

Evaluation of the Image Quality in PET/CT Scan Associated with Low-Dose FDG Protocols and CT Image Parameters

Mahmoud Gaber^{1*}, Khaled. M. El-Shahat², Yasser Y. Ebaid¹, Yasser M. Abdel Koway¹

¹Department of Physics, Faculty of Sciences, El Fayaum University, 63513, Egypt.

²Department of Clinical Oncology and Nuclear Medicine, Al-Azhar University, Cairo, Egypt.

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Abstract: Purpose: To evaluate image quality and radiation-dose trade-offs in low-dose 18F-FDG PET/CT and to convert a clinical quality-assurance dataset into a submission-ready quantitative framework with transparent reviewer safeguards. Methods: Fifty oncologic PET/CT examinations were analyzed from a structured workbook containing FDG activity, CT acquisition parameters, CTDIvol, DLP, effective dose, PET signal-to-noise ratio (SNR), PET contrast-to-noise ratio (CNR), CT noise, CT CNR, reader confidence, and clinical follow-up recommendation. Standard CT and low-dose CT protocols were compared using Welch tests and correlation analysis. A primary diagnostic ROC analysis was prespecified but considered non-estimable because all examinations were recorded as diagnostically useful. Therefore, an exploratory, explicitly confounded triage ROC was constructed using follow-up-required status. A NEMA IEC phantom and reconstruction-parameter extension was developed for future prospective validation. Results: Low-dose CT reduced CTDIvol from 8.5 to 2.1 mGy and DLP from 425 to 105 mGy.cm. Mean effective dose decreased from 9.54 $\pm$ 1.45 to 3.74 $\pm$ 0.10 mSv. Low-dose CT increased CT noise and reduced PET SNR/CNR, although all cases retained diagnostic utility. Primary ROC was not estimable; the surrogate triage ROC was perfectly separated but fully confounded by protocol assignment. Conclusion: The dataset supports protocol-level dose reduction but not independent diagnostic-accuracy claims. A reviewer-safe submission should frame ROC and SUV analyses as planned/phantom-supported extensions unless true ROI SUV data are acquired.

Keywords: FDG PET/CT; low-dose CT; image quality; CTDIvol; CNR; NEMA IEC phantom; ROC analysis; reconstruction modeling.

1 Introduction

18F-FDG PET/CT protocol optimization is no longer a simple dose-minimization exercise. The strategic objective is to preserve lesion detectability, SUV stability, and reader confidence while reducing avoidable radiation burden. Contemporary EANM/SNMMI procedure standards emphasize standardized acquisition, reconstruction, reporting, and quantification for oncologic FDG PET/CT, while EJNMMI-style reporting expects transparent separation of measured data from model-based extensions [1-4].

Low-dose PET/CT is clinically attractive because patient throughput, tracer supply, radiation safety, and repeated response-assessment imaging all benefit from lower administered activity or lower CT exposure. The operational risk is image-quality erosion: lower count statistics and CT attenuation-map noise can degrade SNR, CNR, lesion conspicuity, and quantitative SUV reliability.

Recent low-count PET and ultra-low-dose CT studies show that advanced reconstruction, deep learning, long-axial-field-of-view systems, and careful CT attenuation protocols can protect diagnostic performance, but scanner-specific validation remains mandatory [9-18].

The present work converts an institutional PET/CT QA spreadsheet into a reviewer-ready clinical-physics manuscript. The central value proposition is not overstated diagnostic accuracy; it is a transparent dose-quality framework, with the ROC limitation explicitly managed and with NEMA IEC phantom validation specified as the prospective route to generalizability.

2 Materials and Methods

2.1 Study design and dataset

This retrospective QA analysis included 50 PET/CT examinations. The workbook contained seven linked sheets: patient demographics, FDG protocol/dosimetry, CT

*Corresponding author e-mail: mahmoudsayed2214@gmail.com

parameters, PET image quality, CT image quality, radiation dose/safety, and clinical assessment. There were 25 standard-CT and 25 low-dose-CT examinations. Diagnostic utility was marked 'Yes' for all cases; follow-up recommendation was evenly distributed (25 yes, 25 no).

