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Original Research

TITLE: Feasibility of ultra-low ^{18}F-FDG activity acquisitions using total-body PET/CT

SHORT RUNNING TITLE: Ultra-low FDG activity and total-body PET/CT

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KEY RESULTS: The image quality of ultra-low FDG activity injection (0.37 MBq/kg) in total-body PET/CT with 8 min acquisition time was found to be clinically acceptable and equivalent to that with a 2 min acquisition in the full activity group (3.7MBq/kg). Ultra-low FDG activity in total-body PET/CT was feasible for oncological studies with a clinical diagnostic-level image quality.

SUMMARY STATEMENT: An ^{18}F-FDG injection with 0.37MBq/kg in total-body PET/CT did not compromise image quality for clinical reporting.

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ABSTRACT

The present study aimed to evaluate the feasibility of ultra-low ^{18}F-fluorodeoxyglucose (FDG) activity in total-body positron emission tomography (PET)/computed tomography (CT) oncological studies.

Methods Thirty patients with cancer were enrolled prospectively and underwent a total-body PET/CT examination with an ultra-low ^{18}F-FDG activity (0.37 MBq/kg) after an uptake time of 60 minutes. Among the enrolled patients, 11 were diagnosed with colorectal cancer (CRC). PET raw data were acquired within 15 minutes and reconstructed using data from the first 1, 2, 4, 8, 10 and the entire 15 min (G1, G2, G4, G8, G10, G15). Image quality was assessed qualitatively by two readers using a 5-point Likert scale twice. Cohen's kappa test was performed to investigate the intra-reader and inter-reader agreement. The standard uptake value (SUV)max of lesions, SUVmax, SUVmean, and standard deviation (SD) of the livers, the tumor-to-background ratio (TBR), and the signal-to-noise ratio (SNR) were measured and compared. The acquisition time for a clinically acceptable image quality was determined using an ultra-low activity injection. In a matched-pair study, 11 patients with CRC who received a full FDG activity (3.7 MBq/kg) with a 2-min PET acquisition were selected retrospectively with matched sex, height, weight, body mass index, glucose level, uptake time, and pathological types with the 11 CRC subjects in the prospective study. Qualitative and quantitative analyses were performed and compared between the 11 patients with CRC in the ultra-low activity-group and their matched full activity controls.

Results Qualitative analysis of image quality showed good intra- and inter-reader agreements (all kappa > 0.7). All the images acquired for 8-min or longer scored over 3 (indicating clinical acceptability). There was no significant difference in TBR and liver SNR among all the images acquired for 8-min or longer. In the matched study, no significant difference was found in the image quality score and quantitative parameters between the ultra-low activity group with an 8-min acquisition and the full activity group

with a 2-min acquisition.

Conclusion Ultra-low FDG activity injection with 8-min acquisition in a total-body PET/CT study can achieve acceptable image quality equivalent to that in the full activity group using 2-min acquisition.

Keywords Ultra-low activity; Image quality; Total-body PET/CT

INTRODUCTION

Positron emission tomography (PET) is an important tool for *in vivo* quantification of physiological, biochemical, or pharmacological processes. ^{18}F-fluorodeoxyglucose (FDG) PET is a sensitive imaging modality for staging, restaging, and therapy response monitoring of malignancies (*1-4*). However, radiation exposure is a concern for adults, and particularly for pediatric patients, because of the summed doses from both the PET and computed tomography (CT) scans. According to the current procedure guidelines of the European Association of Nuclear Medicine (EANM) for FDG-based PET/CT oncological imaging, the minimum time-mass activity-product (TAP), defined as the product of injected activity and the acquisition duration per bed position, is 14 or 7 MBq·min/kg for a PET system that applies a PET bed overlap of ≤ 30% or >30%, respectively (5). This TAP is based on the performance of a current conventional PET scanner with an axial field of view (FOV) of 15–25 cm. With the advent of the total-body PET scanner with ultra-high sensitivity, the TAP of FDG could be significantly reduced. Previously, our group investigated the effects of short acquisition duration on image quality and lesion detectability using a state-of-the-art PET/CT, which demonstrated the feasibility of a significantly shorter acquisition time with preferred image quality and diagnostic performance (*6,7*). By contrast, several studies have proposed a reduction in the injected FDG activity with total-body PET/CT (*8-10*). A recent study investigated the kinetics of FDG using a 10× reduction of the injected activity (0.37 MBq/kg) in a total-body PET/CT scanner, which showed an equivalent image quality compared with that of full-activity imaging in healthy volunteers (*11*). However, to the best of our knowledge, no studies have investigated the effects of a 10× reduction of the injected activity on FDG PET image quality in patients with various types of cancers. In the abovementioned study, “full activity” had different definitions, 3.7 or 4.4 MBq/kg, according to the adjusted routine practice in our department. Thus, a lower value of 3.7 MBq/kg was used as the full activity in the present study. The purpose of the study was to investigate the feasibility of a 10× reduction

of the injected activity for FDG PET imaging in a total-body PET/CT for oncological application.

