



Comparison of standardized uptake values obtained from two- and three-dimensional modes of fluorine-18 fluorodeoxyglucose PET-CT in oncological cases

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PURPOSE

We investigated the usability of standardized uptake values (SUV) obtained from both two- and three-dimensional (2D and 3D) positron-emission tomography and computed tomography (PET-CT) imaging, and compared the images obtained from these techniques in terms of image quality, lesion detectability, and the presence of artifacts.

MATERIALS AND METHODS

Image data from 100 patients, who had undergone two PET imagings obtained in 2D and 3D mode after a low dose CT, were evaluated prospectively. Subjective analysis of 2D and 3D images was performed by two readers evaluating the following criteria: overall image quality, detectability of each identified lesion, and the presence of artifacts. The lesions recognized by the readers were also analyzed quantitatively by measuring SUV values.

RESULTS

There was a significant difference between the SUVs obtained in 2D and 3D modes. Regardless if the first scan was performed in 2D or 3D mode, the values obtained from 3D imaging were significantly lower than those obtained from 2D imaging (mean SUV_{max} was 10.48 ± 7.57 for 2D, and 9.66 ± 6.93 for 3D, $P < 0.001$). Visual analysis did not reveal significant differences regarding lesion detectability between two modes.

CONCLUSION

In oncological PET-CT applications, SUV values are significantly lower in 3D compared with 2D mode. Thus when serial scanning is needed to evaluate response to therapy in the same patient, the imaging modality should be taken into account and performed with the same method to avoid misinterpretation. Additionally, 3D PET-CT imaging can be used instead of 2D PET-CT due to its shorter scanning time without loss of lesion detectability.

Positron emission tomography (PET) using fluorine-18 fluorodeoxyglucose (^{18}F -FDG) is an important clinical tool, particularly in oncology. ^{18}F -FDG PET is now routinely used in detecting, staging, and evaluating treatment response of various tumors (1–4). The combination of PET and computed tomography (CT) provides the ability to accurately register the metabolic and molecular aspects of disease with anatomical findings, adding further information to the diagnosis and staging of tumors. PET-CT is a fast growing imaging modality worldwide (2).

PET scanners from some vendors can acquire data in both two-dimensional (2D) and three-dimensional (3D) modes, whereas others can only acquire data in 3D mode (5). A shorter scan time and improved efficiency of ^{18}F -FDG use due to higher sensitivity in the 3D mode could theoretically be the main advantage of 3D acquisition compared to standard 2D (6).

There are diverse approaches to assess the amount of ^{18}F -FDG uptake, though standardized uptake values (SUVs) are widely employed as a semi-quantitative index for tumor uptake (7, 8). SUV can be affected by various factors, such as time of acquisition after radiopharmaceutical injection, plasma glucose level, partial volume effect, reconstruction parameters, and attenuation correction methods. In addition, SUV is known to depend on acquisition parameters and region of interest (ROI) selection. Therefore, SUVs may not only change with different modes of acquisition (2D or 3D mode), but also with the use of different scanners, image reconstruction and data analysis software. A potential problem in the present use of combined PET-CT scanners is that SUVs may not necessarily show the same absolute values and the same degree of reliability as those obtained from stand-alone PET scanners, in which attenuation correction factors are calculated using external 511-keV rod sources (9). Variability in SUV methodology hampers direct comparison of results obtained in different studies and prevents comparison of results obtained in different centers (10).

In this study, we investigated the cross usability of SUVs obtained from both 2D and 3D PET-CT imaging, and compared the images obtained from these techniques in terms of image quality, lesion detectability, and presence of artifacts.

