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Original Article / *Özgün Makale*

Quantitative volumetric metabolic measurement of solitary pulmonary nodules by F-18 fluorodeoxyglucose positron emission tomography-computed tomography

Soliter pulmoner nodüllerin F-18 florodeoksiglikoz pozitron emisyon tomografisi-bilgisayarlı tomografi ile kantitatif volümetrik metabolik ölçümü

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ABSTRACT

Background: This study aims to evaluate the effect of quantitative volumetric metabolic measurements in F-18 fluorodeoxyglucose positron emission tomography-computed tomography to distinguish benign and malignant solitary pulmonary nodules.

Methods: We retrospectively reviewed 78 patients (56 males; 22 females; mean age 61±11.9 years; range, 32 to 82 years) with solitary pulmonary nodules who underwent F-18 fluorodeoxyglucose positron emission tomography-computed tomography. Patients were classified as benign, malignant and metastatic lesions according to pathology results. Metabolic volume, maximum standardized uptake value, mean standardized uptake value, maximum metabolic index and mean metabolic index were measured. Mean, median and standard error values were calculated for each group. Nonparametric tests were used for the comparison of each group. Partial correlation analysis was used for the relationship between parameters. For all parameters, cut-off values were obtained with receiver operating characteristic analysis.

Results: Of 78 lesions, 10 were benign (12.8%), 38 were primary lung carcinoma (48.7%) and 30 were metastatic lung nodules (38.5%). There was a significant difference between benign lesions and primary lung cancer and between primary lung cancer and metastatic groups in all parameters ($p<0.05$). We determined highly significant positive correlation between maximum standardized uptake value and maximum metabolic index ($r=0.73$; $p<0.05$), and moderate positive correlation between mean standardized uptake value and mean metabolic index ($r=0.56$; $p<0.05$). In receiver operating characteristic analysis, maximum standardized uptake value and mean standardized uptake value were found to be the most sensitive and specific methods for benign/malignant discrimination. In the cut-off value=2.59, the sensitivity and specificity for maximum standardized uptake value were 98.0% and 91.7%, respectively. In the cut-off value=1.65, the sensitivity and specificity for mean standardized uptake value were 94.0% and 91.7%, respectively.

Conclusion: Maximum metabolic index value is highly correlated with maximum standardized uptake value in benign/malignant solitary pulmonary nodules discrimination by F-18 fluorodeoxyglucose positron emission tomography-computed tomography. Maximum metabolic index can also be used for discrimination of primary/metastatic malignant lesions.

Keywords: F-18 fluorodeoxyglucose positron emission tomography-computed tomography, metabolic index, solitary pulmonary nodule, standardized uptake value.

ÖZ

Amaç: Bu çalışmada benign ve malign soliter pulmoner nodülleri ayırmak için F-18 florodeoksiglikoz pozitron emisyon tomografisi-bilgisayarlı tomografide kantitatif volümetrik metabolik ölçümlerin etkisi değerlendirildi.

Çalışma planı: F-18 florodeoksiglikoz pozitron emisyon tomografisi-bilgisayarlı tomografi uygulanan, soliter pulmoner nodülleri olan 78 hasta (56 erkek; 22 kadın; ort. yaş 61±11.9 yıl; dağılım, 32-82 yıl) retrospektif olarak değerlendirildi. Hastalar patoloji sonuçlarına göre benign, malign ve metastatik lezyonlar olarak sınıflandırıldı. Metabolik volüm, maksimum standardize tutulum değeri, ortalama standardize tutulum değeri, maksimum metabolik indeks ve ortalama metabolik indeks ölçüldü. Her grup için ortalama, ortanca ve standart hata değerleri hesaplandı. Her grubun karşılaştırılması için nonparametrik testler kullanıldı. Parametrelerin arasındaki ilişki için parsiyel korelasyon analizi kullanıldı. Tüm parametreler için sınır değerler alıcı işletim karakteristik analizi ile elde edildi.

