Determine a proper protocol for routine 18F-FDG uEXPLORER Total-Body PET/CT scan

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Abstract

Background

The axial length of a conventional PET/CT scanner is about 15–30 cm. However, uEXPLORER Total-Body PET/CT has an ultra-long axial field of view of 194 cm. By taking full use of all the scintillation photons, uEXPLORER has a 40 times higher sensitivity for photon detection relative to the conventional PET/CT. Ordered subset expectation maximization (OSEM) is a commonly used iterative algorithm in PET, however, it has a limitation that the image noise will increase when large number iteration is selected. A new penalized-likelihood iterative PET reconstruction, termed HYPER Iterative, was invented and now is available on the uEXPLORER Total-Body PET/CT. To date, its impact in lesion conspicuity in the patients with full injected dose or half injected dose was unclear. The goal of this study is to determine a proper protocol for routine ^{18}F-FDG uEXPLORER Total-Body PET/CT scan.

Results

The quality of the 5 min PET image was excellent (score 5) for all the dose and reconstructed methods. Using the HYPER iterative method, PET image reached the excellent quality at 1 min with full-dose, and at 2 min with half-dose. While PET image reached a similar excellent quality at 2 min with full-dose and 3 min with half-dose using OSEM. The noise in OSEM reconstruction was higher than that by HYPER Iterative. Compared to OSEM, HYPER Iterative had slightly higher SUVmax and TBR of the lesions for large positive lesions (≥ 2cm) (SUVmax: up to 9% higher in full-dose and up to 13% higher in half-dose; TBR: up to 9% higher in full-dose and up to 23% higher in half-dose). For small positive lesions(≤ 10mm), HYPER Iterative had obviously higher SUVmax and TBR of the lesions (SUVmax: up to 45% higher in full-dose and up to 75% higher in half-dose; TBR: up to 45% higher in full-dose and up to 94% higher in half-dose).

Conclusions

Our study demonstrates that 1min scan with full dose and 2 min with half dose is proper for clinical diagnosis using HYPER Iterative, and 2 to 3 min scan for OSEM reconstruction. For detection of the small lesions, HYPER Iterative reconstruction is preferred.

Introduction

Positron emission tomography/computed tomography (PET/CT) is a non-invasive imaging modality for diagnosis, staging, treatment evaluation, and prognosis prediction for the malignant diseases [1–6]. It also plays an important role in the diagnosis of cardiovascular and neurological diseases [7, 8]. ^{18}F-fluorodeoxyglucose (^{18}F-FDG) which is the most widely used tracer, can provide some important information like tumor glycolysis in the lesions to reflect the proliferative activity of tumors [9, 10].

The axial length of a conventional PET/CT scanner is about 15–30 cm [11], and a large number of the scintillation photons outside axial field of view (AFOV) were wasted, resulting in a low system sensitivity. Besides, a whole body image need a multiple (6 ~ 8) bed positions acquisition [12, 13]. Currently, the uEXPLORER Total-Body PET/CT has been developed, which was composed of 8 detector units with a long 194 cm AFOV and is able to cover the total body with a single bed position [14, 15]. By taking full use of all the scintillation photons, uEXPLORER has a 40 times higher sensitivity for photon detection relative to the conventional PET/CT [16, 17]. Fast PET acquisition for the total body has been achieved now [18, 19].

Ordered subset expectation maximization (OSEM) is a commonly used iterative algorithm in PET, however, it has a limitation that the image noise will increase when large number iteration is selected. To control the noise, the number of iteration is always selected at 2 or 3 [20], which reduces the reconstruction accuracy and lesion contrast [21]. A new penalized-likelihood iterative PET reconstruction, termed HYPER Iterative, was invented and now is available on the uEXPLORER Total-Body PET/CT. HYPER Iterative embedded the internal denoise regularized function into OSEM to compress image noise when a larger number of iteration is used [22–24]. It was reported by Haojun Yu et al, that the lesion conspicuity scores were significantly higher in HYPER Iterative reconstructions than in OSEM ($P < 0.05$) in a study with ultra low ^{18}F-FDG activity on TB PET/CT scan [25]. However, its impact in lesion conspicuity in the patients with full injected dose or half injected dose was unclear.

Although an expert consensus on oncological ^{18}F-FDG total-body PET/CT imaging (version 1) has currently proposed, the procedure was based on OSEM reconstruction, but not HYPER Iterative [26]. HYPER Iterative reconstruction may bring about some changes in the procedure. The goal of this study is to determine a proper protocol for routine ^{18}F-FDG uEXPLORER Total-Body PET/CT scan.

Materials And Methods

1.1Patients

This study was performed at PET center, Nanfang Hospital of Southern Medical University, which was approved by the institutional review board, and written informed consent from every patient before undergoing PET/CT was received. From April to July 2021, 20 patients for tumor staging were enrolled in this study. The patients included 16 males and 4 females, aged from 34 to 73 years. Among them, 18 patients were diagnosed to have lung cancer, one esophageal cancer and one colon cancer. The diagnosis was established on the histopathology. Ten patients were injected with full-dose ^{18}F-FDG (3.7MBq/kg) (Named as full-dose group). Another 10 patients were injected with half-dose ^{18}F-FDG (1.85MBq/kg) (Named as half-dose group). All the patients fasted for more than 6 hours before injection of ^{18}F-FDG, and the fasting blood glucose was controlled within the normal range. The relevant clinical data of the enrolled patients were as shown in Table 1.

1.2 Total-body PET/CT examination

At approximate 60 min after injection with ^{18}F-FDG, 20 patients underwent Total-Body PET/CT imaging (uEXPLORER, United Imaging Medical Technology Co., Ltd., Shanghai, China). A single bed was acquired for each patient with 5 min 3D list-mode PET acquisition. Each PET data was reconstructed using both OSEM and HYPER Iterative algorithms. The entire 5min dataset was then split into 4min, 3min, 2min, 1min, 30s, and 10s images to simulate different time acquisition. The parameters for both the OSEM reconstruction were as follows: TOF and PSF modeling, 3 iterations and 20 subsets, matrix 192 × 192, slice thickness 2.886 mm, FOV 600 mm (pixel size 3.125 × 3.125 × 2.89 mm^3) with a Gaussian postfilter (3 mm) and attenuation and scatter correction. The parameters for the HYPER Iterative reconstruction were as follows: regularization intensity 0.28, matrix 192 × 192, slice thickness 2.886 mm, FOV 600 mm, with attenuation and scatter correction. The CT scan parameters were as follows: tube voltage 120 kV, tube current 140 mAs, pitch 1.0, collimation 0.5 mm, and reconstructed slice thickness 0.5 mm.

