REVIEW

FDG Whole-Body PET/MRI in Oncology: a Systematic Review

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Abstract The recent advance in hybrid imaging techniques enables offering simultaneous positron emission tomography (PET)/magnetic resonance imaging (MRI) in various clinical fields. ^{18}F-fluorodeoxyglucose (FDG) PET has been widely used for diagnosis and evaluation of oncologic patients. The growing evidence from research and clinical experiences demonstrated that PET/MRI with FDG can provide comparable or superior diagnostic performance more than conventional radiological imaging such as computed tomography (CT), MRI or PET/CT in various cancers. Combined analysis using structural information and functional/molecular information of tumors can draw additional diagnostic information based on PET/MRI. Further studies including determination of the diagnostic efficacy, optimizing the examination protocol, and analysis of the hybrid imaging results is necessary for extending the FDG PET/MRI application in clinical oncology.

Keywords FDG · Oncology · PET/MRI · Positron emission tomography/magnetic resonance imaging
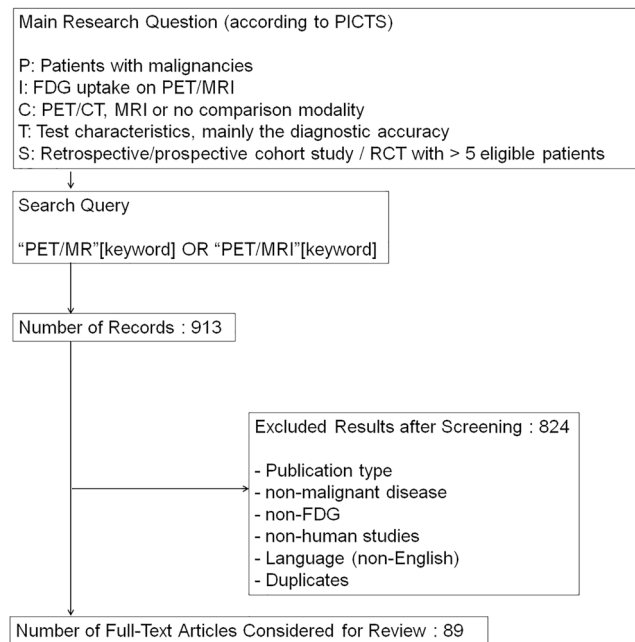
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Introduction

The new hybrid imaging modality, whole-body positron emission tomography (PET)/magnetic resonance imaging (MRI), has become more promising in oncologic and non-oncologic clinical fields. Comprehensive structural information from MRI and functional characteristics from PET can be obtained in a single session examination. PET scan using ^{18}F-fluorodeoxyglucose (FDG) has been an established modality in initial diagnosis, planning treatments, and monitoring patients in various cancers.

Measurement of glucose metabolism by PET/MRI showed reproducible results and the PET image quality from PET/MRI is not deteriorated when comparing with that from PET/CT scans [1–4]. Furthermore, PET/MRI provide superior soft tissue contrast to PET/CT and its roles for accurate diagnosis and evaluating therapeutic response in oncologic patients has been expanded [5, 6].

In this review article, the current status of hybrid FDG PET/MR imaging in malignancies is discussed.

Materials and Methods

A systematic literature search was based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement [7] (Fig. 1). The main research question was determined by the Eligible patients, Index test, Comparator/reference test, Target condition and Study design (PICTS) strategy [8, 9]. Literature searches using PubMed database were performed on October 10 and 29, 2015, by keyword "PET/MRI" and "PET/MR", respectively. Exclusion criteria of original articles were followed: 1) review papers, letters to the editor, abstracts, small case series that includes less than five patients, 2) patients with non-malignant disease, 3) radiotracers other than FDG, 4)

Main Research Question (according to PICTS)

P: Patients with malignancies
I: FDG uptake on PET/MRI
C: PET/CT, MRI or no comparison modality
T: Test characteristics, mainly the diagnostic accuracy
S: Retrospective/prospective cohort study / RCT with > 5 eligible patients

