Texture Feature Comparison Between Step-and-Shoot and Continuous-Bed-Motion ^{18}F-FDG PET

Shozo Yamashita[1], Koichi Okuda[2], Tetsu Nakaichi[1], Haruki Yamamoto[1], and Kunihiko Yokoyama[3]

[1]Division of Radiology, Public Central Hospital of Matto Ishikawa, Ishikawa, Japan; [2]Department of Physics, Kanazawa Medical University, Kahoku, Japan; and [3]PET Imaging Center, Public Central Hospital of Matto Ishikawa, Ishikawa, Japan

Our objective was to investigate the differences in texture features between step-and-shoot (SS) and continuous-bed-motion (CBM) imaging in phantom and clinical studies. **Methods:** A National Electrical Manufacturers Association body phantom was filled with ^{18}F-FDG solution at a sphere-to-background ratio of 4:1. SS and CBM were performed using the same acquisition duration, and the data were reconstructed using 3-dimensional ordered-subset expectation maximization with time-of-flight algorithms. Texture features were extracted using the software LIFEx. A volume of interest was delineated on the 22-, 28-, and 37-mm spheres with a threshold of 42% of the maximum SUV. The voxel intensities were discretized using 2 resampling methods, namely a fixed bin size and a fixed bin number discretization. The discrete resampling values were set to 64 and 128. In total, 31 texture features were calculated with gray-level cooccurrence matrix (GLCM), gray-level run length matrix, neighborhood gray-level different matrix, and gray-level zone length matrix. The texture features of the SS and CBM images were compared for all settings using the paired *t* test and the coefficient of variation. In a clinical study, 27 lesions from 20 patients were examined using the same acquisition and image processing as were used during the phantom study. The percentage difference (%Diff) and correlation between the texture features from SS and CBM images were calculated to evaluate agreement between the 2 scanning techniques. **Results:** In the phantom study, the 11 features exhibited no significant difference between SS and CBM images, and the coefficient of variation was no more than 10%, depending on resampling conditions, whereas entropy and dissimilarity from GLCM fulfilled the criteria for all settings. In the clinical study, the entropy and dissimilarity from GLCM exhibited a low %Diff and excellent correlation in all resampling conditions. The %Diff of entropy was lower than that of dissimilarity. **Conclusion:** Differences between the texture features of SS and CBM images varied depending on the type of feature. Because entropy for GLCM exhibits minimal differences between SS and CBM images irrespective of resampling conditions, entropy may be the optimal feature to reduce the differences between the 2 scanning techniques.

Key Words: step-and-shoot; continuous bed motion; texture feature; resampling; sphere size

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SUV is generally applied for semiquantitative evaluation of PET images in clinical practice. Specifically, SUV_{max} and SUV_{mean} are the most popular features to provide information about the metabolic activity in tumors. Further, metabolic tumor volume and total lesion glycolysis, which is defined as metabolic tumor volume × SUV_{mean}, have been proposed to measure the tumor volume and metabolic activity, respectively (*1*). These parameters, however, cannot measure the intratumoral spatial distribution in tumors, because SUV_{max} is derived from the concentration in a single voxel, and SUV_{mean} is the average value of all voxels within a volume of interest (VOI).

In recent years, texture analysis has been used to evaluate the intratumoral heterogeneity in oncologic PET imaging. Texture analysis can potentially provide beneficial information to predict therapy response and assess prognosis for various tumors (*2–8*). However, texture features are greatly influenced by various technical factors, such as reconstruction settings, acquisition modes (2- and 3-dimensional), segmentation, resampling, and respiratory motion (*9–14*). Although texture features are sensitive to these factors, differences between the texture features of step-and-shoot (SS) and continuous-bed-motion (CBM) images have yet to be investigated. When comparing the image quality of SS and CBM images, we found that on visual analysis, CBM images showed slightly more noise than SS images, and on quantitative SUV analysis, CBM images exhibited slightly less uniformity and higher variability (*15*). Since texture analysis considerably depends on image quality (*10,13*), texture analysis could be sensitive to subtle differences in image quality between the 2 scanning techniques. Therefore, we need to investigate whether the SS and CBM techniques produce comparable results when we perform texture analysis. The objectives of this study, therefore, were to investigate differences between the texture features of SS and CBM images and to find features that reduce differences between the 2 scanning techniques using phantom and clinical studies.

