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Diagnostic value of ^{18}F-FDG PET/CT in discriminating between benign and malignant lesions of the ribs

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Abstract

Purpose: Imaging biomarkers for rib mass are needed to optimize treatment plan. We investigated the diagnostic value of metabolic and volumetric parameters from ^{18}F-fluorodeoxyglucose (FDG) positron-emission tomography/computed tomography (PET/CT) in discriminating between benign and malignant lesions of the ribs.

Patients and methods: Fifty-seven patients with pathologically proven diagnosis of rib lesions were retrospectively enrolled. The size of rib lesions, the maximum, mean, and peak standardized uptake value (SUVmax, SUVmean, SUVpeak), tumor-to-background ratio (TBR), metabolic tumor volume (MTV), and total lesions glycolysis (TLG) were measured. The FDG uptake patterns (segmental and discrete) and CT findings (soft tissue involvement and fracture) were also reviewed.

Results: Among the multiple parameters extracted from PET/CT, the MTV of malignant lesions was significantly higher than that of benign lesions (median; 4.7 vs 0.2, respectively, $P = .041$). In receiver operating characteristics curve analysis, MTV had the largest area under curve of 0.672 for differentiating malignant from benign lesions. For identifying malignant lesions, an MTV threshold of 0.5 had a sensitivity of 85.0%, specificity of 47.1%, positive predictive value of 79.1%, negative predictive value of 57.1%, and accuracy of 73.7%. The presence of adjacent soft tissue involvement around rib lesions showed a significant association with malignancy (odds ratio = 6.750; 95% CI, 1.837–24.802, $P = .003$).

Conclusions: The MTV is a useful PET/CT parameter for assisting in the differential diagnosis of suspected malignant lesions of the ribs. CT finding of adjacent soft tissue involvement around rib was significantly associated with malignant lesions of the ribs.

Abbreviations: AUC = area under curve, FDG = fluorodeoxyglucose, MTV = metabolic tumor volume, NPV = negative predictive value, OSEM = ordered subsets expectation maximization, PET/CT = positron emission tomography/computed tomography, PSF = point-spread-function, PPV = positive predictive value, ROC = receiver operating characteristics, SD = standard deviations, SUV = standardized uptake value, TBR = tumor-to-background ratio, TLG = total lesion glycolysis, TOF = time-of-flight, VOI = volume of interest.

Keywords: fluorodexoyglucose f18, metabolic tumor volume, positron-emission tomography computed tomography, rib, sensitivity and specificity, standardized uptake value

1. Introduction

Neoplasms of the ribs account for 3%–8% of skeletal masses.[1–3] The spectrum of rib lesions ranges from benign tumors such as fibrous dysplasia to malignancies, including metastasis or direct invasion from adjacent malignancies such as breast cancer, lung cancer, and mediastinal tumor.[4] Patients with rib tumors usually have chest wall pain, a palpable mass, or both. Although some primary rib tumors exhibit characteristic imaging features, many other types have nonspecific characteristics. Given the low prevalence of rib tumors and their overlapping imaging features, accurate diagnosis before histological examination can be challenging for clinicians.

^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography/computed tomography (PET/CT) has been widely used to differentiate malignant bone tumors from benign lesions and to predict their prognosis.[5,6] Several studies revealed that ^{18}F-FDG

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uptake is typically higher in malignant bone lesions than in benign lesions.[7–10] In particular, when bone tumors of the same histologic type, such as chondrosarcoma, were compared, the ^{18}F-FDG uptake of high-grade tumors was greater than that of low-grade tumors. The metabolic parameters derived from ^{18}F-FDG PET/CT, such as maximum standardized uptake value (SUVmax), improved the prediction of clinical outcomes and recurrence for primary bone tumors.[11,12] Peak SUV (SUVpeak) was also reported as a prognostic factor in osteosarcoma,[13] and the ^{18}F-FDG avidity of some benign bone tumors, such as giant cell tumor of the bone, was higher than that of low-grade malignant bone tumors.[14,15] In addition to PET-derived parameters, the morphologic features obtained from CT images simultaneously acquired with PET data could be helpful for determining the aggressive biological potential of bone lesions.

Metabolic tumor volume (MTV) is defined as the metabolically active volume of tumor tissues above a predefined SUV threshold measured by ^{18}F-FDG PET/CT, and total lesion glycolysis (TLG) is calculated as the measured MTV multiplied by mean SUV (SUVmean). A number of studies have evaluated the clinical value of volumetric parameters derived from ^{18}F-FDG PET/CT, including MTV and TLG, and demonstrated their prognostic significance for osteosarcoma.[13,16,17] However, few studies have reported the clinical significance of the volumetric parameters of ^{18}F-FDG PET/CT for patients with rib neoplasms, which may be attributed to their rarity among malignant bone tumors. In this study, we hypothesized that volumetric parameters and morphologic features obtained from CT images may have additive value in distinguishing malignant rib lesions. In this study, we analyzed the diagnostic value of metabolic and volumetric parameters derived from preoperative ^{18}F-FDG PET/CT images obtained from patients with suspected malignant rib lesions. In addition, we reviewed the morphologic findings on CT for the further discrimination of malignant rib lesions.

