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ORIGINAL RESEARCH ARTICLE

Reducing scan time using time-of-flight protocol in clinical [18F]FDG-PET/CT imaging: A feasibility study

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ABSTRACT

Introduction: This study evaluates scan time reduction using time-of-flight (TOF) PET, when quantitative parameters including volumetric measures are considered.
Methods: 32 patients were included in the study. The reconstruction parameters for TOF were 2 iterations, 18 and 24 subsets, and for non-TOF was 3 iterations and 18 subsets. A post smoothing filter with FWHM of 5.4 mm and 6.4 mm were used for TOF and 6.4 mm for non-TOF. TOF reconstruction was performed with 2, 2.5 and 3 min/bed position, and 3 min/bed position scan time was applied in non-TOF. Quantitative parameters such as coefficient of variation (COV), signal-to-noise ratio (SNR), lesion-to-background ratio (LBR), metabolic tumor volume (MTV) and total lesion glycolysis (TLG) were utilized. Standard uptake value (SUV) was also measured. Different segmentation thresholds were studied.
Results: Improvement in SNR for TOF relative to non-TOF was observed when utilizing 18 subsets, 5.4 mm filter size with 3 min scan time/bed position (P-value<0.0001), and for 18 subsets, 6.4 mm filter size when 2.5- and 3-min scan time/bed positions was applied (P-value≤0.02). Scan time reduction did not illustrate significant variation for the SUVs and lesion size. In all TOF protocols for both TLG and MTV, the measured values decreased with increasing segmentation thresholds, as expected, with significantly more impact for higher thresholds (70%, 75%). Meanwhile, higher values were observed for higher post smoothing filter in each specified threshold. With increasing of the threshold, ΔTLG was increased with more impact for higher post smoothing filter. ΔMTV were -10.10±11.09 (-1.35±8.59) and 0.68±17.51 (12.42±18.90) in 2 min/bed position with 5.4 (6.4 mm post smoothing filter) for threshold of 45% and 75% respectively.
Conclusion: Scan time reduction from 3 to 2 min can be obtained with TOF in comparison with non-TOF, especially when higher segmentation threshold values with higher subset number (24) and 6.4 mm filters are utilized.

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INTRODUCTION

Positron emission tomography/computed tomography (PET/CT) with ^{18}F-2-fluoro-2-deoxy-D-glucose ([^{18}F]FDG) has been used in diagnosis and staging evaluation of treatment response, disease recurrence and radiotherapy treatment planning. Today, commercially available PET/CT scanners enable modeling of the point spread function (PSF), aiming to improve the spatial resolution of images [1, 2] and allowing reduction of the partial volume effect (PVE) in PET images [3-5]. Using time-of-flight (TOF) information in the reconstruction can improve the localization of annihilation photons [6, 7] to increase signal-to-noise ratio (SNR) [8] and contrast [9, 10]. These effects are with more impact in clinical images of heavy patients and low count rate data [11-13].

Previous study showed that TOF can also decrease respiratory artifacts [9]. Reduction of scan time and/or injection of lower activity can be also seen for PET images reconstructed with TOF method [13, 14]. SUVmean, SUVmax and SUVpeak are common semi-quantitative parameters used for quantification of PET images [15]. It was seen that low count rates can lead to upward bias in SUVmean up to 15% due to decrease in SNR [16]. The bias is more severe for SUVmax owing to increase in noise [5, 17]. Todays, SUVmax is a popular index for evaluation of [^{18}F]FDG uptake in PET/CT imaging. As SUVs indicate to one or some voxels in defined tissue, it may not introduce correct findings of metabolic activity [18]. In recent years, significant improvement and development is performed for quantification of PET/CT images in the application of treatment planning and treatment response evaluation [19]. It is observed that volumetric parameters obtained with PET/CT imaging such as metabolic tumor volume (MTV) and total lesion glycolysis (TLG) can deliver important information for tumor burden and prognosis findings in evaluation of patient treatment response [20-22].