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For correspondence or reprints contact: Shozo Yamashita, Public Central Hospital of Matto Ishikawa, 3-8 Kuramitsu, Hakusan, 924-8588, Japan.
E-mail: y.shozo57@gmail.com
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MATERIALS AND METHODS

This study was conducted using the data of a previous research study (*15*).

Phantom Study

Phantom Preparation. A National Electrical Manufacturers Association International Electrotechnical Commission body phantom (Data Spectrum Corp.) with spheric objects 10, 13, 17, 22, 28, and 37 mm in diameter was used. The phantom was filled with an ^{18}F-FDG solution at a sphere-to-background radioactivity ratio of 4:1. The hot spheres and background radioactivity were set to 13.2 and 3.3 kBq/mL, respectively. The background radioactivity simulated normal soft-tissue uptake, especially in the mediastinum or abdomen of patients who received the injected dose at our institution.

Data Acquisition and Image Reconstruction

All PET/CT data were acquired using a Biograph mCT Flow 20-4R (Siemens Medical Solutions USA, Inc.). The scanner comprises 4 detector rings 842 mm in diameter with 48 detector blocks in each ring, covering an axial field of view (FOV) of 216 mm and a transaxial FOV of 700 mm. The detector comprises an array of 32,448 lutetium oxyorthosilicate crystals with dimension of $4 \times 4 \times 20$ mm. The coincidence timing window and the time-of-flight time resolution were 4.1 ns and 540 ps, respectively.

The phantom was scanned using the SS and CBM techniques, with a different phantom for each experiment. Images acquired using the SS technique were obtained over the 8 bed positions that are typical during clinical imaging. Hot spheres were placed at the center of the axial FOV, which corresponds to the center of the overlap between bed positions 4 and 5. The acquisition time was 1.5 min/bed position. The CBM protocol matched the axial FOV of the SS technique. The table speed was set at 1.5 mm/s to be consistent with the total scan time of the SS technique; the CBM acquisition time was 12 min 13 s. Considering the statistical variability of PET images, each image acquisition was performed 5 times.

The PET data were reconstructed using 3-dimensional ordered-subset expectation maximization and time-of-flight algorithms with iteration–subset combinations of 3–21. In addition, a gaussian filter of 5 mm in full width at half maximum was used. The reconstructed voxel size was $4.0 \times 4.0 \times 3.0$ mm, and the matrix size was 200×200. All PET images were converted into SUV units normalized by the patient body weight using the following formula: tissue radioactivity (Bq/mL)/[injected radioactivity (Bq)/body weight (g)]. Further, attenuation correction using the CT data was performed with the following scanning parameters: tube voltage, 120 kV; quality reference, 40 mAs; rotation time, 0.5 s; pitch, 1.0; slice thickness, 3.0 mm; transaxial FOV, 780 mm; and matrix size, 512×512. The CT images were reconstructed using the sinogram-affirmed iterative reconstruction algorithm.

Texture Analysis

The texture features were extracted using LIFEx software, version 4.00 (*16*). The VOI was delineated on the 3 largest spheres (22–37 mm) with a threshold of 42% of SUV_{max}, which was selected on the basis of previous work (*17*). Analysis of spheres 17 mm or smaller was not possible because of an insufficient number of voxels, as LIFEx calculates the features only for VOIs of at least 64 voxels. Moreover, delineations were performed by 2 observers to examine interobserver differences. The original voxel intensities were discretized using 2 resampling methods, namely a fixed-bin-size (FBS) discretization with scale bounds between 0 and 20 SUV and a fixed-bin-number (FBN) discretization with scale bounds between minimum and SUV_{max}. The discrete values were set at 64 and 128 for these methods, and the bin widths of the FBS discretization were 0.31 and 0.16 SUV, respectively. In total, 31 texture features were calculated, including parameters from gray-level cooccurrence matrix (GLCM), gray-level run length matrix (GLRLM), neighborhood gray-level different matrix, and gray-level zone length matrix (GLZLM). All features are presented in Table 1. The GLCM was calculated using a distance of 1. Detailed descriptions of texture calculations can be found at http://www.lifexsoft.org.

The coefficient of variation (CV) was calculated for each sphere size. The CV was calculated using the ratio of SD to the average values, applying 10 datasets (5 datasets per observer).

