Original Article

A two-way comparison of whole-body ^{18}FDG PET-CT and whole-body contrast-enhanced MRI for distant metastasis staging in patients with malignant tumors: a meta-analysis of 13 prospective studies

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Background: The correct staging of distant metastasis is crucial in deciding an adequate course of therapy for cancer patients. This meta-analysis was carried out to produce an evaluation and comparison of the performances of ^{18}F-fluorodeoxyglucose positron emission tomography-computed tomography (^{18}FDG PET-CT) and contrast-enhanced magnetic resonance imaging (MRI) in detecting distant metastasis in patients suffering malignant tumors. Systematic literature searches of the MEDLINE and Embase databases were conducted to identify relevant studies in the period from December 31, 1950 to August 1, 2019. We used the following search terms: MRI, magnetic resonance imaging, PET, positron emission tomography, staging, distant metastasis, and distant recurrence. The searches were carried out by two independent reviewers. We only included relevant studies that evaluated both ^{18}FDG PET-CT and contrast-enhanced MRI in relation to distant metastasis detection in the same patients with malignant tumors. The two reviewers independently extracted relevant data from the eligible studies, and the quality of each study was determined with "Quality Assessment of Diagnostic Accuracy Studies-2". Using the bivariate model, we obtained pooled estimates for sensitivity and specificity. The area under the curve (AUC) of summary receiver operating characteristic (SROC) curves for ^{18}FDG PET-CT and contrast-enhanced MRI was used to extra and synthesize, respectively.

Methods: Pooled sensitivities and specificities, and the AUC of SROC curves for ^{18}FDG PET-CT and contrast-enhanced MRI were used to measure the main outcomes, respectively.

Results: Across all 13 studies (1,465 patients), ^{18}FDG PET-CT had similar sensitivity (0.84 *vs.* 0.85) and specificity (0.96 *vs.* 0.98) to contrast-enhanced MRI. In the 5 studies related to head and neck cancer (511 patients), ^{18}FDG PET-CT had similar sensitivity (0.82 *vs.* 0.81) and specificity (0.97 *vs.* 0.98) to contrast-enhanced MRI. In the 6 lung cancer-related studies (779 patients), sensitivity (0.72 *vs.* 0.85) and specificity (0.95 *vs.* 1.00) tended to be lower in ^{18}FDG PET-CT than in contrast-enhanced MRI.

Conclusions: ^{18}FDG PET-CT and contrast-enhanced MRI both performed well as detectors of distant metastasis in the diagnosis of cancer patients. The subgroup analysis suggests that 18FDG PET-CT and contrast-enhanced MRI may possess different advantageous qualities for distant metastasis staging of patients with various types of tumor.

Keywords: Malignant tumors; distant metastasis; magnetic resonance imaging (MRI); positron emission tomography-computed tomography (PET-CT)

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Introduction

For patients with malignant tumors, the effective detection of distant metastasis makes a vital contribution to their prognosis. The TNM staging system informs the classification of most malignant tumors, and when the presence of distant metastasis is confirmed, the patient's course of therapy and prognosis are decided. Accurate staging of distant metastasis is crucial for choosing adequate oncological therapy. With the simultaneous acquisition of functional and anatomical datasets, ^{18}F-fluorodeoxyglucose positron emission tomography-computed tomography (^{18}FDG PET-CT) could provide a precise method by which to assess distant metastasis staging for a range of different cancers, especially those affecting the head and neck, lungs, breasts, and the digestive system (1). Due to improvements in sequencing, multi-channel technology, movable table platforms, and multiplanar reconstruction, magnetic resonance imaging (MRI) is increasingly being used in the whole-body staging of distant metastasis (2). Our previous meta-analysis of 9 studies with data on a per-patient analysis of 1,070 patients demonstrated that ^{18}FDG PET-CT and contrast-enhanced MRI performed comparably as detectors of distant metastasis in patients with malignant tumors (2). Moreover, more prospective studies of ^{18}FDG PET-CT and contrast-enhanced MRI for the staging of distant metastasis in various types of cancer have been reported (3-6). We carried out an updated meta-analysis to produce an evaluation and comparison of ^{18}FDG PET-CT and contrast-enhanced MRI through the analysis of studies that focused on both diagnostic methods for the same patients with malignant tumors.

