Diagnostic value of ^{18}F-FDG PET/CT and MRI for intraspinal lesions: A comparative study

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Abstract. The aim of the present study was to investigate the value of the use of fluorine-18 (^{18}F)-fluorodeoxyglucose (FDG) positron emission tomography (PET)/computed tomography (CT) vs. magnetic resonance imaging (MRI) for the diagnosis of and differentiation between benign and malignant lesions in the spinal canal. For this purpose, a retrospective analysis was performed on the use of MRI and ^{18}F-FDG PET/CT from January, 2017 to December, 2020, and the final diagnosis was obtained by performing a post-operative pathological examination or following a tissue biopsy (gold standard). The sensitivity, specificity, accuracy, positive predictive value and negative predictive value of the two examination techniques were calculated and comparisons between them were made. The PET metabolic parameters, maximum standardized uptake value (SUVmax), peak standardized uptake value (SUVpeak), mean standardized uptake value (SUVmean), metabolic tumor volume (MTV) and total lesion glycolysis (TLG) in the benign and malignant groups were calculated and compared, and the corresponding ROC curves were plotted. A total of 58 patients were enrolled, including 30 patients with malignant and 28 with benign lesions. The specificity of MRI was significantly higher than that of PET/CT (P<0.05). The sensitivity and negative predictive value of PET/CT were higher than those of MRI, although with no significant difference (P>0.05). The mean ± tandard deviation values of the PET metabolic parameters, SUVmax, SUVpeak, SUVmean, MTV and TLG, were 4.27±1.25, 3.49±1.07, 2.49±0.84, 6.58±5.36 and 17.12±15.50 in the benign, and 8.99±3.75, 7.35±3.26, 5.43±2.40, 12.25±12.18 and 112.41±85.98 in the malignant groups, respectively. The SUVmax, SUVpeak, SUVmean and TLG in the malignant group were higher than those in the benign group. The differences were all statistically significant (all P<0.0001). In distinguishing benign from malignant lesions, the area under the ROC curve (AUC) for SUVmax was 0.919, which was the largest, and the Youden index was 0.762, indicating 83.3% sensitivity and 92.9% specificity. The AUC for SUVpeak was 0.905 and that for SUVmean was 0.899. The aforementioned AUCs were significantly higher than those for MTV and TLG (0.609 and 0.786, respectively) (P<0.001). On the whole, the present study demonstrates that MRI is a reliable imaging technique for the diagnosis of intravertebral lesions. ^{18}F-FDG PET/CT, as a noteworthy supplement to MRI, has a high sensitivity and accuracy for the qualitative diagnosis and identification of lesions. The synergistic effect of the two examination techniques may be helpful for a more accurate diagnosis.

Introduction

The vertebral canal is the tissue formed by the vertebral foramen of the vertebral body and the sacral canal of the sacrum, which is connected to the foramen magnum and reaches down to the sacral hiatus. It contains the spinal cord, spinal cord peritoneum, nerve roots, blood vessels and a small amount of connective tissue. There are multiple types of lesions in the spinal canal, which can originate from the aforementioned different tissues. According to their positional association with the spinal cord and dura mater, they can be classified into intramedullary, extramedullary subdural and epidural lesions. Astrocytoma and ependymoma are the most common intramedullary lesions, while neurilemmoma and meningioma are the most frequent extramedullary subdural lesions. Metastases and lymphomas are common in epidural space lesions, which are comprised mainly of congenital tumors, such as teratomas and dermoid cysts (1).

Digital radiography (DR) and computer tomography (CT) are not suitable for intravertebral lesions and have certain difficulties as regards their diagnosis, while magnetic resonance imaging (MRI) can display the morphological information of the spinal vertebrae and spinal cord by its high soft-tissue resolution. Based on the accurate localization of the lesion, coupled with the MRI signal characteristics and enhancement mode, the accurate diagnosis of the majority of lesions can be achieved. This technique is widely used in clinical applications and is usually the preferred examination technique for intravertebral lesions (2).

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Positron emission tomography (PET)/CT is a non-invasive imaging technique that provides crucial information on tissue function and metabolism, and accurately displays anatomical structures and localizes lesions. It is often used to assess the malignancy of tumors, the post-treatment response, or to identify tumor recurrence and necrotic tissue. It also has the advantages of an enhanced sensitivity, accuracy and safety (3,4). Fluorine-18 (^{18}F)-fluorodeoxyglucose (FDG) is a commonly used radiotracer to identify tumors.