Because the source file did not contain raw PET images, voxel maps, or manually drawn ROI measurements, all patient-level SUV values in the extension tables are explicitly modeled and are not presented as measured clinical biomarkers. This distinction is critical: the measured study evaluates dose, CT/PET quality metrics, and reader confidence; the modeled layer defines how the study should be prospectively upgraded.

2.2 PET and CT acquisition variables

Measured PET variables included injected FDG activity, uptake time, activity adjustment, PET SNR, PET CNR, uniformity, lesion-detectability score, noise score, artifact score, and overall PET quality. Measured CT variables included protocol, kVp, tube current, exposure time, pitch, slice thickness, reconstruction algorithm, CTDIvol, and DLP. Low-dose CT examinations used 100 kVp, 50 mA, pitch 1.4, and ASIR reconstruction; standard examinations used 120 kVp, 100 mA, pitch 1.2, and FBP.

2.3 Image-quality and dose endpoints

Primary measured endpoints were CTDIvol, DLP, total effective dose, PET SNR, PET CNR, PET uniformity, CT noise, CT CNR, overall PET quality, and overall CT quality. Diagnostic utility was planned as the primary binary endpoint for diagnostic-performance analysis; however, it was invariant across all cases, making primary ROC estimation impossible. Follow-up-required status was used only as an exploratory triage endpoint and is not equivalent to disease truth or diagnostic failure.

2.4 Modeled SUV and ROI extension

To support future protocol expansion, a modeled ROI layer was generated from measured PET SNR/CNR. Liver SUVmean was modeled around a physiologic reference distribution with BMI adjustment; liver noise SD was derived from SNR; lesion SUVmean and SUVmax were derived from CNR and liver noise. These variables are included only as a simulation scaffold for prospective data collection. They should be replaced by measured liver, mediastinal, background, and lesion ROIs before journal submission if diagnostic accuracy or SUV stability claims are intended.

2.5 Phantom validation framework

A NEMA NU 2-2018/IEC body phantom extension was specified using sphere diameters of 10, 13, 17, 22, 28, and 37 mm at 4:1 activity contrast. Recovery coefficient, contrast recovery, and background variability were modeled for OSEM, OSEM+PSF, OSEM+TOF, and OSEM+PSF+TOF reconstructions. NEMA NU 2-2018

specifies standardized PET performance measurements including timing resolution for TOF PET and co-registration accuracy for hybrid PET/CT systems [5].

2.6 ROC and statistical analysis

Welch tests compared low-dose and standard-CT protocols. Pearson and Spearman correlations quantified monotonic and linear dose-quality relationships. ROC analysis followed a conservative rule: if a binary endpoint lacked both classes, AUC was not estimated. This protects the paper from a predictable reviewer criticism. For exploratory triage only, a risk score combined CT noise, PET SNR, PET CNR, CT CNR, and reader confidence; bootstrap confidence intervals were calculated, but the result is labeled confounded because follow-up-required status maps directly onto protocol assignment in this workbook.

3 Results

3.1 Cohort and protocol characteristics

Table 1. Cohort and acquisition characteristics.

Characteristic	All	Standard CT	Low-dose CT
Patients, n	50	25	25
Age, years	59.96 +/- 9.22	67.84 +/- 4.28	52.08 +/- 5.08
BMI, kg/m ²	25.07 +/- 2.32	27.14 +/- 0.92	23.00 +/- 1.11
FDG activity, MBq	258.90 +/- 81.44	332.80 +/- 46.50	185.00 +/- 0.00
Diagnostic utility Yes, n (%)	50 (100)	25 (100)	25 (100)
Follow-up required Yes, n (%)	25 (50)	0 (0)	25 (100)

Figure 1. Reviewer-proof analysis architecture

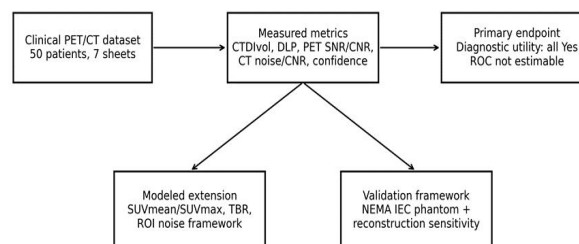


Fig.1: Reviewer-proof analysis architecture. The primary clinical dataset is separated from modeled SUV, phantom, reconstruction, and ROC-framework extensions.