2. Materials and Methods

2.1. Study subjects

The subjects included in this retrospective study were patients with rib lesions suspected to be malignant and who underwent ^{18}F-FDG PET/CT between January 2010 and December 2020 (Fig. 1). All patients underwent excisional or needle biopsy and/or surgical resection, and their final diagnosis was confirmed histologically. Patients with any reported primary/synchronous malignancies on ^{18}F-FDG PET/CT were excluded from this study. Patients with hematologic malignancies combined with bone marrow involvement and those with more than 5 newly appeared bone lesions showing FDG uptake were also excluded from this study.[10] The study design and waiver of informed consent were approved by the institutional review board of our institution (no. 2021-1027).

2.2. PET/CT image acquisition

All patients fasted for at least 6 hours before PET/CT scanning. The plasma glucose level measured before ^{18}F-FDG injection was <150 mg/dL in all patients. ^{18}F-FDG was intravenously administered at a dose of 5.18 MBq/kg (range, 114.3–488.4 MBq); 1 hour after ^{18}F-FDG administration, PET/CT scanning was performed with different systems (Discovery PET/CT 690, 690 Elite, 710; GE Healthcare; Biograph 40 TruePoint PET/CT; Siemens). First, low-dose CT acquisition was performed from the skull base to the upper thigh using the following parameters: 120 kVp, automatic mA, 40 mm collimation, and 3.75 mm thickness for the GE Healthcare machines; 120 kVp, CARE Dose 4D, 28.8 mm collimation, and 5.0 mm thickness for the Siemens machine. A PET scan of the same area was acquired after the CT scan in the 3-dimensional mode with 6 to 7 beds (2 and 2.5 minutes per bed position on the GE Healthcare and Siemens machines, respectively). Images were corrected for attenuation and reconstructed using the 3-dimensional ordered subset expectation maximization (OSEM) method with time-of-flight (TOF) and point-spread-function (PSF) algorithms (192 × 192 matrix, 4 iterations, 18 subsets, 4 mm postsmoothing on GE Healthcare; 168 × 168 matrix, 3 iterations, 21 subsets, 3 mm postsmoothing on Siemens).

2.3. Visual analysis of PET/CT

The pattern of FDG uptake on PET images was classified as segmental or focal and discrete or nondiscrete. Segmental FDG uptake was defined as FDG uptake along the length of the rib lesion that was at least twice that of the width.[10] A discrete uptake pattern was defined as FDG uptake intensity at least twice that of contralateral rib uptake. The CT images were further analyzed by searching for the presence of fracture and evidence of the involvement of soft tissue in lesions demonstrating FDG uptake. Multiple lesions were defined as more than 1 rib lesion.

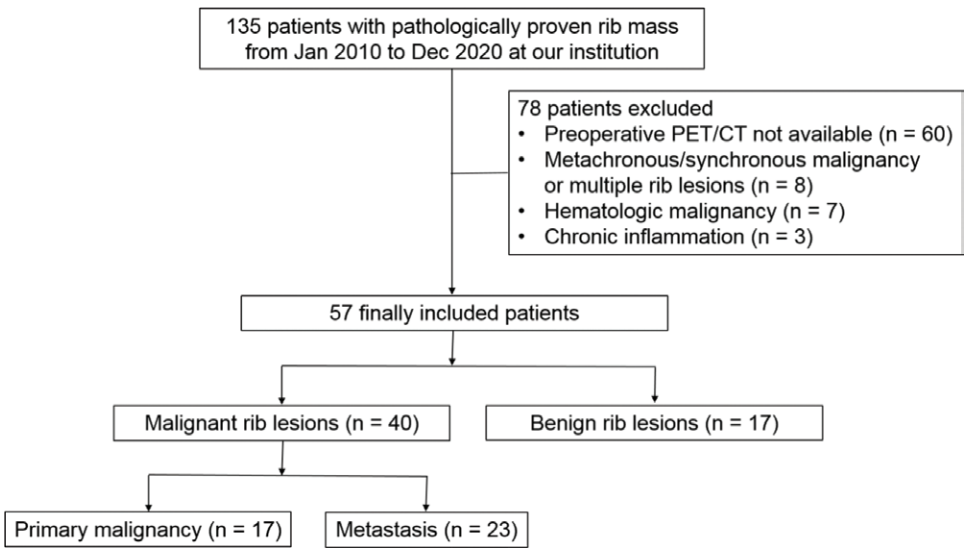

Figure 1. Flowchart of subject enrollment.

2.4. Quantitative analysis of PET/CT images

^{18}F-FDG PET/CT images were reviewed by a nuclear medicine board-certified physician (S.J.C) who was blinded to the clinical data using a dedicated workstation and software (Mirada XD3; Mirada Medical). The size of rib lesions on transaxial CT images was measured. For the quantitative analysis of ^{18}F-FDG PET/CT images, volumes of interest were delineated around rib lesions showing higher than normal FDG uptake on transaxial images, and SUVmax, SUVmean, and SUVpeak were measured. The SUVs were normalized to the lean body mass. The tumor-to-background ratio (TBR) was calculated as the SUVmax of a rib lesion divided by the SUVmean of the contralateral rib. The SUVmean of the contralateral rib was measured using a spherical volume of interest (VOI) (1 cm in diameter) placed on the rib contralateral to a suspected malignant rib lesion. The MTV was measured using an automated contouring program with a threshold of liver SUVmean plus 2 standard deviations (SDs).[13] The liver SUVmean and SDs were measured using a spherical VOI (3 cm diameter) placed on the right lobe of the liver. The TLG was calculated by multiplying the MTV by its corresponding SUVmean.