Bulgular: Yetmiş sekiz lezyonun 10'u benign (%12.8), 38'i primer akciğer karsinomu (%48.7) ve 30'u metastatik akciğer nodülü (%38.5) idi. Tüm parametrelerde benign lezyonlar ile primer akciğer kanseri arasında ve primer akciğer kanseri ve metastatik gruplar arasında anlamlı farklılık vardı ($p<0.05$). Maksimum standardize tutulum değeri ve maksimum metabolik indeks arasında anlamlı pozitif ilişki ($r=0.73$; $p<0.05$), ortalama standardize tutulum değeri ve ortalama metabolik indeks arasında orta pozitif ilişki ($r=0.56$; $p<0.05$) saptandı. Alıcı işletim karakteristik analizinde, maksimum standardize tutulum değeri ve ortalama standardize tutulum değerinin benign/malign ayrımında en hassas ve özgül yöntemler olduğu bulundu. Sınır değer=2.59 iken maksimum standardize tutulum değeri için duyarlılık ve özgüllük sırasıyla %98.0 ve %91.7 idi. Sınır değer=1.65 iken ortalama standardize tutulum değeri için duyarlılık ve özgüllük sırasıyla %94.0 ve %91.7 idi.

Sonuç: Maksimum metabolik indeks değeri F-18 florodeoksiglikoz pozitron emisyon tomografisi-bilgisayarlı tomografi ile benign/malign soliter pulmoner nodüllerin ayrımında maksimum standardize tutulum değeri ile yüksek derecede ilişkilidir. Maksimum metabolik indeks primer/metastatik malign lezyonların ayrımında da kullanılabilir.

Anahtar sözcükler: F-18 florodeoksiglikoz pozitron emisyon tomografisi-bilgisayarlı tomografi, metabolik indeks, soliter pulmoner nodül, standardize tutulum değeri.

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Circular pulmonary nodules smaller than 3 cm, surrounded by normal lung tissue and not accompanied by lymph nodes, atelectasis, or pneumonia, are defined as solitary pulmonary nodules (SPNs).[1] Although most SPNs are benign, around 30-40% are malignant.[2] Early diagnosis and exclusion of malignancy are important for successful treatment of SPNs. Correct diagnosis of malignant nodules is essential for preventing false diagnosis of lung cancer and unnecessary, costly and invasive diagnostic procedures. Solitary pulmonary nodule can be diagnosed noninvasively by computed tomography (CT), magnetic resonance imaging (MRI) and F-18 fluorodeoxyglucose (FDG) positron emission tomography (PET)-CT. Fluorodeoxyglucose PET-CT can distinguish benign from malignant nodules.[3] Fluorodeoxyglucose is a glucose analog used in PET-CT. Fluorodeoxyglucose is taken up at a high rate by malignant cells because of their increased glucose metabolism.[4] In a retrospective study, the sensitivity and specificity of F-18 FDG PET-CT were 97% and 85%, respectively, in patients with SPN with FDG uptake.[5] In contrast, the probability of malignancy in nodules without FDG involvement is very low.[6,7] However, FDG uptake by activated macrophages in the presence of infection and/or inflammation can lead to false-positive results. In addition, false negativity may be seen in some types of tumor; e.g., carcinoid, bronchoalveolar, and mucinous cancers.[8,9]

The commonly used standardized uptake value (SUV) is a semi-quantitative analysis parameter for PET images.[8] The maximum SUV (SUV_{max}) is obtained for a one-pixel region of interest corresponding to the maximum pixel value in the tumor. However, SUV_{max} does not reflect the total tumor glycolytic activity for the whole tumor mass in FDG PET. Although SUV_{mean} may be more suitable than SUV_{max} for describing total tumor glycolytic activity, the heterogeneous tumor uptake may reduce SUV_{mean} excessively.[10] Another way of evaluation of total tumor glycolytic activity is to use volumetric PET parameters such as metabolic tumor volume (MTV) and total lesion glycolysis. Metabolic tumor volume is a volumetric measurement of tumor cells with high glycolytic activity. Volumetric parameters are usually researched for prognostic purposes or the prediction of therapeutic response.[10] However, there is limited study about the diagnostic usage of volumetric PET parameters for discrimination of malign lesions from benign lesions. As a volumetric PET parameter, the metabolic index (MI) is calculated by multiplying the MTV by the SUV (maximum or mean) and is used to evaluate the prognosis of some types of tumor.[11] In this study, we aimed to evaluate the effect of quantitative volumetric metabolic measurements in F-18 FDG PET-CT to distinguish benign and malignant SPNs.