Methods

Literature search

Digital literature searches of the MEDLINE and Embase databases were performed to collect relevant published articles comparing the performances of whole-body ^{18}FDG PET-CT and whole-body contrast-enhanced MRI in assessing distant metastasis in same cancer patients. Our searches were based on combinations of the following terms: MRI, magnetic resonance imaging, PET, positron emission tomography, staging, distant metastasis, and distant recurrence. We searched for articles published in the period from December 31, 1950 to August 1, 2019. We screened the references of the articles that were initially returned in our searches to identify any other research of potential interest. When information vital for our meta-analysis was not included in the relevant studies, we made direct contact with the authors for further data. We applied no restrictions on language in our search and selection of relevant studies.

Study selection

Studies were included in our meta-analysis if the following criteria were met: (I) whole-body ^{18}FDG PET-CT and whole-body contrast-enhanced MRI were both used to evaluate distant metastasis on the same patients with malignant tumors; (II) distant metastasis was confirmed by the histology and imaging follow-up data; (III) analysis was carried out on a per-patient basis; (IV) the study was based on a minimum sample size of 20 patients; (V) in cases where the same data or subsets of data were repeated, the study with the larger sample size was considered for inclusion; (VI) the whole-body MRI must have included basic sequences of T_1 and contrast enhanced T_1. T_2 sequence and short-time inversion recovery (STIR) sequence may be used as the selective sequences. Studies were not included if they met the following criteria: (I) the totals of true positives, false positives, true negatives, and false negatives were not included; (II) only contrast-enhanced MRI or ^{18}FDG PET-CT was performed; (III) the diffusion-weighted imaging (DWI) sequence was carried out for whole-body MRI; (IV) non-original articles (conference abstracts, comments, letters to the editors, reviews, etc.).

Data extraction and quality assessment

Data was extracted from the relevant studies by two reviewers independently extracted the relevant. In the case of disputes, a consensus was reached through discussion. The following data was recorded: first author's name; the study's publication year and country; patient sample size; patient characteristics including age, sex, and primary tumor locations; the technical protocols of contrast-enhanced MRI and ^{18}FDG PET-CT; reference standard; and study results (number of true positives, false positives, true negatives, and false negatives).

Two reviewers conducted independent assessments of the methodological quality of the studies using "Quality Assessment of Diagnostic Accuracy Studies (QUADAS)-2" (7). This updated tool assesses risk of bias and applicability concerns in four core areas: patient selection, index test, reference standard, and flow and timing). Each of these was

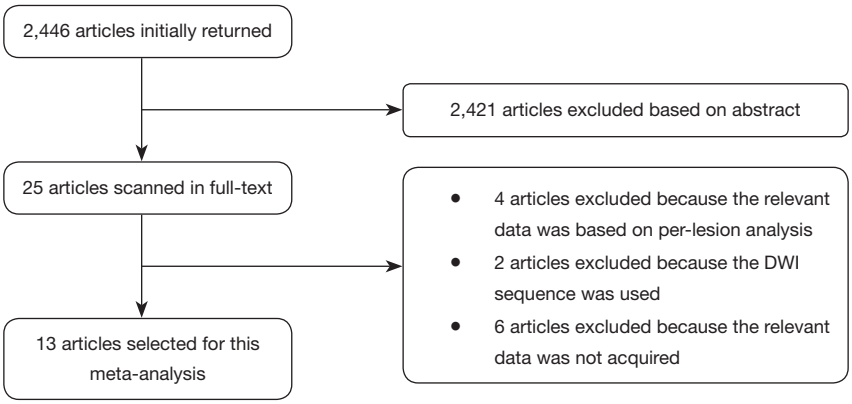

Figure 1 The flow diagram of the systematic literature search for the meta-analysis.

assessed as low, high, or unclear risk.

Statistical analysis

All analyses were conducted with Stata version 11.0 (Stata Corporation, TX, USA). A bivariate model was used to calculate weighted overall estimates for sensitivity, specificity, diagnostic odds ratios (DORs), positive likelihood ratios (PLRs), and negative likelihood ratios (NLRs) with 95% confidence interval (CI) as our primary outcome measures. We then constructed summary receiver operating characteristic (SROC) curves for ^{18}FDG PET-CT and contrast-enhanced MRI, respectively (8-10).

