IMPACT OF CT TUBE VOLTAGE AND ANODE CURRENT ON PET/CT IMAGE QUALITY A NEMA IQ Phantom Study

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Scientific paper
https://doi.org/10.2298/NTRP2602152C

Positron emission tomography/computer tomography is a crucial modality for the quantification of metabolic activity and anatomical structure. Reducing radiation dose, especially in repeated imaging, remains a significant challenge. This study focuses on optimizing computer tomography parameters to reduce dose, while maintaining image quality. The aim of this research was to determine the impact of varying computer tomography tube voltage and anode current, on the quantification of standardized uptake value, contrast-to-noise ratio, and radiation exposure (volume CT dose index, dose-length product). A NEMA IQ body phantom was scanned using various combinations of tube voltage and anode current. Standardized uptake value, contrast-to-noise ratio, volume CT dose index and dose-length product, were evaluated from the different scans. The obtained results were statistically assessed. Reducing tube voltage and anode current did not significantly affect standardized uptake value accuracy but, reduced radiation dose. Image quality (contrast-to-noise ratio) remained diagnostically acceptable, supporting the potential for optimization without compromising accuracy. Optimization of computer tomography parameters (tube voltage, anode current) is feasible and beneficial in clinical practice, as it reduces patient radiation burden while maintaining image quality and standardized uptake value accuracy.

Key words: PET/CT, standardized uptake value, quantification, dose optimization, image quality, tube voltage, anode current, parameter variation

INTRODUCTION

Positron emission tomography combined with computed tomography (PET/CT) is one of the most advanced hybrid imaging modalities, combining metabolic information from PET with detailed anatomical imaging from CT [1]. This technology plays a crucial role in clinical practice, particularly in oncology, where it enables early detection of malignant changes, monitoring of therapy response, and accurate localization of metastases. The PET/CT is also indispensable in neurology and cardiology for detecting neurodegenerative diseases, evaluating cerebral and cardiac perfusion, and assessing myocardial viability [2]. A primary concern in the use of PET/CT devices is patient exposure to ionizing radiation [1]. The CT component, in particular, significantly contributes to the overall radiation dose, making the optimization of imaging parameters essential to reduce exposure without compromising image quality [2]. The CT uses X-rays to create cross-sectional images of internal body structures. Key parameters in image formation are the X-ray tube voltage (kV) and the anode current (expressed as mAs) [3]. These parameters directly affect image quality and patient radiation burden. Optimizing these parameters is crucial for achieving a balance between image quality and minimal radiation dose, thereby reducing the risk to the patient, especially in repeated examinations [4]. The optimization process becomes particularly important for patients who require multiple examinations, where the cumulative radiation dose can become significant [4]. Technological advancements, such as iterative reconstruction and automatic parameter adjustment, enable the reduction of radiation dose while maintaining adequate image quality [5, 6]. The standardized uptake value (SUV) is a key parameter in the quantification of metabolic activity in PET studies, especially in oncology, where the accuracy of SUV values allows for precise monitoring of disease and treatment response [5]. The SUV is used to measure the amount of administered radiopharmaceutical that has accumulated in tissues, allowing for accurate assessment of metabolic processes at the molecular level. Its use is particularly important in oncological diagnostics, as it enables the

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differentiation of tumor tissue from normal and inflamed tissue based on their increased metabolic activity [7]. The calculation of SUV in PET/CT does not directly depend on CT image quality, as CT data do not enter the SUV calculation equation directly. The SUV values are based on the reconstructed activity concentration in PET images, normalized to the administered activity (corrected for radioactive decay) and the patient's body mass [8]. In this context, SUV is not directly dependent on CT image quality, as CT values are not included in the SUV calculation itself [9]. However, this assumption of independence is not absolute, since CT data are essential for CT-based attenuation correction (CTAC), which directly influences the reconstructed PET activity distribution and therefore may indirectly affect SUV quantification [10].

Despite the widespread clinical use of PET/CT, there is still a limited evidence on how systematic variations in CT acquisition parameters affect quantitative PET metrics, such as SUV, through CT-based attenuation correction, and how these effects simultaneously relate to CT image quality and radiation dose.