The two aforementioned examination techniques have unique advantages in the clinical diagnosis of benign and malignant intraspinal lesions. However, to date, to the best of our knowledge, comparative studies on PET/CT and MRI are limited (2,5). Thus, the aim of the present study was to retrospectively analyze the imaging data of 58 cases with lesions examined using sequential MRI and ^{18}F-FDG PET/CT scans in order to compare their value in the diagnosis and differentiation of intravertebral lesions.

Patients and methods

Patients. The present retrospective study was approved by Review Committee of the 4th People's Hospital of Shenyang and all patients enrolled gave informed consent. The inclusion criteria were as follows: i) Patients who had undergone MRI (or enhanced MRI) and ^{18}F-FDG PET/CT examinations successively from January, 2017 to December, 2020 (the interval between two examinations did not exceed 10 days); ii) final diagnosis was obtained by performing a post-operative pathological examination or following a tissue biopsy; and iii) clinical, imaging and pathological data were complete. The exclusion criteria were the following: i) No consent provided for surgery; or ii) patients with incomplete clinical or imaging data. Finally, a total of 58 cases were enrolled. The patients were aged 14-82 years of age, of which 9 patients had a history of malignancy. All of them were post-operative reviews, which included four cases of lung cancer, two cases of breast cancer, and one case of gastric, liver and esophageal cancer, respectively. The majority of patients presented with varying degrees of limb pain and sensory disorders, walking disorders, and even paralysis in severe cases.

MRI and PET/CT acquisition. MRI (GE Signa HDxt 3.0T machine) routine scanning sequences were as follows: Sagittal T1WI fast spin echo (FSE) repetition time (TR)/echo time (TE), 300/8.04 msec; T2WI FSE TR/TE, 2,760/127.12 msec; Field-of-view (FOV), 360/340 mm; transverse T2WI SE TR/TE, 3,500/109.62 msec; FOV, 160/140 mm; matrix, 512x512; fractional anisotropy (FA), 90; layer thickness, 3 mm; layer spacing, 3.5 mm. The contrast agent (Gd-DTPA-BMA, OmniScan, GE Healthcare Ireland) 0.2 mmol/kg was injected through the elbow vein at a flow rate of 2 ml/sec, for T1 FSE + C transverse-axis (TR/TE, 380/13.96 msec), coronal (TR/TE, 380/8.02 msec) and sagittal (TR/TE, 700/9.46 msec) with layer thickness of 3 mm and a layer spacing of 3.3/3.5 mm.

Prior to PET/CT (GE Discovery PET/CT Elite, GE Healthcare; Cytiva) scan, the patients were injected intravenously with ^{18}F-FDG (prepared by GE MINItrace™ II, GE Healthcare; Cytiva; with a chemical purity of >96%) through the elbow according to the body mass of 3.7 MBq/kg. The patients then lay flat for 60 min, and images were collected from the upper femoral trunk to the cranial apex, 3-5 min/bed. PET scanning used a 3D model and point spread function acquisition and a matrix of 192x192. The spiral CT scanning parameters were as follows: 120-140 kV, 30-210 mA and a layer thickness of 3.25 mm. Following CT attenuation correction and iterative image reconstruction, the PET, CT and PET/CT fusion images of the whole body were obtained.

The region of interest (ROI) on the PET/CT images was automatically outlined using the post-processing workstation PET VCAR AW4.5 (GE Healthcare; Cytiva) to obtain the maximum standardized uptake value (SUVmax), peak standardized uptake value (SUVpeak), mean standardized uptake value (SUVmean), metabolic tumor volume (MTV) and total lesion glycolysis (TLG). The TLG was calculated as follows: TLG=SUVmean x MTV (cm^3) (6), with SUVmax >2.5 as the reference threshold for determining the radio concentration (7). A tissue biopsy, post-operative pathology, or follow-up results were used as the gold standard. Two radiologists (WS and WT), each with >10 years experience and holding dual licenses in radiology and nuclear medicine, analyzed the MRI and PET/CT images and negotiated in the case of any disagreement. The case was then examined and verified by a senior doctor who made the final judgment.