1.3 Analysis of PET/CT imaging

Image quality of PET images was visually assessed by two experienced nuclear medicine physicians independently. Three key points for assessing were: overall impression of image quality, image noise, and lesion visibility. A 5-point Likert scale was used to score the overall image quality (1 = unacceptable image quality for diagnosis, 2 = acceptable image quality with no need to repeat the scan, 3 = fair image quality as in the routine practice, 4 = good image quality with performance excessed the routine practice, and 5 = excellent image quality).

Quantitative indexes were measured by an experienced technician under the supervision of a nuclear medicine physician. To evaluate uniform distribution of radioactivity, a circular region of interest (ROI) with the diameter 2 cm was placed on a homogeneous radioactivity area in the aortic arch as the blood pool, and in the right liver lobe which need kept away from the lesion, blood vessels, and intrahepatic bile duct. For homogeneous radioactivity background in blood pool and the liver, a larger SD in the ROIs represented a higher noise. On the PET image, ROI was drawn around the margin of the lesion on the axial PET images and automatically adapted to a three-dimensional volume-of-interest at a 60% is contour for large PET-positive lesion (diameter≥2cm) and small PET-positive lesion (diameter≤10mm). All ROIs were copied onto the PET images for the different scan time to ensure the same location and size of the ROIs. The maximum standard uptake value (SUVmax) and standard deviation (SD) of each ROI were calculated. TBR was defined by dividing the SUVmax of the lesion by the mean standardized uptake value of the background activity in blood pool.

1.4 Statistical analysis

Statistical analyses were performed with SPSS 24.0 software for Windows (IBM SPSS Inc., Armonk, NY, USA), and P values < 0.05 were considered significant. The inter-rater agreement of visual scores for image quality was tested with the weighted kappa test, and a kappa value > 0.81 was considered to indicate excellent agreement. The Wilcoxon signed-rank test was used to compare the scores and PET parameters of the HYPER Iterative and OSEM reconstruction algorithms with different scan time and injected dose.

Results

2.1Visual evaluation for the image quality

In the full-dose group, OSEM-10s, OSEM-30s and OSEM-1min images were noisier and characterized by roughness and poor homogeneous (Fig.1), which were scored 1.00±0.00, 1.90±0.32 and 2.80±0.42, respectively. These three groups could not meet the high quality requirement for clinical diagnosis (Table 2). The image quality of OSEM-2min reached the nearly excellent level with a score of 4.80±0.84(Fig.1and Table 2). As increased the scan time, the images of the OSEM-3min to OSEM-5min were all excellent (Scores, 5.00±0.00) (Fig.1and Table 2). For the HYPER Iterative reconstructed PET images, HYPER Iterative-10s and HYPER Iterative-30s had smaller noise and were better than their counterparts using OSEM(Fig.1). The corresponding scores were 2.80±0.42 and 4.10±0.32, respectively, which were significantly higher than those of OSEM-10s and OSEM-30s(P<0.003) (Table 2), but still did not reach the excellent level. The image quality of PET nearly reached the excellent level at 1min with a score of 4.90±0.32(Fig.1and Table 2). After that, images of HYPER Iterative-2min to HYPER Iterative-5min were all excellent with each score of 5.00±0.00(Fig.1 and Table 2).

In half-dose group, OSEM-10s, OSEM-30s, OSEM-1min and OSEM-2min were worse than their counterparts of the full-dose group (Fig.2), and their scores were 1.00±0.00, 1.80±0.42, 2.70±0.48, and 3.80±0.42, respectively (Table 2). The quality of OSEM-3min images nearly reached the excellent level with a score of 4.90±0.32. Both OSEM-4min and OSEM-5min images reached excellent with a score of 5.00±0.00. The images of HYPER Iterative-10s, HYPER Iterative-30s and HYPER Iterative-1min were better in quality than those of their counterparts reconstructed using OSEM. Their scores were 2.00±0.00, 3.00±0.00 and 3.80±0.42, respectively, but not reached an excellent level. The image quality of PET reconstructed by HYPER Iterative reached the excellent level at 2 min with a score of 4.80±0.42. The images from HYPER Iterative-3min to HYPER Iterative-5min were all excellent (Score, 5.00±0.00).

2.2 Quantitative evaluation of PET/CT image quality

2.2.1 The effect of two reconstruction algorithms on homogeneous radioactivity areas

In both the full-dose and half-dose groups, the shorter image acquisition time resulted in the larger SD in the liver and mediastinal blood pool. Compared to the HYPER Iterative reconstruction, OSEM reconstruction had a higher SD in each scan time from 10 sec to 5 min (all P<0.05), but the difference turned smaller as

increasing the acquisition time (Table 3). For the full-dose group, the SD by OSEM reconstruction with scan time of 10 sec was up to 4 5 times higher than that by the HYPER Iterative reconstruction(Table 3).The difference increased to about 8 times higher in the liver in the half-dose group at 10 sec (Table 3). The SDs generated by OSEM reconstruction or HYPER Iterative were found to be larger in half-dose than that in full-dose.

The SUVmax of blood pool and liver reconstructed by OSEM was significantly higher than that by HYPER Iterative reconstruction at 10 sec to 2 min. The falsely higher SUVmax in blood pool and liver homogeneous radioactivity areas reconstructed by OSEM occurred within 2 min, with up to about 28% 34% higher in full dose at 10 sec and up to 42% 50% higher in half-dose at 10 sec(Table 4).With the scan time was extended to 2-5 min, the SUVmax of blood pool and the liver gradually decreased to a stable small level. Compared to the full-dose, the falsely higher SUVmax in blood pool reconstructed by OSEM was more obvious in half-dose (Table 4).