Fixed thresholding based on SUVmax has been applied in biological target delineation and patient treatment response [23, 24]. It is illustrated that various reconstruction methods and PET/CT segmentation techniques in clinical PET/CT can also produce an important discrepancy in MTV and tumor delineation [25, 26]. One of the main challenges in PET-based quantitative purpose especially for patient treatment response depends on the technical issues such as scan time, reconstruction methods and reconstruction parameters, which affect the uptake value, target size and target shape [27, 28]. Albano et al. [29] stated that percentage of variation for MTV and TLG with consideration of baseline and end of treatment are strongly correlated to progression-free survival and overall survival for patient with Burkitt's lymphoma. Ketabi et al. revealed that the relative difference of SUVs (SUVmax and SUVpeak) in high and low background activity was more important for the lesion sizes with less than four times the FWHM of the scanner resolution versus other lesion sizes [18]. However, this behavior was seen with less impact for SUVpeak. It should be noted that image quality can be also changed by lesion to background ratio, lesion activity and background activity separately [30]. In the study performed by Sharma et al., SUVmax, SUVmean, and tumor-to-background ratio of baseline PET/CT scan did not illustrate strong behavior as prognostic indicators for overall survival of patients with non-small cell lung cancer that performing platinum-based chemotherapy, that was not in agreement with their finding for MTV and TLG [31]. Gencturk et al. revealed that PET/CT imaging prior to treatment for patients with salivary gland adenoid cystic carcinoma with consideration of metabolic parameters may be useful for predicting distant metastasis-free survival, progression-free survival and overall survival [32]. Ye et al. also have shown that metabolic volumetric parameters (MTV and TLG) correlate with the level of preoperative serum cancer antigen 125 (CA 125), so might be predicators for survival in ovarian CCC patients [33]. Optimum reconstruction parameters are also critical in quantitative analysis [5, 34, 35]. Reduction of scan time has the potentials to increase patient throughput and to reduce motion induced artifacts in images. In previous investigations the range of optimum reconstruction parameters was selected according to our patients' data [9, 18, 19, 36].

The aim of this study was to evaluate the impact that reducing scan time has on the quantitative metabolic and volumetric parameters. The contribution of scan time reduction was assessed when combination of TOF and PSF protocols were considered for clinical data. The patient's administered activity was not changed (4.6 MBq/kg).

METHODS

Patients

Thirty-two patients (23–78 years) including 19 men and 13 women with lesions located in thorax area with range of 18.31-42.70 mm in FWHM; 1.60-6.76 in signal to background ratio (SBR) (defined as SUVmax in lesion to SUVmean in normal liver); as measured in our routine protocol, were retrospectively assessed. The patient data were classified as follow: 5 lung cancer, 4 non-Hodgkin lymphoma, 3 kidney cancer, 3 Hodgkin lymphoma, 3 colon cancer, 4 renal cell carcinoma, 1 pancreatic cancer, 1 gastric cancer, 3 breast cancer, 4 esophageal cancer, and 1 unknown primary. Patients with fasting blood sugar level higher than 200 mg/dL were not included in this study. After 6-8 hours fasting period, 4.6 MBq/kg of [^{18}F]FDG was injected intravenously according to European Association of Nuclear Medicine (EANM) guidelines [37]. Patient' BMI were 24.04±2.01 with weight range of 58-89 kg. Patients were scanned after 61.1±1.3 minutes uptake time and asked to void before imaging procedure.

Data acquisition and image reconstruction

All data was acquired on Discovery 690 VCT (GE Healthcare, Milwaukee, USA) equipped with 64-slice CT (Light Speed VCT). The PET system consists of 24 detector rings, covering 15.7 cm and 70 cm axial and trans-axial field-of-view (FOV), respectively. The PET scanner comprises a total of 13,824 lutetium-yttrium oxyorthosilicate (LYSO) crystals with dimension of 4.2×6.3×25 mm^3. The coincidence time window is 4.9 ns and timing resolution is 555 ps.

First, the CT scan was performed for attenuation correction and localization purposes from head to mid-thigh, using the automatic current modulation method. Next, the emission data were collected in list mode with 3 min/bed position. Both scatter and attenuation correction were applied on FDG-PET raw data which were reconstructed with two algorithms of TOF (OSEM +PSF+TOF) and non-TOF (OSEM +PSF; routine protocol in our department with 3 min per bed position). The reconstruction parameters for TOF protocol were 2 iterations, 18 and 24 subsets, and those for routine protocol (non-TOF) were 3 iterations and 18 subsets. A Gaussian filter as a post smoothing filter with a full width at half maximum (FWHM) of 5.4 mm and 6.4 mm were used for TOF and those for non-TOF was 6.4 mm. All parameters used in TOF protocols were optimum, based on our previous studies [9, 18, 19, 36]. All data were reconstructed into a 256×256 image matrix. In order to evaluate the effect of scan time reduction on PET images, the list mode data were reconstructed with 2, 2.5 and 3 min per bed position in all TOF protocols.