Search Query

"PET/MR"[keyword] OR "PET/MRI"[keyword]

Number of Records : 913

Excluded Results after Screening : 824

- Publication type
- non-malignant disease
- non-FDG
- non-human studies
- Language (non-English)
- Duplicates

Number of Full-Text Articles Considered for Review : 89

Fig. 1 The study-selection protocol in this review. PICTS strategy demonstrates the Eligible patients, Index test, Comparator/reference test, Target condition and Study design; *FDG* ^{18}F-fluorodeoxyglucose, *PET* positron emission tomography, *MRI* magnetic resonance imaging, *CT* computed tomography, *RCT* randomized controlled trial

non-human studies, 5) articles that were written in languages other than English, and 6) duplicated publications [10]. Representative cases were originated from previous research approved by the Institutional Review Board of our hospital (1306-055-495).

Retrospective Image Fusion of PET and MRI

Coregistration of PET and MRI from separated examinations has been studied for accurate detection of tumor lesions and additive diagnostic information provided by combination of anatomical and functional imaging. Earlier studies assessed spatial relationship between PET and MRI in brain imaging by development of spatial normalization technique. FDG PET enabled us to detect regional brain activation for pre-operative planning [11]. In this study, results of FDG PET scans after activation tasks of upper and lower extremities were compared with those of direct cortical stimulation by surgically placed electrodes. FDG PET could suggest a 95 % of diagnostic accuracy for detecting functional activation zone. FDG uptake of brain tumor is related with malignancy grade, and direct comparison of PET and MRI images provided additive diagnostic information such as tumor location, boundary, and heterogeneity [12–14].

Coregistration of PET and MRI in body part raises concern about quality of fused images in terms of global quality, alignment, and diagnostic confidence. Relatively good image quality can be achieved in head, thorax, and pelvic area [15]. In head and neck cancer, accurate T staging by fused PET/MRI was superior

to that by PET/CT (87 % vs. 67 %) and N staging by PET/MRI was superior to that by MRI (77 % vs. 63 %) [16]. The level of diagnostic confidence was higher in fused PET/MRI than in PET/CT (85.9 % vs. 70.3 %) [17]. PET/MRI coregistration reading showed additional diagnostic information that altered the management plan in 46 % of the study population and no additional information in 18 % in patients with thyroid cancer [18]. The image fusion of PET and MRI improved anatomic correlation of PET and MRI finding, but little effect was observed in view of decision making in pancreas cancer (one of eight patients having additive information by image fusion) [19]. Another study reported that fused PET/MRI improved diagnostic accuracy for pancreas cancer compared with PET/CT (96.6 % vs. 86.6 %) and showed additional findings, especially for cystic lesions [20]. T1-weighted images as well as T2-weighted images on MRI (93.0 and 90.7 %) were more helpful for increasing diagnostic accuracy than PET/CT (88.4 %) [21]. In one study, the sensitivity of fused PET/MRI for detecting liver metastases of colorectal cancer was 98.3 %, which is higher than that of PET/CT (84.2 %) [22]. Improvement of sensitivity in PET/MRI was not more significant than MRI [23]. In uterine cervical cancer, fused PET/MRI and non-fused PET/MRI showed higher diagnostic accuracy of T-staging (83.3 %) than PET/CT (53.3 %). Difference of diagnostic accuracy for N-staging between fused PET/MRI (90.0 %), PET/CT (90.0 %), and MRI (86.7 %) showed no statistical difference [24]. In endometrial cancer, fused PET/MRI showed better sensitivity for detecting myometrial invasion than PET/CT (90.5 % vs. 76.2 %) and metastatic lymph nodes than MRI (100 % vs. 66.7 %) [25]. Fused PET/MRI improved lesion depiction, localization, and quality of diagnosis more than PET/CT in gynecologic malignancy [26]. MR signal intensity assessment on fused PET/MRI improved diagnostic accuracy for pre-operative staging more than PET/CT in lung cancer (97.1 % vs. 85.0 %, respectively) [27].