This analysis included data regardless of the locations of the primary tumor. The heterogeneity among the different studies for ^{18}FDG PET-CT and contrast-enhanced MRI was analyzed and assessed by a χ^2 test and I^2 statistics (11-12). Heterogeneity was considered to exist when I^2>50% and P<0.05 (11-12).

We used our pooled sensitivity and specificity estimates to work out the negative predictive values of ^{18}FDG PET-CT and contrast-enhanced MRI when distant metastasis was assumed to have a prevalence rate of 10%, 20%, and 30%, respectively (10).

We also performed subgroup analyses for ^{18}FDG PET-CT and contrast-enhanced MRI according to locations of the primary tumor (head and neck cancer *vs.* lung cancer) (8-10).

The publication bias was evaluated using Deeks' funnel plot (13), which was conducted by means of a regression test of the natural logarithm of the DOR on the inverse of the adequate sample size. The presence of publication bias was indicated by asymmetry in the funnel plot, with P<0.05 indicating significant asymmetry.

Results

Study selection and description

The flow diagram of the systematic literature review is shown in *Figure 1*. After being independently reviewed, 13 articles involving 1,465 patients (3-6,14-22) were deemed eligible for inclusion in this meta-analysis (*Table 1*). The study sample sizes ranged from 34 to 203 patients (median, 103 patients). In 1 study (43 patients), only occult cancer patients were enrolled. In 2 studies (132 patients) patients with various cancers were included. In 4 studies (511 patients), only patients with head and neck cancer were included. In 6 studies (779 patients), only lung cancer patients were enrolled. All 13 studies stated that they were conducted prospectively.

Study quality

The quality assessment results conducted using QUADAS-2 are presented in *Table 2*. The risk of bias concerning patient selection was low in 9 of the 13 studies. Each of the studies had a low risk of bias in relation to the index test. These results were interpreted independently from the reference standard results. However, risk of bias in each of the 13 studies was high in relation to the reference standard as the reference standard was not carried out independently from the index test results.

Accuracy of contrast-enhanced MRI and ^{18}FDG PET-CT

Summary of sensitivity, specificity, PLR, and NLR estimates

The weighted overall estimates of sensitivity, specificity, PLR, and NLR for ^{18}FDG PET-CT and contrast-enhanced MRI were 0.84 (95% CI, 0.72 to 0.91) and 0.85 (95% CI,

Table 1 The clinical and technical characteristics of contrast-enhanced MRI and ^{18}FDG PET-CT

Locations of tumor	First author	Year of publication	Origin	Type of staging	No. of patients	Age (y)	Male (%)	Follow-up, time (m)	Technical characteristics of MRI			Technical characteristics of PET-CT			
									Strength (T)	CE	Sequences	Dose	Uptake time (min)	CE	Analysis methods
All	Antoch (14)	2003	Germany	IS	98	27–94	64.3	9 (mean)	1.5	Yes	T_1, T_2	350 MBq	60	No	QL + QN
	Schmidt (15)	2005	Germany	IS	34	21–81	43.9	≥6	1.5	Yes	T_1, T_2, STIR	202–372 MBq	60	No	QL
Lung	Plathow (16)	2008	Germany	IS	52	49–71	69.2	2.7 (mean)	1.5	Yes	T_1, T_2, STIR	360–400 MBq	55–65	No	QL + QN
	Yi (17)	2008	Korea	IS	154	61 (mean)	75.8	19.5 (mean)	3.0	Yes	T_1, T_2	370 MBq	45	No	QL
	Ohno (18)	2008	Japan	IS	203	73 (mean)	53.7	≥12	1.5	Yes	T_1, T_2, STIR	3.3 MBq/Kg	60	No	QL
	Ohno (3)	2013	Japan	RS	134	72 (mean)	58.2	NR	3.0	Yes	T_1, T_2, STIR	3.3 MBq/Kg	60	No	QL
	Ohno (4)	2015	Japan	IS	140	47–83	53.6	≥6	3.0	Yes	T_1, STIR	3.3 MBq/Kg	60	No	QL
	Ohno (5)	2017	Japan	RS	96	72 (mean)	54.2	≥6	3.0	Yes	T_1, STIR	3.3 MBq/Kg	60	No	QL
Head and neck	Ng (19)	2009	Taiwan	IS	150	17–84	74	≥12	3.0	Yes	T_1, T_2, STIR	370 MBq	50–70	No	QL
	Ng (20)	2010	Taiwan	RS	179	19–84	76	≥6	3.0	Yes	T_1, T_2, STIR	370 MBq	50–70	No	QL
	Chan (21)	2011	Taiwan	IS	103	54 (mean)	94.2	≥12	3.0	Yes	T_1, T_2, STIR	370 MBq	50–70	No	QL
	Ng (22)	2011	Taiwan	RS	79	33–74	88.6	≥12	3.0	Yes	T_1, T_2, STIR	370 MBq	50–70	No	QL
Occult cancer	Sekine (6)	2017	Switzerland	IS	43	20–86	51.2	≥17.1	3.0	Yes	T_1, T_2, STIR	4.5 MBq/Kg	40	Yes	QL