2.5. Statistical analysis

Pearson chi-square test and Fisher exact test were used to compare the pattern of FDG uptake and CT findings between benign and malignant lesions. The ^{18}F-FDG PET/CT parameters (size, SUVmax, SUVmean, SUVpeak, TBR, MTV, and TLG) of benign and malignant lesions of the ribs were compared using the Mann–Whitney U test. Receiver operating characteristic (ROC) curve analysis of the PET/CT parameters was performed, and their diagnostic performance was compared. A P value < 0.05 was considered statistically significant. Statistical analyses were performed using a dedicated software (SPSS Statistics, version 18.0; IBM).

Table 1

Patient characteristics.

Characteristics	Number (n = 57)
Age at diagnosis (years, median [range])	52.0 [9–79]
Sex	
Male	33
Female	24
Rib lesion size (cm, median [range])	4.8 [1.4–19.3]
Interval between PET/CT and biopsy or surgery (days, median [range])	22.0 [1–129]
Benign lesions	17
Fibrous dysplasia	5
Langerhans cell histiocytosis	5
Aneurysmal bone cyst	1
Giant cell tumor	1
Intraosseous hemangioma	1
Intramedullary cartilaginous lesion	1
Liposclerosing myxofibrous tumor	1
Osteochondroma	1
Schwannoma	1
Primary malignant lesion	17
Chondrosarcoma	7
Ewing sarcoma	4
Osteosarcoma	3
Plasmacytoma	2
Low grade sarcoma	1
Metastatic malignant lesion	23
Metastatic hepatocellular carcinoma	8
Metastatic renal cell carcinoma	5
Metastatic lung cancer	5
Metastatic breast cancer	2
Metastatic thyroid cancer	1
Metastatic synovial sarcoma	1
Metastatic urothelial cell carcinoma	1

SD = standard deviation.

3. Results

3.1. Profile of the included patients

Among 135 patients with a pathologically proven rib mass, 57 patients were finally enrolled in this study. The clinical characteristics of these patients are summarized in Table 1. Of these 57 patients, 40 patients (40/57, 71.2%) were diagnosed with malignant lesions on histological analysis. These malignant lesions were categorized as primary malignant tumors (17/40, 42.5%) or metastatic malignant lesions (23/40, 57.5%). The mean of interval days between PET/CT and biopsy or surgery was median 22.0 days. All benign rib lesions were single lesions.

3.2. Visual analysis

Segmental FDG uptake was observed in 27 malignant lesions (27/40, 67.5%) and 8 benign lesions (8/17, 47.1%). The rates of discrete FDG uptake in benign and malignant lesions were high (88.2% and 80.0%, respectively). Adjacent soft tissue involvement around rib lesions was significantly more common with malignant lesions than with benign lesions (odds ratio = 6.750; 95% CI, 1.837–24.802, P = .003; Table 2).

3.3. Quantitative analysis

A comparison of the quantitative PET/CT parameters is presented in Table 3. The MTV values (median, interquartile) of benign and malignant lesions were 0.2 [0.1; 7.6] and 4.7 [1.2; 22.4], respectively, which were significantly different (P = .041; Fig. 2). Other PET/CT parameters (size, SUVmax, SUVmean, SUVpeak, TBR, and TLG) did not show significant differences between benign and malignant lesions. In ROC curve analysis, the largest area under the curve (AUC) among the PET/CT parameters was 0.672 with a sensitivity of 85.0%, specificity of 47.1%, positive predictive value (PPV) of 79.1%, negative predictive value (NPV) of 57.1%, and accuracy of 73.7% when 0.5 was used as the MTV cut-off value for the differential diagnosis (Fig. 3). Data on the diagnostic performance of various MTV cut-off values for distinguishing between benign and malignant lesions are presented in Supplemental Table 1, http://links.lww.com/MD/G864. The diagnostic performance of all PET/CT parameters according to a cut-off value is summarized in Table 4, and representative cases are shown in Figs. 4–6.

4. Discussion

In this retrospective study, we evaluated the diagnostic value of metabolic and volumetric parameters derived from ^{18}F-FDG PET/CT for patients with suspected malignant rib lesions. The MTV calculated using a relative threshold (liver SUVmean + 2 SDs) showed a significant difference between benign and malignant rib lesions and had the highest diagnostic value. Therefore, the MTV was the best PET/CT parameter for characterizing the malignancy of rib lesions.

The volumetric parameters of ^{18}F-FDG PET/CT (e.g., MTV or TLG) have been introduced to overcome the limitations of the metabolic parameters of ^{18}F-FDG PET/CT (e.g., SUVmax or SUVpeak), and several studies have published diagnostic values for differentiating malignant from benign bone and soft tissue tumors.[18,19] These studies evaluated the diagnostic performance of the MTV and TLG using various threshold values with a fixed SUVmax of 2.0 or 2.5 or 40%, 50%, and 75% of SUVmax. Additionally, Chen et al presented a regression model using SUVmax and a heterogeneity factor (calculated from a

Table 2

Comparison of PET uptake patterns and morphologic features on CT images between benign and malignant lesions.