MATERIALS AND METHODS

Patients

A total of 30 patients with various cancers, referred for a total-body FDG PET/CT study from June to September 2020, were enrolled prospectively in the first part of this study. All patients had pathologically diagnosed malignant tumors. The exclusion criteria included: No uptake of FDG in primary lesions, disease in the liver precluding measurement of quantitative metrics in the normal liver, body mass index (BMI) ≥ 30 kg/m^2, blood glucose level > 7.0 mmol/L, and an FDG uptake time of more than 70 min. Based on our previous work, ultra-low activity (0.37 MBq/kg) was administered (*11*). Patients were instructed to stay quietly in a warm room for about 60 minutes and drink 0.5–1 L water during the uptake phase. In the subsequent matched study, 11 patients with colorectal cancer (CRC) who received full activity (3.7 MBq/kg) total-body FDG PET/CT imaging were selected retrospectively from our database, and matched with the same demographic and pathological results of the 11 patients with CRC in the ultra-low activity group; the sex, height, weight, BMI, blood glucose level, and uptake time, were well matched. The uptake procedure was the same as those in the ultra-low activity group. The study was approved by the Institutional Review Board of Zhongshan Hospital, Fudan University and written informed consent was obtained from all the subjects in the prospective part. Written informed consent was waived for the 11 patients in the retrospective matched study who received full-activity (3.7 MBq/kg) PET/CT, given its retrospective design with anonymous retrieval of imaging data.

Data Acquisition and Reconstruction

All patients fasted for at least 6 h before FDG injection and their level of fasting blood glucose was no more than 7.0 mmol/L. All PET/CT scans were performed in a total-body PET/CT scanner (uEXPLORER, United Imaging Healthcare, Shanghai, China) with an

axial FOV (AFOV) of 194 cm. The PET images of the ultra-low activity group were acquired with 15 min, and then reconstructed using the first 1, 2, 4, 8, and 10 min data by temporally down sampling from the acquired 15-min raw data to simulate faster acquisitions, hereinafter referred as G1, G2, G4, G8, G10, and G15. The PET images of the full-activity group were reconstructed using 2 min of acquisition, hereinafter noted as g2. PET reconstructions were performed using the ordered subset expectation maximization (OSEM) algorithm with the following parameters: Time of flight (TOF) and point spread function (PSF) modelling, 3 iterations, and 20 subsets, matrix of 192 × 192, slice thickness of 1.443 mm, and a full width at half maximum of the Gaussian filter function of 3 mm.

Image Quality Assessment

The PET image quality was assessed independently by two nuclear medicine physicians with over 5 years' experience of interpreting PET/CT images (H: 5 year, and L: 7 years). The qualitative analysis of image quality was scored on a scale of 1 – 5 (1, unacceptable image quality: extremely poor contrast with significant noise; 2, poor image quality: low contrast with noise; 3, acceptable image quality: moderate contrast with noise; 4, good image quality: good contrast with less noise; 5, excellent image quality: perfect contrast with minimal noise). A score of 3 indicated the minimum acceptable image quality for clinical reporting. For each patient, all the PET images were loaded into the viewer by the software (uWS-MI, R001, United Imaging Healthcare). The order of the PET images was randomized by an independent operator. The patient's demographic information, medical history, and acquisition duration were also blinded to the readers. In addition, each reader re-assessed the image quality one week later to eliminate the memory effect, using an alternative patient order (the order of the PET images was also randomized). The values of each observer were averaged and compared between the two groups.

In a separate session performed one week after the second qualitative assessment, the quantitative analysis of image quality was first performed by one of the two nuclear

medicine physicians by manually drawing a 2D circular region-of-interest (ROI) with a diameter of 2 cm on the homogeneous area of the right lobe of the liver. ROIs were placed automatically at exactly the same location and slice for all the loaded PET series. The ROI was carefully drawn to avoid lesions and was at least 1 cm away from the edge of the liver. The maximum standard uptake value (SUVmax), the mean standard uptake value (SUVmean), and the standard deviation (SD) were recorded. The SUVmax of the primary lesion was delineated at the corresponding PET transverse slice with the maximum diameter in the CT images for comparison of image datasets. The size of the ROIs was adapted to the lesion size. The liver signal-to-noise ratio (SNR) was calculated by dividing the SUVmean by its SD, and the tumor-to-background ratio (TBR) was calculated by dividing the lesion SUVmax by the liver SUVmax.