The aim of this research is to optimize/evaluate CT parameters within a PET/CT examination, ensuring that the optimization does not alter the quantitative values SUV. The primary goal of this research is to reduce the radiation dose received by the patient during imaging while maintaining diagnostic accuracy and the accuracy of SUV quantification.

MATERIALS AND METODS

Experimental procedures

In this study, we analyzed a NEMA IQ phantom. The NEMA IQ phantom is a standard acrylic cylindrical phantom filled with water, specifically designed to simulate the anatomical characteristics of the human body. The phantom contains six spheres of different diameters: 10 mm, 13 mm, 17 mm, 22 mm, 28 mm, and 37 mm. The spheres are suspended in the central part of the phantom and are used to evaluate the quantitative capabilities of PET scanners. Each sphere is filled with the radiopharmaceutical ^{18}F-fluorodeoxyglucose (FDG), allowing for detailed analysis of activity quantification in structures of different sizes. The NEMA IQ body phantom was filled with a solution of the radiopharmaceutical ^{18}F FDG in an activity concentration ratio between the background and the spheres of 1:10. The background activity was 60.4 MBq in 10 liters of solution, yielding a concentration of 6.04 kBq(ml)$^{-1}$. In the spheres, the activity was 60.3 MBq in 1 liter, or 60.3 kBqml^{-1}. The phantom was scanned on a Siemens Biograph mCT PET/CT scanner, which combines a patented PET system with lutetium oxyorthosilicate (LSO) with time-of-flight (ToF) technology and a 128-slice CT. The parameters for the CT scan were varied in different combinations are shown in the tab. 1.

Table 1. The CT scan parameters

	CT scan parameters									
Tube voltage [kV]	140	140	120	120	100	100	80	70	80	70
Anode current [mAs]	80	30	80	30	80	30	80	70	30	130

Quantitative image analysis was performed using SINGOVIA software. On each NEMA IQ phantom image, regions of interest (RoI) were drawn around the spheres of different diameters, consistent with the known dimensions of the spheres, and SUVmax and SUVmean were evaluated. The RoI were also placed on the background region, with the diameter of the largest sphere used to determine the accuracy of the analysis.

The SUV was calculated as

$$SUV = \frac{(\text{activity concentartion }[\text{kBq(mL)}^{-1}])}{(\text{injected activity }[\text{kBq}]/\text{ body mass }[\text{kg}])}$$

A constant phantom mass (water-equivalent mass of 10 kg) was assumed for all measurements to ensure consistency across acquisitions.

On attenuation-corrected SPECT images reconstructed using different CT attenuation maps, the contrast-to-noise (CNR) ratio was evaluated. The CNR quantifies the contrast between the object (sphere) and the background while accounting for image noise, and is commonly used to assess object detectability and overall image quality [11].

The CNR for SPECT images was calculated as

$$CNR = \frac{[S - Sbg]}{SDbg} \times 100\ [\%]$$

where S is the mean signal within the sphere, Sbg – the mean background signal, and $SDbg$ – the standard deviation of the background signal. Percentage scaling (×100) was applied consistently across all datasets to ensure comparability.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics software (version 23). To evaluate the impact of variations in CT acquisition parameters (kV and mAs) on radiation dose, computed tomography dose index volume (CTDIvol), and dose-length product (DLP) were calculated, and correlation analysis was conducted using Pearson's correlation coefficient. This approach enabled assessment of both the strength and direction of the relationship between changes in kV/mAs settings and CTDIvol and DLP values.

The interpretation of Pearson's correlation coefficient (r) followed a five-level scale:

– $r < 0.20$ – very weak correlation,
– $0.20 \le r < 0.40$ – weak correlation,

– 0.40 $r < 0.60$ – moderate correlation,
– 0.60 $r < 0.80$ – strong correlation,
– r 0.80 – very strong correlation.

Normality of data distribution was assessed using the Shapiro-Wilk test, confirming a normal distribution of the analyzed variables. The effects of changes in CT acquisition parameters on quantitative metrics (SUV_{max}, SUV_{mean}, CNR_{max}, and CNR_{mean}) were evaluated using one-way analysis of variance (ANOVA). When statistically significant differences were observed, F-values and corresponding p-values were reported to quantify between-group variability.

For all statistical tests, a significance level of $p < 0.05$ was applied.