Assessment strategy

The impact of scan time reduction in all TOF protocols versus non-TOF protocol was evaluated by various quantitative and semi quantitative analysis in PET/CT images. Coefficient of variation (COV), signal-to-noise ratio (SNR), and lesion-to-background ratio (LBR) were calculated. 9 ROIs with 30 mm in diameter were depicted on the 3 axial slices in the largest and uniform liver section and around this section (3 ROIs in each slice) with regard not to include the porta-hepatis and major vessels; COV was evaluated according to the equation 1:

$$\mathrm{COV}(\%)=\frac{SD_{Liver}}{C_{Liver}}\times 100 \qquad (1)$$

where C_{Liver} is the average activity concentration and SD_{Liver} is the average of standard deviations in 9 ROIs.

SNR was also measured according to the equation 2:

$$\mathrm{SNR}=\frac{C_{Lesion}-C_{Liver}}{SD_{Liver}} \qquad (2)$$

where C_{Lesion} is the max activity concentration in lesion.

In addition, LBR was assessed according to the equation 3:

$$\mathrm{LBR}=\frac{C_{Lesion}}{C_{Liver}} \qquad (3)$$

Semi-quantitative analysis consisted of SUVmax, SUV50% (using 50% thresholding with respect to SUVmax) was performed. In addition, total lesion glycolysis (TLG) with various thresholds (45%, 50%, 70% and 75%) was also measured according to the equation 4:

$$\mathrm{TLG}=\mathrm{SUVmean}\times\mathrm{MTV} \qquad (4)$$

where SUVmean is the average of SUV in thresholding value that corresponding to metabolic tumor volume (MTV).

The effect of scan time reduction on lesion size was also assessed by calculation of maximum lesion diameter. In order to calculate the maximum diameter (called lesion size), the lesion profile was drawn in the direction in which the lesion had the largest size (the direction was chosen on the non-TOF image). Then, an appropriate Gaussian curve was fitted. The full width at half maximum of Gaussian curve was considered as the estimation of maximum lesion diameter [9].

The relative differences for TLG, MTV, SUV and lesion size between TOF and non-TOF protocols were calculated according to the equation 5:

$$\Delta\mathrm{MTV}/\Delta\mathrm{TLG}/\Delta\mathrm{SUV}/\Delta\mathrm{lesion\_size}=\frac{Value_{TOF}-Value_{non-TOF}}{Value_{non-TOF}}\times 100 \qquad (5)$$

It should be noted that visual qualitative assessment of image quality for different scan time was also performed by two expert physicians.

Statistical analysis

Statistical analysis was done using the SPSS packages (SPSS, version 22.0; IBM Corp., Armonk, New York, USA). Normality evaluation was performed by Shapiro-Wilk method. Variables with normally distributed were evaluated by Paired t-test, while for non-normally distributed variables Wilcoxon signed ranks test was applied. Lin concordance correlation coefficient (Lin CCC) was also used for the agreement between the variables. In all measurements, P-value< 0.05 was considered as statistically significant.

RESULTS

Table 1 shows the mean of COV, SNR and LBR in all reconstruction protocols. Although, decreasing the acquisition time led to increased COV for all TOF protocols, no statistically significant differences for COV can be seen between non-TOF and TOF protocols with 18 subsets and 6.4 mm filter size for all scan time (3, 2.5 and 2 min), 18 subsets with 5.4 mm filter size for 3- and 2.5-min scan time and 24 subsets with 6.4 mm filter size for 3 min scan time. Statistically significant improvement in SNR between TOF protocols and non-TOF was observed with 18 subsets, 5.4 mm filter size with 3 min scan time per bed position (P-value=0.00) and 18 subsets, 6.4 mm filter size when 2.5- and 3-min scan time were applied per bed position (P-value≤0.02). The statistical analysis of image quality in terms of LBR showed that all TOF protocols with various scan times produced the significant improvement versus non-TOF protocol.