Materials and methods

One hundred consecutive randomized patients (45 females, 55 males; mean age, 54.98 ± 14.18 years; age range, 6–80 years) referred to our clinic for ^{18}F -FDG PET-CT imaging with known or suspected malignancy were prospectively included in the study. These patients suffered from lung cancer (n=31), breast cancer (n=17), Hodgkin lymphoma (n=10), non-Hodgkin lymphoma (n=8), colon cancer (n=6), cervix cancer (n=4), larynx cancer (n=3), stomach cancer (n=2), gallbladder cancer (n=2), pancreas cancer (n=2), epidermoid cancer (n=1), nasopharynx cancer (n=1), ovarian cancer (n=1), tonsilla cancer (n=1), hard palate cancer (n=1), invasive thymoma (n=1), thyroid cancer (n=1), squamous cell

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cancer (n=1), bladder cancer (n=1), rectum cancer (n=1), renal cell carcinoma (n=1), malign fibrous histiocytoma (n=1), and metastatic disease of unknown primary origin (n=3).

The Institutional Ethics Committee approved this prospective study and prior to imaging, all patients gave written informed consent.

Patient preparation

Patients fasted for at least four hours before the study. One hour before injection of radiopharmaceutical, 30 cc oral contrast diluted with 1.5 L water was given. Before injection of ^{18}F -FDG, blood sugar levels were controlled. Patients whose fasting blood glucose (FBG) levels were over 200 mg/dL were not included in the study and imaging was not performed. The mean FBG value for patients included in the study was 101.23 ± 23.76 mg/dL. The mean FBG measurements of the patients whose first acquisition mode was 2D (n=52) and 3D (n=48) were 98.83 ± 19.78 mg/dL and 103.83 ± 27.40 mg/dL, respectively. There was no statistical difference in FBG levels between these two groups ($P = 0.295$ for 2D; $P = 0.301$ for 3D).

An average standard dose of ^{18}F -FDG 539.82 ± 75.68 MBq (14.58 ± 2.04 mCi) was administered intravenously from a cannula placed on the antecubital vein or dorsum of hand. After injection, patients rested in a dark and quiet room without speaking until the acquisition began. After uptake duration time, they were taken to whole body PET-CT imaging.

PET-CT imaging

The patients were randomized into two groups. For Group 1 (52 patients), 2D acquisition was applied initially. For Group 2 (48 patients), the first acquisition mode was 3D. It is well-known that ^{18}F -FDG accumulates progressively in malignant cells, reflecting an increase in SUV over time. Therefore, after the first mode acquisition, the patients continued directly with the acquisition in the other mode without changing their position. The first imaging started on average 83.04 ± 25.31 min after injection, and the second imaging was performed 111.59 ± 25.45 min after ^{18}F -FDG injection. The first and second imaging times after injection for Group 1 were 84.71 ± 27 and 114.31 ± 26.67 , respectively, and for Group 2 were 81.23 ± 23.49 and 108.65 ± 23.98 min. There was no

statistical difference between the groups in terms of waiting time (both for two groups and two acquisition modes, $P > 0.05$) (Table 1).

PET-CT imaging was performed on a GE Discovery STE System (General Electric Company, Milwaukee, Wisconsin, USA) with advanced detector technology with improved sensitivity, spatial resolution and retractable septa, allowing scanning in 2D or 3D mode with a field of view (FOV) 17 cm and a transaxial resolution of 5.47 mm for 2D, and 6 mm for 3D full width at half maximum at the center. The system includes an eight-slice helical CT scanner.

Patients were in a supine position with their arms positioned overhead if possible. For patients unable to maintain this position, the arms were positioned laterally. First, the CT scan was acquired from head to thigh with a tube current of 80 mA, and a tube voltage of 140 kV with a speed of 0.8 per rotation. CT imaging was performed during normal respiration. Immediately after CT imaging, PET acquisition started during normal respiration. The acquisition time in 2D mode was four minutes per table position and three slices overlaps between table positions; the 3D acquisition time was three minutes per table position and seven slices overlaps between table positions. Between these two acquisition modes, the dimension difference that resulted from the number of overlaps was corrected by subtracting the excessive area at the upper thigh region. CT data was used for attenuation correction. PET raw data were reconstructed for 2D (28 subsets, two iterative steps, 128×128 matrix, post-filter 6 mm full width at half maximum, loop filter 5.47 mm full width at half maximum) ordered-subset expectation maximization (OSEM) and for 3D (28 subsets, two iterative steps, 128×128 matrix, post-filter 6 mm full width at half maximum) fully 3D iterative algorithms.