To search the texture features for a reduction in differences between SS and CBM images in the uniform phantom, we defined criterion A as follows: first, confirmation that there were no significant differences in texture features between SS and CBM images in any sphere size, and second, confirmation that SS and CBM images had a CV of no more than 10% for all sphere sizes.

Clinical Study

Whole-body ^{18}F-FDG PET/CT images acquired by SS and CBM were obtained in a clinical setting. In total, 27 lesions from 20 patients (male, 10; female, 10; average age, 69.1 ± 11.9 y, average body mass index, 23.4 ± 3.7 kg/m^2) were retrospectively examined; these lesions included 1 in the salivary glands, 4 in the thyroid, 6 in the lung, 1 in the breast tissue, 2 in the esophagus, 1 in the liver, 2 in the pancreas, 1 in the adrenal, 1 in the lumbar spine, 5 in the lymph nodes, and 3 in the lower abdomen. All subjects were asked to fast for at least 5 h before undergoing imaging. ^{18}F-FDG was intravenously injected with radioactivity of 4.4 MBq/kg (maximum dose, 330 MBq), and PET images were acquired 60 min after tracer injection. Both PET and CT images were acquired during free breathing. A subset of 6 patients with 8 lesions was imaged using the SS technique, followed immediately by the CBM technique (SS→CBM). The remaining 14 patients with 19 lesions were scanned in the reverse order (CBM→SS). The image acquisition and reconstruction protocols were the same as those described for the phantom study. This study was approved by the ethics committee of our institution. Written informed consent was obtained from all patients.

Data Analysis

The process of texture analyses for the clinical study was identical to that described for the phantom study. To evaluate differences between the texture features of SS and CBM images, percentage difference (%Diff) was calculated as follows;

$$\%\text{Diff} = \left| \frac{TF\_SS - TF\_CBM}{(TF\_SS + TF\_CBM)/2} \times 100 \right| (\%),$$

where *TF_SS* is the texture feature from an SS image and *TF_CBM* is the texture feature from a CBM image. In addition, Pearson correlation coefficients (r) were calculated to evaluate agreement between the 2 scanning techniques. Moreover, for each observer, the %Diff and r values were calculated.

To confirm whether the differences between SS and CBM images were reduced in the clinical setting, we defined criterion B as follows: a %Diff of no more than 10% and an r value of at least 0.80.

TABLE 1
Texture Features

Matrix	Feature
GLCM	Homogeneity
	Energy
	Contrast
	Correlation
	Entropy, log10
	Dissimilarity
GLRLM	Short-run emphasis (SRE)
	Long-run emphasis (LRE)
	Low gray-level run emphasis (LGRE)
	High gray-level run emphasis (HGRE)
	Short-run low gray-level emphasis (SRLGE)
	Short-run high gray-level emphasis (SRHGE)
	Long-run low gray-level emphasis (LRLGE)
	Long-run high gray-level emphasis (LRHGE)
	GLNU
	Run length nonuniformity (RLNU)
	Run percentage (RP)
Neighborhood gray-level different matrix	Coarseness
	Contrast
	Busyness
GLZLM	SZE
	Long-zone emphasis (LZE)
	Low gray-level zone emphasis (LGZE)
	High gray-level zone emphasis (HGZE)
	Short-zone low gray-level emphasis (SZLGE)
	Short-zone high gray-level emphasis (SZHGE)
	Long-zone low gray-level emphasis (LZLGE)
	Long-zone high gray-level emphasis (LZHGE)
	GLNU
	Zone length nonuniformity (ZLNU)
	ZP

TABLE 2
Significant Differences Between Texture Features of SS and CBM Images

Resampling method	Discrete value	Sphere size (mm)	GLCM						GLRLM							NGLDM		GLZLM								
			Homogeneity	Energy	Contrast	Correlation	Entropy_log10	Dissimilarity	SRE	LRE	LGRE	HGRE	SRLGE	SRHGE	LRLGE	LRHGE	GLNU	RLNU	RP	Coarseness	Contrast	Busyness	SZE	LZE	LGZE	HGZE	SZLGE	SZHGE	LZLGE	LZHGE	GLNU	ZLNU	ZP
FBS	64	22	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		28	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		37	+	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	–	–
	128	22	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		28	–	–	–	–	–	–	+	+	–	–	–	–	–	+	–	–	+	–	–	–	–	+	–	–	+	–	–	–	–	–	–
		37	+	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–
FBN	64	22	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		28	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		37	+	–	–	+	–	–	+	+	–	–	–	–	–	+	–	–	+	–	–	–	–	+	–	–	–	+	–	–	–	–	–
	128	22	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		28	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–
		37	–	–	–	–	–	–	–	–	–	+	–	+	–	+	–	–	+	–	–	–	–	+	–	–	+	–	–	+	–	+*	–