PATIENTS AND METHODS

This study was conducted at Pamukkale University Medical Faculty. In total, 111 patients with SPN who applied between November 2015 and December 2017 and underwent F-18 FDG PET-CT imaging were evaluated retrospectively. All patients were sent from the department of chest diseases. The diagnosis and follow-up parameters of patients with SPN were performed in accordance with the European Society of Radiology and the European Respiratory Society guideline (Eur Respir J 2015; 46: 61-79). Thirty-three patients were excluded from the study; 16 were not pathologically evaluated and 17 did not match a diagnosis of SPN; therefore, a total of 78 patients (56 males; 22 females; mean age 61±11.9 years; range, 32 to 82 years) were evaluated. All patients underwent a preoperative bronchoscopic procedure. All lesions were verified histopathologically. The following procedures were used for histopathological diagnosis: 36 (46.2%) transthoracic needle biopsies, 35 (44.8%) wedge resections, two (2.6%) lobectomies, two (2.6%) pneumonectomies, three (3.8%) thoracenteses. Patients who underwent surgical procedure underwent the following methods: 20 thoracotomies and 15 video-assisted thoracic surgeries. The study protocol was approved by the Pamukkale University Medical Faculty Ethics Committee. A written informed consent was obtained from each patient. The study was conducted in accordance with the principles of the Declaration of Helsinki.

The patients were divided into benign and malignant groups based on the pathology results. Patients in the malignant group were classified into primary lung cancer and metastatic nodule subgroups. Immunohistochemical analysis was performed to all patients in the malignant and metastatic groups during pathological evaluation.

After fasting and resting for six h, the patients received 259-407 MBq (7-11 mCi) of F-18 FDG intravenously when their fasting blood glucose level was <200 mg/dL. All patients were screened 60 min after injection. Pre-injection activity and post-injection injector activity were counted in PET-CT. The actual dose of radioactivity given to the patient was thus calculated. The patients were examined using a dedicated PET/CT scanner (Gemini TF TOF PET-CT; Philips Healthcare, Cleveland, OH, USA; 3D mode, slice thickness of 5 mm, 4×4×22 mm LYSO

crystal, number of crystals 28.336, 256×256 matrix (voxel size 2.6×2.6×2.4 mm^3), transverse field of view (FOV) 576 mm and axial FOV 180 mm). Emission scans were acquired from the calvaria base to the middle of the thigh for 1.5 min per position without intravenous contrast medium injection. Transmission images were obtained by low-dose CT (50-120 mAs, 90-140 kVp, 16 number of CT detectors, slice thickness of 5 mm). Attenuation correction was performed for PET images using CT findings and the ordered subsets-expectation maximization algorithm (33 subsets, three iterations). Positron emission tomography images were reconstructed by the iterative method. Transverse, sagittal, and coronal sections (5 mm thickness) were created from PET-CT fusion images and evaluated using Philips Fusion Viewer software (version 2.1; Philips Healthcare, Best, The Netherlands).

The images were transferred to Tumor Tracking EBW NM 2.0 (Philips Healthcare, Cleveland, OH, USA) to calculate metabolic parameters. This software has three methods for calculating metabolic parameters: the bounded (limited), threshold, and interactive methods. Using the bounded method, volumetric areas of interest (VOIs) were automatically drawn around all lung nodules in PET/CT fusion axial images using a VOI limit of 42.5% (40-60%) without considering background activity (mediastinal blood pool, liver, contralateral lung, etc.). And then, the isocontours were manually adjusted so that the lesion border on PET and CT overlapped. Sagittal and coronal PET-CT fusion sections were reviewed to confirm that the lesion was included in the VOI in all three sections. Lesion size and volume were measured in millimeters and milliliters. The metabolic volume, SUV_{max}, and SUV_{mean} of VOIs were automatically calculated and the maximum metabolic index (MI_{max}; SUV_{max} × metabolic volume) and mean metabolic index (MI_{mean}; SUV_{mean} × metabolic volume) values were determined.

