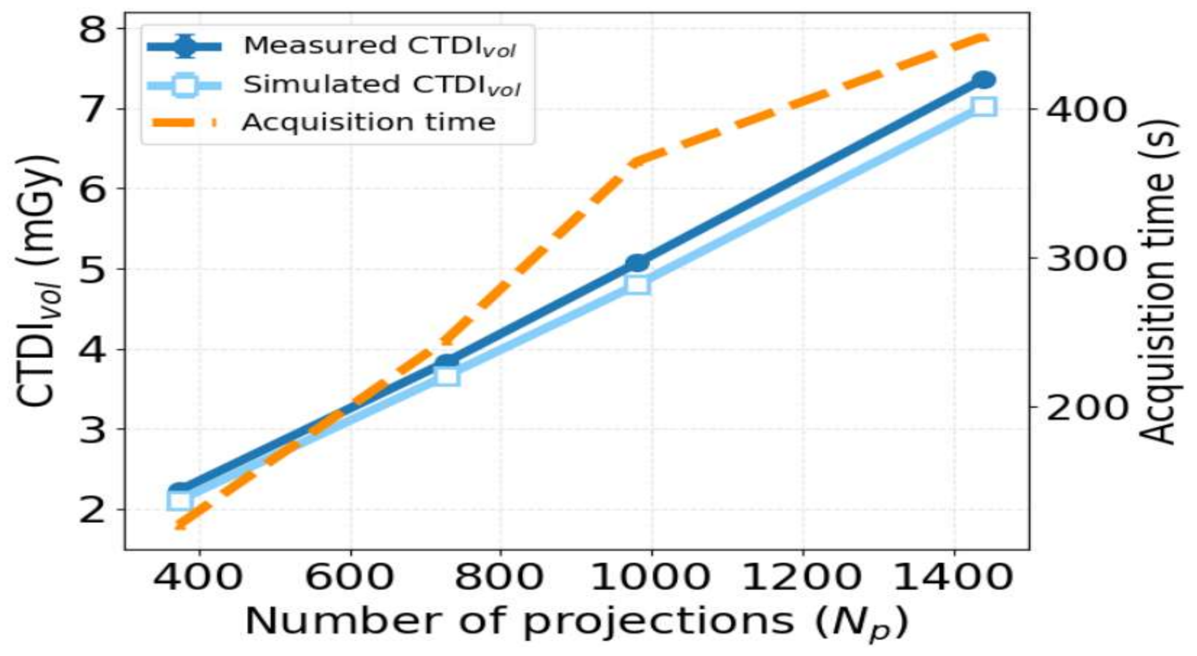

Figure. 2. Acquisition time, simulated and experimental dose as a function of Np.