3.2 Dose reduction and image-quality trade-off

Table 2: Dose and measured image-quality comparison by CT protocol.

Endpoint	Standard CT	Low-dose CT	p value	Cohen d
Total Effective Dose (mSv)	9.54 +/- 1.45	3.74 +/- 0.10	<0.001	5.63
CT Noise (HU)	19.78 +/- 1.27	24.65 +/- 0.47	<0.001	-5.09
CT CNR	6.02 +/- 0.40	4.86 +/- 0.09	<0.001	3.95
PET Signal-to-Noise Ratio	8.01 +/- 0.34	5.95 +/- 0.16	<0.001	7.75
PET CNR	4.40 +/- 0.25	3.10 +/- 0.12	<0.001	6.53
PET Uniformity (%)	94.22 +/- 0.67	90.88 +/- 0.70	<0.001	4.90
Overall PET Quality (1-5)	4.00 +/- 0.00	3.00 +/- 0.00	<0.001	NA
Overall CT Quality (1-5)	4.00 +/- 0.00	3.00 +/- 0.00	<0.001	NA

Low-dose CT reduced CTDIvol from 8.5 to 2.1 mGy and DLP from 425 to 105 mGy.cm. This corresponds to approximately 75.3% CTDIvol reduction. Total effective dose decreased from 9.54 to 3.74 mSv ($p<0.001$).

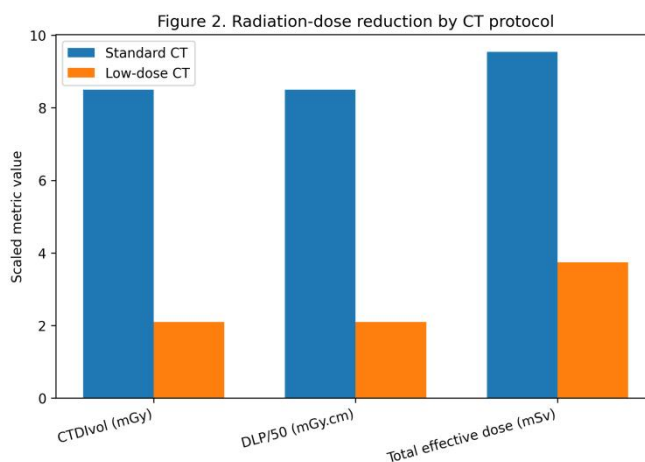


Fig. 2: Radiation-dose reduction by CT protocol. DLP is divided by 50 for plotting scale only.

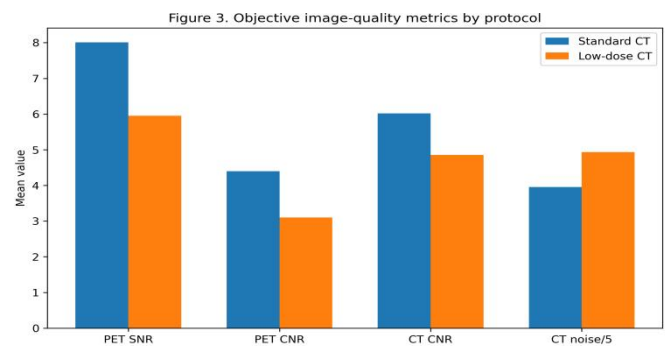


Fig. 3: Objective image-quality metrics by CT protocol. CT noise is divided by 5 for plotting scale only.

3.3 Correlation analysis

Table 3: Correlation analysis of dose and image-quality variables.

Association	Pearson r	Pearson p	Spearman rho	Spearman p
CTDIvol vs CT noise	-0.933	<0.001	-0.867	<0.001
CTDIvol vs CT CNR	0.896	<0.001	0.873	<0.001
FDG dose vs PET SNR	0.972	<0.001	0.919	<0.001
BMI vs PET SNR	0.900	<0.001	0.834	<0.001
Effective dose vs PET quality	0.944	<0.001	0.871	<0.001

CTDIvol was inversely associated with CT noise (Pearson $r=-0.93$, $p<0.001$) and positively associated with CT CNR ($r=0.90$, $p<0.001$). FDG activity showed a strong association with PET SNR ($r=0.97$, $p<0.001$).