*Confirmed interobserver difference.
+ = significant difference; – = nonsignificant difference. Other abbreviations are listed in Table 1 or defined in the article.

Statistical Analysis

Data are expressed as mean ± SD. In the phantom study, the texture features of the SS and CBM images were compared by a 2-tailed paired *t* test. An interobserver difference exists for a feature if a significant difference is found for at least 1 observer. In the clinical study, a 2-tailed unpaired *t* test was used to compare the uptake times between the SS and CBM, and a 2-tailed paired *t* test was used to compare SUVs and VOIs between the 2 scan techniques. The strength of association was assessed by the Pearson correlation coefficient. An interobserver difference existed if a texture feature did not fulfill criterion B for at least 1 observer. *P* values of less than 0.05 were considered statistically significant. All analyses were performed using JMP software, version 11.2.1.

RESULT

Phantom Study

The significant differences between the texture features of SS and CBM images are shown in Table 2. The detailed values of texture features are provided in Supplemental Tables 1–8 (supplemental materials are available at http://jnmt.snmjournals.org). Irrespective of resampling method, discrete value, and sphere size, the following 16 features indicated no significant difference between SS and CBM images: energy, contrast, entropy, and dissimilarity for GLCM; low gray-level run emphasis, short-run low gray-level emphasis, long-run low gray-level emphasis, gray-level nonuniformity (GLNU), and run length nonuniformity for GLRLM; coarseness, contrast, and busyness for neighborhood gray-level different matrix; and short-zone emphasis (SZE), low gray-level zone emphasis, GLNU, and zone percentage (ZP) for GLZLM. Using the FBS discretization, the following 4 features indicated no significant difference between SS and CBM images irrespective of the discrete value and sphere size: high gray-level run emphasis, short-run high gray-level emphasis, and long-run high gray-level emphasis for GLRLM and zone length nonuniformity for GLZLM. Using the FBN discretization, the following 8 features indicated no significant difference between SS and CBM images irrespective of the discrete value and sphere size: homogeneity for GLCM; short-run emphasis, long-run emphasis, and run percentage for GLRLM; and high gray-level zone emphasis, short-zone low gray-level emphasis, short-zone high gray-level emphasis, and long-zone low gray-level emphasis for GLZLM. An interobserver bias was found between SS and CBM images in zone length nonuniformity for GLZLM. The *P* values of the 2 observers were 0.034 and 0.064, respectively.

Regarding sphere sizes, the numbers of features with significant differences for the 22-, 28-, and 37-mm spheres were in the ranges of 1–2, 0–2, and 4–9, respectively, depending on resampling conditions (i.e., method and discrete value). When the sphere size was 37 mm, the number of features with significant differences increased irrespective of the resampling condition.

Regarding resampling conditions, using the FBS discretization, the number of features with significant differences increased with the increase in discrete values. When the discrete values were 64 and 128, the numbers were 5 and 13, respectively. In contrast, using the FBN discretization, the number was 8 irrespective of the discrete value.

The CV for different settings is shown in Supplemental Figure 1. First, the CV was calculated individually for each observer. Since the CVs between the 2 observers were very similar and had almost no differences (Supplemental Fig. 2), they were therefore merged. Independent of the scan type, resampling condition, and sphere size, the following 6 features had a CV of no more than 10%: homogeneity, entropy, and dissimilarity for GLCM and short-run emphasis, long-run emphasis, and run percentage for GLRLM. Using the FBS discretization, the 4 features with a CV of no more than 10% irrespective of the scan type and sphere size were energy and contrast for GLCM and high gray-level run emphasis and long-run high gray-level emphasis for GLRLM, although the contrast and long-run high gray-level emphasis were limited in the discrete value of 64. Using the FBN discretization, the 3 features with a CV of no more than 10% irrespective of the scan type, discrete value, and sphere size were GLNU for GLRLM and SZE and ZP for GLZLM.