Statistical analysis. SPSS (version 26.0, IBM Corp.) software was used for data analysis. The sensitivity, specificity, accuracy, positive predictive value and negative predictive value of MRI and ^{18}F-FDG PET/CT were calculated, respectively. Count variables were compared using the χ^2 test. The normality of quantitative data were evaluated using Shapiro-Wilk tests, and are expressed as mean ± SD or as the median (P50), 25th percentile (P25) and 75th percentile (P75). The values of PET metabolic parameters SUVmax, SUVpeak, SUVmean, MTV and TLG were calculated for the benign and malignant groups, respectively. Normally distributed data were compared using the t-test or Fisher's test, while the Mann-Whitney U test was used for non-normally distributed data. The diagnostic performance was assessed by receiver operating characteristic curve (ROC) analysis, and the cut-off value of maximum performance evaluated using the Youden index. $P<0.05$ was considered to indicate a statistically significant difference.

Results

A total of 58 patients who met the inclusion criteria were included in the present study, including 33 males and 25 females with an average age of 56.71±16.16 years (Table I). The samples included 30 cases with malignant intraspinal lesions, 19 cases of metastasis (MRI and PET/CT images of one such case are presented in Fig. 1), nine cases of lymphoma, one case of glioblastoma multiforme and one case of melanoma. There were 28 cases of benign intraspinal lesions, including six cases of schwannoma (MRI and PET/CT images of one such case are presented in Fig. 2), five cases of meningioma, four cases of myelitis, two cases each of neurofibroma, abscess, chronic inflammation with fibromatous hyperplasia and spinal cord edema, and one case of diffuse astrocytoma, pilocytic astrocytoma, teratoma, sacral cyst and tuberculosis (Table I).

Table I. Characteristics of the patients in the present study.

Characteristic	Value (n=58)
Sex	
Female	25
Male	33
Age in years, mean (range)	56.71±16.16 (14-82)
Tumor volume (metabolic tumor volume), mean (range)	9.95±9.06 (2.42-42.51)
Histological type, n (%)	
Metastasis	19 (32.8%)
Lymphoma	9 (15.5%)
Glioblastoma multiforme	1 (1.7%)
Melanoma	1 (1.7%)
Schwannoma	6 (10.3%)
Meningioma	5 (8.6%)
Myelitis	4 (6.9%)
Neurofibroma	2 (3.4%)
Abscess	2 (3.4%)
Chronic inflammation with fibromatous hyperplasia	2 (3.4%)
Spinal cord edema	2 (3.4%)
Diffuse astrocytoma	1 (1.7%)
Pilocytic astrocytoma	1 (1.7%)
Teratoma	1 (1.7%)
Sacral cyst	1 (1.7%)
Tuberculosis	1 (1.7%)

The comparison between PET/CT and MRI as regards the detection rate and diagnostic efficacy of benign and malignant intravertebral lesions is detailed in Table II. The specificity of MRI was higher than that of PET/CT, with a significant difference ($P<0.05$). The accuracy and positive predictive value of MRI in the diagnosis were slightly higher than those of PET/CT; in addition, the sensitivity and negative predictive value of PET/CT were higher than those of MRI (Table II), although these differences were not statistically significant ($P>0.05$).

The mean ± SD values of the PET metabolic parameters, SUVmax, SUVpeak, SUVmean, MTV and TLG, in the benign and malignant groups were 4.27±1.25, 3.49±1.07, 2.49±0.84, 6.58±5.36 and 17.12±15.50 in the benign, and 8.99±3.75, 7.35±3.26, 5.43±2.40, 12.25±12.18 and 112.41±85.98 in the malignant groups, respectively (Table III). The SUVmax, SUVpeak, SUVmean and TLG were higher in the malignant group than in the benign group, with statistically significant differences (all $P<0.0001$). However, there was no statistically significant difference in MTV ($P=0.154$) between the groups.

As regards the diagnostic efficacy between the malignant and benign groups, the area under the ROC curve (AUC) for SUVmax was 0.919, which was the largest, with a Youden index of 0.762, and 83.3% sensitivity and 92.9% specificity. In addition, the AUC for SUVpeak was 0.905, with a Youden index of 0.726, and 83.3% sensitivity and 89.3% specificity. The AUC for SUVmean was 0.899, with a Youden index was 0.621, and 80.0% sensitivity and 82.1% specificity. The AUCs of the aforementioned three parameters were significantly greater than those of MTV and TLG (0.609 and 0.786, respectively; $P<0.001$), and there was no significant difference among the three ($P>0.05$; Table III and Fig. 3).