Table 1. The mean±SD value of image quality parameters and P-value between TOF and non-TOF protocols

Reconstruction protocol	COV		SNR		LBR	
	mean±SD	P-Value	mean±SD	P-Value	mean±SD	P-Value
non-TOF[a]	6.79±0.55		28.12±18.91		2.97±1.40	
TOF[b]_3 min	6.79±0.66	0.28	34.92±18.49	**0.00**	3.53±1.38	**0.00**
TOF[b] _2.5 min	7.31±0.90	0.08	31.93±16.16	0.09	3.53±1.36	**0.00**
TOF[b] _2 min	8.08±1.25	**0.02**	28.42±14.31	0.90	3.53±1.39	**0.00**
TOF[c]_3 min	6.05±0.58	0.50	35.61±19.54	**0.00**	3.31±1.62	**0.01**
TOF[c] _2.5 min	6.49±0.79	0.65	32.75±17.26	**0.02**	3.31±1.58	**0.01**
TOF[c] _2 min	7.19±1.12	0.12	28.96±15.18	0.67	3.30±1.57	**0.01**
TOF[d]_3 min	7.42±0.81	0.05	30.18±15.86	0.24	3.42±1.43	**0.00**
TOF[d] _2.5 min	7.89±1.00	**0.03**	28.30±14.21	0.94	3.42±1.40	**0.00**
TOF[d] _2 min	8.75±1.14	**0.01**	25.56±12.72	0.36	3.43±1.40	**0.00**

a. 3it, 18 subset, 6.4 mm filter.
b. 2it, 18 subset, 5.4 mm filter.
c. 2it, 18 subset, 6.4 mm filter.
d. 2it, 24 subset, 6.4 mm filter.

The findings of SUV agreement in various reconstruction methods are shown in Table 2. The moderate agreement (0.90 ≤ CCC < 0.95) was illustrated for both SUVmax and SUV50% separately, between non-TOF and TOF protocol in all scan time (3,2.5 and 2min) with 18 subsets and 5.4 mm post smoothing filter. Although, Substantial agreement (0.95 ≤ CCC < 0.99) and almost perfect agreement (CCC≥0.99) was also seen for both SUVmax and SUV50% in other protocols.

The relative differences for SUVmax, SUV50% and lesion size between all TOF protocols with various scan time and non-TOF are illustrated in Table 3. The smaller variation was seen in TOF protocol for all scan time when 18 subsets and 6.4 mm filter size were applied. Regarding SUV and lesion size variations, it seems that the more impact is seen for smaller filter size (5.4 mm) versus higher subset number (24).

The relative differences for volumetric parameters (TLG45%, MTV45%, TLG50%, MTV50%, TLG70%, MTV70%, TLG75% and MTV75%) between all TOF protocols and non-TOF for various scan time are shown in Table 4. With increasing of threshold value from 45% to 75%, ΔTLG is increased. For 3 min scan time per bed position, in TOF protocol with 18 subsets and 5.4mm post smoothing filter, ΔTLG varied from 6.77±12.24 to 13.01±14.37. Although ΔTLG changed also from 9.29±12.76 to 22.45±17.48 in TOF protocol with 24 subsets and 6.4 mm post smoothing filter in 3 min per bed position when threshold varied from 45% to 75%. It is emphasized that the variation of ΔTLG is more emphasized for higher threshold values (70%, 75%) especially when 6.4 mm post smoothing filter was applied.

Table 2. Lin Concordance Correlation Coefficients between SUV measured with different protocols