Image fusion of PET and MRI can enable us to localize metabolically active tumor focus exactly. One study reported that the histopathologic response to neoadjuvant chemotherapy was significantly correlated with high standardized uptake value (SUV) on residual tumor tissue in patients with osteosarcoma [28]. In addition to the maximum SUV, metabolic tumor volume on FDG PET aided by volume measure on MRI had a further predictive value of chemotherapy response in patients with osteosarcoma [29].

Diagnostic Performance of Hybrid PET/MR Imaging in Major Cancers

Head and Neck Cancer

Early PET/MRI study has been applied in diagnosis of Head and Neck (HN) cancer because of MRI information for accurate T staging and development of prototype hybrid PET/MRI

scanner. PET scans acquired from PET/MRI scanner showed better image resolution in comparison to PET/CT scans, and results of FDG uptake in normal tissue and tumor were highly correlated between PET/MRI and PET/CT [30].

Precise diagnosis and staging of HN cancer is important for planning treatment modality such as radical surgery and/or combined chemoradiation therapy. PET/MR provided more accurate T staging of HN cancer than PET/CT and MRI (75, 59, 50 %, respectively), but could not achieve statistical significance. N staging results also showed no significant difference between these modalities [31]. One study reported that PET/MRI increased sensitivity for detecting cervical lymph node metastasis over MRI only (89.5 % vs. 65.8 %, respectively) but there was no significant difference with standalone PET (86.8 %) [32]. In another study, diagnostic performance of PET/MRI showed 80.5 % of sensitivity, 88.2 % of specificity, 75.6 % of positive predictive value (PPV), and 92.5 % of negative predictive value (NPV) and those of PET/CT showed 82.7, 87.3, 73.2, and 92.4 %, respectively [33].

Detecting lymph nodes and/or distant metastases of HN cancer is comparable between PET/MRI and PET/CT (k value of interreader agreement of 0.85 and 0.70) [34]. Another study reported that combined PET/MRI using regional PET images increased sensitivity for a suspicious metastatic lymph node resulting in re-classification of stage in two of ten patients [35]. CT scans have limitation for evaluating oral cavity lesion when metallic and/or dental artifact exists. One study showed that most artifacts are noted in the suprahyoid region in CT and infrahyoid region in MRI [36]. PET/CT and PET/MRI would be considered as alternative diagnostic modality of HN cancer according to the location of primary tumor (Fig. 2).

Advanced MRI techniques can provide multiple parameters of tumor such as perfusion index (K^{trans}, k_{ep}) and cell density (apparent diffusion coefficient (ADC), Ve). One study reported a significant correlation between the region of interest (ROI) area, SUV, and metabolic parameters such as metabolic tumor volume (MTV) measured from PET/CT and PET/MRI. ADC value showed significant negative correlation with both of K^{trans} and SUV [37]. However, another study showed that adding diffusion weighted imaging (DWI) sequence in PET/MRI examination did not improve diagnostic accuracy more than PET/MRI without DWI (84.0 % vs. 86.7 %, respectively) [38].

FDG PET/CT has been a useful modality for evaluating histopathologic differentiation and monitoring of recurrence in patients with differentiated thyroid cancer (DTC) [39]. In DTC, PET/MRI showed equal performance of detecting local relapse, lymph node, and bone metastases. However, PET/CT was superior to PET/MRI to detect pulmonary metastatic lesions [40].

Breast Cancer

MRI has shown high diagnostic accuracy for primary breast cancer lesions. PET/CT has established modality for the detection of lymph node and/or distant metastasis of breast cancer. Hence, simultaneous PET/MRI has been evaluated for the improvement of diagnostic performance in breast cancer.