RESULTS

Impact of tube voltage and currennt variations on CTDIvol and DLP

The CTDIvol and DLP values according to the applied variations in tube voltage (kV) and tube current (mAs) are presented in tab. 2. The analysis demonstrated a strong positive correlation between the kV/mAs parameters and CTDIvol and DLP values ($r > 0.9$; $p < 0.05$).

The scatter plot illustrates the relationship between CTDIvol (mGy) and DLP (mGy·cm) in fig. 1. A strong positive linear correlation is observed, indicating that DLP increases proportionally with CTDIvol. This is consistent with the theoretical relationship, as DLP is directly dependent on CTDIvol and scan length.

The data points are closely aligned along the regression line, suggesting low variability and good consistency in the acquisition protocol. Minor deviations from the trend line may reflect slight differences in scan length or acquisition settings. Overall, the results confirm a stable and predictable dose relationship across the examined measurements.

Table 2. The combination of tube voltage and anode current used and their mpact on the variations of CTDIvol and DLP

Tube voltage [kV]	Anode current [mAs]	CTDIvol [mGy]	DLP [mGycm]
140	80	6.23	233.2
120	80	5.39	152.8
100	80	3.15	89.3
140	30	3.09	87.3
120	30	2.02	57.3
70	130	1.50	42.5
80	80	1.49	42.1
100	30	1.18	33.5
70	80	0.92	26.1
80	30	0.56	15.8

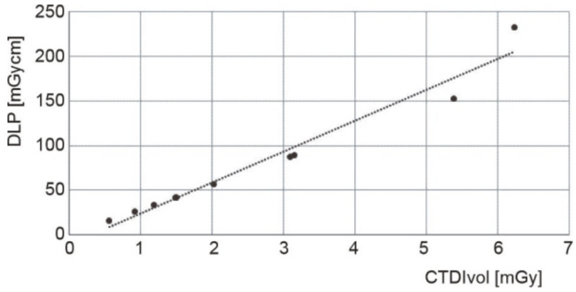

Figure 1. Relationship between CTDIvol and DLP

Impact of CT parameter variations on SUV quantification

Statistical evaluation using ANOVA demonstrated no significant differences in SUV_{max} (F = 0.0009; p = 0.999) and SUV_{mean} (F = 0.0006; p = 0.999) across the various CT acquisition protocols. These findings indicate that alterations in tube voltage (kV) and anode current product (mAs) do not induce statistically significant variations in PET quantification under the current experimental conditions. The observed stability of SUV values across all parameter combinations is further detailed in tabs. 3 and 4.

Regression analysis was employed to evaluate the relationship between SUV quantification and radi-

Table 3. The SUVmax values at a background /sphere ratio of 1:10

PET/CT: kV in mAs	SUV_{max} values in different spheres					
	10 mm	13 mm	17 mm	12 mm	28 mm	37 mm
140 kV 80 mAs	5.66	10.50	11.80	11.50	11.20	11.50
140 kV 30 mAs	5.66	10.50	11.80	11.50	11.20	11.50
120 kV 80 mAs	5.66	10.50	11.80	11.50	11.20	11.50
120 kV 30 mAs	5.66	10.50	11.80	11.50	11.30	11.50
100 kV 80 mAs	5.67	10.50	11.80	11.50	11.30	11.50
100 kV 30 mAs	5.67	10.50	11.80	11.50	11.30	11.50
80 kV 80 mAs	5.68	10.50	11.80	11.60	11.30	11.60
80 kV 30 mAs	5.71	10.60	11.90	11.60	11.30	11.60
70 kV 130 mAs	5.69	10.60	11.80	11.60	11.30	11.60
70 kV 80 mAs	5.69	10.50	11.80	11.60	11.30	11.60

Table 4. The SUV_{mean} values at a background/ sphere ratio of 1:10

PET/CT: kV in mAs	SUV_{mean} values in different spheres					
	10 mm	13 mm	17 mm	22 mm	28 mm	37 mm
140 kV 80 mAs	4.84	6.48	7.68	7.43	8.66	8.84
140 kV 30 mAs	4.84	6.46	7.68	7.44	8.67	8.85
120 kV 80 mAs	4.84	6.46	7.68	7.44	8.68	8.84
120 kV 30 mAs	4.85	6.46	7.69	7.46	8.70	8.85
100 kV 80 mAs	4.85	6.47	7.69	7.46	8.70	8.85
100 kV 30 mAs	4.85	6.48	7.69	7.46	8.70	8.88
80 kV 80 mAs	4.87	6.50	7.70	7.48	8.73	8.87
80 kV 30 mAs	4.88	6.52	7.72	7.49	8.74	8.89
70 kV 130 mAs	4.87	6.50	7.70	7.49	8.75	8.87
70 kV 80 mAs	4.86	6.49	7.69	7.48	8.74	8.87