On the basis of these results, the texture features fulfilling criterion A are listed in Table 3. Among these 13 features, only 2—entropy and dissimilarity from GLCM—fulfilled the criterion A overall resampling conditions. The remaining 11 features depended on the resampling conditions.

Clinical Study

The parameters of the 2 scanning techniques are shown in Table 4. Although there was a significant difference in uptake times between SS and CBM imaging ($P = 0.018$), the SUVs and VOIs did not exhibit significant differences between the 2 scanning techniques.

In view of the results of the phantom study, the texture features meeting criterion A were examined in the clinical study. Table 5 shows mean %Diff between the texture features of SS and CBM images for both observers. The following 8 features had a %Diff of no more than 10%: homogeneity, entropy, and dissimilarity for GLCM; short-run emphasis, long-run emphasis, and run percentage for GLRLM; and SZE and ZP for GLZLM. An interobserver

TABLE 3
Texture Features Fulfilling Criterion A for Both Observers

Resampling method	Discrete value	GLCM					GLRLM						GLZLM	
		Homogeneity	Energy	Contrast	Entropy	Dissimilarity	SRE	LRE	HGRE	LRHGE	GLNU	RP	SZE	ZP
FBS	64	—	○	○	○	○	—	—	○	○	—	—	—	—
	128	—	○	—	○	○	—	—	○	—	—	—	—	—
FBN	64	○	—	—	○	○	○	○	—	—	○	○	○	○
	128	○	—	—	○	○	○	○	—	—	○	○	○	○

Abbreviations are listed in Table 1 or defined in the article. ○ = fulfilling the criterion; — = not fulfilling the criterion.

TABLE 4
Parameters of SS and CBM Techniques

Parameter	SS	CBM	*P*
Uptake time (min)	68.7 ± 6.5	63.1 ± 7.8	0.018
SUV_{mean}	5.4 ± 3.8	5.4 ± 3.8	0.933
SUV_{max}	8.5 ± 5.6	8.6 ± 5.7	0.628
VOI (mL)	16.0 ± 22.8	15.9 ± 22.7	0.915

difference was observed for GLNU from GLRLM because the mean %Diff from observer 2 was over 10%, although no significant differences for discrete values of 64 ($P = 0.15$) and 128 ($P = 0.10$) were found using a 2-tailed paired *t* test. Table 6 shows correlation coefficients between the texture features of the 2 scanning techniques for both observers. The following 8 features showed *r* values of at least 0.80: homogeneity, energy, contrast, entropy, and dissimilarity from GLCM and high gray-level run emphasis, long-run high gray-level emphasis, and GLNU from GLRLM.

On the basis of these results, the texture features fulfilling criterion B are listed in Table 7. Both entropy and dissimilarity met the criterion B overall resampling conditions. Homogeneity met the criterion, although the resampling conditions were limited to the FBN discretization.

DISCUSSION

In the phantom study, differences between the texture features of SS and CBM images depended on sphere sizes and resampling conditions. Regarding sphere sizes, the 22- and 28-mm spheres had between 0 and 2 features with significant differences. In analyzing the 37-mm sphere, we observed a drastic increase in the number of features with significant differences. This observation might be because of the image noise for each sphere. In our previous study, variability in SUV increased as sphere diameter decreased, indicating that small spheres possess higher noise than large ones (*15*). Pfaehler et al. reported that a larger number of features are sensitive to image noise (*13*). For the 22- and 28-mm spheres, it might be difficult to achieve statistical significance since fluctuations in feature values were largely due to higher image noise. For the 37-mm sphere, on the other hand, the increase in the number of features with significant differences may have occurred because they were small, which was due to the lower image noise. Moreover, the CV of the 37-mm sphere tended to be smaller than the CVs of the other spheres in this phantom study. Therefore, it can be inferred that the subtle differences found between the 2 techniques were indicated accurately in the 37-mm sphere.

Because the resampling conditions have a crucial impact on texture features (*12*), the 2 resampling methods and the discrete values were analyzed. For FBS discretization, the number of features with significant differences increased when the discrete values increased. Contrarily, FBN discretization was not influenced by the discrete values, possibly because of the magnitude of the change in bin width. Thus, the change in bin width for FBN discretization was much smaller than that for FBS discretization.