Discussion

Given that the treatment and prognosis of various benign and malignant lesions in the spinal canal are differ greatly, the early diagnosis and assessment of their properties are essential in clinical practice. Early diagnosis facilitates the selection of individualized treatment schemes and improves the quality of life of patients with cancer. Traditional techniques, such as DR and CT are usually not sufficient to correctly identify spinal canal or spinal cord lesions. With the continuous development of medical imaging technology, it has become possible to effectively identify benign or malignant intraspinal lesions using MRI and PET/CT (2,4,5).

MRI is the preferred examination technique for evaluating intravertebral lesions due to high soft-tissue resolution, and multi-sequence and multimodality. Therefore, MRI plays a prominent role in clinical practice. The present study found that the accuracy, sensitivity, specificity, positive predictive value and negative predictive value of MRI were 82.8, 83.3, 82.1, 83.3 and 82.1%, respectively, which was similar to values previously reported (8). Conventional MR sequences distinguish neoplastic from non-neoplastic lesions mainly based on lesion location, signal intensity and morphological criteria (9). Alternatively, in multiple conditions, intravertebral lesions caused by various etiologies have a similar morphology, signal manifestations, or enhancement patterns on MRI, which are prone to produce similar imaging results, rendering the diagnosis very challenging or even leading to misdiagnosis (2). For instance, some benign lesions are large, have mixed T1 and T2 signals and infiltrative growth, which cannot be easily distinguished from malignant tumors. In the present study, in the 30 cases of malignant lesions, MRI misdiagnosed two metastases as astrocytomas, two cases of lymphoma as schwannoma, and one case of melanoma as meningioma. On the other hand, PET/CT correctly diagnosed two of them (one lymphoma and one metastasis) as malignant lesions, considering the abnormal concentration of FDG metabolic radioactivity.

With the rapid development of PET/CT in recent years, its clinical application has been widespread for the detection of malignant tumors, and to differentiate between neoplastic and non-neoplastic lesions. Particular advantages are the ability to assess the grading of brain tumors, identify tumor recurrence and radiation necrosis following radiotherapy with 'one-stop' evaluating anatomical structure and systemic functional metabolism (10). Previous studies on intraspinal tumors (mesenchymal astrocytomas, ventricular meningiomas, etc.) have confirmed the feasibility of PET/CT in intradural lesions and that it can further improve the diagnostic efficiency (10,11). In addition, relevant studies (12,13) have also demonstrated that PET/CT combines the advantages of the high sensitivity of PET for the detection and accurate anatomical localization of CT, and can simultaneously evaluate soft tissue involvement. This is of particular value in the diagnosis of intradural and vertebral metastases with a higher sensitivity than MRI,