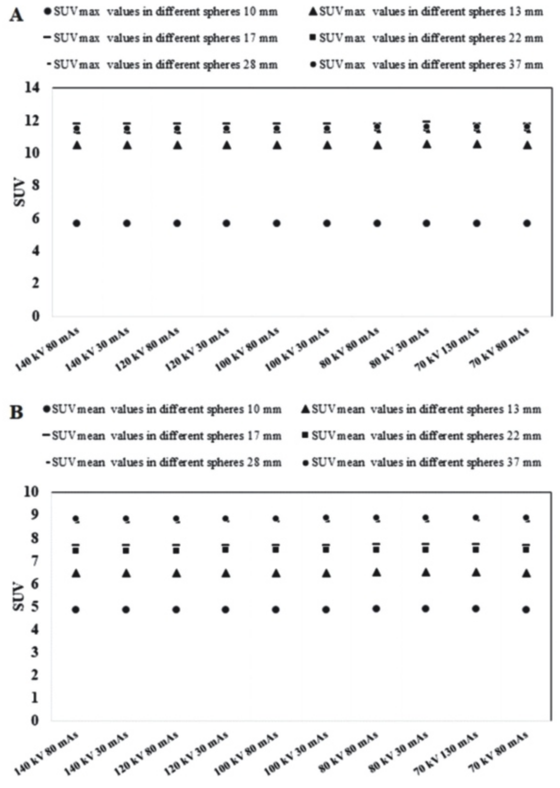

Figure 2. SUV_{max} and SUV_{mean} at different CT parameters at a background/sphere ratio of 1:10

ation dose metrics (CTDIvol and DLP). The results, fig. 2, confirm that SUV remains independent of the CT dose level, suggesting that dose reduction strategies in the CT component of PET/CT imaging can be implemented without compromising the accuracy of SUV based quantification for attenuation correction.

Analysis of image quality indicators

To further evaluate the impact of CT parameter variations on PET image quality, the CNR was calculated for both maximum (CNR_{max}) and mean (CNR_{mean}) values. The results, summarized in tabs. 5 and 6, provide a quantitative assessment of image fidelity across different acquisition settings. Statistical analysis using ANOVA revealed no significant differences in CNR_{max} ($F = 0.0009$; $p = 0.999$) and CNR_{mean} ($F = 0.0006$; $p = 0.999$) values among the various combinations of tube voltage (kV) and anode current product (mAs). These results demonstrate that modifications to the CT protocol within the investigated range do not adversely affect the characteristics of the reconstructed PET images. The consistency of these indicators (tabs. 4 and 5) further supports the stability of the PET/CT system's performance across diverse radiation dose levels. Figure 3 illustrates the distribution of CNR_{max} and CNR_{mean} for the six spheres of the NEMA IQ phantom, showing stable image quality regardless of the CT settings employed for attenuation correction.

Figure 3, displays the CNR_{max} and CNR_{mean} values for the six different spheres in the NEMA IQ phantom at various combinations of CT parameters in the 1:10 ratio experiment.

Table 5. The CNR_{max} at a background/sphere ratio of 1:10

PET/CT: kV in mAs	CNR_{max} values in different spheres					
	10 mm	13 mm	17 mm	22 mm	28 mm	37 mm
140 kV 80 mAs	46.00	94.40	107.40	104.40	101.40	104.40
140 kV 30 mAs	45.90	94.30	107.30	104.30	101.30	104.30
120 kV 80 mAs	46.00	94.40	107.40	104.40	101.40	104.40
120 kV 30 mAs	46.00	94.40	107.40	104.40	102.40	104.40
100 kV 80 mAs	46.10	94.40	107.40	104.40	102.40	104.40
100 kV 30 mAs	46.10	94.40	107.40	104.40	102.40	104.40
80 kV 80 mAs	46.10	94.30	107.30	105.30	102.30	105.30
80 kV 30 mAs	46.40	95.30	108.30	105.30	102.30	105.30
70 kV 130 mAs	46.20	95.30	107.30	105.30	102.30	105.30
70 kV 80 mAs	46.20	94.30	107.30	105.30	102.30	105.30