A simple uniform phantom was used in this study to investigate differences in texture features between the SS and CBM techniques. Considering the differences observed in the simple phantom, the clinical study aimed to investigate the differences in more detail. We defined criterion A to find the texture features that reduce differences between the SS and CBM images. Thirteen features met the criterion; however, the phantom study was limited by the use of uniform objects, a sphere-to-background ratio and radioactivity concentration, and large sphere sizes of 22–37 mm. Therefore, these features were further examined in the clinical setting. In the results, entropy, dissimilarity and homogeneity met criterion B, indicating high agreement between the 2 scanning techniques. Among them, both entropy and dissimilarity met the criteria for overall resampling conditions. Especially, entropy was high because its %Diff was lower than that of dissimilarity. Entropy from GLCM has the potential to provide valuable clinical information such as differentiation of malignant from benign bone and soft-tissue lesions, prediction of TN staging, and therapy response in esophageal carcinoma (*6,8,18*). Furthermore, regarding technical aspects, it is independent of reconstruction setting, acquisition mode, and delineation technique (*8–11*). In addition, it is highly repeatable and reproducible (*19,20*). This study has successfully demonstrated that entropy from GLCM is robust between SS and CBM techniques. Although this robust feature is dependent on grid size and volume, it can still be effectively applied for routine clinical use and in multicenter clinical trials.

Although the %Diff of dissimilarity was slightly worse than that of entropy, agreement between the 2 scanning techniques was high irrespective of resampling conditions. Dissimilarity could become the suboptimal feature to reduce differences between the 2 scanning techniques. In addition, homogeneity from GLCM might be a suitable feature for reducing differences, although the resampling conditions were limited. All 3 features were derived from GLCM. The features from GLCM might be insensitive to subtle differences between SS and CBM images because GLCM, being calculated on a small scale of a few voxels, quantifies relationships between neighboring voxels. In contrast, the other matrices, such as GLRLM and GLZLM, are calculated on a large scale of relatively many voxels.

In the phantom study, the hot spheres were placed such that they had overlapping regions. The phantom position could influence the results because the sensitivity of SS technique varies depending on the scanning position (*21*); however, the clinical findings indicate that the impact is small, as clinical data were obtained from the various positions.

To study interobserver differences, texture analyses were performed by 2 observers. The minor interobserver differences were due to slight differences in volume for normal

TABLE 5
%Diff Between Texture Features of SS and CBM images Derived From 2 Observers

Observer	Resampling method	Discrete value	GLCM					GLRLM						GLZLM	
			Homogeneity	Energy	Contrast	Entropy	Dissimilarity	SRE	LRE	HGRE	LRHGE	GLNU	RP	SZE	ZP
1	FBS	64	—	17.36 ± 27.71	16.40 ± 14.37	3.18 ± 3.18	8.78 ± 7.32	—	—	12.84 ± 8.19	12.31 ± 9.66	—	—	—	—
		128	—	15.56 ± 29.52	—	2.49 ± 2.69	8.97 ± 7.33	—	—	12.99 ± 8.06	—	—	—	—	—
	FBN	64	7.10 ± 4.78	—	—	2.51 ± 2.03	7.08 ± 5.02	0.28 ± 0.18	1.07 ± 0.75	—	—	8.55 ± 7.52*	0.36 ± 0.24	3.29 ± 1.98	4.61 ± 2.88
		128	8.92 ± 6.17	—	—	2.52 ± 2.03	7.01 ± 5.02	0.22 ± 0.15	0.89 ± 0.61	—	—	8.53 ± 6.74*	0.30 ± 0.20	2.77 ± 1.88	3.85 ± 2.62
2	FBS	64	—	17.73 ± 27.70	16.80 ± 13.63	3.16 ± 3.21	8.80 ± 7.21	—	—	12.74 ± 8.91	12.47 ± 9.89	—	—	—	—
		128	—	16.11 ± 29.58	—	2.54 ± 2.73	8.85 ± 7.32	—	—	12.87 ± 8.81	—	—	—	—	—
	FBN	64	7.51 ± 5.72	—	—	2.88 ± 2.50	7.44 ± 5.19	0.27 ± 0.21	1.11 ± 0.80	—	—	11.41 ± 10.76*	0.37 ± 0.27	3.30 ± 2.63	4.65 ± 3.46
		128	9.44 ± 6.81	—	—	2.89 ± 2.58	7.37 ± 5.20	0.22 ± 0.16	0.89 ± 0.63	—	—	11.02 ± 8.83*	0.30 ± 0.21	2.82 ± 2.05	3.82 ± 2.62

*Confirmed interobserver difference
Abbreviations are listed in Table 1 or defined in the article.