Statistical analysis

The PASW for Windows version 17.0 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Mean and median values were calculated. Nonparametric tests were used to compare mean values. The correlations of measurement methods were assessed by partial correlation analysis. Receiver operating characteristic (ROC) analysis was performed to assess the ability of the parameters to differentiate benign from malignant lesions and threshold values were calculated. P values <0.05 were deemed to indicate statistical significance.

RESULTS

The histopathological diagnosis was benign in 10 (12.8%) and malignant in 38 (48.7%) lesions; 30 (38.5%) of the 78 lesions were metastatic lung nodules. Nodule sizes in benign, primary lung cancer and metastatic groups were 15.9±5.4; 26.6±7.6; 15.8±5.6 mm,

Table 1. Histopathologic results of benign, malignant and metastatic solitary pulmonary nodules

Benign SPNs (n=10)	n	Malignant SPNs (n=38)	n	Metastatic SPNs (n=30)	n
Pneumonitis	3	Squamous cell carcinoma	16	Lymphoma	5
Chronic inflammation	2	Adenocarcinoma	13	Pancreas cancer	3
Hamartoma	2	Small cell carcinoma	9	Breast cancer	3
Granuloma	1			Malignant melanoma	2
Neuroendocrine cell hyperplasia	1			Colon cancer	2
Pneumoconiosis	1			Laryngeal cancer	2
				Stomach cancer	2
				Rectum cancer	2
				Bladder cancer	2
				Cervical cancer	2
				Neuroendocrine tumor	1
				Adrenal cancer	1
				Multiple myeloma	1
				Esophageal cancer	1
				Osteosarcoma	1

SPN: Solitary pulmonary nodule.

Table 2. Maximum standardized uptake value, maximum metabolic index, mean standardized uptake value and mean metabolic index values of benign, malignant and metastatic groups

	SUV_{max}	MI_{max}	SUV_{mean}	MI_{mean}	SUV_{max}		MI_{max}		SUV_{mean}		MI_{mean}	
	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Median	Min-Max	Median	Min-Max	Median	Min-Max	Median	Min-Max
Benign (n=10)	2.3±0.4	18.4±7.4	1.3±0.2	9.9±3.8	1.94	1-6	10.63	2-83	1.51	1-3	6.10	1-43
Metastatic (n=30)	4.4±0.7	46.1±24.9	3.2±0.7	21.2±9.6	3.1	1-17	11.34	4-755	1.83	1-20	6.22	2-289
Malign (n=38)	7.9±0.7	186.4±51.1	4.7±0.4	110.9±31.3	7.35	2-22	84.46	3-1493	4.41	1-13	47.94	2-921

SUV: Standardized uptake value; MI: Metabolic index; SE: Standard error.

respectively. All lesions were histopathologically diagnosed (Table 1).

There were nine small-cell lung cancers (SCLCs) (17%) and 29 non-SCLCs (83%) in 38 patients with primary lung cancer (Table 1). The lesions diagnosed as malignant by PET-CT were pathologically defined as primary lung cancer (true positive), and the 10 lesions diagnosed as benign by PET-CT were pathologically defined as benign. The remaining two lesions were defined as histopathologically (false-negative) as lung cancer (adenocancer, mixed type).

The mean and median SUV_{max}, SUV_{mean}, MI_{max}, and MI_{mean} were lowest in the benign group and highest in the primary lung cancer group. A nonparametric Kruskal-Wallis test showed significant differences among the three groups (p=0.001; p=0.027; p=0.004; p=0.017, respectively). Significant differences were found in SUV_{max}, MI_{max}, SUV_{mean} and MI_{mean} between the benign-primary lung cancer (p=0.001; p=0.010;