Table 6. The CNRmean at a background/sphere ratio of 1:10

PET/CT: kV in mAs	CNR_{mean} values in different spheres					
	10 mm	13 mm	17 mm	22 mm	28 mm	37 mm
140 kV 80 mAs	37.80	54.20	66.20	63.70	76.00	77.80
140 kV 30 mAs	37.70	53.90	66.10	63.70	76.00	77.80
120 kV 80 mAs	37.80	54.00	66.20	63.80	76.20	77.80
120 kV 30 mAs	37.90	54.00	66.30	64.00	76.40	77.90
100 kV 80 mAs	37.90	54.10	66.30	64.00	76.40	77.90
100 kV 30 mAs	37.90	54.20	66.30	64.00	76.40	78.20
80 kV 80 mAs	38.00	54.30	66.30	64.10	76.60	78.00
80 kV 30 mAs	38.10	54.50	66.50	64.20	76.70	78.20
70 kV 130 mAs	38.00	54.30	66.30	64.20	76.80	78.00
70 kV 80 mAs	37.90	54.20	66.20	64.10	76.70	78.00

DISCUSSION

In this study, we analyzed NEMA IQ phantom data acquired during PET/CT examinations, with a specific focus on the impact of variations in CT tube voltage (kV) and anode current (mAs) on the quantification of SUV values. These results are essential for improving radiation dose optimization in clinical practice, where the goal is to reduce radiation dose while maintaining diagnostic value and the accuracy of quantitative values. Based on the collected data, it was confirmed that variations in CT parameters, particularly tube voltage (kV) and anode current (mAs), did not cause statistically significant changes in SUV values. These results indicate that high image quality can be achieved even at lower tube voltage and current values, while maintaining the accuracy of SUV quantification, suggesting the possibility of a significant reduction in radiation dose without compromising diagnostic accuracy. Our results are largely supported by

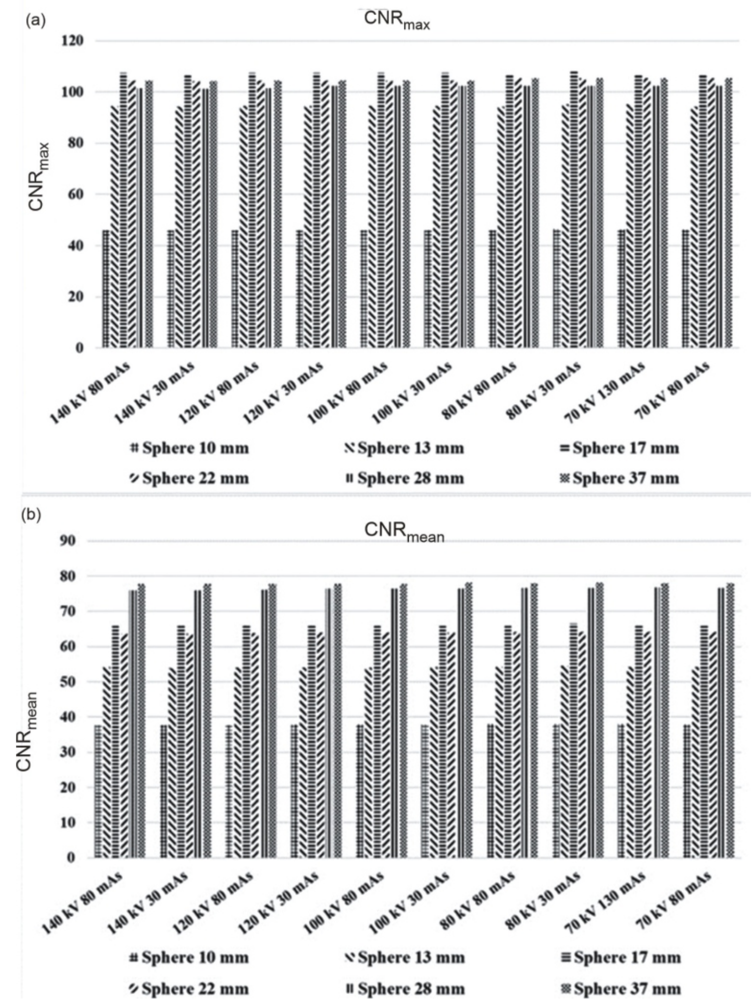

Figure 3. The CNR_{max} (a) and CNE_{mean} (b) values for different CT parameters at a 1:10 background/sphere ratio