Analysis was done on a GE Advantage Workstation. Calculation of SUVs was performed with the help of software, and ROIs were automatically drawn in three dimensions using a 42% threshold value.

Subjective image analysis

PET data were evaluated by two blinded readers in a randomized fashion and without knowledge of which mode the acquisition was performed, so they were not aware of the nature of the image reconstruction. Information

regarding diagnosis, stage of the tumor, and prescan applied therapy was given to the readers. However, they were not aware of previous radiological imaging findings in both analyses.

The images obtained in 2D and 3D modes were separately evaluated by both readers. Overall image quality was evaluated using a five-point scale as follows: 5, excellent; 4, good; 3, acceptable; 2, poor; 1, nondiagnostic. For lesion detectability, a three-point scale was used as follows: 3, easy to recognize; 2, moderately recognizable; 1, difficult to recognize. Additional lesion and image artifacts were evaluated depending on presence (1) or absence (0).

Objective image analysis

Lesions recognized by the readers were investigated by measuring SUV_{max} (maximum standard uptake value) and SUV_{lbm} (maximum of the standard uptake value adapted to lean body mass).

Statistical analysis

To compare the SUV measurements, a paired samples t test was used. The one-sample t test was applied to determine whether the absolute differences between the SUVs obtained in 2D and 3D modes were statistically different from zero. To determine the inter-observer variability, a kappa test was used. Scores obtained from each observer were analyzed separately using Mann-Whitney U test. Artifact differences between two acquisition modes were investigated with chi-square test. $P < 0.05$ was considered to indicate a significant difference.

A computer software (Statistical Package for Social Sciences version 9.0, SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis. Measured values were expressed as mean \pm standard deviation.

Results

In our patient population, a total of 455 lesions were detected and SUV measurements were performed for all of them. Of these, 313 lesions were detected in Group 1, and 142 lesions were detected in Group 2.

Quantitative analysis: $\text{SUV}_{\text{max,lbm}}$

There was a statistically significant difference between the SUVs obtained from 2D and 3D modes, independent of the imaging sequence of the modes.

Comparison of SUV_{max} and SUV_{lbm} values and across both patient groups is shown in Table 2.

Absolute differences of SUVs

The mean absolute differences of SUVs for the patient Groups 1 and 2, and total patient population are given in Table 3. These values were also statistically different from zero (one tailed t test, $P < 0.001$). The comparison of SUVs according to body mass index

To assess the effect of body mass index (BMI) on the SUVs obtained from two different imaging modes, the pa-

tients were divided into three groups according to BMI: BMI < 20 kg/m², BMI 20–25 kg/m², and BMI > 25 kg/m².

The comparison of SUV_{max} and SUV_{lbm} values obtained in 2D and 3D modes in patient groups classified according to BMI is given in Table 4. The difference between two different acquisition modes was statistically significant for all three groups.

Subjective analysis

There was no significant diagnostic difference in lesion detectability, total image quality and presence of artifacts between images acquired in 2D and 3D modes ($P > 0.05$). There was also no difference between the observers' evaluation of 2D and 3D images in terms of total image quality, lesion detectability, presence of artifacts, and additional lesions. Regarding total image quality for both 2D and 3D mode images, there was a good agreement between the readers ($\kappa = 0.68$ for 2D, $\kappa = 0.64$ for 3D). In terms of lesion detectability, there was excellent agreement for 2D images ($\kappa = 1$), and good agreement for 3D images ($\kappa = 0.64$).

Regarding the presence of artifacts, there was a good agreement for 2D ($\kappa = 0.73$) and very good agreement for 3D ($\kappa = 0.83$) between the two readers.