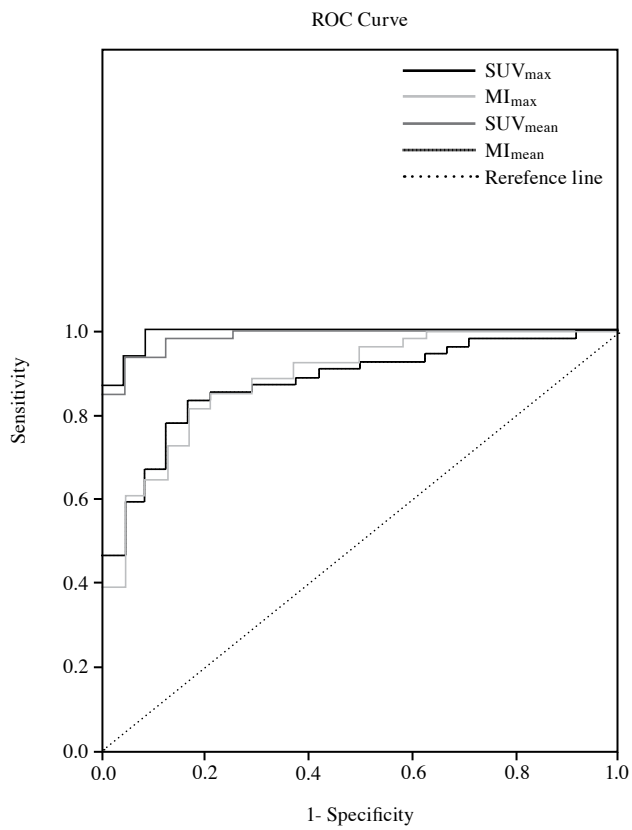

Figure 1. Receiver operating characteristic analysis of maximum standardized uptake value, maximum metabolic index, mean standardized uptake value, and mean metabolic index ratio.

ROC: Receiver operating characteristic; SUV: Standardized uptake value; MI: Metabolic index.

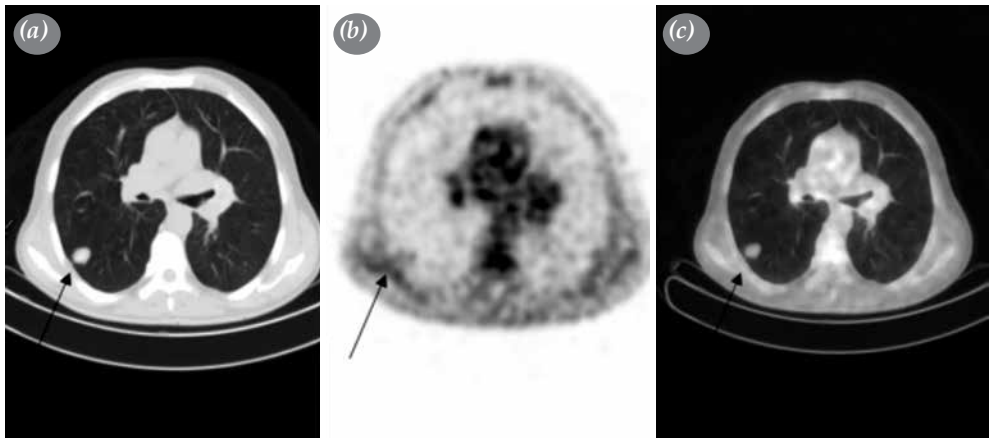

Figure 2. Positron emission tomography/computed tomography of a 60-year-old male patient with a solitary pulmonary nodule (arrows) on right lung (true negative on scan). Maximum standardized uptake value: 1.77, maximum metabolic index: 15.94, mean standardized uptake value: 0.94, mean metabolic index: 8.46. **(a)** computed tomography, **(b)** computed tomography-attenuated positron emission tomography, (c) fusion positron emission tomography/computed tomography (histopathology: organized pneumonia).

p=0.002; p=0.045, respectively) and metastatic-primary lung cancer groups (p=0.001; p=0.018; p=0.040; p=0.010, respectively) by Mann-Whitney U test. The SUV_{max} and SUV_{mean} differed significantly between the benign and metastatic lung lesion groups (p=0.010; p=0.088, respectively) (Table 2).

There was a significant correlation (r=0.73; p=0.001) between SUV_{max} and MI_{max}, and a moderate correlation between SUV_{mean} and MI_{mean} (r=0.56; p=0.001).