2.2.2 The effect of two reconstruction algorithms on large and small positive lesions

For large positive lesions≥2.0cm, the SUVmax reconstructed by HYPER Iterative in the full-dose was significantly higher than that reconstructed by OSEM in 2 min to 5 min(P<0.05), which was about 9% higher at 5 min(Fig.3,5 and Table 5). A similar trend occurred for the half-dose with up to 13% higher at 5 min (Fig.4,5 and Table 5). However, no significant difference of SUVmax between two reconstruction algorithms was observed within 1 min(P>0.05), either in the full-dose or the half-dose. For small positive lesions≤10mm, the SUVmax of HYPER Iterative reconstruction in the full-dose was higher at 1 min to 5 min(P<0.05) than that of OSEM reconstruction, which was 45% higher at 5 min. In the half-dose, this difference was increased up to 75% at 5 min(P<0.05). No significantly difference of SUVmax in small lesions was found between two reconstruction algorithms within 30 sec(P>0.05), either in the full-dose or the half-dose.

Similar to SUVmax, the TBR of large lesions reconstructed by HYPER Iterative was higher than that reconstructed by OSEM within 2 min to 5 min(P<0.05). HYPER Iterative reconstruction was 9% higher than OSEM reconstruction in the full-dose at 5 min and 23% higher than OSEM reconstruction in the half-dose at 5 min (Fig. 6) (Table 6). However, no significant difference between two reconstruction algorithms was observed within 1 min(P>0.05). For small lesions, the TBR of small lesions reconstructed by HYPER Iterative was higher than that reconstructed by OSEM within 1 min to 5 min(P<0.05). At 5 min, HYPER Iterative reconstruction was 45% and 94% higher in the full-dose and half-dose groups, respectively (Fig.6 and Table 6). Although no significantly difference was found between two reconstruction algorithms within 30 sec(P>0.05).

Discussion

Benefit from the single-bed total-body imaging capability and its 40 times higher sensitivity for photon detection compared to the conventional PET/CT, uEXPLORER Total-Body PET/CT is able to complete the total body PET/CT scan in a very short time [16, 17]. Our study confirms that a high quality total-Body PET can be gained with a very short scan time, especially using HYPER Iterative reconstruction. When HYPER Iterative reconstruction was used, it needed only 1 min acquisition to generate the high quality image for the patients injected with full dose ^{18}F-FDG, or 2 min needed for half dose. If the above PET data reconstructed by OSEM, a slight longer time needs to gain high quality images with 2 min for full dose and 3 min for half dose. Compared to the 20–30 minutes acquisition for the conventional PET/CT whole-body [27–30], the efficiency of uEXPLORER Total-Body PET/CT is dramatically improved. This ultra-high imaging efficiency brings great benefits to clinic: (1) easier adaption for patients with physical weakness, unbearable pain and claustrophobia or difficult to cooperate; (2) higher daily throughput (60–80 patients /day) to meet the large amount of PET/CT imaging requirements; (3) reduce the radioactive exposure by decreasing the injected dose and slightly prolong the scan time (from 1 minute to 2 minutes), which is very important for the adolescent patients who suffer from lymphoma and need multiple PET/CT imaging [31–35].

The present study had shown that high PET image quality can be obtained in a shorter time by using HYPER Iterative reconstruction compared with OSEM. The difference the image quality between these two reconstruction algorithms is more obvious at the very short scan time, such as 10 sec and 30 sec. Quantitative analysis showed the noise was larger due to low count rate and the larger statistical fluctuations at a very short time scan. The signal noise generated by OSEM reconstruction was much larger than that by HYPER Iterative reconstruction with up to 5 times higher in full dose and 8 times higher in half dose at 10 sec, which lead to very poorer image quality reconstructed by OSEM. Meanwhile, a falsely higher SUVmax was accordingly generated by OSEM reconstruction, especially in the patients with half injected dose. The advantage of HYPER Iterative reconstruction is utmost important for dynamic imaging because it always needs to assign very short intervals, such as 10 sec or 30 sec, to observe the rapid change of radioactivity, especially in the early phase [36, 37]. It is also useful for the patients, who receive a very low injected dose and meanwhile the total body scan needs to be completed in a short time [38, 39].

The present study implies that HYPER Iterative reconstruction is useful for visualization of the positive lesions. For positive lesions, the detection accuracy of PET/CT depends on two main parameters: the uptake of imaging agent in the lesion and the signal contrast, such as TBR. The higher the SUVmax and TBR, the more clearly can the lesion be depicted and more easily be detected [40–42]. Our study showed that the SUVmax and TBR of lesions obtained by HYPER Iterative reconstruction were higher than those obtained by OSEM reconstruction. For the large lesion, in the full-dose group, HYPER Iterative bring up to 9% higher SUVmax and up to 9% higher TBR compared to OSEM reconstruction. In the half-dose group, up to 13% higher SUVmax and up to 23% higher TBR were obtained by HYPER Iterative reconstruction. The effect of HYPER Iterative reconstruction on small lesions was more obvious. In the full-dose group, up to 45% higher SUVmax and TBR were generated by HYPER Iterative reconstruction, however, in the half-dose group, the increase reached up to 75% higher SUV and up to 94% higher TBR. It is very important to sensitively detect the small lesion, not only for diagnosing the early cancer, but also for accurate staging [43–45]. Higher SUVmax in small lesions, especially higher TBR, resulted from the HYPER Iterative reconstruction, will improve the diagnostic ability of PET/CT for malignant tumors.

There are some limitations in this study: (1) The whole scan time for each patient was relatively short (5 min) and the effect of two reconstruction algorithms on image quality and lesion visualization for longer scan time was not illuminated. (2) The sample size is too small and more research is warranted to confirm

our findings. (3) The present study was only performed for static imaging, the effect of two reconstruction algorithms on dynamic imaging needed to further identified.

Conclusion

Our study demonstrates the excellent imaging performance of uEXPLORER PET/CT for total body imaging, which can be acquired with a high quality within a very short time (1 ~ 2 minutes). Compared with OSEM, HYPER Iterative reconstruction can obtain a higher quality PET image with a less signal noise in a shorter scan time. One min scan with full dose and 2 min scan with half dose is proper for clinical diagnosis using HYPER Iteration, and 2 and 3 min scan for OSEM reconstruction. Higher SUVmax and TBR can be obtained using HYPER Iterative reconstruction compared to OSEM, especially for small lesions. Therefore, for detection of the small lesion, HYPER Iteration reconstruction is preferred, especially when the patient is injected with half dose ^{18}F-FDG. More research is warranted to confirm our findings.