One study reported that PET/MRI and MRI provided identical performance for correct T-staging (82 %) and were superior to PET/CT (68 %). For the N-staging, PET/MRI showed similar results of diagnostic accuracy with PET/CT (86 % vs. 88 %) and tended to be higher than MRI (80 %) [41]. Another study showed that PET/MRI provided lower sensitivity for primary tumor than MRI (77 % vs. 100 %), but higher specificity (100 % vs. 67 %). For the N-staging, difference between PET/MRI and MRI was not statistically significant [42].

PET/MRI showed superior sensitivity to PET/CT for detecting bone metastasis of breast cancer (0.96 vs. 0.85) [43]. PET/MRI mammography using dedicated radiofrequency coil for breast improved detection sensitivity of breast cancer

Fig. 2 (**a**) The maximal intensity projection (MIP) image of whole-body PET in patient with right tonsil cancer. The post-contrast computed tomography (CT) (**b**) and T1-weighted MR image (**c**) showed moderately enhanced cervical lymph nodes in bilateral neck. On the contrary, PET image (**d**) and fusion image (**e**) showed focal hypermetabolism in right cervical lymph node (*red arrow*). This lymph node was pathologically proven as a metastatic node
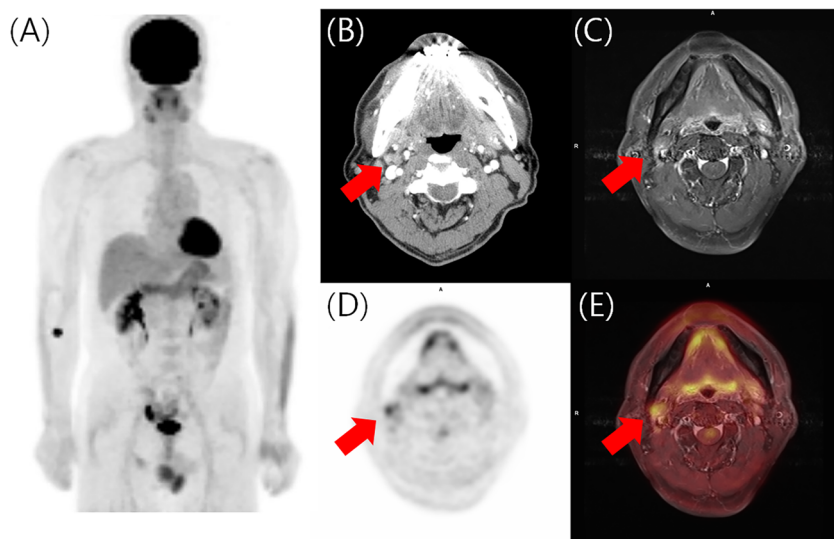
lesions more than PET alone or whole-body PET/MRI images (100, 79.2, 87.5 %, respectively) [44].

Cancer in Gastrointestinal Tract and Abdomen

The recent technical advances of PET/MRI modality allow improved diagnostic accuracy of malignancies in intraabdominal organs. Advanced MRI protocols including dynamic contrast scans and diffusion weighted imaging provided could provide higher diagnostic confidence of liver metastasis, and additive information for FDG non-avid lesions [45]. Sensitivity and NPV of PET/MRI has been reported to be 92.2 and 95.1 %, higher than those of PET/CT (sensitivity 67.8 % and NPV 82.2 %, respectively). Non-enhanced fast T1 weighted MR imaging showed superiority to low-dose CT in terms of conspicuity rating in liver lesions [36]. Benign lesions of liver as well as metastatic lesions were better characterized by PET/MRI than PET/CT [46] (Fig. 3).