		SUVmax										SUV50%									
		non-TOF[a]	TOF[b]_3 min	TOF[b]_2.5 min	TOF[b]_2 min	TOF[c]_3 min	TOF[c]_2.5 min	TOF[c]_2 min	TOF[d]_3min	TOF[d]_2.5 min	TOF[d]_2 min	non-TOF[a]	TOF[b]_3 min	TOF[b]_2.5 min	TOF[b]_2 min	TOF[c]_3 min	TOF[c]_2.5 min	TOF[c]_2 min	TOF[d]_3min	TOF[d]_2.5 min	TOF[d]_2 min
SUVmax	non-TOF[a]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[b]_3min	0.94	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[b]_2.5 min	0.94	**1.00**	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[b]_2min	0.94	**1.00**	**1.00**	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[c]_3min	**0.98**	**0.99**	**0.99**	**0.99**	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[c]_2.5 min	**0.98**	**0.98**	**0.99**	**0.99**	**1.00**	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[c]_2min	**0.98**	**0.98**	**0.98**	**0.99**	**1.00**	**1.00**	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[d]_3min	**0.97**	**0.99**	**0.99**	**0.99**	**1.00**	**1.00**	**1.00**	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[d]_2.5 min	**0.97**	**0.99**	**0.99**	**0.99**	**1.00**	**1.00**	**1.00**	**1.00**	---	---	---	---	---	---	---	---	---	---	---	---
	TOF[d]_2min	**0.97**	**0.98**	**0.99**	**0.99**	**0.99**	**0.99**	**1.00**	**1.00**	**1.00**	---	---	---	---	---	---	---	---	---	---	---
SUV50%	non-TOF[a]	0.70	0.78	0.55	0.55	0.62	0.62	0.62	0.59	0.59	0.59	---	---	---	---	---	---	---	---	---	---
	TOF[b]_3min	0.84	0.70	0.71	0.71	0.77	0.78	0.78	0.74	0.74	0.74	0.93	---	---	---	---	---	---	---	---	---
	TOF[b]_2.5 min	0.83	0.70	0.70	0.70	0.77	0.78	0.77	0.74	0.74	0.74	0.93	**1.00**	---	---	---	---	---	---	---	---
	TOF[b]_2min	0.83	0.69	0.69	0.70	0.76	0.77	0.77	0.73	0.73	0.73	0.93	**1.00**	**1.00**	---	---	---	---	---	---	---
	TOF[c]_3min	0.77	0.63	0.63	0.63	0.70	0.70	0.70	0.67	0.67	0.67	**0.97**	**0.99**	**0.99**	**0.99**	**---**	---	---	---	---	---
	TOF[c]_2.5 min	0.76	0.62	0.63	0.63	0.69	0.70	0.70	0.66	0.66	0.66	**0.97**	**0.98**	**0.99**	**0.99**	**1.00**	---	---	---	---	---
	TOF[c]_2min	0.76	0.61	0.62	0.62	0.69	0.69	0.69	0.66	0.66	0.66	**0.97**	**0.98**	**0.98**	**0.99**	**1.00**	**1.00**	---	---	---	---
	TOF[d]_3min	0.79	0.64	0.64	0.65	0.71	0.72	0.72	0.68	0.69	0.68	**0.96**	**0.99**	**0.99**	**0.99**	**1.00**	**1.00**	**1.00**	---	---	---
	TOF[d]_2.5 min	0.78	0.64	0.64	0.64	0.71	0.71	0.71	0.68	0.68	0.68	**0.96**	**0.99**	**0.99**	**0.99**	**1.00**	**1.00**	**1.00**	**1.00**	---	---
	TOF[d]_2min	0.78	0.63	0.64	0.64	0.71	0.71	0.71	0.68	0.68	0.68	**0.96**	**0.99**	**0.98**	**0.99**	**0.99**	**0.99**	**1.00**	**1.00**	**1.00**	---

Lin Concordance Correlation Coefficients (CCC) greater than 0.95 are in bold.

a. 3it, 18 subset, 6.4 mm filter.
b. 2it, 18 subset, 5.4 mm filter.
c. 2it, 18 subset, 6.4 mm filter.
d. 2it, 24 subset, 6.4 mm filter.

Table 3. The relative difference for two types of SUVs and lesion size between TOF and non-TOF protocols

Reconstruction protocol	ΔSUVmax	ΔSUV50%	ΔFWHM
TOF[a]_3 min	20.11±9,87	20.59±10.57	-10.95±7.08
TOF[a]_2.5 min	20.63±10.07	21.77±10.73	-10.46±7.88
TOF[a]_2 min	20.90±11.39	21.20±11.50	-10.71±9.85
TOF[b]_3 min	12.35±7.86	12.81±8.23	-5.70±7.90
TOF[b]_2.5 min	12.82±7.79	13.61±8.35	-5.55±8.43
TOF[b]_2 min	12.92±9.39	13.70±9.43	-5.27±9.98
TOF[c]_3 min	16.52±9.39	16.71±10.50	-10.17±7.91
TOF[c]_2.5 min	17.30±11.21	18.09±11.12	-9.99±8.20
TOF[c]_2 min	18.73±15.53	19.51±12.74	-10.54±10.85

a. 2it, 18 subset, 5.4 mm filter.
b. 2it, 18 subset, 6.4 mm filter.
c. 2it, 24 subset, 6.4 mm filter.