Declarations

Author Contributions

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All authors read and approved the final manuscript.

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Data Availability

All data were transparent. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Compliance with Ethical Standards

Conflict of interest

The authors declare that they have no conflict of interest.

Ethics approval

Ethical approval was waived by the local Ethics Committee of Southern Medical University in view of the retrospective nature of the study.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

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Tables

Table 1 Clinical information of patients

Characteristic	full dose group (n=10)	half dose group (n=10)	*P*
Age (years)	60.6±10.8 (range 38 73)	50.9±10.9 (range 34 68)	0.971
Sex			0.264
Female	9	7	
Male	1	3	
Height (cm)	171.6±7.2	163.1±6.2	0.015
Weight (kg)	70.4±11.8	59.9±7.3	0.075
BMI (kg/m²)	23.8±2.5	22.5±2.7	0.631
Blood glucose level before injection (mmol/L)	5.7±1.1	6.2±1.0	0.123
Injected dose (MBq)	259.1±45.5	118.6±16.5	0.001
Histopathology			0.329
Lung cancer	8	10	
Esophagus cancer	1	0	
Colorectal cancer	1	0	

Table 2 Visual scores of PET images with different scan time and injected dose reconstructed by HYPER Iterative and OSEM

Time	Reconstruction algorithm	Full dose group (n=10)							Half dose group (n=10)					
		Score 5	Score4	Score3	Score 2	Score 1	Average score	*P*	Score 5	Score 4	Score3	Score 2	Score 1	Average score
10s	OSEM	0	0	0	0	10	1.00±0.00	0.003	0	0	0	0	10	1.00±0.00
	HYPER Iterative	0	0	8	2	0	2.80±0.42		0	0	0	10	0	2.00±0.00
30s	OSEM	0	0	0	9	1	1.90±0.32	0.002	0	0	0	8	2	1.80±0.42
	HYPER Iterative	1	9	0	0	0	4.10±0.32		0	0	10	0	0	3.00±0.00
1min	OSEM	0	0	8	2	0	2.80±0.42	0.002	0	0	7	3	0	2.70±0.48
	HYPER Iterative	9	1	0	0	0	4.90±0.32		0	8	2	0	0	3.80±0.42
2min	OSEM	8	2	0	0	0	4.80±0.42	0.157	0	8	2	0	0	3.80±0.42
	HYPER Iterative	10	0	0	0	0	5.00±0.00		8	2	0	0	0	4.80±0.42
3min	OSEM	10	0	0	0	0	5.00±0.00	1	9	1	0	0	0	4.90±0.32
	HYPER Iterative	10	0	0	0	0	5.00±0.00		10	0	0	0	0	5.00±0.00
4min	OSEM	10	0	0	0	0	5.00±0.00	1	10	0	0	0	0	5.00±0.00
	HYPER Iterative	10	0	0	0	0	5.00±0.00		10	0	0	0	0	5.00±0.00
5min	OSEM	10	0	0	0	0	5.00±0.00	1	10	0	0	0	0	5.00±0.00
	HYPER Iterative	10	0	0	0	0	5.00±0.00		10	0	0	0	0	5.00±0.00

Table 3 SD of radioactivity distribution in homogeneous background in the liver and blood pool in different scan time and injected dose reconstructed by HYPER Iterative and OSEM

homogeneous background	Time	Full dose group (n=10)				Half dose group (n=10)			
		HYPER Iterative	OSEM	SD_{OSEM}/SD_{HYPER}	*P*	HYPER Iterative	OSEM	SD_{OSEM}/SD_{HYPER}	*P*
Liver SD	10s	0.11±0.08	0.49±0.38	3.50±2.05	0.005	0.13±0.11	1.17±1.65	8.29±7.00	0.005
	30s	0.04±0.04	0.11±0.07	2.45±1.51	0.005	0.06±0.04	0.25±0.13	3.48±1.66	0.005
	1min	0.02±0.02	0.05±0.03	1.40±0.71	0.005	0.05±0.03	0.14±0.10	2.34±1.37	0.005
	2min	0.02±0.01	0.04±0.02	1.09±0.47	0.005	0.02±0.01	0.07±0.03	1.95±0.53	0.005
	3min	0.02±0.01	0.03±0.02	0.87±0.55	0.005	0.01±0.01	0.03±0.02	1.24±0.54	0.005
	4min	0.02±0.01	0.03±0.02	0.42±0.34	0.007	0.01±0.01	0.03±0.01	1.03±0.83	0.005
	5min	0.01±0.01	0.02±0.01	0.29±0.28	0.022	0.01±0.01	0.02±0.02	0.97±0.54	0.005
Blood pool SD	10s	0.07±0.04	0.35±0.20	4.84±3.26	0.005	0.11±0.06	0.54±0.34	4.90±1.67	0.005
	30s	0.04±0.05	0.14±0.13	2.38±1.20	0.005	0.04±0.02	0.13±0.07	2.52±1.08	0.005
	1min	0.03±0.01	0.07±0.03	1.32±0.56	0.005	0.03±0.02	0.09±0.06	1.62±1.00	0.005
	2min	0.02±0.02	0.04±0.03	0.95±0.41	0.005	0.02±0.02	0.05±0.03	1.48±0.69	0.005
	3min	0.01±0.01	0.02±0.02	0.92±0.60	0.005	0.02±0.01	0.04±0.02	1.16±0.45	0.005
	4min	0.01±0.01	0.02±0.01	0.74±0.50	0.005	0.02±0.01	0.03±0.02	0.91±0.39	0.005
	5min	0.01±0.01	0.01±0.01	0.74±0.51	0.005	0.02±0.01	0.03±0.02	0.60±0.20	0.005

Table 4 SUVmax of radioactivity distribution in homogeneous background in the liver and blood pool in different scan time and injected dose reconstructed by HYPER Iterative and OSEM