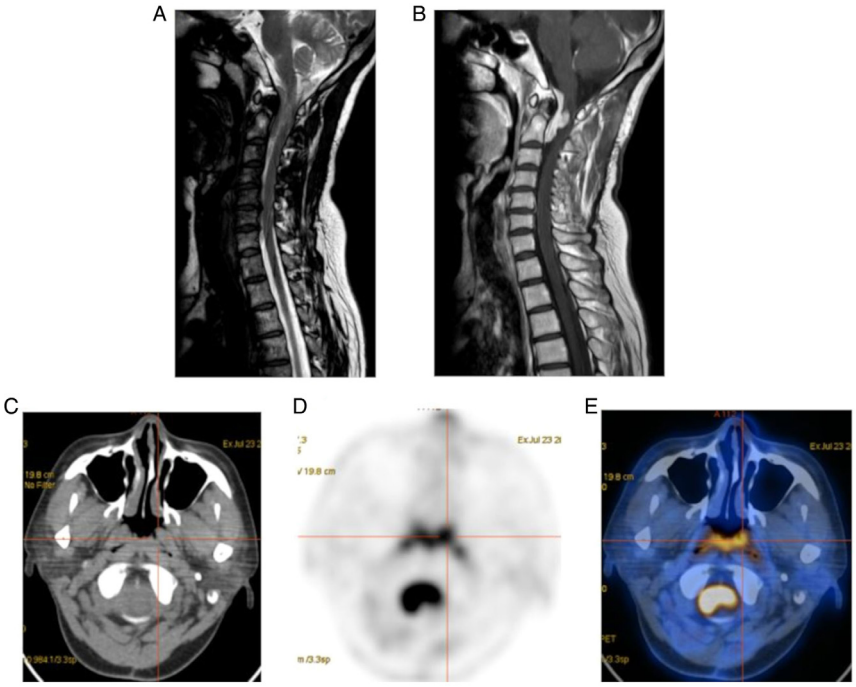

Figure 1. Female patient, 48 years of age, reviewed after breast cancer surgery. (A) Sagittal T2WI; (B) sagittal T1WI + C showing an irregular T1WI, low T2WI, slightly high signal mass in the medulla oblongata and anterior to the spinal cord at the level of cervical 1-2. The enhanced scan reveals a significant enhancement, spinal cord compression, poorly demarcated from the lesion, and localized signal elevation. (C) Transverse CT; (D) transverse PET; (E) PET-CT fusion image showing a slightly hyperdense occupancy with a CT value of ~55 HU and a significantly increased FDG metabolism at the level of cervical 1-2 spinal canal with maximum standardized uptake value, 17.35; peak standardized uptake value, 15.8; mean standardized uptake value, 10.63; metabolic tumor volume, 23.13 and total lesion glycolysis, 245.872. Metastasis was considered in the MRI and PET/CT of this case, which was confirmed by a post-operative pathological examination combined with immunohistochemistry. PET, positron emission tomography; CT, computed tomography.

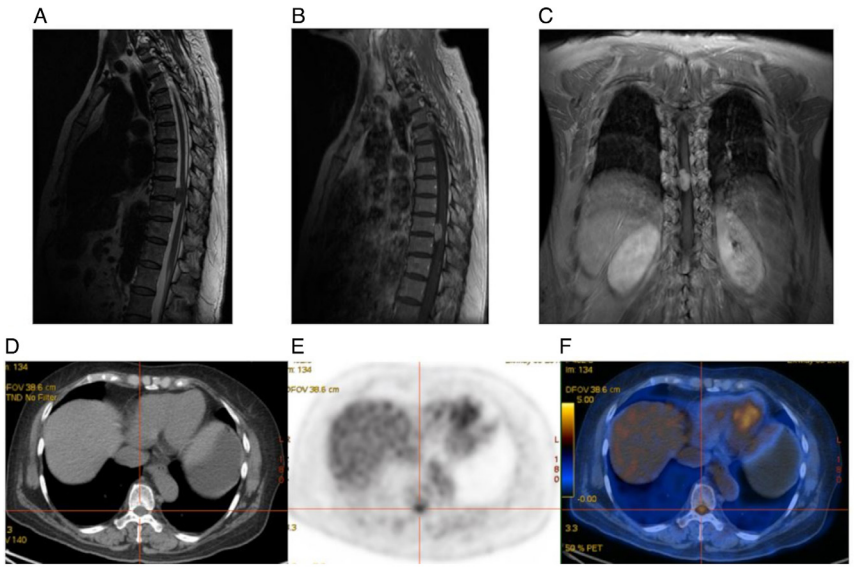

Figure 2. Female patient, 60 years of age, with numbness in both lower limbs and paresthesia. (A) Sagittal T2WI; (B) sagittal T1WI + C; (C) coronal T1WI + C showing a nodular T1 low T2 low signal shadow with clear borders in the extramedullary dura at the level of thoracic 9-10 vertebrae, with adjacent spinal cord compression, and significant enhancement with more uniform enhancement. (D) Transverse CT; (E) transverse PET; and (F) PET-CT fusion images showing slightly heterogeneous density within the thoracic 9-10 spinal canal, no significant enlargement, no destruction of adjacent bone, mildly increased FDG metabolism; maximum standardized uptake value, 3.71; peak standardized uptake value, 3.57; mean standardized uptake value, 2.46; metabolic tumor volume, 4.39; and total lesion glycolysis, 10.799. Meningioma was considered in the MRI and PET/CT, and the post-operative pathological diagnosis was schwannoma. PET, positron emission tomography; CT, computed tomography.

providing richer imaging information for clinical diagnosis and treatment.

The present study demonstrated that PET/CT had a high diagnostic efficacy with a sensitivity of 90.0%, an accuracy of 77.6%, and a negative predictive value of 85.7% for the diagnosis of intravertebral lesions. Among the 30 malignant lesions, 27 cases were correctly diagnosed, apart from two cases of lymphoma and one case of a metastatic tumor with

Table II. Comparison of the diagnostic efficacy of PET/CT and MRI for benign and malignant intravertebral lesions.