the findings of the study by Bebbington *et al*., [12] which validated CARE kV technology for automatic tube voltage selection in PET/CT examinations. This study showed that reducing tube voltage with the CARE kV system allows for a significant reduction in radiation dose while maintaining the accuracy of SUV quantification and image quality.

The differences between our studies relate to the choice of phantoms, where Bebbington et al. used four different phantoms – Lungman, Lungman plus fat, Esser, and NEMA IQ – which allowed them to analyze various anatomical scenarios [12]. In contrast, we used only the NEMA IQ phantom, which provides a standardized basis for assessing image quality and dose but limits generalization to specific anatomical differences. Bebbington *et al*. [12] used the CARE kV system to automatically adjust voltage based on the characteristics of each phantom, which further optimized radiation. Similar results on the benefits of automatic tube voltage control with CARE kV technology are shown in the study by Yu *et al*., [13] which highlights the clinical advantage of this method in terms of accuracy and dose consistency. Gould *et al*. [14] further emphasize the benefits of combining automatic exposure control (AEC) with advanced iterative reconstructions, achieving high image quality at lower tube voltage (kV) and anode current (mAs) values, which aligns with the findings of our study regarding maintaining diagnostic image quality while reducing dose [14]. Similarly, McCollough *et al*. [15] provided a comprehensive review of AEC systems for reducing radiation dose in CT imaging, which is consistent with our conclusions. Although we did not use AEC systems but rather manual voltage adjustment, the results are comparable, as reducing tube voltage did not affect image quality, indicating the effectiveness of a manual approach to achieving similar results under controlled conditions.

The SUV quantification parameter has been used as a key indicator in numerous studies dealing with dose and image quality optimization in PET/CT imaging. For example, the study by Brady and Shulkin, which was also based on the NEMA IQ phantom, showed that reducing tube voltage (kV) and anode current (mAs) allows for maintaining the accuracy of SUV quantification while reducing dose, which is consistent with our findings [16].

Their study provides theoretical support for our experimental results, demonstrating that optimization techniques are effective in maintaining image quality at lower radiation doses. Furthermore, Reid *et al*. [17] investigated the impact of tube voltage (kV) and anode current (mAs) parameters on image quality and radiation dose in pediatric CT imaging, showing that optimizing these parameters allows for dose reduction without compromising image quality. Although their study focused on CT imaging in the pediatric population, their principles confirm the universality of this approach and the applicability of our results to different populations. In addition, Parisi *et al*., [4] in their study on the optimization of PET/CT imaging in pediatric patients, highlighted the challenges in maintaining image quality in younger patients, indicating potential difficulties in preserving image quality at lower doses, which our phantom study has not yet been able to capture. Similarly, Lee *et al*. [18] examined the difference in image quality and radiation dose between 120 kV and 140 kV in patients with elevated BMI, emphasizing that tube voltage optimization contributes to reducing radiation dose without loss of diagnostic image accuracy. Their results support our findings, showing similar benefits of dose optimization even in patients with specific body characteristics, further confirming the potential applicability of our findings in various clinical settings. In the study by Hu *et al*., [19] reducing tube voltage and mAs in abdominal CT imaging resulted in a slight deterioration of image quality, which differs from our results on PET/CT phantoms. This difference may be due to the specific anatomical characteristics of abdominal imaging, while PET/CT phantoms have stable CNR even at reduced doses, indicating the specificity of parameters for different anatomical regions.