Discussion

PET is regularly used as a functional imaging modality, particularly in the field of oncology (3). Most PET studies depend on the visual qualitative interpretation of whole body images after injection of ¹⁸F-FDG. However, the most important advantage of PET over other imaging techniques is that it allows for accurate calculation of in vivo activity distribution. The most popular index used as a quantitative parameter is SUV (4). SUVs are affected from many factors such as imaging mode, patient size, reconstruction parameters and scanner type (5–8).

In our study, SUVs were lower in 3D mode. This result is thought to be related to the shorter imaging time per bed position in 3D mode compared to 2D mode. We used 3 min/bed position for 3D mode and 4 min/bed position for 2D mode; we also used a shorter acquisition time for 3D mode since it is more sensitive than 2D. Our aim was to compare SUV values with standard parameters for 2D and 3D that are routinely used in our clinic. Since septa are removed and the sensitivity of the detector increases in 3D mode, we used a shorter acquisition time for 3D mode. However, there are more random and scatter counts in 3D mode, which may affect total accepted counts. Another reason for the lower SUV values in 3D mode could be the reconstruction technique (we used OSEM, for 2D and fully 3D iterative algorithms for 3D). SUV values may also shift due to differences in reconstruction algorithms (6, 7, 9, 10).

According to our knowledge, there is only one published study in the liter-

Table 1. Characteristics of patients included in the study

	Group 1	Group 2	Total
Patients (n)	52	48	100
Age (years, mean±SD)	52.79±12.72	57.35±15.40	54.98±14.19
Gender (M/F, n)	25/27	30/18	55/45
FBG (mg/dL, mean±SD)	98.83±19.78	103.83±27.40	101.23±23.76
Diabetes mellitus (n)	4	5	9
¹⁸ F-FDG (MBq, mean±SD)	554.35±65.66	524.07±83.06	539.82±75.68
Number of lesions	313	142	455

FBG, fasting blood glucose; ¹⁸F-FDG, fluorine-18 fluorodeoxyglucose; M/F, male/female; SD, standard deviation.

Table 2. Comparison of SUV_{max} and SUV_{lbm} values for the study group

	Group 1 (n=52)			Group 2 (n=48)			Total (n=100)		
	2D	3D	P	2D	3D	P	2D	3D	P
SUV _{max}	10.72±7.42	10.20±7.04	<0.001	9.95±7.90	8.48±6.58	<0.001	10.48±7.57	9.66±6.93	<0.001
SUV _{lbm}	7.16±5.18	6.79±4.88	<0.001	7.81±6.21	6.66±5.18	<0.001	7.36±5.53	6.75±4.97	<0.001

2D, two-dimensional; 3D, three-dimensional; SUV_{max}, maximum standard uptake value; SUV_{lbm}, maximum of the standard uptake value adapted to lean body mass.

Table 3. Mean absolute differences of SUVs for the study groups

	Group 1 (n=52)		Group 2 (n=48)		Total (n=100)	
	2D–3D	P	2D–3D	P	2D–3D	P
SUV _{max}	1.11±1.06	<0.001	1.60±2.01	<0.001	1.27±1.44	<0.001
SUV _{lbm}	0.78±0.80	<0.001	1.15±1.46	<0.001	0.95±1.07	<0.001

2D, two-dimensional; 3D, three-dimensional; SUV_{max}, maximum standard uptake value; SUV_{lbm}, maximum of the standard uptake value adapted to lean body mass.