Statistical Analysis

Statistical analysis was conducted using SPSS 20.0 (IBM Corp., Armonk, NY, USA) and GraphPad Prism 6.0 (GraphPad Software Inc., San Diego, CA, USA). Numerical parameters are presented as the mean ± standard deviation and categorical variables are described as frequencies. A p-value < 0.05 indicated statistical significance. The intra-observer and inter-observer agreement for the qualitative scores were analyzed using Cohen's kappa test (0.00–0.20, low; 0.21–0.40, medium; 0.41–0.60, moderate; 0.61–0.80, good; 0.81–1.00, excellent). The Kolmogorov–Smirnov test was performed to test the normality of the objective image quality and the Wilcoxon rank-sum test was used to compare these parameters in G1–G10 with those in G15. Fisher's exact test and an independent sample t test were used to compare the categorical and numerical variables between the ultra-low activity and full activity groups, respectively.

RESULTS

Patient Demographics

The patient demographics in the ultra-low activity group are summarized in Table 1. A total of 30 subjects were enrolled in the prospective part of the study (20 men and 10

women; mean age of 66.10 ± 8.44 years). The average fasting blood glucose level was 5.75 ± 0.66 mmol/L and the mean uptake time post injection was 60.97 ± 5.96 min. Diagnoses of the malignancy were confirmed using pathological examinations.

Image Quality of Oncology Patients in the Group of Ultra-low Activity Group

The subjective image quality scores of the ultra-low activity group are summarized in Table 2. The intra-observer and inter-observer agreements were good for the subjective image quality score (all kappa > 0.7). In groups with an acquisition duration of 8-min and longer, the agreement was excellent (all kappa > 0.85). There was a significant difference in image quality regarding the Likert scale between G15 and the other groups (G1–G10) ($p < 0.001$). All images with 8-min acquisition time or longer had a score over 3 and were judged acceptable for clinical reporting (Figure 1).

As shown in Table 3 and Figure 2, the lesion SUVmax increased with the duration of acquisition; however, the difference was only significant for an acquisition time of 1 minute compared with that for G15 (all $p > 0.05$). The liver SUVmax decreased with longer acquisition time and the TBR increased; however, the difference was only significant for acquisition times shorter than 4 minutes ($p < 0.05$). The liver SUVmean, SD, and SNR are summarized in Table 4. There was no difference in the liver SUVmean among all the groups ($p > 0.05$). The liver SD decreased rapidly from G1 to G15, while the SNR increased progressively. However, there was no statistical differences between G8, G10, and G15 ($p > 0.05$). Thus, images from G8 could yield comparable image quality to those from G15 and were suitable for clinical reporting.

Demographics of Matched Patients with CRC in the Ultra-low Activity and Full Activity Groups

Eleven patients (seven male and four female of each group) with CRC (10 well-moderately differentiated adenocarcinoma and 1 high-grade intraepithelial neoplasia) were enrolled in the matched study. The demographics of the patients with CRC in G8 and g2 are provided in Table 5. As expected, a significant difference in the injected dose was

showed between the G8 and g2 ($p < 0.001$), while other variables including sex, BMI, blood glucose, uptake time, and pathological classification were well matched without significant differences (all $p > 0.05$).

Comparison of the Image Quality in Patients with CRC between the G8 and g2 Groups

The subjective and objective analyses of image quality in the G8 and g2 groups are shown in Table 6. The visual image quality score in G8 was 3.91 ± 0.30, which was equivalent to that in g2 (3.82 ± 0.60). The lesion SUVmax and TBR in G8 (23.43 ± 8.64 and 7.07 ± 2.74) were slightly lower than those of g2 (24.22 ± 12.15 and 7.56 ± 3.51) but without statistical significance (all $p > 0.05$). The liver SUVmean and SD were similar in the G8 and g2 groups (SUVmean: 2.78 ± 0.33 *vs*. 2.84 ± 0.47, and SD: 0.21 ± 0.05 *vs*. 0.23 ± 0.08, respectively). The SNRs in the G8 and in g2 groups were 13.77 ± 2.14 and 13.40 ± 2.90, respectively, without a significant difference ($p = 0.716$). None of the quantitative parameters showed significant differences between the groups (all $p > 0.05$), indicating an equivalent performance between the two groups (Figure 3 & 4).