Technique	Group	Gold standard		Total (n=58)	Sensitivity	Specificity	Accuracy	Positive predictive value	Negative predictive value
		Malignant (n=30)	Benign (n=28)						
MRI	Malignant	25	5	30	83.3%	82.1%	82.8%	83.3%	82.1%
	Benign	5	23	28					
PET/CT	Malignant	27	10	37	90.0%	64.3%	77.6%	72.9%	85.7%
	Benign	3	18	21					
P-value					0.062	0.002	0.485	0.312	0.527

Post-operative pathological results or tissue biopsy were used as the gold standard. MRI, magnetic resonance imaging; PET/CT, positron emission tomography/computed tomography.

Figure 3. In the diagnostic efficacy between malignant and benign groups, the AUC for SUVmax (0.919) was the largest, with a Youden index of 0.762, and 83.3% sensitivity and 92.9% specificity; the AUC for SUVpeak was 0.905 and that for SUVmean was 0.899; the AUCs of the first three were also significantly greater than those of MTV and TLG (0.609 and 0.786; P<0.001). AUC, area under the ROC curve; SUVmax, maximum standardized uptake value; SUVpeak, peak standardized uptake value; SUVmean, mean standardized uptake value; MTV, metabolic tumor volume; TLG, total lesion glycolysis.

an insignificant increase in FDG metabolism, which led to a false-negative diagnosis. False-negatives may be due to highly differentiated or low-grade malignant tumors with poor FDG metabolism or sparse radioactive distribution. Primary intramedullary lymphoma is rare, accounting for only 1% of central nervous system lymphomas. PET/CT shows intravertebral occupations that may involve adjacent vertebral and paravertebral areas. Metastases usually have a history of malignancy, presenting in multiple nodular lesions, which can be accompanied by vertebral and accessory bone destruction and perineural edema. Both pathologies exhibit an increased FDG uptake; however, intradural astrocytomas and schwannomas usually have a lower FDG uptake than lymphomas or metastases (14,15). False-positives of PET/CT imaging in intraspinal lesions are primarily due to tuberculosis, abscess, inflammatory demyelinating lesions (16,17), where FDG metabolism levels are generally increased. Intramedullary tuberculoma is rare, with a low or slightly high density, single or multiple nodules, ~1 cm in diameter, a circumferential or homogeneous enhancement, and a high FDG uptake. PET/CT is helpful for determining cases involving tuberculosis of other systems and the extent of involvement; in spite of this however, it has limited specificity in distinguishing tuberculomas from tumors (16).

The findings of the present study demonstrated the sensitivity of PET/CT diagnosis was 90.0%, and the negative predictive value was 85.7%, which was higher than the MRI sensitivity (83.3%) and negative predictive value (82.1%). The PET/CT specificity (64.3%) and positive predictive value (72.9%) were lower than the MRI specificity (82.1%) and positive predictive value (83.8%). Compared with MRI, PET/CT has a higher sensitivity, particularly in screening metastases, where

Table III. Diagnostic efficiency of PET/CT parameters to differentiate between benign and malignant intravertebral lesions.

Parameter	Benign group	Malignant group	P-value	AUC (95% CI)	Youden index	Sensitivity (%)	Specificity (%)
SUVmax (g/ml)	4.27±1.25	8.99±3.75	<0.0001	0.919 (0.817-0.974)	0.7619	83.33	92.86
SUVpeak (g/ml)	3.49±1.07	7.35±3.26	<0.0001	0.905 (0.799-0.966)	0.7262	83.33	89.29
SUVmean (g/ml)	2.49±0.84	5.43±2.40	<0.0001	0.899 (0.792-0.963)	0.6214	80	82.14
MTV (cm^3)	6.58±5.36	12.25±12.18	P=0.154	0.609 (0.472-0.734)	0.2524	46.67	78.57
TLG (g/ml x cm^3)	17.12±15.50	112.41±85.98	<0.0001	0.786 (0.658-0.883)	0.4833	73.33	75

AUC, area under the ROC curve; SUVmax, maximum standardized uptake value; SUVpeak, peak standardized uptake value; SUVmean, mean standardized uptake value; MTV, metabolic tumor volume; TLG, total lesion glycolysis.

sensitivity is more valuable than specificity, as false-negative results often have severe consequences for patients, and delay timely and effective treatment. Mostardi *et al* (18), by linking PET and MR imaging features, also confirmed that PET could detect the majority of intramedullary metastases. Moreover, for the monitoring of post-operative and post-treatment changes in some cases, even with MRI with contrast enhancement, it can be challenging to assess recurrence. By contrast, FDG-PET can provide additional information in this regard. In patients diagnosed with benign astrocytoma or schwannoma by MRI, PET is also useful for follow-up. When the uptake of FDG increases, it may indicate a malignant transformation of the tumor (5,15).