Viscera	Time	full dose group (n=10)				half dose group (n=10)			
		HYPER Iterative	OSEM	Difference (%)	*P*	HYPER Iterative	OSEM	Difference (%)	*P*
Liver SUVmax	10s	3.07±0.44	3.91±0.66	28.43±20.45	0.005	2.78±0.88	4.26±2.31	49.68±38.73	0.005
	30s	2.79±0.42	3.21±0.42	15.47±6.42	0.005	2.67±0.58	3.18±0.78	18.53±9.18	0.005
	1min	2.75±0.44	2.90±0.49	5.32±2.76	0.007	2.50±0.62	2.85±0.80	13.39±5.13	0.005
	2min	2.67±0.38	2.77±0.38	4.07±1.50	0.005	2.41±0.55	2.60±0.62	7.66±2.41	0.005
	3min	2.64±0.36	2.72±0.37	3.08±1.42	0.005	2.36±0.54	2.50±0.58	6.21±0.81	0.005
	4min	2.68±0.35	2.73±0.37	1.99±1.32	0.009	2.35±0.54	2.47±0.59	4.98±1.94	0.005
	5min	2.60±0.31	2.64±0.33	1.33±1.29	0.017	2.31±0.52	2.40±0.56	3.74±1.73	0.005
Blood pool SUVmax	10s	2.34±0.45	3.14±0.89	33.97±24.03	0.005	2.23±0.50	3.18±0.86	42.01±19.67	0.005
	30s	2.14±0.42	2.62±0.54	23.12±16.11	0.005	2.00±0.42	2.49±0.61	25.94±23.79	0.005
	1min	2.00±0.26	2.37±0.35	18.78±13.34	0.005	1.96±0.48	2.29±0.45	20.19±26.34	0.005
	2min	1.97±0.29	2.06±0.35	4.43±3.71	0.005	1.89±0.49	2.03±0.53	7.50±3.13	0.005
	3min	1.91±0.26	1.99±0.28	3.75±2.71	0.005	1.84±0.48	1.95±0.52	5.77±3.75	0.005
	4min	1.89±0.23	1.94±0.25	2.67±2.45	0.007	1.83±0.49	1.92±0.54	4.22±2.70	0.005
	5min	1.87±0.20	1.91±0.20	2.19±1.84	0.013	1.84±0.51	1.90±0.53	3.08±1.59	0.005

Table 5 SUVmax of large and small lesions in different scan time and injected dose reconstructed by HYPER Iterative and OSEM

Lesion	Time	Full dose group (n=10)				Half dose group (n=10)			
		HYPER Iterative	OSEM	Difference(%)	*P*	HYPER Iterative	OSEM	Difference(%)	*P*
SUVmax (large lesion)	10s	13.93±6.55	14.85±7.10	4.51±6.53	0.074	13.28±3.69	14.73±5.40	4.15±30.48	0.139
	30s	14.83±5.54	13.94±6.07	8.83±15.03	0.139	14.06±3.96	13.45±4.51	6.99±20.83	0.333
	1min	14.69±5.76	13.82±6.04	8.07±15.01	0.114	14.22±3.98	13.54±4.69	7.92±20.44	0.203
	2min	14.65±5.70	13.66±5.76	8.37±11.80	0.017	14.29±3.99	13.32±5.19	12.10±20.79	0.047
	3min	14.82±5.87	13.75±5.64	8.40±10.57	0.009	14.28±4.11	13.34±5.23	11.77±20.66	0.047
	4min	14.94±5.94	13.80±5.64	8.76±10.54	0.013	14.39±4.02	13.29±5.01	12.76±20.87	0.047
	5min	15.08±6.13	13.89±5.83	9.03±10.61	0.013	14.45±4.00	13.27±4.82	12.52±19.20	0.047
SUVmax (Small lesion)	10s	4.09±1.30	4.73±1.84	4.95±64.93	0.333	3.26±2.09	3.85±2.35	4.84±68.96	0.139
	30s	4.45±2.82	4.14±1.35	1.82±31.29	0.878	4.47±1.94	3.70±1.89	28.21±36.80	0.139
	1min	5.12±2.35	4.06±1.36	24.19±28.95	0.028	5.86±1.90	3.86±1.91	61.46±29.27	0.005
	2min	5.57±2.45	4.13±1.53	33.30±22.22	0.007	5.89±1.61	3.75±1.87	71.70±46.61	0.005
	3min	5.77±2.74	4.19±1.69	36.11±20.51	0.005	5.98±1.59	3.78±1.89	73.96±47.79	0.005
	4min	6.16±2.79	4.29±1.81	44.17±20.94	0.005	5.96±1.59	3.79±1.95	74.27±47.42	0.005
	5min	6.18±2.99	4.29±1.94	45.21±22.57	0.005	5.99±1.64	3.81±1.99	74.96±48.77	0.005

Table 6TBR of large and small lesions in different scan time and injected dose reconstructed by HYPER Iterative and OSEM

Lesion	Time	Full dose group (n=10)				Half dose group (n=10)			
		HYPER Iterative	OSEM	Difference(%)	*P*	HYPER Iterative	OSEM	Difference(%)	*P*
TBR (large lesion)	10s	7.60±3.37	8.27±3.81	6.77±9.00	0.074	10.97±9.09	12.25±10.05	2.38±34.91	0.203
	30s	8.24±2.19	7.83±2.41	6.58±11.52	0.169	12.00±10.22	10.76±7.96	11.17±24.75	0.508
	1min	8.22±2.39	7.78±2.57	6.99±13.69	0.241	12.02±11.15	10.27±8.07	15.15±23.62	0.074
	2min	8.39±2.45	7.85±2.46	7.55±10.95	0.028	12.32±11.96	10.70±9.87	17.63±25.59	0.037
	3min	8.60±2.64	8.01±2.53	7.67±9.73	0.013	12.45±12.23	10.68±10.01	19.40±29.94	0.013
	4min	8.68±2.73	8.05±2.60	8.31±9.85	0.013	12.80±12.76	10.64±9.73	23.13±35.54	0.047
	5min	8.84±2.93	8.15±2.75	8.69±9.72	0.013	12.84±12.58	10.53±9.15	23.39±34.15	0.028
TBR (small lesion)	10s	1.90±0.98	2.52±1.35	5.43±14.19	0.074	2.50±1.97	2.87±2.22	4.15±58.74	0.445
	30s	2.58±1.88	2.43±1.01	0.23±31.59	0.878	3.54±1.99	2.77±1.87	38.04±58.65	0.169
	1min	2.84±1.57	2.37±0.97	23.18±29.32	0.028	4.68±3.06	2.77±1.89	77.21±63.31	0.005
	2min	3.29±1.69	2.47±1.13	32.37±22.13	0.007	4.80±3.42	2.70±1.67	85.43±77.43	0.005
	3min	3.45±1.90	2.53±1.24	35.27±20.43	0.005	4.88±3.46	2.68±1.63	89.92±77.90	0.005
	4min	3.70±2.01	2.60±1.33	43.69±21.22	0.005	4.90±3.35	2.70±1.69	92.26±75.32	0.005
	5min	3.74±2.13	2.60±1.41	44.91±23.00	0.005	4.89±3.19	2.71±1.72	93.73±76.68	0.005