PET/CT finding	Benign lesions (n = 17)	Malignant lesions (n = 40)	Odds ratio (95% CI)	*P* value
Number of lesions				
Single	17 (100.0%)	32 (80.0%)	0.653 (0.533–0.801)	0.090
Multiple	0	8 (20.0%)		
PET uptake pattern				
Segmental	8 (47.1%)	27 (67.5%)	1.817 (0.541–6.101)	0.331
Discrete	15 (88.2%)	32 (80.0%)	0.533 (0.101–2.823)	0.706
CT finding				
Soft tissue involvement	4 (23.5%)	27 (67.5%)	6.750 (1.837–24.802)	0.003*
Fracture	5 (29.4%)	11 (27.5%)	0.910 (0.260–3.187)	0.883

CI = confidence interval.
*$P < 0.05$.

Table 3

Median of PET parameters in the overall population as well as comparatively between the 2 groups of benign and malignant rib lesions [interquartile range].

PET/CT parameters	Overall	Benign lesions	Malignant lesions	*P* value
Size (cm)	4.8 [2.8; 6.8]	5.5 [4.5; 6.7]	4.4 [2.8; 7.5]	0.232
SUVmax	5.0 [3.5; 7.6]	3.1 [22; 6.5]	5.1 [3.8; 7.6]	0.631
SUVmean	1.6 [1.1; 2.5]	1.1 [0.9; 2.4]	1.6 [1.1; 2.5]	0.780
SUVpeak	3.5 [2.4; 5.1]	2.2 [1.7; 4.4]	3.5 [2.5; 5.1]	0.588
TBR	7.8 [5.6; 11.0]	5.5 [3.7; 10.1]	8.0 [6.3; 10.9]	0.577
MTV	4.0 [0.5; 22.4]	0.2 [0.1; 7.6]	4.7 [1.2; 22.4]	0.041*
TLG	10.9 [1.6; 53.9]	0.5 [0.2; 34.4]	17.2 [3.4; 53.9]	0.054

MTV = metabolic tumor volume, SUVmax = maximum standardized uptake value, TBR = tumor-to-background ratio, TLG = total lesion glycolysis.
*$P < 0.05$.

metabolism volume-threshold function from 40% to 80%) and found that it showed diagnostic performance superior to that of individual volumetric parameters.[19] Im et al reported that the MTV and TLG obtained using a liver-based threshold (liver SUVmean + 2 SDs) were the parameters with the most statistically significant predictive value for event-free survival (hazard ratios = 11.774 and 13.121, respectively, at posttherapy).[13] We evaluated the MTV and TLG using a liver-based threshold, which would be less influenced by the variability in SUV measurements caused by multiple PET/CT systems. Although the MTV cut-off was as small as 0.5, the MTV yielded the largest AUC among the various parameters of ^{18}F-FDG PET/CT investigated in our study. On the other hand, the TLG showed lower sensitivity, accuracy, and AUC values, which may be attributed to the heterogeneous SUVmean values of benign lesions with aggressive features in our cohort. In addition, there may be errors in the SUV calculation due to differences in scan acquisition or image reconstruction parameters across various PET/CT systems.[20,21] Despite these conditions, the MTV demonstrated a statistically significant difference between malignant and benign rib lesions in our study.

Although the metabolic and volumetric parameters derived from ^{18}F-FDG PET/CT have been used in the diagnosis of bone tumors, morphologic assessment remains necessary to investigate their malignant biological potential. CT as part of a PET/CT examination provides additional anatomical information. On CT, the edge of more aggressive tumors may appear fuzzy or unsharp, indicating active osteolysis.[9] The lack of a sclerotic margin might be a high-risk feature suggesting an excessive rate of osteolysis caused by the tumor. Moreover, aggressive tumors often extend through the bone cortex directly into adjacent soft tissues.[22] Our study showed that a higher odds ratio was obtained for bone lesions with adjacent soft tissue involvement compared with lesions showing a segmental FDG uptake pattern in patients with malignant lesions. There are some contradictory findings related to the diagnostic value of SUVmax for differentiating malignant fractures in the acute phase. A number of studies found significantly higher FDG uptake in malignant fractures than in benign fractures in the acute to subacute phase.[7,23] However, Ravenel et al reported a SUV of 9.3 for acute benign fractures of the pelvic bone.[24] These findings highlight the diagnostic value of CT findings on PET/CT images.