The ROC analysis showed that SUV_{max} and SUV_{mean} were more significant than MI_{max} and MI_{mean} (Figure 1). The cut-off values that provided the optimal sensitivity and specificity were 2.59 for SUV_{max} (sensitivity 98%, specificity 91.7%), 1.65 for SUV_{mean} (sensitivity 94%, specificity 91.7%), 9.27 for MI_{max} (sensitivity 92.6%, specificity 72.5%), and 5.40 for MI_{mean} (sensitivity 89%, specificity 91.7%) (Table 3).

DISCUSSION

Determination of risk for malignancy of SPNs is important. F-18 FDG PET-CT allows noninvasive assessment of the metabolic function of tumoral lesions.[12] The SUV is a semiquantitative parameter that reflects FDG uptake and reportedly facilitates differentiation of benign from malignant pulmonary nodules.[13-16] We found significant differences in SUV_{max} and SUV_{mean} among the benign, primary lung cancer, and metastatic lung cancer groups (p<0.05). The mean SUV_{max} and SUV_{mean} were 2.3±0.4 and 1.3±0.2 for the benign group, 7.9±0.7 and 4.7±0.4 for primary lung cancer group, and 4.4±0.7) and 3.2±0.7 for metastatic lung cancer group, respectively.

Table 3. Sensitivity, specificity and area under the curve values of threshold value for maximum standardized uptake value, maximum metabolic index, mean standardized uptake value, and mean metabolic index

	AUC	Sensitivity	Specificity	NPV	PPV	Accuracy	95% CI	
		%	%	%	%	%	Lower bound	Upper bound
SUV_{max}: 2.59	0.99	98	91.7	97.3	81.8	93.8	0.89	1.00
MI_{max}: 9.27	0.89	92.6	72.5	96.7	62.3	79.2	0.74	0.96
SUV_{mean}: 1.65	0.98	94	91.7	97.1	78.5	89.6	0.86	1.00
MI_{mean}: 5.40	0.87	89	91.7	96.7	77.1	79.2	0.72	0.95

AUC: Area under the curve; NPV: Negative predictive value; PPV: Positive predictive value; CI: Confidence Interval SUV: Standardized uptake value; MI: Metabolic index.

Zhao et al.[13] reported that among 175 SPNs, the SUV_{max} was 1.9±1.4 in the benign group and 4.9±4.1 in the malignant group; the difference was significant. Lopez et al.[17] reported that among 55 SPN lesions, the SUV_{max} was 2.3±1.3 and 4.5±2.8 in benign and malignant groups, respectively. Similarly, in our study, the SUV_{max} and SUV_{mean} of malignant lesions were significantly higher than those of benign lesions. Yilmaz and Tasdekin[14] reported SUV_{max} values of 241 benign, malignant, and metastatic SPN lesions of 3.5±3.0, 7.7±4.1, and 3.2±3.1, respectively. The mean SUV_{max} of malignant lesions was significantly higher than that of benign lesions, while the mean SUV_{max} did not differ significantly between the benign and metastatic lesions. In contrast, in our study, the SUV_{max} of metastatic lesions was significantly higher than that of benign lesions.

The SUV provides information on metabolic activity independent of lesion size. The MTV is defined as the volume of tumor tissue showing increased FDG uptake and is regarded as a prognostic factor.[18] The SUV provides only information on metabolic activity, while MTV reflects the proportion of the lesion that shows high metabolic activity. We aimed to identify a parameter that enables effective differentiation of benign from malignant SPNs by combining the SUV and MTV; i.e., the MI. Xie et al.[11] reported that MI is significantly related to the prognosis of nasopharyngeal carcinoma. To our knowledge, no study has reported that MI is predictive of malignancy in SPNs. In our study, the MI_{max} values were 18.4±7.4, 46.1±24.9, and 186.4±51.1 in the benign, metastatic, and malignant groups, respectively. Significant differences were found in MI_{max} between the benign-primary lung cancer and between primary lung cancer-metastatic group.