Although MTV value of TOF protocols is lower than non-TOF protocol in lower threshold value, MTV exhibits higher value versus non-TOF when threshold is increased with more impact for 6.4 mm post smoothing filter. The ΔMTV value were -10.10±11.09(-1.35±8.59), 7.15±14.24(2.30±12.36), -3.50±18.57(10.07±18.17) and 0.68±17.51(12.42±18.90) for TOF protocol in 2 min per bed position with 18subsets and 5.4 mm post smoothing filter (with 18subsets and 6.4 mm post smoothing filter), when threshold values were 45% ,50%,70% and 75% respectively.
The coronal and transverse view of CT and PET images of a typical patient with some lesions in lung are shown in Figure 1. Scan time reduction from 3min to 2 min per bed position cannot significantly cause image degraded even for larger post smoothing filter when higher subset number (24) with 2 min per bed position was used. It should be clear that there is significant variation for MTV and TLG value separately when threshold was changed from 45% to 75%. It seems that, more variation for both TLG and MTV value is seen for TOF protocols with larger post smoothing filter. TLG45 %(MTV45%) were 11525.70(1871.9) and 12158.62(2111.81) for TOF protocol with 18 subsets and 5.4 mm post smoothing filter and TOF protocol with 24 subsets and 6.4 mm post smoothing filter in 2 min per bed position respectively. Although TLG75% (MTV75%) were 3263.22 (391.19) and 3790.16 (488.99) for above reconstruction protocols.

Table 4. The relative difference in four types of TLGs between TOF and non-TOF protocols

Reconstruction protocol	ΔTLG45%	ΔMTV45%	ΔTLG50%	ΔMTV50%	ΔTLG70%	ΔMTV70%	ΔTLG75%	ΔMTV75%
TOF[a]_3 min	6.77±12.24	-10.39±12.14	7.56±13.17	-9.02±16.20	11.99±15.51	-4.97±17.15	13.01±14.37	-2.68±15.62
TOF[a] _2.5 min	7.38±11.22	-9.90±12.18	7.65±11.32	-9.63±15.08	14.38±12.10	-3.59±14.68	16.79±15.01	1.25±18.56
TOF[a] _2 min	6.35±9.49	-10.10±11.09	8.51±10.0	-7.15±14.24	13.80±15.93	-3.50±18.57	17.37±16.20	0.68±17.51
TOF[b]_3 min	11.70±12.74	-1.26±11.36	12.70±13.61	0.92±13.90	16.17±17.52	5.08±20.12	22.79±13.98	10.81±14.72
TOF[b] _2.5 min	12.47±11.37	-1.22±10.63	13.42±11.92	0.60±13.53	20.19±14.92	6.84±19.78	22.75±13.18	11.12±15.97
TOF[b] _2 min	12.15±11.01	-1.35±8.59	12.90±10.28	2.30±12.36	21.09±13.45	10.07±18.17	23.30±16.40	12.42±18.90
TOF[c]_3 min	9.29±12.76	-5.60±11.03	11.31±13.43	-1.98±14.45	13.98±15.10	-1.13±18.83	22.45±17.48	8.44±18.00
TOF[c] _2.5 min	10.32±11.50	-4.33±11.17	11.53±10.46	-2.88±12.55	18.02±14.65	1.08±18.89	26.80±17.89	12.34±18.96
TOF[c] _2 min	9.50±9.87	-4.81±11.29	10.11±9.63	-3.97±12.19	16.54±16.74	0.35±20.95	21.28±20.17	7.83±23.93

a. 2it, 18subset,5.4mm filter.
b. 2it, 18subset,6.4mm filter.
c. 2it, 24subset, 6.4mm filter.

DISCUSSION

Patient motion can produce some error in qualitative and quantitative assessments of PET/CT images [27, 38-40] . Shorter acquisition time can reduce motion artifact especially for patient suffering of pain in oncology PET/CT imaging. It was shown that the evaluation of parameters that related to SUV and volumetric indicators can be important for assessment of high-risk for recurrence after total thyroidectomy in differentiated thyroid cancer patients with primary MTV > 10.0 cm^3 [41]. Current work assessed the feasibility of scan time reduction for combination of PSF and TOF protocols (TOF) versus non-TOF protocol (OSEM+PSF), when quantitative including volumetric parameters were evaluated. In general, our study demonstrated that scan time reduction can lead to increase in noise level. In addition, TOF reconstruction with 2 iterations, 18 subsets and 5.4 mm (2min per bed position) and TOF reconstruction with 2 iterations, 24 subsets and 6.4 mm (2.5 and 2 min) introduced significantly high noise level compared to non-TOF.