DISCUSSION

The 194 cm long total-body PET/CT system has a spatial resolution of approximately 3.0 mm and a system sensitivity up to 174 kcps/MBq with NEMA NU-2-2018 (*12*). The system enables excellent image quality and provides new opportunities to assess clinical imaging protocol modifications such as short scan durations, low tracer activity injection, or delayed imaging. The current study assessed the feasibility of using a low FDG injected activity. The dominant physical characteristic of the total-body PET scanner is its high sensitivity, being 40-fold higher compared with that of current conventional systems (*13*). The SNR in PET images, representing the image quality, is proportional to the square root of the product of system sensitivity, injected activity, and acquisition time (*14*). For the total-body PET/CT scanner, the data quality is as important as the data quantity (i.e., total true counts). Data quality is often measured as noise equivalent counts (NEC), which is

calculated as: NEC = T^2/(T+R), where T and R are the trues and randoms, respectively. The random rate is considered to be proportional to the square of the injected activity, while the true rate is proportional to the injected activity, so the random rate is approximately 100 × higher in the full activity situation than that in the 1/10 activity situation. As a result, if the ultra-low activity data and the full activity data have equivalent total trues, the ultra-low activity data would have a higher NEC, that is, better data quality. Therefore, it is possible to achieve comparable image quality with a shorter acquisition time than that estimated from the rule of constant product of the acquisition time and the activity. Our previous studies demonstrated the capability of the total-body PET to achieve good image quality with a reduced injected activity up to 1/2 and 1/7 of the recommended standard in the clinic (3.7 MBq/kg) (*9*,*15*). However, these studies were only from small number of cases without evaluating both the qualitative and quantitative aspects. Therefore, the current study aimed to provide qualitative and quantitative assessments with ultra-low FDG injected activity in oncological patients using the total-body PET-CT scanner.

Our results demonstrated that images acquired with a duration of 8 min and an ultra-low injected activity provided acceptable image quality for clinical reporting. The liver SUVmean showed good consistency for all PET series, without significant differences between the groups in G1 – G15. However, the liver SNR only showed a lack of significant differences between groups in G8 – G15. Compared with G15, there was no significant difference in the lesion SUVmax and TBR in both the G8 and G10 groups. Based on the above results, an 8 min PET acquisition with an ultra-low injection activity protocol could yield diagnostic-level quality for clinical oncological applications. In this study, we found that lesion SUVmax increased along with the acquisition time, which was inconsistent with a previous study (6). We hypothesized that the additional uptake time (with a maximum of 15 minutes) will be more noticeable when the acquired counts were reduced. The effect on the increased accumulation of FDG in the malignant lesions will be more significant and thus increase the lesion SUV, as observed in the time-activity curves in previous

studies(*16,17*). Additionally, a discrepancy between visual and quantitative analysis was found. In the objective analysis, the TBR and SNR of G10 – G15 were higher than that in G8, but without statistical differences. The liver SD decreased as the acquisition time increased, but still no significant difference was observed between G8 and G15. In this study, we simply used lesion TBR, liver SNR, and SD as the indices of objective image quality. However, the visual analysis process was far more complex than the simple evaluation of those parameters, which can be influenced by the reader's experience, preference, and training before the analysis.

In conventional whole-body PET/CT imaging, PET acquisition is performed in a step-and-shoot mode with 6 – 7 bed positions. The total-body PET/CT imaging uses a one-step acquisition mode because the 194-cm AFOV can cover the patient's entire body in one bed position. Our previous study reported that total-body PET images with a 2 min acquisition and an injected activity of 4.4 MBq/kg could yield images superior to the average image quality (*6*). The liver SUVmax and SD in the two studies showed the similar tendency with the acquisition time, but with different values. This is mainly caused by the difference in the uptake time of the enrolled patients between the two studies. Although a 60-s acquisition can maintain the diagnostic performance at a sufficient level, as reported in the previous study (6), the injected activity was 18% higher than the full activity in this study. Thus, in the matched-pair part of this study, a 2 min acquisition was selected as the control to evaluate the image quality and feasibility of ultra-low activity in total-body PET/CT imaging. Compared with full activity using 2-min of acquisition, the image quality of ultra-low activity using 8 min of acquisition revealed an equivalent result. The ultra-low activity PET scan provides several benefits. One is the significant reduction of radiation from the PET radiotracers, which is approximately 7 mSv in a conventional PET whole body examination (*18*). If activity can be reduced to 1/10, it implies a broader use of PET scan in radiation-sensitive populations (infants, children, and adolescents). For pediatric imaging, there are risks associated with the acquisition duration and injected dose. An

increased injected activity is associated with an increased risk of radiation-induced cancer in the pediatric population (*19*). According to recently published guidelines, images with diagnostic image quality with the lowest possible dose are desired in pediatric FDG PET/CT for oncology (*5*). The ultra-low injected activity PET scan, with reduced radiation exposure, will provide a more feasible solution for pediatric imaging. In addition, the ultra-low injected activity PET scan can be very attractive for repeated scans for monitoring treatment response. It may become an effective strategy for patient management without concerns related to the cumulative absorbed dose.