SUVmax is a PET/CT parameter widely used for quantitative analysis. Several previous studies on rib tumors used

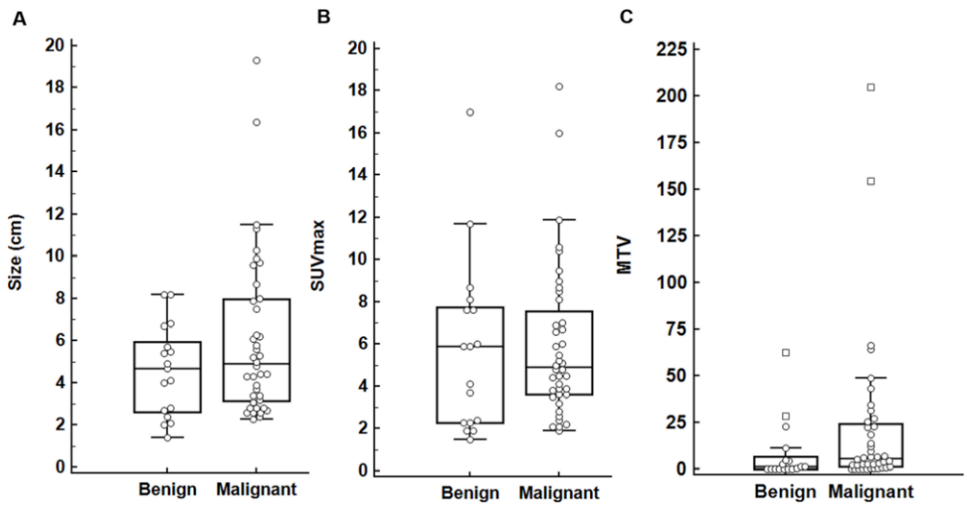

Figure 2. Comparison of ^{18}F-FDG PET/CT parameters for benign and malignant lesions of the ribs. (A) Size (P = .232), and (B) SUVmax (P = .631) showed no significant difference and also revealed a high range of overlap compared with MTV. However, (C) MTV (P = .041) showed significantly higher values in malignant rib lesions than in benign lesion of ribs.

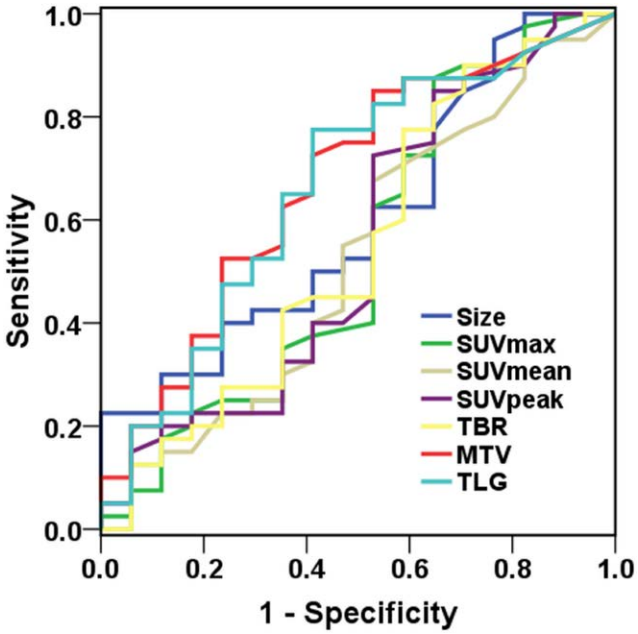

Figure 3. Receiver operative characteristics (ROC) curve analysis of quantitative parameters of ^{18}F-FDG PET/CT for determining cut-off value. The AUC of MTV (liver SUVmean plus 2 SDs) was 0.672 (P = .041). The sensitivity and specificity of an MTV cut-off value of 0.5 were 85.0% and 47.1%, respectively.

SUVmax and reported sensitivity values in the range of 68.0 to 89.5% with cut-off values of 2.7–4.7.[7,11,12,25] Annovazzi et al reported that a SUVmax cut-off of 2.6 discriminated low-grade chondrosarcoma from enchondroma,[25] and another study reported a significantly higher SUVmax for high-grade chondrosarcoma compared with low-grade chondrosarcoma.[11] SUVmax showed a similar diagnostic value in recurrent chondrosarcoma, which was associated with the tumor grade.[12] Additionally, malignant fractures showed increased intramedullary FDG uptake compared with that of benign fractures.[7] However, Choi et al reported that SUVmax was significantly higher for rib metastases (58 lesions) compared with benign rib lesions (206 lesions) with a SUVmax cut-off of 2.4, which is contrary to our result.[10] One possible reason for the discrepancy might be the small sample size in our study (40 malignant and 17 benign lesions). Another possible reason might be the large proportion of low-grade primary malignant lesions included in this study (25.0%; e.g., chondrosarcoma, plasmacytoma, and low-grade sarcoma).

Benign bone lesions such as Langerhans cell histiocytosis and giant cell tumor are thought to originate from monocyte-macrophage lineage cells.[26,27] Macrophages play a key role in the inflammatory process, and high FDG uptake in inflammatory cells due to intracellular glucose metabolism is a well-known feature. A number of publications reported that Langerhans cell histiocytosis and giant cell tumor can have a high SUV and mimic malignancy.[14,15] The highest SUVmax of our false positive lesions was 17.0 (giant cell tumor). Another benign bone lesion, fibrous dysplasia (FD), is one of the most common benign lesions and has morphologic features showing intramedullary bone expansion, which is well-defined on radiographic and CT images. Several studies have stated that the appearance of FD might mimic that of malignant lesions. Su et al reported that the SUVs of 11 patients with FD ranged from 1.76 to 11.4 and found that FD lesions with a low CT density often had higher SUVs compared with those of lesions with a high CT density. Therefore, it should be noted that the use of SUVmax alone would be limited in differentiating between benign and malignant lesions considering the variability in the SUVmax range of benign bone tumors.