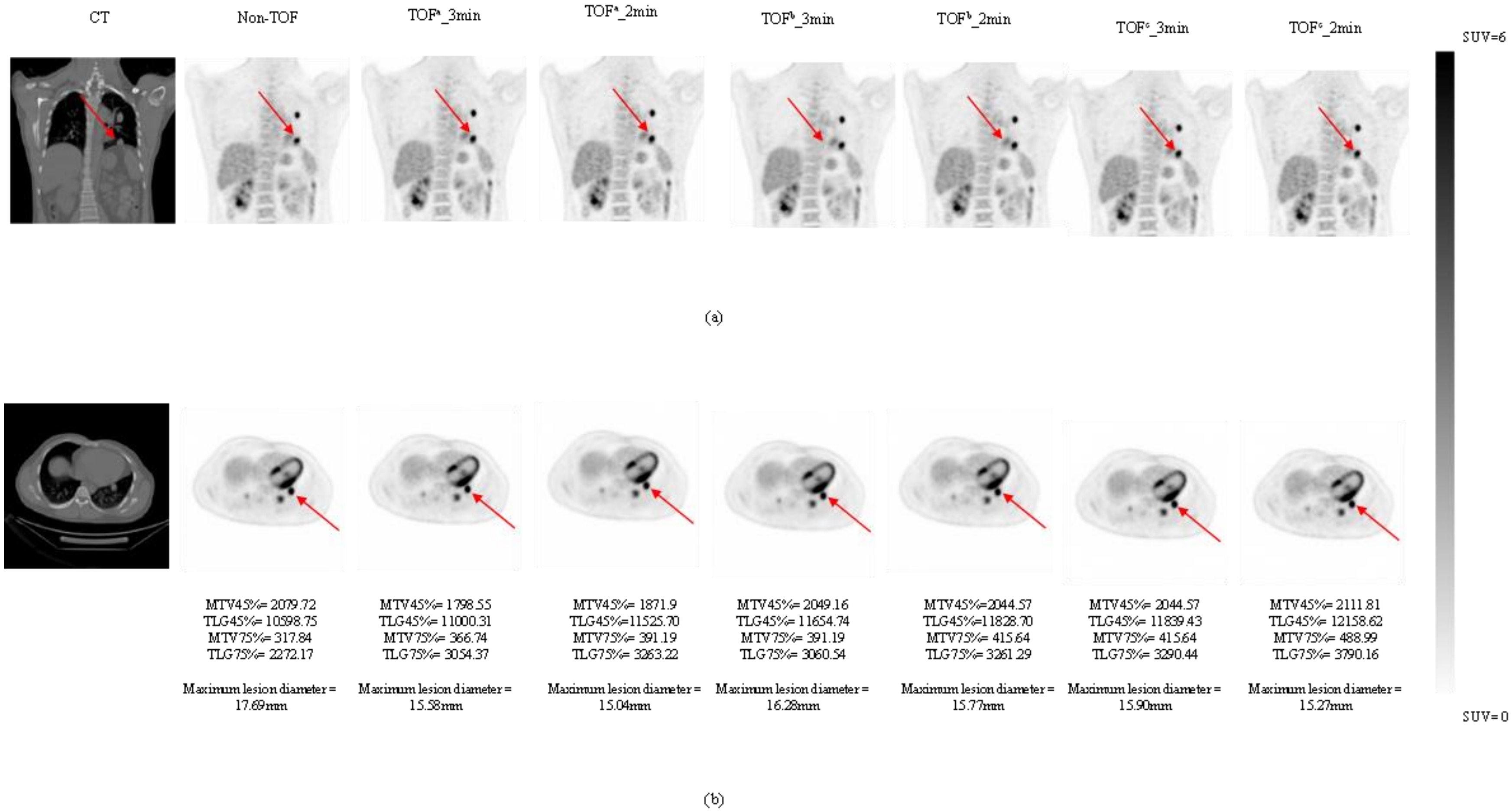

Fig 1. Comparison of coronal (a) and transverse (b) views of reconstructed CT and PET images of a typical patient (70 Kg weight and administration of 328 MBq of [^{18}F]FDG with some abnormal lesions in lung region for different scan time per bed position. From left to right: CT, non-TOF, TOF^a_3min , TOF^a_2min, TOF^b_3min , TOF^b_2min, TOF^c_3min and TOF^c_2min; non-TOF(routine protocol; 3it, 18subset,6.4mm filter), TOF^a(2it, 18subset,5.4mm filter), TOF^b(2it, 18subset,6.4mm filter)and TOF^c(2it, 24subset, 6.4mm filter)

It seems interesting that although SNR improvement can be seen in TOF protocols even in shorter acquisition time, the more caution is needed for TOF protocol with higher subsets (24) especially with shorter scan time (2 min scan time per bed position).