Our study has several limitations. First, 30 patients with ten types of cancer were enrolled prospectively in the study. The highest weight was only up to 88 kg. Image quality can be influenced by patient size (weight, BMI), and image quality might be degraded because of excessive attenuation in larger weight patients (*5*). Additionally, only patients with colorectal cancer were validated in the matched study. Although they were well matched based on the demographic and pathological features, some marginal differences remained. The relatively small number of patients enrolled in the matched study meant that there is a potential selection bias. Second, although FDG is the most widely used radiotracer in oncological studies, it is not applicable for all types of cancer, because not all tumors are FDG-avid. Furthermore, the extent of FDG uptake is easily affected by certain factors. Respiratory motion might blur the lesions where the impact of the SUV measurement on the lesions may differ with different acquisition time (*20*). We selected the lesions with a size of $\geq$ 10 mm (measured on CT images), for which the error induced by the respiratory motion can be minimized. Finally, the 2D ROI did not necessarily capture the true SUVmax of the whole tumor volume, as limited by the current measurement software. The reconstruction parameters used in this study were the same as those with the standard activity in our department without specific modification. However, these parameters were based on the high counts and the clinical requirements for diagnosis. To improve lesion detection, we applied PSF modeling in the PET reconstruction, the same as

in routine practice, which may cause a bias in the quantitative estimate. In future studies, the comparison between the PSF and non-PSF reconstruction, and the optimal reconstruction parameters with the ultra-low injected activity protocol should be investigated.

CONCLUSION

The study demonstrated that ultra-low injected FDG activity (0.37 MBq/kg) in total-body PET/CT was feasible for oncological studies, with a clinical diagnostic-level image quality in our department. Further investigation will be performed to explore the optimal reconstruction parameters for ultra-low FDG activity in the clinic.

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DISCLOSURE

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KEY POINTS

QUESTION: Does ultra-low injected FDG activity (0.37 MBq/kg) in total-body PET/CT compromise image quality in the clinic?

PERTINENT FINDINGS: This study demonstrated that the image quality gained using ultra-low injected FDG activity (0.37 MBq/kg) in total-body PET/CT meets clinical requirements.

IMPLICATIONS FOR PATIENT CARE: Total-body PET/CT imaging with an ultra-low FDG activity (0.37 MBq/kg) can be performed in radiation-sensitive populations such as infants, children, and adolescents, as well as in patients who need repeated scans to monitor treatment response.

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TABLES

TABLE 1. Demographics of patients with ultra-low activity

Variable	Dataset
Sex*	
Men	20
Women	10
Age (years)†	66.1 ± 8.44 [range: 48.00–77.00]
Height (cm)†	165.5 ± 7.25 [range: 157.00–186.20]
Weight (kg)†	62.28 ± 10.2 [range: 44.80–88.00]
BMI (kg/m^2)†	22.73 ± 3.28 [range: 15.76–29.75]
Blood Glucose (mmol/L)†	5.75 ± 0.66 [range: 4.80–7.00]
Waiting Time (min)†	60.97 ± 5.96 [range: 51.00–70.00]
Injected Dose (MBq)†	25.53 ± 4.07 [range: 17.76–33.67]
Primary tumor type*	
HCC and ICC	4
Colorectal cancer	11
Lung cancer	1
Pancreatic cancer	3
Esophageal cancer	2
Mediastinal sarcoma	1
Bladder cancer	4
Ovarian cancer	2
Lymphoma	1
Laryngeal cancer	1

Body mass index, BMI; Hepatocellular Carcinoma, HCC; Intrahepatic Cholangiocarcinoma, ICC

*indicated as the number of patients.

†Data are presented as the mean ± SD [range].

TABLE 2. Subjective image quality score in the ultra-low activity group

Acquisition duration (min)	Image quality score			
	Observer 1*	Observer 2*	Intra-kappa-value (95% CI)	Inter-kappa-value (95% CI)
1	1.10 ± 0.31	1.14 ± 0.35	0.898 (0.694–1.000)	0.849 (0.530–1.000)
2	2.07 ± 0.37	2.10 ± 0.41	0.902 (0.711–1.000)	0.885 (0.674–1.000)
4	3.00 ± 0.38	2.90 ± 0.49	0.895 (0.688–1.000)	0.750 (0.492–1.000)
8	4.07 ± 0.53	3.97 ± 0.63	0.900 (0.701–1.000)	0.852 (0.638–1.000)
10	4.38 ± 0.49	4.38 ± 0.49	0.921 (0.738–1.000)	0.854 (0.648–1.000)
15	4.62 ± 0.49	4.59 ± 0.50	0.945 (0.812–1.000)	0.930 (0.790–1.000)

*The mean value and SD were calculated based on the subjective scores for each patient. Confidence interval, CI.