PET/MRI showed detailed information for initial staging of colorectal cancer. Accurate identification of disease involvement in mesorectal fat and/or fascia allow an accurate plan for patient management. PET/MRI also provided comparable diagnostic accuracy for N and M staging with PET/CT (true positive findings in 86 % vs. 71 %, respectively) [47]. In initial diagnosis and clinical follow-up, metastasis of colorectal cancer occurs in lymph nodes, peritoneum, and distant organ. Comprehensive PET/MRI study improved diagnostic accuracy of liver metastasis more than PET/CT (0.74 vs. 0.56) and peritoneal seeding more than MRI (0.55 vs. 0.37) [48]. In this study, diagnostic accuracy of mucinous cancer decreased when comparing non-mucinous cancer even with PET/MRI (0.52 vs. 0.76). Further investigation will be needed to improve diagnostic accuracy of mucinous tumors.

Incidentalomas from cysts to malignancy in abdominal organs are frequently detected in whole-body and/or abdominal imaging. PET/MRI can detect a greater number of incidental

findings than PET/CT (635 vs. 407), and reduce the indeterminate diagnostic finding [49].

## Gynecologic Cancer and Pelvic Malignancy

High soft tissue contrast information from MRI provides greater improvement of primary tumor delineation by PET/MRI than PET/CT in terms of tissue invasion, relation to surrounding structures, and characterization [50]. In patients with suspected recurrence of cervical or ovarian cancer, detection rate of malignant lesion was higher in simultaneous PET/MR imaging than MRI alone (98.9 % vs. 88.8 %) and diagnostic confidence increased in PET/MRI more than MRI or PET/CT [51, 52]. MR DWI and ADC imaging show increases in tissue cellularity and improve the diagnostic confidence in differentiating malignancy from benign [53]. However, recent study showed that DWI had no additional information for diagnosis of pelvic malignancy [54]. Optimized PET/MRI study for whole-body MRI can be applied to oncologic patients for accurate diagnostic information and reduced examination time [55, 56].

FDG PET/CT has limitation for evaluation of bladder cancer because of urinary FDG activity and possible misregistration of PET and CT images due to time-delay between image acquisitions. Simultaneous PET/MRI acquisition reduced misregistration of bladder wall, mass, and pelvic lymph nodes resulting in improvement of diagnostic confidence [57].

Lung Cancer

Accurate diagnosis and staging of non-small cell lung cancer (NSCLC) is needed to decide treatment modality such as surgery and/or concurrent chemoradiation therapy. FDG PET/CT showed high diagnostic accuracy in NSCLC although limited specificity in false-positive lymph node. PET/MRI showed high diagnostic accuracy for lymph node metastasis of NSCLC when comparing with PET/CT (concordance rate of 91 %) [58]. Another study reported that diagnostic

Fig. 3 This patient with treated breast cancer underwent PET/MRI examination for evaluation of hepatic metastases (**a** MIP image of PET). (**b**) Delayed-phase (10 min) of post-contrast MR image revealed additional hepatic metastasis lesion (*white arrow*) without hypermetabolism (**c** PET). Furthermore, whole-body PET/MR imaging enabled us to detect asymptomatic brain metastasis (*red arrow*) (**d** apparent diffusion coefficient image; **e** PET)
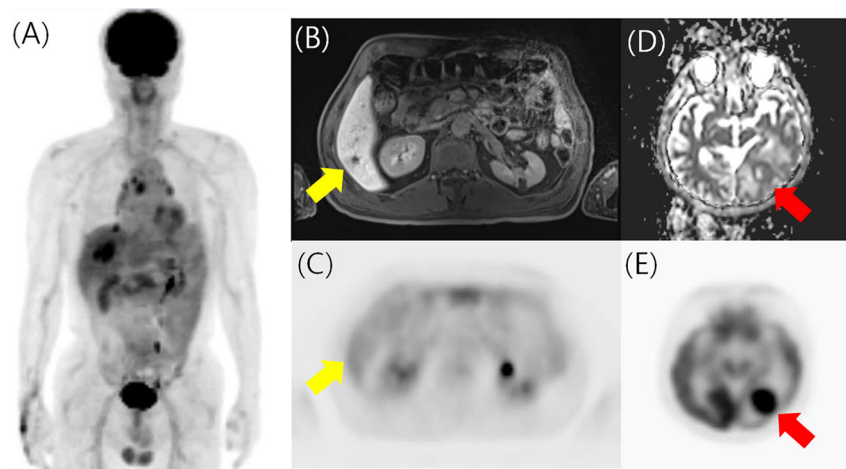
performance of PET/CT for N staging is a sensitivity of 0.75, specificity of 0.79, PPV of 0.75, NPV of 0.79, and 0.70, 0.75, 0.71, 0.73 for PET/MRI, respectively [59]. Diagnostic accuracy for intial staging was not significantly different in PET/MR and PET/CT [60–62].