SUVmax, which is defined as the highest voxel within a drawn VOI, may be affected by signal noise and might indicate statistical fluctuations in the count when the acquisition time is too short.[28] Therefore, SUVpeak has been recommended

Table 4

Results of ROC curve analysis of PET/CT parameters in the diagnosis of malignant rib lesions.

PET/CT parameters	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)	AUC	Cut-off value	*P* value
Size (cm)	22.5	100.0	100.0	32.4	45.6	0.601	8.5	0.232
SUVmax	87.5	35.3	76.1	54.5	71.9	0.540	2.5	0.631
SUVmean	67.5	47.1	75.0	38.1	61.4	0.524	1.2	0.780
SUVpeak	85.0	35.3	75.6	50.0	70.2	0.547	2.0	0.589
TBR	90.0	29.4	75.0	55.6	70.2	0.547	5.0	0.577
MTV	85.0	47.1	79.1	57.1	73.7	0.672	0.5	0.041*
TLG	77.5	58.8	81.6	52.6	71.9	0.662	3.3	0.054

AUC = area under the curve, NPV = negative predictive value, PPV = positive predictive value, ROC = receiver operating characteristics.
*$P < 0.05$.

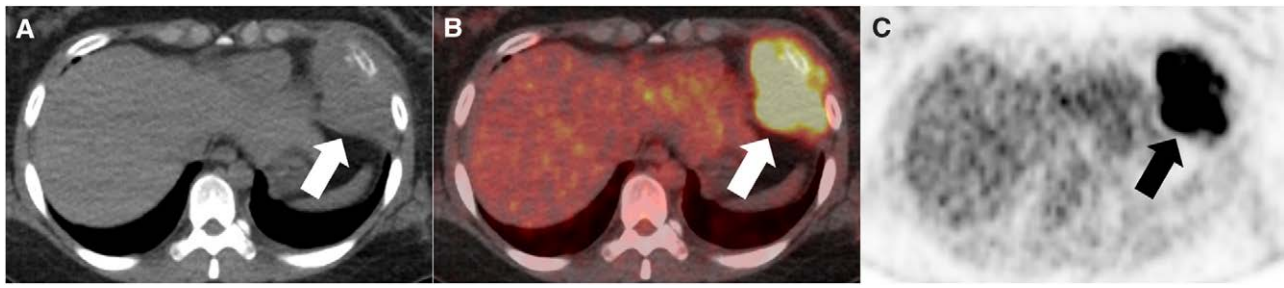

Figure 4. Ewing sarcoma, a malignant lesion of a rib in a 24-year-old woman. Axial CT image (A) of the anterior arc of the left fifth to seventh ribs reveals a soft tissue density mass with bone destruction and minimal periosteal reaction. On fusion PET/CT and PET images (B, C), the maximum standardized uptake value (SUVmax) of the left rib mass was 10.6 (arrows). The metabolic tumor volume (MTV) and total lesion glycolysis (TLG) measured using a threshold of the liver SUVmean plus 2 SDs were 204.6 and 913.7, respectively.

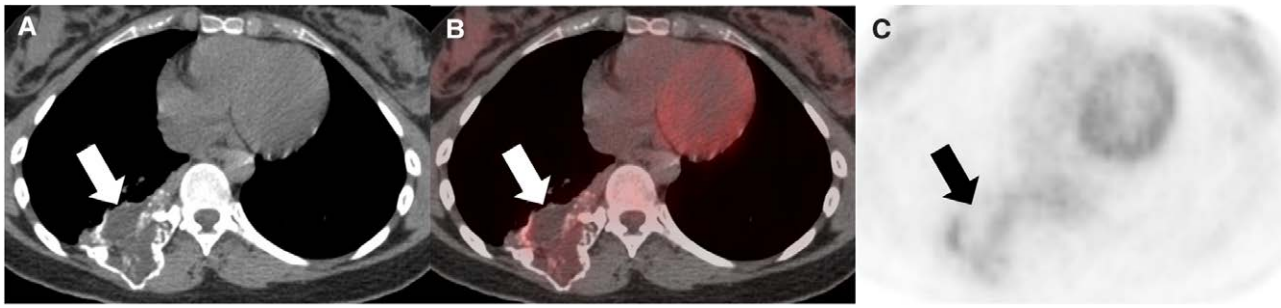

Figure 5. Fibrous dysplasia, a benign lesion of a rib in a 21-year-old woman. Axial CT image (A) of the posterior arc of the right ninth rib shows a radiolucent lesion with expansile remodeling. On fusion PET/CT and PET images (B, C), the SUVmax of the right rib mass with mild heterogeneous hypermetabolic activity was 2.3 (arrows). The MTV and TLG measured using a threshold of liver SUVmean plus 2 SDs were 0.1 and 0.3, respectively.