In the ROC analysis, the cut-off values that provided the optimal sensitivity and specificity were 2.59 for SUV_{max} (sensitivity 98%, specificity 91.7%), 1.65 for SUV_{mean} (sensitivity 94%, specificity 91.7%), 9.27 for MI_{max} (sensitivity 92.6%, specificity 72.5%), and 5.40 for MI_{mean} (sensitivity 89%, specificity 91.7%). The areas under the curve showed that SUV_{max} and SUV_{mean} were more effective than MI_{max} and MI_{mean} for differentiation of benign from malignant SPNs. Various optimal cut-off SUV_{max} values for prediction of malignancy have been reported. Demir et al.[19] reported that a SUV_{max} cut-off of >2.5 had a sensitivity of 94% and specificity of 75%. In a study involving 186 patients, a SUV_{max} cut-off of 2.5 had a sensitivity of 86.7% and specificity of 50%.[15] Several studies support a SUV_{max} >2.5 as the cut-off for differentiation of benign from malignant lesions by PET/CT.[8,20-22] Nguyen et al.,[23] in a retrospective study involving 143 patients, showed that a SUV_{max} cut-off of >3.6 had a sensitivity and specificity of 81% and 94%, respectively. Yi et al.[24] conducted a study with 119 patients: a cut-off SUV_{max} of >3.5 had a sensitivity of 96% and a specificity of 88%. In the retrospective study by Lopez et al.[17] involving 55 patients, a SUV_{max} cut-off of >1.95 had a sensitivity of 80% and specificity of 53.3%. As the SUV_{max} cut-off increases, the sensitivity decreases, and the specificity increases. In contrast, as the SUV_{max} decreases, the specificity decreases significantly. No consensus regarding the SUV_{max} cut-off that provides the best diagnostic performance has been established. In this study, a SUV_{max} cut-off of >2.59 provided good sensitivity and specificity, in agreement with most previous reports.[19-22]

To our knowledge, no previous study has evaluated the usefulness of MI for the diagnosis of SPN. In this study, MI_{max} and MI_{mean} cut-offs of >9.27 and >5.40 provided the best diagnostic performance. In the ROC analysis, SUV_{max} and SUV_{mean} were more significant than MI_{max} and MI_{mean}. Some large SPN lesions had low SUV values and some small SPN lesions had high SUV values, possibly due to differences in metabolic volume.

There was a significant correlation between SUV_{max} and MI_{max} (r=0.73; p=0.001), and a moderately significant correlation between SUV_{mean} and MI_{mean} (r=0.56; p=0.001). Therefore, MI_{max} can be used together with SUV_{max} for differentiation of benign from malignant lesions.

In our study, 30 of 78 SPNs were metastatic lung nodules (38.5%). Few studies have investigated the SUVs of metastatic lung nodules and benign or malignant primary lung lesions. Yilmaz and Tastekin,[14] reported mean SUV_{max} values of 3.5±3.0, 7.7±4.1, and 3.2±3.1 for benign, malignant, and metastatic lesions, respectively. There was a significant difference between the malignant and metastatic groups, but not between the benign and metastatic groups. In our study, the SUV_{max} values differed significantly among the three groups, but the MI values were not significantly different between the benign and metastatic nodule groups. Therefore, SUV_{max} enables differentiation of benign lung nodules, primary lung cancer, and metastatic lung nodules. Moreover, MI_{max} can be used to differentiate benign from malignant lung lesions and malignant lung lesions from metastatic nodules.

Furthermore, 10 of 12 benign lesions by PET-CT were pathologically confirmed (true negative). The

remaining two patients with a SUV_{max} <2.5 were pathologically (false-negative) diagnosed with primary lung cancer (adenocancer, mixed type). In the literature, FDG uptake rate of adenocancers with a bronchoalveolar component is significantly lower than that of types without a bronchoalveolar component.[9,25]

All 38 lesions identified as malign by PET-CT were pathologically defined as primary lung cancer. Some infective-inflammatory lesions show high F-18 FDG uptake, which can lead to false-positive results.[8]

This study was limited by its retrospective design, which prevented control of imaging and patient preparation parameters. Also, a relatively small number of patients was enrolled.

In conclusion, maximum metabolic index value showed a significant correlation with maximum standardized uptake value for benign/malignant discrimination of solitary pulmonary nodules. Maximum standardized uptake value (for 2.59 cut-off value) and mean standardized uptake value (for 1.65 cut-off value) were found to be the most sensitive and specific methods for benign/malignant discrimination in solitary pulmonary nodules. All of the metabolic measurements may discriminate primary lung cancer from the metastatic group.

Declaration of conflicting interests

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