One of the key limitations of our study relates to the use of only one type of phantom, specifically the NEMA phantom. Although this phantom is routinely used in diagnostic PET/CT studies due to its consistency and suitability for SUV quantification, its use is limited in reproducing the various anatomical and physiological variations in patients. Studies such as the one by Bebbington *et al*., [12] which included several different phantoms (*Lungman*, *Lungman plus fat*, *Esser*, and *NEMA IQ*), provide a more comprehensive assessment by simulating different body characteristics and diagnostic scenarios, thereby increasing the applicability of the results to a wider range of patients. Our study, which used only the NEMA phantom, provides reliable data but limits the possibility of adapting the conclusions to different body compositions, which is particularly important in PET/CT examinations of patients with specific characteristics, such as high BMI or more complex anatomical structures. Furthermore, we did not use automatic tube voltage adjustment systems, such as the CARE kV system used by Bebbington *et al*. [12]. Automatic systems like CARE kV have proven to be more accurate in controlling and adjusting tube voltage based on the patient's body constitution and imaging needs, further optimizing radiation dose while maintaining image quality [13, 14]. Our manual adjustment approach, although effective under controlled conditions, may lead to variability in clinical practice and requires more operator attention in adjusting to each patient, which automatic systems can overcome in terms of consistency and speed. Likewise, the integration of automatic tube voltage adjustment systems, such as CARE kV technology, could improve the consistency of results and reduce the possibility of errors that may arise from manual parameter adjustment. By combining the CARE kV system with advanced image reconstruction methods, such as iterative reconstructions, which were used in the studies by Gould *et al*., [14] future studies could further reduce radiation dose without compromising image quality. This would allow for the development of new protocols for PET/CT imaging, specifically tailored to the needs of different patients, ensuring an optimal balance between radiation dose and diagnostic image quality in everyday clinical practice

CONCLUSION

In this study, we investigated the impact of different CT parameters, such as tube voltage and anode current, on SUV values, CNR, and patient radiation burden in PET/CT imaging. The results confirmed that variations in tube voltage and anode current allow for a significant reduction in radiation dose without compromising image quality and the accuracy of SUV quantification. This indicates the feasibility of optimizing PET/CT protocols to achieve a balance between minimizing radiation dose and maintaining diagnostic quantitative image quality, which is particularly important for clinical practice.

AUTHORS' CONTRIBUTIONS

M. Čavlin: conceptualization, investigation, formal analysis, data curation, writing original draft. L. Ležaić: data curation, writing review and editing. S. Rep: analysis, methodology, validation, supervision, writing review and editing.

ACKNOWLEDGMENT

We would like to thank the Division of Nuclear Medicine, University Medical Centre Ljubljana, for enabling the execution of the analyses presented in this study.

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Received on June 4, 2025
Accepted on June 18, 2026

Милана ЧАВЛИН, Лука ЛЕЖАИЋ, Себастјан РЕП

УТИЦАЈ НАПОНА СТ ЦЕВИ И АНОДНЕ СТРУЈЕ НА КВАЛИТЕТ РЕТ/СТ СЛИКЕ
Једно проучавање помоћу NEMA IQ фантома

Позитронска емисиона томографија/компјутерска томографија кључна је метода за квантификацију метаболичке активности и анатомске структуре. Смањење дозе зрачења, посебно код поновљеног снимања, остаје значајан изазов. Овај рад фокусира се на оптимизацију параметара компјутерске томографије како би се смањила доза, уз одржавање квалитета слике. Циљ истраживања био је да се утврди утицај напона цеви и анодне струје на квантификацију стандардизоване вредности апсорпције, односа контраста и шума и изложености зрачењу (индекс запреминске СТ дозе, производ дозе и дужине). NEMA IQ фантом тела је скениран коришћењем различитих комбинација напона и струје. Добијени резултати статистички су процењени. Смањење напона цеви и анодне струје није значајно утицало на тачност стандардизоване вредности апсорпције, али је смањило дозу зрачења. Квалитет слике (однос контраста и шума) остао је дијагностички прихватљив, подржавајући потенцијал за оптимизацију без угрожавања тачности. Оптимизација параметара компјутерске томографије (напон цеви, анодна струја) изводљива је и корисна у клиничкој пракси, јер смањује оптерећење зрачењем пацијента уз одржавање квалитета слике и тачности стандардизоване вредности апсорпције.

Кључне речи: ПЕТ/ЦТ, стандардизована вредност апсорпције, квантификација, оптимизација дозе, квалитет слике, напон цеви, анодна струја, варијација параметара