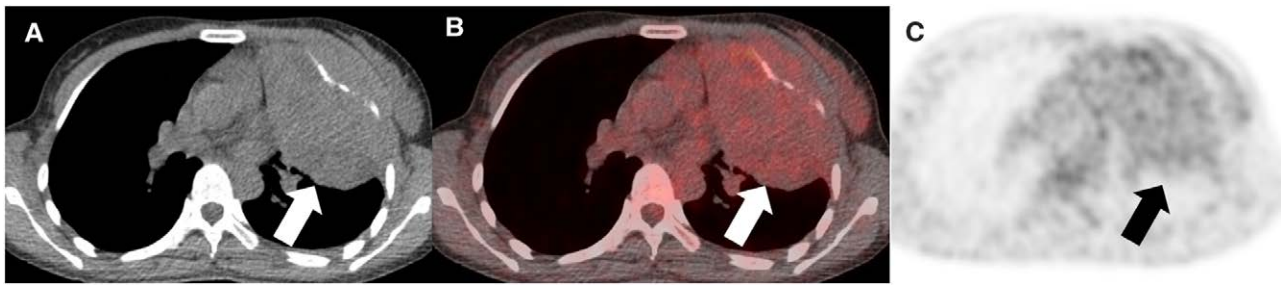

Figure 6. Ewing sarcoma, a malignant soft tissue mass of the left anterior chest wall in a 35-year-old woman. Axial CT image (A) of huge soft tissue mass encase the anterior arcs of left third and fourth ribs. On fusion PET/CT and PET images (B, C), the SUVmax of the left rib lesion with mild hypermetabolic activity was 2.4 (arrows). Both MTV and TLG measured using a threshold of the liver SUVmean plus 2 SDs were 0.9 and 1.9, respectively. MTV could differentiate the malignant bone lesion, while SUVmax and TLG could not.

as an alternative to SUVmax.[29,30] SUVpeak is defined as the average SUV calculated within a fixed VOI, often including the highest pixel value. As a VOI contains several pixels, SUVpeak is presumed to be less affected than SUVmax by signal noise.[31,32] In the discrimination of malignant vertebral bone lesions from benign lesions in oncologic patients, SUVpeak achieved an AUC of 0.671, which was higher than that of SUVmax (0.630).[33] In our study, the AUC of SUVpeak was not significantly different compared with that of SUVmax, and there was no statistically significant difference in sensitivity, specificity, PPV, NPV, and accuracy in the differentiation of malignant lesions. The diagnostic value of the TBR of ^{18}F-FDG PET/CT for bone tumors was first described by Schulte et al,[14] who reported sensitivity, specificity, and accuracy values of 93.0%, 66.7%, and 81.7%, respectively, for discriminating malignant bone lesions using a cut-off value of 3.0. In our study, the TBR showed the highest sensitivity 90.0% and the lowest specificity of 29.4%.

Our study has some limitations. Although we analyzed a cohort of patients who met the inclusion criteria, we evaluated only a relatively small number of patients at a single institution. In addition, some studies investigating the differential diagnostic value of ^{18}F-FDG PET imaging for patients with rib tumors were limited by their retrospective design and the low incidence of these tumors, which are also the limitations of our study.

5. Conclusion

In conclusion, the MTV showed excellent performance in discriminating between benign and malignant lesions of the ribs and better diagnostic accuracy compared with that of SUVmax. Soft tissue involvement around the rib lesions was highly correlated with malignant lesions of the ribs. ^{18}F-FDG PET/CT could be used to determine the treatment strategy for patients with rib lesions.

Author contributions

Conceptualization: Sunju Choi, Yong-il Kim.
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Writing – original draft: Sunju Choi.
Writing – review & editing: Yong-il Kim, Jin-Sook Ryu.

References

[1] Levine BD, Motamedi K, Chow K, et al. CT of rib lesions. AJR Am J Roentgenol. 2009;193:5–13.
[2] Nam SJ, Kim S, Lim BJ, et al. Imaging of primary chest wall tumors with radiologic-pathologic correlation. Radiographics. 2011;31:749–70.
[3] Zarqane H, Viala P, Dallaudière B, et al. Tumors of the rib. Diagn Interv Imaging. 2013;94:1095–108.
[4] Smith SE, Keshavjee S. Primary chest wall tumors. Thorac Surg Clin. 2010;20:495–507.
[5] Liu F, Zhang Q, Zhou D, et al. Effectiveness of (18)F-FDG PET/CT in the diagnosis and staging of osteosarcoma: a meta-analysis of 26 studies. BMC Cancer. 2019;19:323.
[6] Zhang Q, Xi Y, Li D, et al. The utility of (18)F-FDG PET and PET/CT in the diagnosis and staging of chondrosarcoma: a meta-analysis. J Orthop Surg Res. 2020;15:229.
[7] Shin DS, Shon OJ, Byun SJ, et al. Differentiation between malignant and benign pathologic fractures with F-18-fluoro-2-deoxy-D-glucose positron emission tomography/computed tomography. Skeletal Radiol. 2008;37:415–21.
[8] Tian R, Su M, Tian Y, et al. Dual-time point PET/CT with F-18 FDG for the differentiation of malignant and benign bone lesions. Skeletal Radiol. 2009;38:451–8.
[9] Costelloe CM, Chuang HH, Chasen BA, et al. Bone Windows for Distinguishing Malignant from Benign Primary Bone Tumors on FDG PET/CT. J Cancer. 2013;4:524–30.