TABLE 6
Correlation Between Texture Features of SS and CBM Images Derived from 2 Observers

Observer	Resampling method	Discrete value	GLZLM												
			Homogeneity	Energy	Contrast	Entropy	Dissimilarity	SRE	LRE	HGRE	LRHGE	GLNU	RP	SZE	ZP
1	FBS	64	—	0.96 (<0.001)	0.99 (<0.001)	0.97 (<0.001)	0.99 (<0.001)	—	—	0.99 (<0.001)	0.95 (<0.001)	—	—	—	—
		128	—	0.87 (<0.001)	—	0.96 (<0.001)	0.99 (<0.001)	—	—	0.99 (<0.001)	—	—	—	—	—
	FBN	64	0.88 (<0.001)	—	—	0.98 (<0.001)	0.90 (<0.001)	0.66 (<0.001)	0.63 (<0.001)	—	—	1.00 (<0.001)	0.66 (<0.001)	0.61 (<0.001)	0.70 (<0.001)
		128	0.83 (<0.001)	—	—	0.98 (<0.001)	0.90 (<0.001)	0.27 (0.170)	0.17 (0.391)	—	—	1.00 (<0.001)	0.31 (0.115)	0.23 (0.258)	0.29 (0.141)
2	FBS	64	—	0.96 (<0.001)	0.99 (<0.001)	0.97 (<0.001)	0.99 (<0.001)	—	—	0.99 (<0.001)	0.95 (<0.001)	—	—	—	—
		128	—	0.87 (<0.001)	—	0.96 (<0.001)	0.99 (<0.001)	—	—	0.99 (<0.001)	—	—	—	—	—
	FBN	64	0.84 (<0.001)	—	—	0.97 (<0.001)	0.88 (<0.001)	0.62 (<0.001)	0.62 (<0.001)	—	—	1.00 (<0.001)	0.64 (<0.001)	0.53 (0.005)	0.65 (<0.001)
		128	0.80 (<0.001)	—	—	0.97 (<0.001)	0.88 (<0.001)	0.23 (0.244)	0.08 (0.696)	—	—	1.00 (<0.001)	0.25 (0.200)	0.19 (0.340)	0.28 (0.161)

Abbreviations are listed in Table 1 or defined in the article. Data are expressed as *r* value followed by *P* value in parentheses.

TABLE 7
Texture Features Fulfilling Criterion B for Both Observers

Resampling method	Discrete value	GLCM		
		Homogeneity	Entropy	Dissimilarity
FBS	64	—	○	○
	128	—	○	○
FBN	64	○	○	○
	128	○	○	○

○ = fulfilling the criterion; — = not fulfilling the criterion.

tissues close to the tumor. However, agreement correlated strongly, as corresponds to the findings of a similar study (*22*). Therefore, the LIFEx software can provide textural information without interobserver bias.

There are limitations to this study. A fixed thresholding method was used. This simple method may lead to inaccurate tumor delineation because it can underestimate the true tumor volume (*22*). Additional studies using other delineation tools such as adaptive thresholding or a gradient-based method should be investigated (*23*), although we suppose that the relative differences between scanning techniques did not change. In the clinical study, we did not use respiratory gating even though some lesions were in the lung and upper abdomen—areas that can be affected by respiratory motion. Additionally, although small volumes may not be suitable for texture analysis because of the limited spatial resolution of PET imaging (*24*), they were still included in the clinical study. Future studies should include only larger lesions.

CONCLUSION

This study demonstrated that texture analysis is sensitive to scanning technique. However, the magnitude of differences between the texture features of SS and CBM images differed with the type of feature. Because entropy for GLCM exhibited minimal differences between SS and CBM images irrespective of resampling conditions, entropy may be a useful feature to applied for routine clinical use and in multicenter clinical trials.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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