Figures

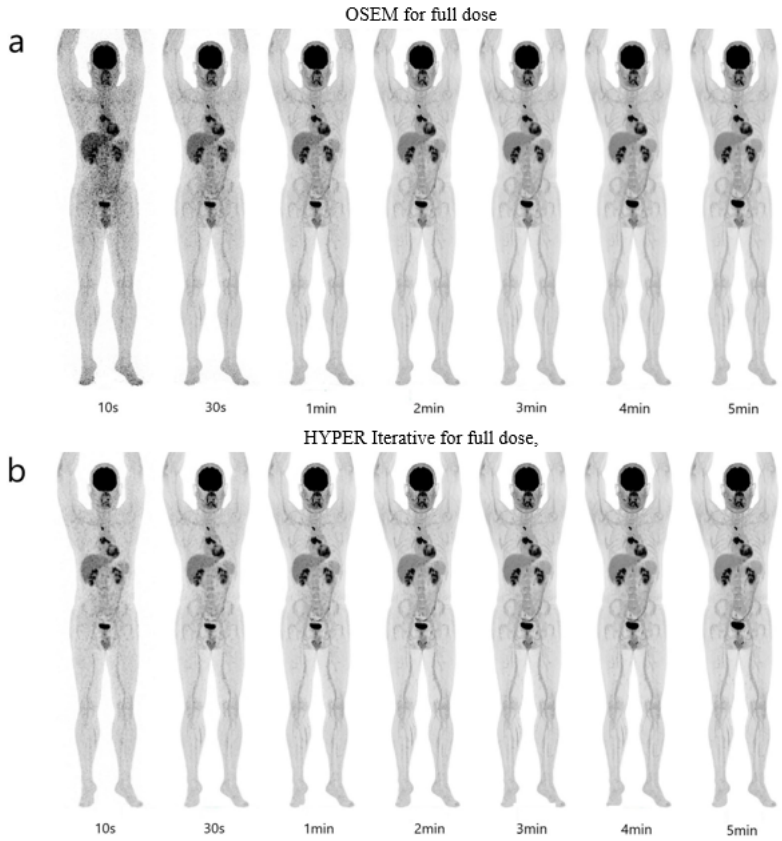

Figure 1

Total-body ^{18}F-FDG PET MIP images of different scan times reconstructed by OSEM and HYPER iterative in a patient with lung cancer injected with full dose ^{18}F-FDG. (a) ^{18}F-FDG PET MIP images of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively reconstructed by OSEM. The quality of OSEM-10s, OSEM-30s and OSEM-1min images were low due to low counting rate and large signal noise, especially the OSEM-10s, OSEM-30s. The OSEM-2min image reached the high quality, either that of OSEM-3min to OSEM-5min. (b) ^{18}F-FDG PET MIP images of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively reconstructed by HYPER Iterative. The quality of HYPER Iterative-10s and HYPER Iterative-30s had lower signal noise and higher quality than the counterparts by OSEM although they were still not excellent. The HYPER Iterative-1min image reached the high quality, either that of HYPER Iterative-2min to HYPER Iterative-5min.