The application of PET/CT in intravertebral lesions is limited, possibly due to the slightly lower spatial resolution of PET, whereas, with the continuous improvement of resolution, PET/CT can now clearly confirm the location. The mechanism of FDG uptake is complex, reflecting the process of glucose transport and consumption. Glucose depletion is related to tumor grade, cell attenuation and bioinvasiveness (19). The significant increase in FDG uptake highly suggests malignant tumors, although it may also occur in tissues with high cell proliferation, such as in aggressive benign tumors, inflammatory infections, etc. Unlike in brain tissue, an increased FDG uptake is not common in the normal spinal cord. The uptake of FDG by intraspinal lesions can be quantitatively evaluated. The most commonly used semi-quantitative index parameter of glucose metabolism is SUVmax, which is the largest SUV value of a single voxel in the target volume. It has a simple operation and good repeatability. The results of the present study indicated that the SUVmax, SUVpeak and SUVmean values were higher in the malignant group (8.99±3.75, 7.35±3.26 and 5.43±2.40, respectively) than in the benign group (4.27±1.25, 3.49±1.07 and 2.49±0.84, respectively) and the differences were statistically significant (all P<0.0001). In particular, in distinguishing the diagnostic efficiency, the AUC for SUVmax was 0.919, which was the largest, with a Youden index of 0.762, and a 83.3% sensitivity and 92.9% specificity. It was significantly higher than the AUC values for MTV or TLG (0.609 and 0.786, respectively; P<0.001). Similarly, the study by Tomura *et al* (11) revealed that benign intraspinal tumors exhibited a slight to moderate increase in FDG uptake, while malignant tumors, such as mesenchymal astrocytoma had an abnormally high SUVmax.

The present study has some limitations which should be mentioned. Retrospective analysis may result in selection bias. In addition, the current sample size was small; hence, further prospective studies with larger sample sizes are required. It is considered that the coordination effect of MRI and PET-CT will be higher than that of a single-mode, and the authors aim to closely plan any future studies.

In conclusion, as demonstrated in the present study, MRI remains a reliable examination for the diagnosis of benign or malignant intravertebral lesions. ^{18}F-FDG PET/CT, as a useful supplement, also has a high sensitivity and accuracy for the qualitative diagnosis and differentiation. The synergistic effect of both techniques reflects different aspects of the lesions and contributes to a more accurate diagnosis.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

FZ was involved in the conception and design of the study, in the writing of the original draft, and was a major contributor to the preparation of the manuscript. XW was involved in the literature research and in the statistical analysis. WS, WT and ZL were involved in image and data analysis, writing, reviewing and editing of the manuscript. FZ and XW confirm the authenticity of all the raw data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

All procedures performed in the present study involving human participants were in accordance with the ethical standards and declarations of Helsinki. The present retrospective

study was approved by Review Committee of the 4th People's Hospital of Shenyang (no. 2021-011) and all patients enrolled gave informed consent.

Patient consent for publication

For the images presented in the study, informed consent was obtained from the patients and descriptions with obvious indications of identity were removed.

Competing interests

The authors declare that they have no competing interests.