The size of the pulmonary nodule is a significant factor for evaluating the diagnostic performance of MRI [63]. The detection rates for small nodules less than 1 cm in diameter on MR images were only 27.3 and 45.5 % of diagnostic CT images when using Dixon volume interpolated breath hold examination (VIBE) sequence, respectively [64]. Non-FDG avid small lung nodules less than 1 cm are usually only detected on CT scan of the PET/CT. Low signal-to-noise ratio for detecting small nodules in aerated lung is a limitation of PET/MR application in lung cancer. However, one study reported that the 96.4 % (81/84) of small non-FDG avid lung nodules missed on PET/MRI showed benign clinical courses such as resolved or stable status [65]. To overcome the size effect, a free-breathing ultrashort echo time (UTE) sequence has been evaluated in patients having small metastatic lung nodules. UTE sequence showed a higher detection rate for lung nodules with small size, non-FDG avid, not-subpleural location ($p < 0.001$) [66]. On the other hand, one study reported that post-contrast VIBE sequence images of MRI could not improve detection rate of pulmonary nodules more than non-contrast VIBE images (jackknife alternative free-response receiver-operating-characteristics value of 0.848 vs. 0.837, respectively) [67].

Others

Diagnosis of bone metastasis in oncologic patients has been crucial for treatment planning and predicting prognosis. Nevertheless, systemic development of bone metastasis is hard to detect by regional anatomic imaging. Whole-body PET/MR showed better detection rate of malignant bone lesions than PET/CT (100 % vs. 94 %), whereas diagnostic confidence of benign bone lesions was higher in PET/CT [68]. MR T1-weighted images in PET/MRI provided more conspicuous results for delineating and differentiating bone lesions than CT [69, 70]. Chemotherapy-related change of

metabolic activity and fat density in proximal bone marrow can be evaluated by PET and MRI [71].

PET/MR imaging has been regarded as a promising alternative modality in pediatric oncologic patients due to reduced radiation exposure. The effective dose from PET/MR examination was about 20~50 % that of PET/CT examinations [72–74]. Despite the SUV decrease in bone marrow in PET with MR-based attenuation correction method, lesion detection performance of PET/MR showed comparable to that of PET/CT (61 focal uptakes among 62 focal uptakes on PET/CT) [73]. Single PET/MR examination could result in a potential change of management plan in five of nine patients based on superior soft tissue contrast of MRI than that of CT [74].

The clinical usefulness of MR or PET/MR has not been clear for diagnosis and staging of lymphoma. One study reported that the sensitivity and specificity of PET/MR were 93.8 and 99.4 % based on the standard of reference [75]. Simultaneous PET/MR imaging identified nodal involvement of lymphoma with higher sensitivity than that of DWI (100 % vs. 62.7 %) and correctly diagnosed bone marrow involvement which was missed by PET/CT scan [76].

Cardiac MR imaging has been essential in the diagnosis of cardiac disease including tumors. Hybrid PET/MR imaging provides the diagnostic cut-off value by FDG PET and morphologic characterization of tissue by MRI, which yields 100 % of sensitivity and 100 % of specificity for differentiating malignancy from benign lesions [77]. PET/MR can provide acceptable diagnostic accuracy for T staging (66.7 %) and better accuracy for N staging (83.3 %) than endoscopic ultrasonography (EUS) or PET/CT in esophageal cancer [78].