TABLE 3. Quantitative image quality in the ultra-low activity group

Acquisition duration (min)	Lesion SUVmax*	Liver SUVmax*	TBR*
1	12.44 ± 5.00†	4.56 ± 0.86†	2.84 ± 1.36†
2	14.58 ± 6.86	3.80 ± 0.60†	3.89 ± 1.80†
4	16.95 ± 7.78	3.53 ± 0.52	4.83 ± 2. 18
8	18.09 ± 8.26	3.31 ± 0.50	5.53 ± 2.50
10	18.37 ± 8.06	3.21 ± 0.46	5.78 ± 2.50
15	18.96 ± 7.93	3.08 ± 0.42	6.18 ± 2.52

* Data are presented as the mean ± SD, based on the measurement in regions of interest (ROIs). Standard uptake value, SUV; tumor-to-background ratio, TBR.

† indicated a significant difference compared to that in G15 ($p < 0.05$).

TABLE 4. SUVmean, SD, and SNR of the liver

	Acquisition duration (min)					
	1	2	4	8	10	15
Liver SUVmean*	2.80 ± 0.48	2.78 ± 0.44	2.77 ± 0.43	2.73 ± 0.38	2.72 ± 0.39	2.70 ± 0.38
Liver SD*	0.56 ± 0.19†	0.38 ± 0.11†	0.28 ± 0.08†	0.21 ± 0.06	0.19 ± 0.06	0.18 ± 0.05
SNR*	5.41 ± 1.53†	7.67 ± 1.88†	10.41 ± 2.54†	13.46 ± 3.13	14.72 ± 3.46	15.65 ± 3.64

*Data are presented as the mean ± SD, based on the measurement in regions of interest (ROIs). Standard uptake value, SUV; tumor-to-background ratio, TBR; signal-to-noise ratio, SNR.

† indicates a significant difference compared to that in G15 ($p < 0.05$).

TABLE 5. Demographics of patients in the G8 and g2

Variable	G8	g2	*P* values
Gender*			0.201
Male	7	7	
Female	4	4	
Height (cm) †	166.05 ± 6.48	167.82 ± 10.01	0.627
Weight (kg) †	62.96 ± 11.87	71.52 ± 18.22	0.208
BMI (kg/m^2) †	22.75 ± 3.46	25.00 ± 3.92	0.168
Blood Glucose (mmol/L) †	5.81 ± 0.61	5.31 ± 0.53	0.054
Waiting Time (min) †	62.91 ± 5.50	58.00 ± 5.57	0.051
Injected Dose (MBq) †	24.79 ± 4.44	271.21 ± 61.42	< 0.001‡
Pathological*			1.000
WMDA	10	10	
HGIN	1	1	

Well-Moderately Differentiated Adenocarcinoma, WMDA; High-Grade Intraepithelial Neoplasia, HGIN; body mass index, BMI.

*indicates the number of patients.

†Data are presented as mean ± SD, based on the data from each subject.

‡ indicates a significant difference between G8 and g2 ($p < 0.001$). G8: ultra-low activity (0.37 MBq/kg) acquired with 8 min; g2: full activity (3.7 MBq/kg) acquired with 2 min.

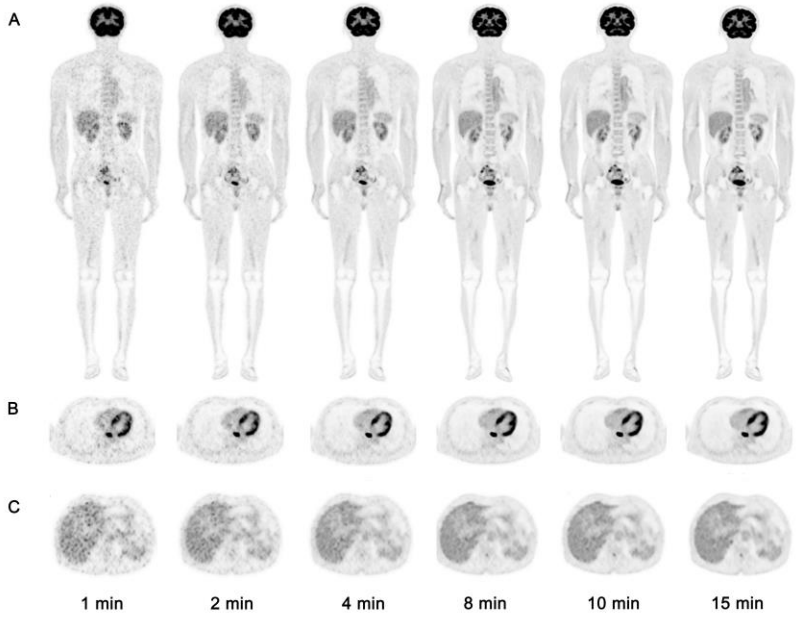
TABLE 6. Qualitative image quality score and quantitative parameters in the ultra-low activity group and full activity group