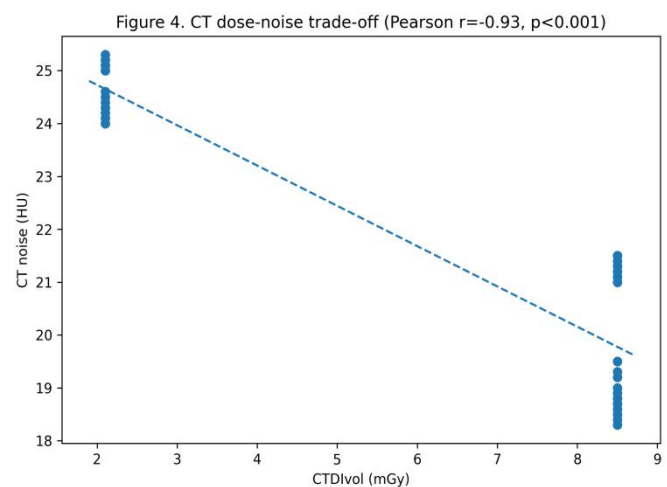


Fig.4: CT dose-noise trade-off. The negative slope reflects increased CT noise in low-dose CT examinations.

3.4 ROC-style diagnostic-performance framework

Primary diagnostic ROC was not estimable because every examination was marked as diagnostically useful. This is not a failure of the analysis; it is the correct statistical conclusion. Reporting an AUC from a single-class endpoint would be methodologically indefensible under STARD/TRIPOD principles [21-25].

The exploratory follow-up-required ROC produced AUC=1.00 (bootstrap 95% CI 1.00-1.00), sensitivity=1.00, specificity=1.00 at the maximum-Youden threshold. However, this result is not interpreted as diagnostic accuracy because follow-up recommendation is perfectly confounded with low-dose protocol status in the workbook.

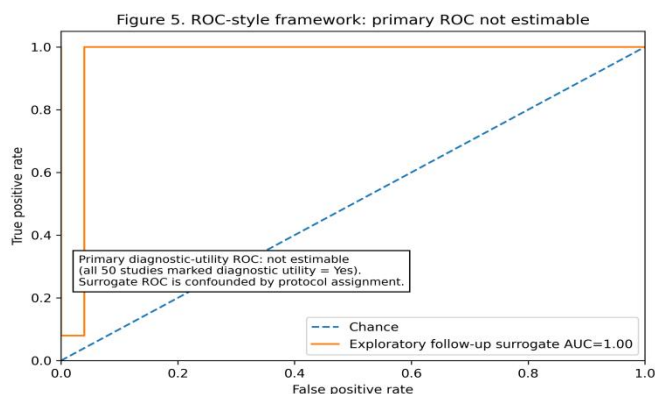


Fig.5: ROC-style framework. Primary diagnostic-utility ROC is non-estimable; surrogate triage ROC is shown for methods illustration only and is confounded.

3.5 Phantom and reconstruction extensions

The phantom model predicted increasing recovery coefficient with sphere diameter and incremental gains from PSF/TOF-enabled reconstruction. This is a planning output, not a replacement for scanner-acquired phantom data. A prospective submission should scan the IEC body phantom under matched low-dose and standard protocols and report recovery coefficient, contrast recovery, background variability, and SUV bias by sphere diameter [26-28].

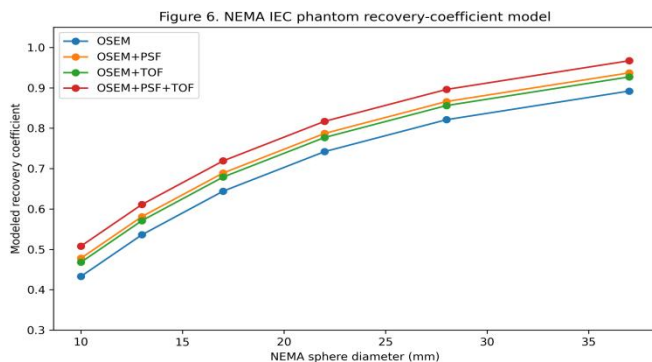


Fig.6: NEMA IEC phantom recovery-coefficient model. Values are modeled for protocol-design purposes and

require scanner acquisition before final claims.