[10] Choi HS, Yoo Ie R, Park HL, et al. Role of ^{18}F-FDG PET/CT in differentiation of a benign lesion and metastasis on the ribs of cancer patients. Clin Imaging. 2014;38:109–14.
[11] Brenner W, Conrad EU, Eary JF. FDG PET imaging for grading and prediction of outcome in chondrosarcoma patients. Eur J Nucl Med Mol Imaging. 2004;31:189–95.
[12] Vadi SK, Mittal BR, Gorla AKR, et al. 18F-FDG PET/CT in diagnostic and prognostic evaluation of patients with suspected recurrence of chondrosarcoma. Clin Nucl Med. 2018;43:87–93.
[13] Im HJ, Zhang Y, Wu H, et al. Prognostic value of metabolic and volumetric parameters of FDG PET in pediatric osteosarcoma: a hypothesis-generating study. Radiology. 2018;287:303–12.
[14] Schulte M, Brecht-Krauss D, Heymer B, et al. Grading of tumors and tumorlike lesions of bone: evaluation by FDG PET. J Nucl Med. 2000;41:1695–701.
[15] Aoki J, Watanabe H, Shinozaki T, et al. FDG PET of primary benign and malignant bone tumors: standardized uptake value in 52 lesions. Radiology. 2001;219:774–7.
[16] Byun BH, Kong C-B, Park J, et al. Initial metabolic tumor volume measured by 18F-FDG PET/CT can predict the outcome of osteosarcoma of the extremities. J Nucl Med. 2013;54:1725–32.
[17] Andersen KF, Fuglo HM, Rasmussen SH, et al. Volume-based F-18 FDG PET/CT imaging markers provide supplemental prognostic information to histologic grading in patients with high-grade bone or soft tissue sarcoma. Medicine. 2015;94:e2319.
[18] Shen CT, Qiu ZL, Sun ZK, et al. Dual time-point (18)F-FDG PET/CT imaging with multiple metabolic parameters in the differential diagnosis of malignancy-suspected bone/joint lesions. Oncotarget. 2017;8:71188–96.
[19] Chen B, Feng H, Xie J, et al. Differentiation of soft tissue and bone sarcomas from benign lesions utilizing (18)F-FDG PET/CT-derived parameters. BMC Med Imaging. 2020;20:85.
[20] Boellaard R. Standards for PET image acquisition and quantitative data analysis. J Nucl Med. 2009;50(Suppl 1):11s–20S.
[21] Aide N, Lasnon C, Veit-Haibach P, et al. EANM/EARL harmonization strategies in PET quantification: from daily practice to multicentre oncological studies. Eur J Nucl Med Mol Imaging. 2017;44:17–31.
[22] Costelloe CM, Chuang HH, Madewell JE. FDG PET/CT of primary bone tumors. AJR Am J Roentgenol. 2014;202:W521–31.
[23] Kato K, Aoki J, Endo K. Utility of FDG-PET in differential diagnosis of benign and malignant fractures in acute to subacute phase. Ann Nucl Med. 2003;17:41–6.
[24] Ravenel JG, Gordon LL, Pope TL, et al. FDG-PET uptake in occult acute pelvic fracture. Skeletal Radiol. 2004;33:99–101.
[25] Annovazzi A, Anelli V, Zoccali C, et al. (18)F-FDG PET/CT in the evaluation of cartilaginous bone neoplasms: the added value of tumor grading. Ann Nucl Med. 2019;33:813–21.
[26] Anderson JM. Multinucleated giant cells. Curr Opin Hematol. 2000;7:40–7.
[27] da Costa CE, Annels NE, Faaij CM, et al. Presence of osteoclast-like multinucleated giant cells in the bone and nonostotic lesions of Langerhans cell histiocytosis. J Exp Med. 2005;201:687–93.
[28] Boellaard R, Krak NC, Hoekstra OS, et al. Effects of noise, image resolution, and ROI definition on the accuracy of standard uptake values: a simulation study. J Nucl Med. 2004;45:1519–27.
[29] Wahl RL, Jacene H, Kasamon Y, et al. From RECIST to PERCIST: Evolving Considerations for PET response criteria in solid tumors. J Nucl Med. 2009;50(Suppl 1):122s–50s.
[30] Sher A, Lacoeuille F, Fosse P, et al. For avid glucose tumors, the SUV peak is the most reliable parameter for [(18)F]FDG-PET/CT quantification, regardless of acquisition time. EJNMMI Res. 2016;6:21.
[31] Krak NC, Boellaard R, Hoekstra OS, et al. Effects of ROI definition and reconstruction method on quantitative outcome and applicability in a response monitoring trial. Eur J Nucl Med Mol Imaging. 2005;32:294–301.
[32] Nahmias C, Wahl LM. Reproducibility of standardized uptake value measurements determined by 18F-FDG PET in malignant tumors. J Nucl Med. 2008;49:1804–8.
[33] Loudini N, Glaudemans A, Jutte PC, et al. The value of prebiopsy FDG-PET/CT in discriminating malignant from benign vertebral bone lesions in a predominantly oncologic population. Skeletal Radiol. 2020;49:1387–95.