	G8	g2	P values
Image quality score*	3.91 ± 0.30	3.82 ± 0.60	0.311
Lesion SUVmax*	23.43 ± 8.64	24.22 ± 12.15	0.863
Liver SUVmax*	3.39 ± 0.54	3.17 ± 0.55	0.354
Liver SUVmean*	2.78 ± 0.33	2.84 ± 0.47	0.747
Liver SD*	0.21 ± 0.05	0.23 ± 0.08	0.544
TBR*	7.07 ± 2.74	7.56 ± 3.51	0.738
SNR*	13.77 ± 2.14	13.40 ± 2.90	0.716

*Data are presented as the mean ± SD. The mean value and SD were calculated based on the Likert score for each patient. The mean value and SD of other quantitative parameters were calculated based on the measurement in regions if interest (ROIs). Standard uptake value, SUV; tumor-to-background ratio, TBR; signal-to-noise ratio, SNR.

FIGURE LEGENDS

FIGURE 1. PET images of a 63-year-old man with esophagus cancer. Coronal slice of the whole-body (A), transverse views of the intense uptake of lesions in the esophagus (B) and transverse view of the liver (C) are showed in G1, G2, G4, G8, G10, and G15 reconstructions. A superior image quality of the liver was observed in G8 than that in G1 and G2 upon visual assessment. PET, positron emission tomography; SUV, standard uptake value.



	Acquisition duration (min)					
	1	2	4	8	10	15
Visual score	1.12 ± 0.32	2.09 ± 0.38	2.97 ± 0.41	4.03 ± 0.56	4.38 ± 0.49	4.60 ± 0.49
Lesion SUVmax	12.44 ± 5.00	14.58 ± 6.86	16.95 ± 7.78	18.09 ± 8.26	18.37 ± 8.06	18.96 ± 7.93
Liver SUVmax	4.56 ± 0.86	3.80 ± 0.60	3.53 ± 0.52	3.31 ± 0.50	3.21 ± 0.46	3.08 ± 0.42
Liver SUVmean	2.80 ± 0.48	2.78 ± 0.44	2.77 ± 0.43	2.73 ± 0.38	2.72 ± 0.39	2.70 ± 0.38

FIGURE 2. The box plot of the lesion SUVmax, liver SUVmax, TBR, liver SUVmean, liver SD, and SNR (A-F). The lesion SUVmax, TBR, and SNR increased with the extension of acquisition time, while the liver SUVmax, liver SUVmean, and SD decreased. Compared with G15, no significant differences for these parameters were found in G8 and G10 (∗ $P < 0.05$; ns, not significant). SD, standard deviation; SNR, signal-to-noise ratio; SUV, standard uptake value; TBR, tumor-to-background ratio.