Consideration for Study Protocol

In recent technical advances of MRI acquisition, PET/MRI examination protocol will be optimized to the patient's indication with reducing the examination time (Tables 1 and 2). Earlier study reported that simultaneous acquisition of PET and MRI could be adopted with high image quality and short acquisition time of less than 20 min including whole-body coronal 2-point

Table 1 Acquisition parameters of clinical torso PET/MRI study (used at the Seoul National University Hospital)

Whole-body protocol	Acquisition time (min)	TR/TE (ms)	FOV (mm)	Acquisition matrix (pixels)	Resolution (mm)
Reference scan (FastView)	0:00:28	2.56/1.44	–		–
Axial VIBE Dixon	0:01:05	3.40/1.22	380	195 × 320	1.6 × 1.2
Coronal T2 HASTE	0:03:00	1200/72	450	181 × 384	1.7 × 1.2
Coronal T1	0:03:00	480/8.8	450	202 × 384	1.7 × 1.2
PET (5 bed × 3 min/bed)	0:15:00	–	594	172 × 172	4.2 × 4.2

HASTE half Fourier acquisition single shot turbo spin echo, *VIBE* volume interpolated breath hold examination

Table 2   Organ-specific MRI sequences for PET/MRI

Organ	Sequences					Total study time
Liver	T2 HASTE axial	T2 TSE FS axial	Diffusion* (echo planar)	Dynamic (pre, arterial, portal, delayed)	15 min delayed axial, coronal	29 min
Nasopharynx	T1 axial, coronal	T2 coronal	T2 axial STIR	Diffusion (echo planar)	Post-contrast axial, coronal, sagittal	28 min
Pelvis	Upper abdomen T1 axial	T2 axial, Coronal, sagittal	Diffusion (echo planar)	Dynamic (pre, 1, 3, 5 min)	T1 sagittal	22 min
Musculoskeletal	T1 axial, coronal	T2 axial	T2 sagittal SPAIR	Pre axial and post axial, coronal (FS)		20 min

FS fat saturation, *HASTE* half Fourier acquisition single shot turbo pin echo, *SPAIR* spectral attenuation inversion recovery, *STIR* short T1 inversion recovery

* Whole-body imaging

Dixon 3-dimensional T1 VIBE sequence which provided T1 in-phase, out-phase images automatically [79].

The advantage of MRI over CT is the easy capability of acquiring specific image sequences for each purpose. Simple PET/MRI examination based on only whole-body T1 weighted images for achieving attenuation correction map could not improve diagnostic accuracy more than PET/CT [80]. MRI sequences for evaluating tumor characteristics have been developed. DWI and ADC measurement has been widely used for diagnosis of malignant lesion. T1 and T2 weighted imaged can be acquired with short TR and TE using advanced techniques such as VIBE sequences and half Fourier acquired single shot turbo spin echo (HASTE) [81]. High resolution contrast-enhanced T1 is also available based on this protocol. Turbo inversion recovery magnitude (TIRM) sequence is used for detecting bone metastasis. Composition of these sequences could omit the non-enhanced T1 images without detrimental effect of diagnostic performance [82].

Previously used MRI sequences have limitations for whole-body imaging which required fast scan time and high image quality. For example, DWI based on a single-shot echo planar imaging (EPI) sequence often presented image distortion, which caused reduced quality of fusion images. Development of fusion-compatible MRI sequences will be helpful for increasing diagnostic accuracy [83–85].

Although results were highly correlated within PET/CT and PET/MR, SUV from PET/MR can be different from PET/CT. Careful interpretation is needed for direct comparison of quantitative PET/MR and PET/CT results [86, 87].