Table 4. Comparison of SUV_{max} and SUV_{lbm} values obtained in 2D and 3D modes in patient groups classified according to BMI

BMI (kg/m ²)	SUV _{max}			SUV _{lbm}		
	2D	3D	P	2D	3D	P
<20	8.18±5.58	7.48±5.49	<0.05	6.87±4.86	6.28±4.78	<0.05
20–25	9.48±7.28	8.29±5.93	<0.001	7.49±5.97	6.55±4.88	<0.001
>25	11.03±7.75	10.34±7.28	<0.001	7.34±5.40	6.86±5.02	<0.001

2D, two-dimensional; 3D, three-dimensional; BMI, body mass index; SUV_{max}, maximum standard uptake value; SUV_{lbm}, maximum of the standard uptake value adapted to lean body mass.

ature comparing SUVs obtained from PET-CT scanner in 2D and 3D imaging modes (11). Although the number of the patients was limited, they found results similar to ours. As the number of patients in our study is larger, our results may be more substantiated to draw definitive conclusions. Since ^{18}F -FDG accumulation increases as time passes in malignant cells, SUVs also increase in time from beginning of ^{18}F -FDG injection to completion of acquisition. In our study, 2D and 3D imagings were obtained consecutively in the same patient without changing the position of the patient to minimize time difference from injection to acquisition, and in a randomized fashion (half of the patients were imaged first in 2D mode then 3D mode, the other half in 3D followed by 2D). Both SUVs obtained in Group 1 and Group 2 were significantly lower in 3D compared to 2D ($P < 0.001$). Because of this randomization, the difference observed in SUVs was thought not to be related to time from injection of radiopharmaceutical to the beginning of acquisition.

Since there is no gold standard method in measuring SUV values, we evaluated whether absolute differences were different from zero. In our study, we used one tailed t test to understand whether the absolute differences of SUVs obtained from 2D and 3D modes were different from zero. In Groups 1, 2, and in the entire patient group, the absolute differences were significantly different from zero ($P < 0.001$). This was similar to the results in the study by Strobel et al., which was composed of thirty-six patients ($P = 0.002$) (11).

SUV is a numerical parameter, helping visual imaging in diagnosis and monitoring of therapy in many cancer types. We observed that SUVs were lower in 3D mode compared to 2D. This situation may be an issue when the last SUVs need to be compared with early ones.

Another factor affecting SUVs is the body weight and BMI of the patients. In our study, we classified the patients into three groups (BMI < 20 kg/m², BMI = 20–25 kg/m², and BMI > 25 kg/m², respectively). In analyzing these three categorized groups, we found statistically significant differences between SUVs obtained in 2D and 3D modes. This condition supports that the observation that BMI is an important factor affecting SUVs. According to our knowledge, there is no study directly investigating the relation between BMI and SUVs;

however, several studies have investigated the relationship between image quality and body weight (12–15).

In our study, we could not find any difference between 2D and 3D acquisition modes in regards to lesion detectability, overall image quality, and presence of artifacts. However, a clinical study suggested that 3D mode could not offer superior overall image quality compared to 2D mode (12). The findings of Strobel et al. (11) supports our results, though they could not compare the total image quality because of low interobserver agreement, which was due to the difference in experience of the observers in reading PET and PET-CT. In our study, both observers had two years of PET-CT reading experience, and there was a good agreement between them. Another advantage of 3D imaging mode, with shortened scanning time, is the increase of patient comfort, which helps to increase the number of patients imaged per day (16).

In conclusion, oncological PET-CT applications SUV_{max} and SUV_{lbm} values in 3D mode are significantly lower compared to those of 2D. For this reason, when serial scanning is needed to evaluate response to therapy in the same patient, the imaging modality should be taken into account and performed with the same method to avoid misinterpretation. Because of increasing demand of PET scanning, production companies are currently developing scanners only in 3D mode. Therefore, when comparing SUVs obtained from ^{18}F -FDG PET-CT data with those from previous studies and cutoff SUVs, we propose that the mode of acquisition should be considered. Because there is no difference in lesion detectability, overall image quality and artifact presence between 2D and 3D modes, except situations requiring serial imaging and comparison of SUVs, we speculate that these two modes can be used interchangeably. In 3D mode, shorter scanning time compared to 2D will theoretically decrease patient movement and related artifacts, so image fusion will be better, and the patient will be more comfortable. In addition, a short acquisition protocol will provide effective and economical use of PET-CT scanner and ^{18}F -FDG, and increase the number of patients accepted to the nuclear medicine clinics.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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