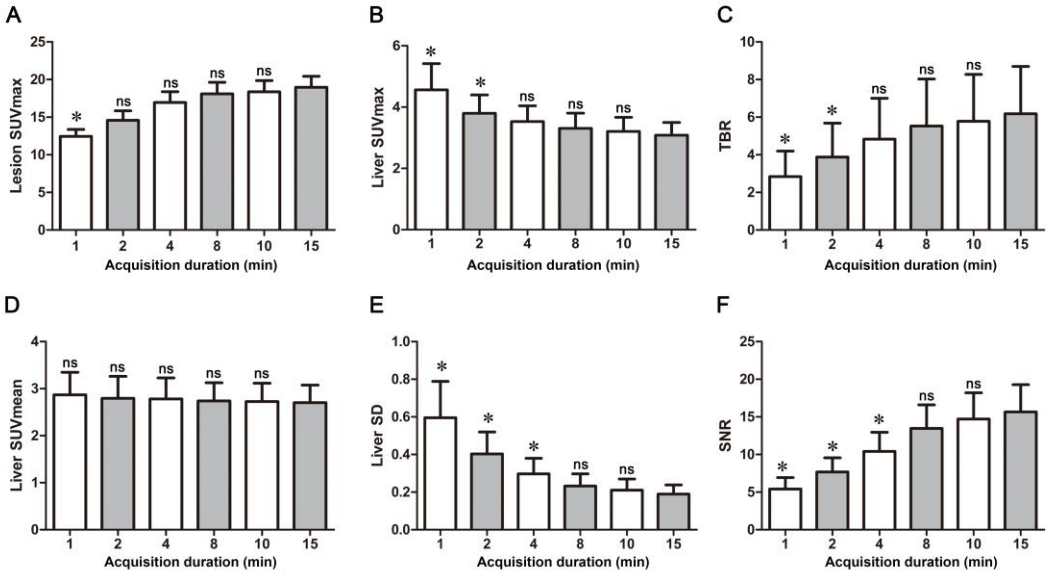
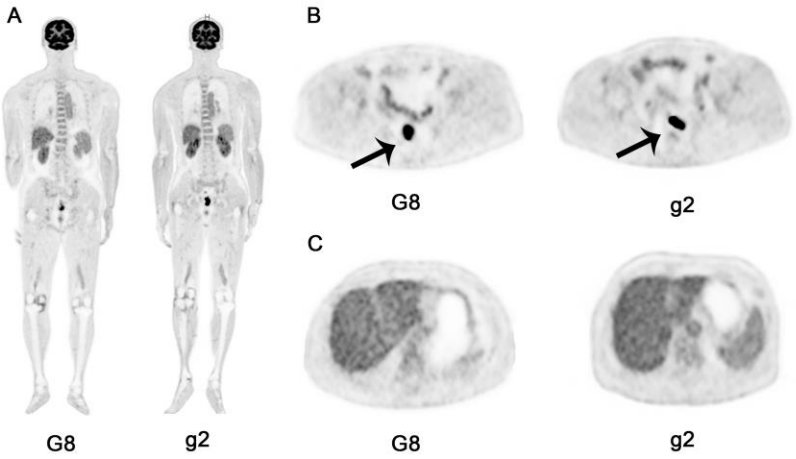
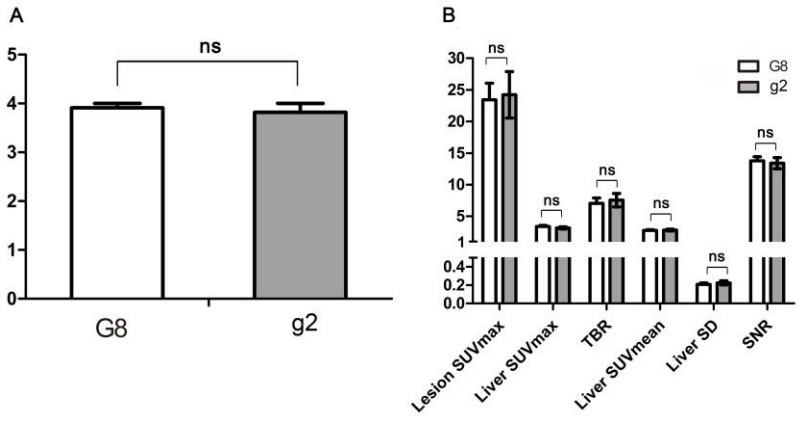


FIGURE 3. PET images of a 63-year-old man with CRC reconstructed in G8 and another 63-year-old man with CRC reconstructed in g2 (A, coronal slice of the whole-body; B, transverse view of a CRC lesion (arrow); C, transverse images of the liver). The image quality in G8 were comparable to those in g2, which meets the demand for clinical diagnosis demand. CRC, colorectal cancer; G8, ultra-low activity (0.37 MBq/kg) acquired with 8 min; g2, full activity (3.7 MBq/kg) acquired with 2 min; PET, positron emission tomography; SUV, standard uptake value.



	G8	g2
Image quality score	3.91 ± 0.30	3.82 ± 0.60
Lesion SUVmax	23.43 ± 8.64	24.22 ± 12.15
Liver SUVmax	3.39 ± 0.54	3.17 ± 0.55
Liver SUVmean	2.78 ± 0.33	2.84 ± 0.47

FIGURE 4. Bar graphs of subjective image quality score (A) and objective parameters (B) between the G8 and g2. A comparable result of quality and quantitative analysis was shown between the two groups (ns, not significant). G8, ultra-low activity (0.37 MBq/kg) acquired with 8 min; g2, full activity (3.7 MBq/kg) acquired with 2 min; SD, standard deviation; SNR, signal-to-noise ratio; SUV, standard uptake value; TBR, tumor-to-background ratio.



Graphical abstract