MRI techniques have been continuously developed and indications of MRI have been growing in the clinical oncology field, but CT also has its own advantages over MRI in several aspects such as easy accessibility, high-resolution image, and lung parenchyma evaluation. The role of PET/CT and PET/MRI might also be rather complementary than competitive for tumor diagnosis. The exact positioning of PET/MRI to reinforce the metabolic characterization of tumors where PET/CT is less useful has to be further investigated.

Complementary Role of PET/MR Imaging

PET/MRI enables high-quality fusion imaging and easy assessment of whole-body disease status, and the complementary role for PET/MR has been evaluated in major cancers (Table 3). Simultaneous acquisition of PET and MRI can provide more accurate spatial registration between two scans than sequential PET/CT acquisition. Improvement of spatial coregistration could be helpful for diagnosis and delineating

Table 3 Suggested complementary role for PET/MR in clinical indications

Indication	Suggested role	Modalities/parameters
Lung cancer	Reduce spatial misregistration	Simultaneous PET and MR acquisition [88]
Breast cancer	Characterization of malignant tumor	Multiparameter approach including perfusion, cellularity, metabolism [99]
Colorectal cancer	Increase diagnostic accuracy and detect liver metastasis	Combined PET and MR analysis with DWI [48]
Bone metastasis	Delineate structural change more clearly	T1 TSE sequence [69], fat component analysis by 3D dual-echo gradient sequence [70]

DWI diffusion weighted imaging, *SUV* standardized uptake value, *TSE* turbo spin echo

treatment target tissue [88]. FDG uptake in a suspicious lesion can be further characterized by adding morphologic and functional information from MRI [89]. One study reported that additional findings revealed on PET/MRI affected clinical management in 17.9 % of patients due to re-evaluation of disease status and detecting metastases [90].

Hybrid PET/MRI enable to measure glucose metabolism and cellular density in tumor by simultaneous FDG, PET, and DWI acquisition. In malignant lesions, inverse correlation was found between SUV and ADC value [91, 92]. Volumetric measurement of tumor is highly correlated when comparing the results from PET images and MRI images (both of T2 weighted images and DWI) [93]. Diagnostic confidence of tumor can be increased by using the complementary information in PET/MRI. Addition of DWI information to PET/MRI increased lesion-based diagnostic accuracy more than PET/CT or PET/MR (0.69 vs. 0.66 and 0.57, respectively) [48]. In peritoneal calcinomatosis, combined information for ADC and SUV could enable us to differentiate histopathology or primary malignancy. Metastatic lesions from colorectal cancer showed relative higher ADC values and lower FDG uptakes than those from ovarian cancer [94].

Volumetric parameters such as MTV or total lesion glycolysis (TLG) driven by PET has been known to be useful for measuring tumor burden [95]. Changes of PET volumetric parameters can predict a more accurate response to chemotherapy than MRI volumetric measurements [96].

PET/MRI enabled us to provide functional parameters by combining tumor metabolism/volumetric parameters from PET and cellularity information from MRI. Glucose metabolism of tumor and/or ADC-corrected glucose metabolism showed linear correlation with tumor staging [97]. Further studies using new functional parameters from PET/MRI will be necessary for detailed characterization of tumor biology.

The role of PET and MRI scans has been increased in management of oncologic patients and performing both examinations could be cost-effective. Hybrid PET/MR imaging provides both the functional and structural information in a single examination, which could be convenient for the patient [98].

Conclusion

Hybrid FDG PET/MRI has become more widely used to overcome the limitation of conventional PET/CT in the oncologic field. PET/MRI showed comparable diagnostic performance and superiority to PET/CT in various malignancies in terms of excellent soft tissue contrast and flexible application of MRI sequences. Replacement of CT by MRI reduced the patient's radiation dose, which becomes a more important issue in pediatric imaging and expansion of medical diagnostic imaging. With developing new hybrid imaging technique, the exact

diagnostic indication and optimizing protocol of FDG PET/MRI in patient management has to be further investigated.

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