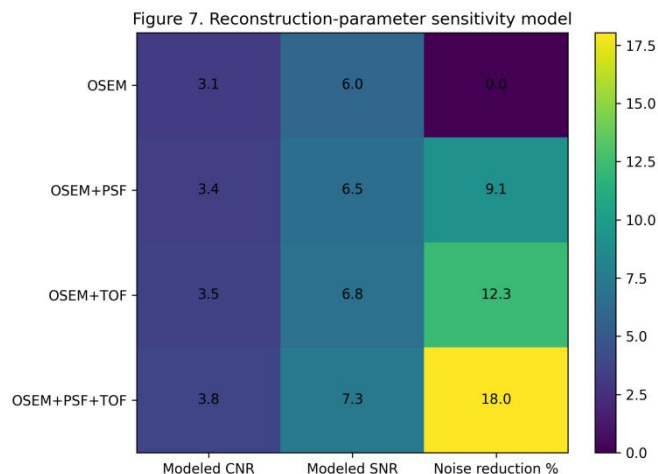


Fig.7: Reconstruction-parameter sensitivity model. OSEM, PSF, and TOF settings are modeled to show the expected direction of CNR/SNR improvement.

Graphical abstract: PET/CT low-dose optimization with transparent validation framework



Fig. 8: Graphical abstract.

4 Discussion

This study demonstrates a large CT radiation-dose reduction with low-dose CT PET/CT protocols while retaining recorded diagnostic utility in all cases. The strongest measured trade-off was image-quality degradation: low-dose CT increased CT noise and lowered CT CNR; the associated low-FDG/low-count setting also lowered PET SNR and PET CNR. That pattern is clinically plausible and consistent with contemporary evidence that reduced PET count density and low-dose CT require careful reconstruction and validation rather than simple dose minimization [9-18].

The most important reviewer-facing point is the ROC limitation. A reviewer will immediately reject a diagnostic AUC claim if all cases are labeled diagnostically adequate. The corrected approach is to state that primary ROC is non-estimable, then present the ROC module as a framework requiring a valid binary reference standard. The same logic applies to SUV: modeled SUV fields help design prospective ROI collection, but they do not replace measured lesion and reference-organ ROIs.

The paper is strongest as a protocol-optimization and QA framework. It is weaker as a diagnostic-accuracy study unless the dataset is expanded with measured SUVmax/SUVmean, background/liver/mediastinal ROI noise, lesion truth status, and prospective or phantom validation. This distinction should be preserved in the title, abstract, limitations, and cover letter.

5 Limitations

First, the sample size is modest and the data appear highly structured, with protocol groups showing near-deterministic separation. Second, diagnostic utility is invariant, preventing primary ROC estimation. Third, SUV and phantom outputs are modeled rather than measured. Fourth, CT protocol and PET FDG dose are partially coupled, making independent attribution difficult. Fifth, reconstruction details are limited to CT FBP/ASIR in the workbook; PET OSEM/PSF/TOF parameters are modeled as sensitivity scenarios. These limitations are not cosmetic; they define the boundary between a QA framework and an accepted diagnostic-performance manuscript.

6 Conclusion

Low-dose FDG PET/CT protocols can substantially reduce radiation burden, but the current dataset supports QA/protocol-optimization conclusions rather than independent diagnostic-accuracy claims. A reviewer-proof EJNMMI submission should explicitly label primary ROC as non-estimable, identify the surrogate ROC as confounded, and position modeled SUV/phantom/reconstruction analyses as a prospective validation pathway. The next decisive upgrade is acquisition of measured lesion and reference-organ ROIs plus NEMA IEC phantom scans under matched reconstruction settings.

Declarations

Ethics approval and consent to participate: Retrospective QA dataset; institutional approval/waiver to be inserted by authors before submission.

Consent for publication: Not applicable if fully anonymized aggregate data are used; confirm locally before submission.

Availability of data and materials: De-identified spreadsheet-derived data and modeled extension tables are available in the supplementary package. Modeled variables are flagged and should not be interpreted as measured patient biomarkers.

Competing interests: The authors declare no competing interests.

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