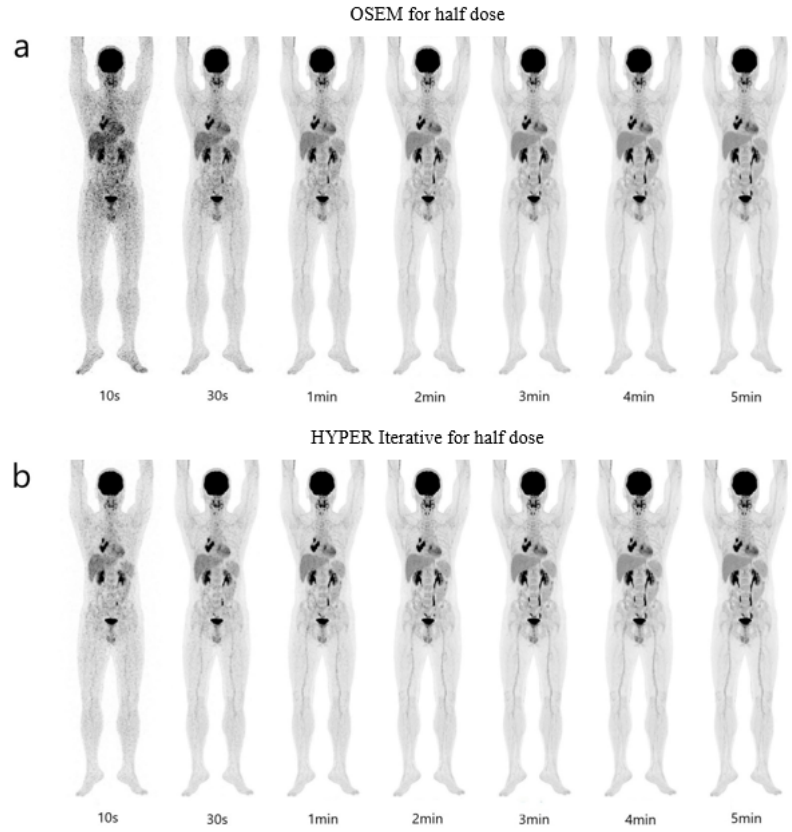

Figure 2

Total-body ^{18}F-FDG PET MIP images of different scan times reconstructed by OSEM and HYPER iterative in a patient with lung cancer injected with half dose^{18}F-FDG. (a) ^{18}F-FDG PET MIP images of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively reconstructed by OSEM. The quality of OSEM-10s, OSEM-30s, OSEM-1min andOSEM-2minimages were low due to low counting rate and large signal noise, especially the OSEM-10s, OSEM-30s. The OSEM-3min image reached the high quality, either that of OSEM-4min and OSEM-5min. (b) ^{18}F-FDG PET MIP images of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively reconstructed by HYPER Iterative. The quality of HYPER Iterative-10s, HYPER Iterative-30s and HYPER Iterative-1min had lower signal noise and higher quality than the counterparts by OSEM although they were still not excellent. The HYPER Iterative-2min image reached the high quality, either that of HYPER Iterative-3min to HYPER Iterative-5min.

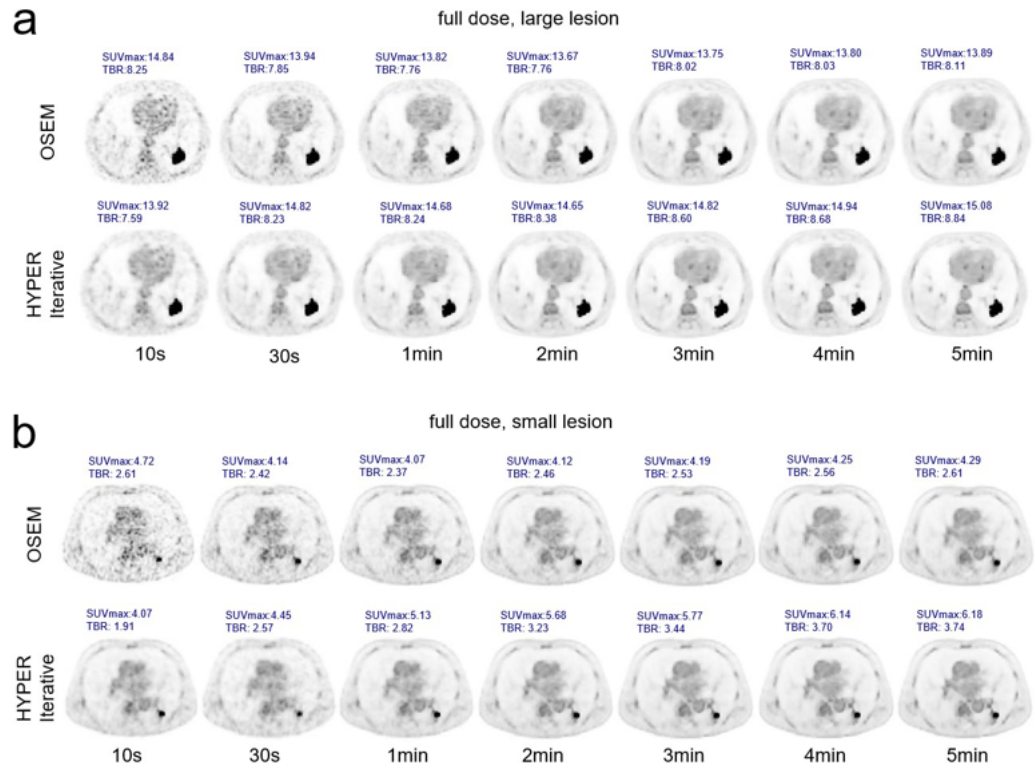

Figure 3

Transverse PET images of large and small lesions reconstructed by HYPER Iterative and OSEM with different scan times in two lung cancer patients injected with full-dose ^{18}F-FDG. (a) ^{18}F-FDG Transverse PET images reconstructed by HYPER Iterative and OSEM for a positive large lesion (diameter:3cm) with different scan times of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively. HYPER Iterative bring about 8% 9% higher SUVmax and 8% 9% higher TBR compared to OSEM reconstruction from 2min to 5 min. (b) ^{18}F-FDG transverse PET images reconstructed by HYPER Iterative and OSEM for a positive small lesion (diameter:8mm) with different scan times of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively. HYPER Iterative bring about 24% 45% higher SUVmax and 23% 45% higher TBR compared to OSEM reconstruction from 1min to 5 min.