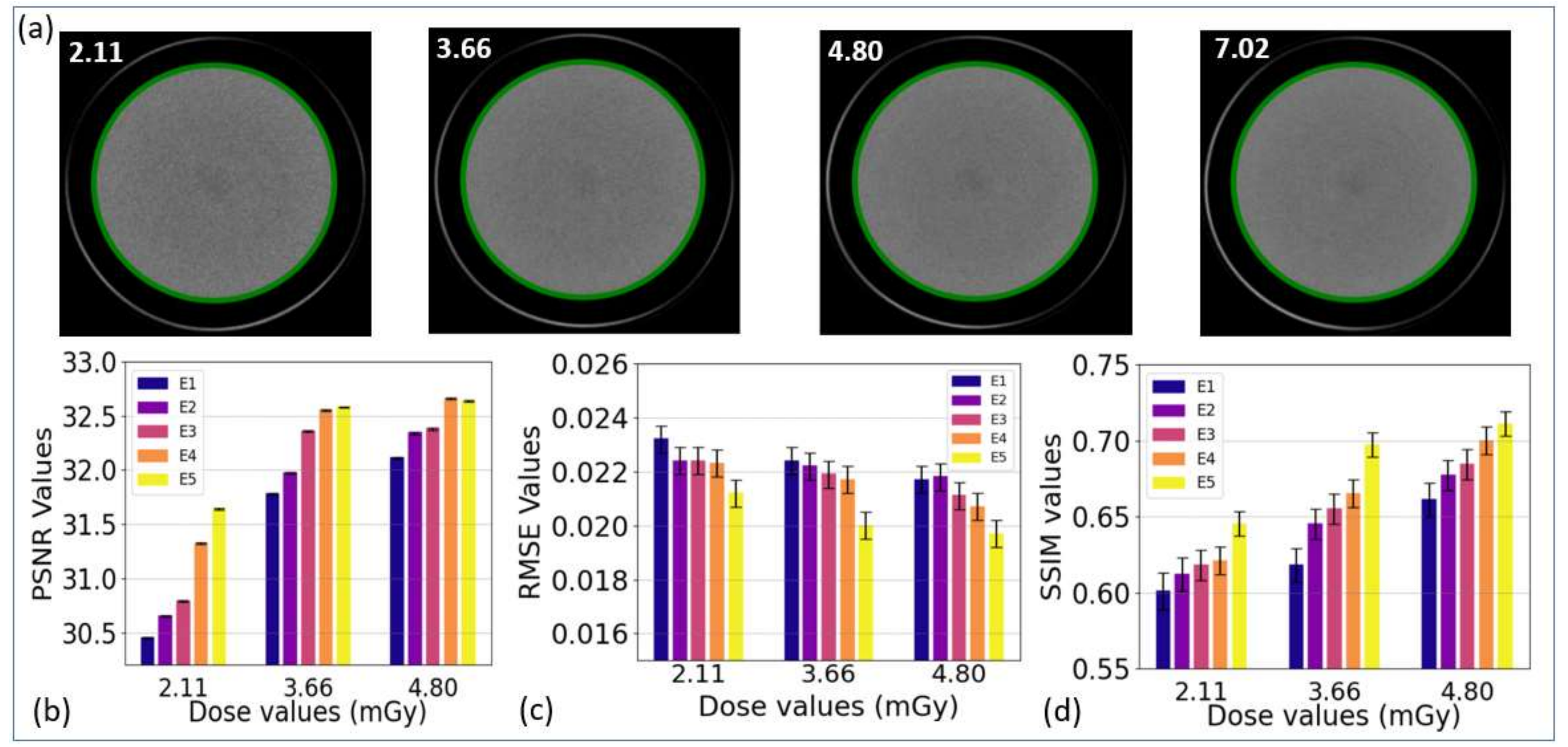

Figure 3. a. Reference images (E5) at four dose levels (2.11-7.02mGy) with ROI(green. (b-d) Image quality metrics (PSNR, RMSE, SSIM) across energy bins (E1-E5) .

Results

Experimental and simulated dose measurements (Figure 1) agreed within 5.3% across all projection numbers Np. The dose values increased linearly with Np. Increasing Np increased acquisition time, with a 272% rise from 373 to 1440.

Figure 3(a): Reference images of the homogeneous phantom (2.11-7.02 corresponding to Np of 373-1440) with ROIs shown in green for the 5th energy bin. The images were represented with approx. similar SNR.

Figures 3(b-d): Slight improvement on Image quality improved with increasing dose: PSNR remained stable (30.5-32.8 dB), RMSE decreased by 3-6%, and SSIM increased by 0.7-3%

Discussion

Photon counting CT offer improved material decomposition, signal to noise ratio (SNR) and spatial resolution compared to conventional CT

Our finding demonstrated excellent agreement between simulated and experimental dose measurements. Radiation dose increased by up to 230% (experimental) and 233% for simulated when Np increased from 373 to 1440.

Image quality improvements were modest despite the substantial dose increase: PSNR increased by ~6%, RMSE decreased by ~ 5%, and SSIM increased by < 3% (2.11-7.02mGy)

Conclusions

Increasing the number of projections beyond moderate levels substantially increased radiation dose, acquisition time, with minimum gain of image quality.

A > 233% increase in radiation dose resulted in only modest improvements in image quality (PSNR ~6%, RMSE ~ 5%, SSIM < 3%). Careful optimizing the number of projections is essential for balancing radiation dose efficiency with SPCCT image performance.

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