Our findings revealed that smaller filter size and higher subset number produced higher LBR. Our result is in agreement with Sadick et al. [42] and Ferretti et al. [43] that explained higher contrast is seen in application of thinner post-smoothing filter. Previous studies also revealed that combination of PSF and TOF [8, 35, 36, 44] and also TOF alone [8, 35] resulted in higher SUV which is in line with our findings. Scan time reduction from 3 to 2 min per bed position did not exhibit significant variation in SUVs value for individual TOF protocol (data were not shown). However, more variation was seen on SUVs value when small post smoothing filter and higher subset value was applied that is in line with the previous studies[18, 36]. We also stated that there was no agreement between SUVmax and SUV50% for all scan time according to Lin concordance correlation coefficient analysis. Our results also showed that all TOF protocols revealed that lesion sizes can be diminished versus non-TOF which is in line with the findings of previous studies [9, 45] ;although the lesion size was not changed significantly with decreasing of scan time.

The behavior of MTV can be different when different LBRs and lesion sizes with various threshold values were applied [18, 19]. Previous phantom study [19] revealed that except for SBR=2(with 10mm sphere diameter) and applying of 40 and 50 thresholding value, smaller post smoothing filter can introduce the lower MTV value in all reconstruction protocols that is in agreement with our results. For MTV value, the more variation between TOF and non-TOF in lower threshold (45%, 50%) was observed for 5.4 mm post smoothing filter and in higher threshold (70%, 75%) was seen for 6.4mm post smoothing filter.

Previous studies have suggested that TLG value can be also affected by the SBR, reconstruction algorithm and lesion size, however, this variation is decreased by increasing of lesion size [18] that is in agreement with our findings. It should be clear that the more variation in TLG value between TOF and non-TOF protocol for all threshold value was seen for 6.4 mm post smoothing filter. Our results notify that in all TOF protocols for both TLG and MTV, the values are decreased with increasing of threshold with significantly more impact for higher threshold (70%, 75%).So as for TOF protocols with 24 subsets, 6.4 mm post smoothing filter size and 3min per bed position, TLG (MTV) were seen 14406.21±12158.98 (3277.97±1902.35), 12359.92±10313.99 (2690.90±1648.53), 5044.37±3774.69 (935.95±625.62) and 3802.36±2627.14 (673.88±419.43) when thresholds were 45%, 50%, 70% and 75% respectively (all data are not shown). Furthermore, higher values for TLG and MTV in all TOF protocols are observed when higher post smoothing filter was applied for each specified threshold value (data are not shown).

It should be emphasized that for each TOF protocols and threshold value, scan time reduction cannot lead to significant variation for both TLG and MTV value. It has been shown that PSF and TOF can improve the image quality [9] and volumetric accuracy[19]. Based on our findings, combination of PSF and TOF protocols (TOF) versus non-TOF protocol (OSEM+PSF) increased TLG values. Our study had some limitations. The lesions did not classify into specified groups according to lesion size and LBR. According to our lesion size (range: 18.31-42.70mm in FWHM) and SBR (range: 1.60-6.76) that evaluated in this study, we concluded that the scan time reduction can be done when combination of TOF and PSF protocol was applied versus non-TOF protocol (PSF only: routine protocol), when administrated activity was not changed (4.6MBq/kg). However, more caution must be taken when higher threshold value was applied especially for higher post smoothing filter and higher subset number.

CONCLUSION

Reduction of scan time utilizing TOF protocol is possible, without affecting measured lesion size and SUV values significantly. However, lower SNRs can be seen on images reconstructed with higher subset number and post smoothing filter for TOF images versus non-TOF ones especially when scan time is decreased. MTV value of TOF protocols is lower than non-TOF protocol in lower threshold value; however, MTV illustrated higher value versus non-TOF when threshold is increased with more impact for 6.4 mm post smoothing filter. TLG for TOF protocols is increased versus non-TOF, when threshold value is increased with more impact for higher threshold value (70%, 75%) especially for 6.4 mm post smoothing filter. In all TOF protocols for both TLG and MTV, the values are decreased with increasing of segmentation threshold, as expected, with significantly more impact for higher threshold

(70%, 75%). Furthermore, higher values for TLG and MTV in all TOF protocols were observed when higher post smoothing filter was applied for each specified threshold value. This study showed that scan time reduction from 3 min to 2 min per bed position, for patients that injected with 4.6 MBq/kg of [^{18}F]FDG with large lesion size (range: 18.31-42.70mm in FWHM) and SBR (range: 1.60-6.76) could be possible in PET/CT images without degrading image quality when combining TOF and PSF protocols relative to non-TOF (PSF only) protocol. However more caution must be exercised for higher subset number (24) and 6.4 mm post smoothing filter size, especially when higher threshold value are utilized.

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