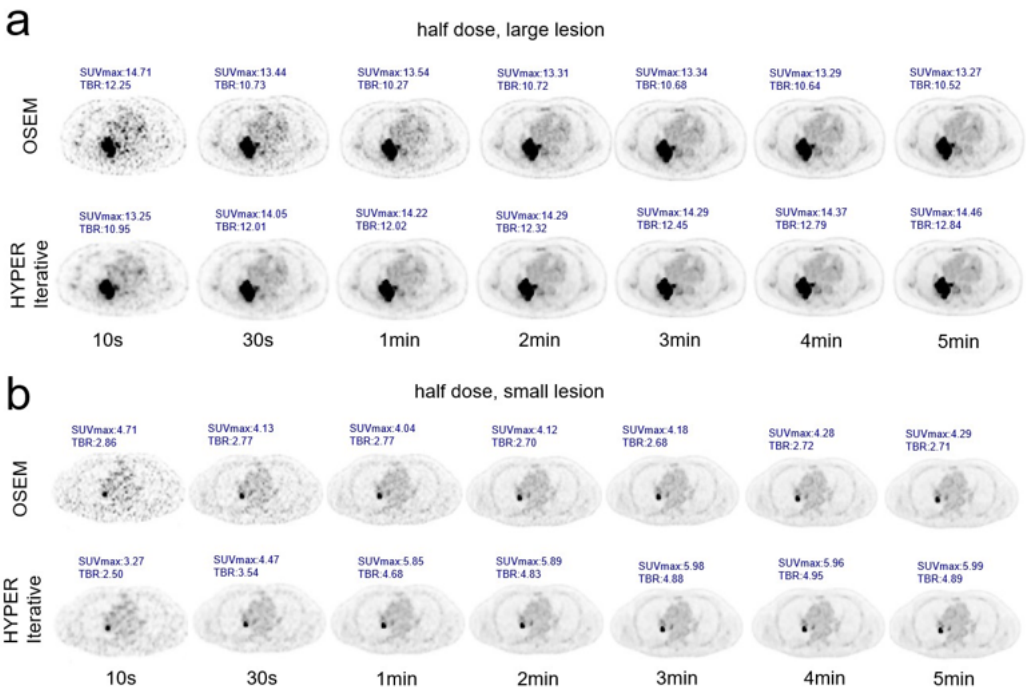

Figure 4

Transverse PET images of large and small lesions reconstructed by HYPER Iterative and OSEM with different scan times in two lung cancer patients injected with half-dose ^{18}F-FDG. (a) ^{18}F-FDG Transverse PET images reconstructed by HYPER Iterative and OSEM for a positive large lesion (diameter:4cm) with different scan times of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively. HYPER Iterative bring about 12% 13% higher SUVmax and 18% 23% higher TBR compared to OSEM reconstruction from 2min to 5 min. (b) ^{18}F-FDG transverse PET images reconstructed by HYPER Iterative and OSEM for a positive small lesion (diameter:7mm) with different scan times of 10s, 30s, 1min, 2min, 3min, 4min and 5min respectively. HYPER Iterative bring about 61% 75% higher SUVmax and 77% 94% higher TBR compared to OSEM reconstruction from 1 min to 5 min.

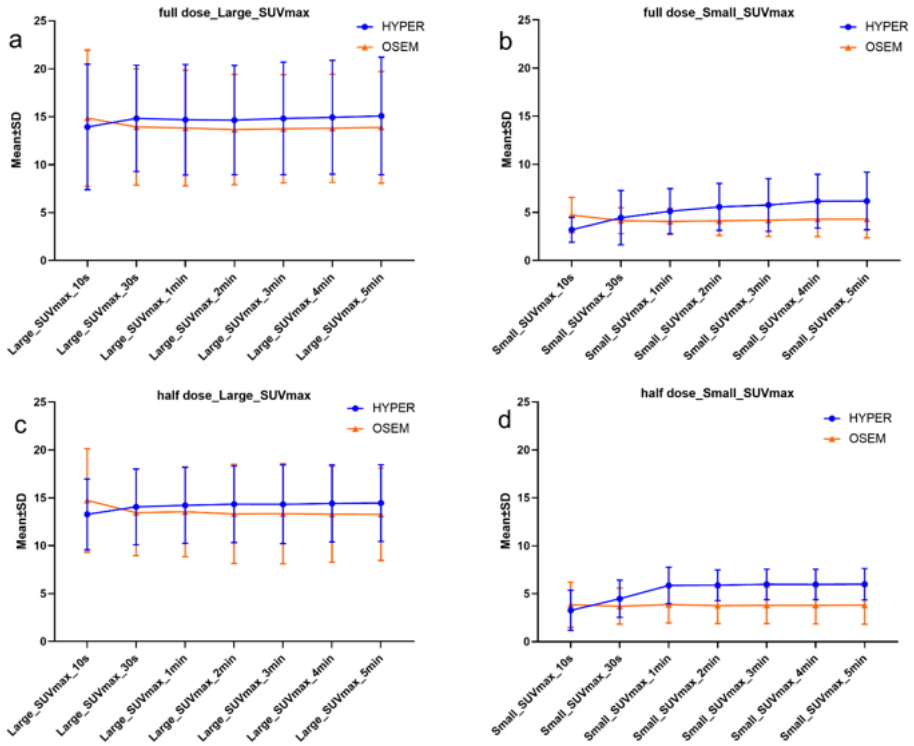

Figure 5

The SUVmax of positive large and positive small lesions in full-dose and half-dose groups reconstructed by OSEM and HYPER Iterative algorithms at different scan times.

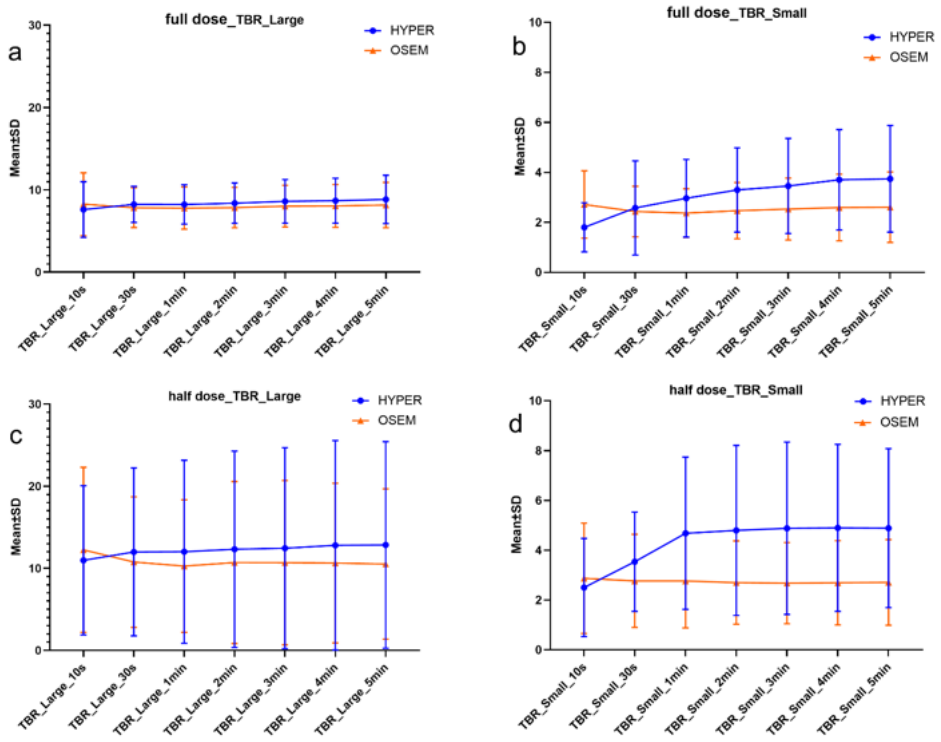

Figure 6

The TBR of positive large and small lesions in full-dose and half-dose groups reconstructed by OSEM and HYPER Iterative algorithms at different scan times.