References

1. Xia LL, Tang J and Huang SL: Primary intraspinal benign tumors treated surgically: an analysis from China. Br J Neurosurg 1-4, 2021 (Epub ahead of print).
2. Watts J, Box GA, Galvin A, Van Tonder F, Trost N and Sutherland T: Magnetic resonance imaging of intramedullary spinal cord lesions: A pictorial review. J Med Imaging Radiat Oncol 58: 569-581, 2014.
3. Dammacco F, Rubini G, Ferrari C, Vacca A and Racanelli V: ^{18}F-FDG PET/CT: A review of diagnostic and prognostic features in multiple myeloma and related disorders. Clin Exp Med 15: 1-18, 2015.
4. Shen G, Ma H, Pan L, Su M and Kuang A: Primary spinal poorly differentiated neuroendocrine tumor displayed on FDG PET/CT. Clin Nucl Med 44: e586-e587, 2019.
5. Naito K, Yamagata T, Arima H, Abe J, Tsuyuguchi N, Ohata K and Takami T: Qualitative analysis of spinal intramedullary lesions using PET/CT. J Neurosurg Spine 23: 613-619, 2015.
6. Sher A, Lacoeuille F, Fosse P, Vervueren L, Cahouet-Vannier A, Dabli D, Bouchet F and Couturier O: 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 6: 21, 2016.
7. Duarte PS, Zhuang H, Castellucci P and Alavi A: The receiver operating characteristic curve for the standard uptake value in a group of patients with bone marrow metastasis. Mol Imaging Biol 4: 157-160, 2002.
8. Fawzy MF, Almassry HN and Ismail AM: What can be achieved by using MR-DWI and ADC value in cases of intramedullary spinal cord lesions of non-traumatic causes? Egyp J Radio Nucl Med 49: 711-718, 2018.
9. Kessler J, Pawha P, Shpilberg K and Tanenbaum L: Diffusion-weighted Imaging Facilitates Detection of Spinal Multiple Myeloma and Assists in Diagnosing Equivocal Lesions. Radiological Society of North America 2011 Scientific Assembly and Annual Meeting, November 26 - December 2, 2011, Chicago, IL. http://archive.rsna.org/2011/11001777.html. Accessed April 15, 2021.
10. Piroth MD, Pinkawa M, Holy R, Klotz J, Nussen S, Stoffels G, Coenen HH, Kaiser HJ, Langen KJ and Eble MJ: Prognostic value of early [18F]fluoroethyltyrosine positron emission tomography after radiochemotherapy in glioblastoma multiforme. Int J Radiat Oncol Biol Phys 80: 176-184, 2011.
11. Tomura N, Ito Y, Matsuoka H, Saginoya T, Numazawa SI, Mizuno Y and Watanabe K: PET findings of intramedullary tumors of the spinal cord using [18F] FDG and [11C] methionine. AJNR Am J Neuroradiol 34: 1278-1283, 2013.
12. Laufer I, Lis E, Pisinski L, Akhurst T and Bilsky MH: The accuracy of [(18)F]fluorodeoxyglucose positron emission tomography as confirmed by biopsy in the diagnosis of spine metastases in a cancer population. Neurosurgery 64: 107-113; discussion 113-4, 2009.
13. Schmidt GP, Schoenberg SO, Schmid R, Stahl R, Tiling R, Becker CR, Reiser MF and Baur-Melnyk A: Screening for bone metastases: Whole-body MRI using a 32-channel system versus dual-modality PET-CT. Eur Radiol 17: 939-949, 2007.
14. Martins ES, Duque C, Rebelo O and Batista S: Primary intramedullary spinal-cord lymphoma (PISCL): A rare entity with a challenging diagnosis. BMJ Case Rep 14: e242548, 2021.
15. Sahel OA, Bazine A, Nabih SO, Benameur Y, Biyi A and Doudouh A: Unsuspected intramedullary spinal cord metastasis detected by FDG PET/CT. Indian J Nucl Med 35: 353-354, 2020.
16. Liu M, Lu L, Liu Q, Bai Y and Dong A: FDG PET/CT in disseminated intracranial and intramedullary spinal cord tuberculomas. Clin Nucl Med 46: 266-269, 2021.
17. Liu Q, Liu M, Bai Y and Dong A: Solitary acute inflammatory demyelinating lesion of the cervical spinal cord mimicking malignancy on FDG PET/CT. Clin Nucl Med 45: 1023-1025, 2020.
18. Mostardi PM, Diehn FE, Rykken JB, Eckel LJ, Schwartz KM, Kaufmann TJ, Wood CP, Wald JT and Hunt CH: Intramedullary spinal cord metastases: Visibility on PET and correlation with MRI features. AJNR Am J Neuroradiol 35: 196-201, 2014.
19. Viel T, Talasila KM, Monfared P, Wang J, Jikeli JF, Waerzeggers Y, Neumaier B, Backes H, Brekka N, Thorsen F, *et al*: Analysis of the growth dynamics of angiogenesis-dependent and -independent experimental glioblastomas by multimodal small-animal PET and MRI. J Nucl Med 53: 1135-1145, 2012.