MRI, magnetic resonance imaging; ^{18}FDG PET-CT, ^{18}F-fluorodeoxyglucose positron emission tomography-computed tomography; QL, qualitative; QN, quantitative; CE, contrast enhanced; STIR, short time inversion recovery.

Table 2 QUADAS-2 results for all 13 included studies

Studies	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Antoch (14), 2003	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Schmidt (15), 2005	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Plathow (16), 2008	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Yi (17), 2008	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Ohno (18), 2008	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Ohno (3), 2013	High risk	Low risk	High risk	Low risk	High risk	Low risk	Low risk
Ohno (4), 2015	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Ohno (5), 2017	High risk	Low risk	High risk	Low risk	High risk	Low risk	Low risk
Ng (19), 2009	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Ng (20), 2010	High risk	Low risk	High risk	Low risk	High risk	Low risk	Low risk
Chan (21), 2011	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
Ng (22), 2011	High risk	Low risk	High risk	Low risk	High risk	Low risk	Low risk
Sekine (6), 2017	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk

Table 3 Diagnostic accuracy of ^{18}FDG PET-CT and contrast-enhanced MRI

Locations of tumors	System	No. of studies (no. of patients)	Independent estimates		Likelihood ratio (95% CI)	
			Sensitivity (95% CI)	Specificity (95% CI)	PLR (95% CI)	NLR (95% CI)
All tumors	PET-CT	13 (1,477)	0.84 (0.72 to 0.91)	0.96 (0.94 to 0.97)	18.8 (13.9 to 25.4)	0.17 (0.10 to 0.30)
	MRI	13 (1,477)	0.85 (0.73 to 0.93)	0.98 (0.96 to 0.99)	55.1 (19.4 to 157.0)	0.15 (0.08 to 0.29)
Head and neck	PET-CT	4 (511)	0.82 (0.69 to 0.90)	0.97 (0.94 to 0.98)	23.9 (14.1 to 40.6)	0.19 (0.11 to 0.34)
	MRI	4 (511)	0.81 (0.64 to 0.90)	0.98 (0.95 to 0.99)	36.5 (13.7 to 97.5)	0.20 (0.10 to 0.39)
Lung	PET-CT	6 (779)	0.72 (0.53 to 0.85)	0.95 (0.93 to 0.96)	13.5 (9.4 to 19.5)	0.30 (0.17 to 0.53)
	MRI	6 (779)	0.83 (0.62 to 0.94)	1.00 (0.86 to 1.00)	400.8 (4.8 to 33130.6)	0.17 (0.07 to 0.42)

^{18}FDG PET-CT, ^{18}F-fluorodeoxyglucose positron emission tomography-computed tomography; MRI, magnetic resonance imaging; PLR, positive likelihood ratio; NLR, negative likelihood ratio; CI, confidence interval.

0.73 to 0.93), 0.96 (95% CI, 0.94 to 0.97) and 0.98 (95% CI, 0.96 to 0.99), 18.8 (95% CI, 13.9 to 25.4) and 55.1 (95% CI, 19.4 to 157.0), and, 0.17 (95% CI, 0.10 to 0.30) and 0.15 (95% CI, 0.08 to 0.29), respectively (*Table 3*). This study confirmed that significant heterogeneity existed in ^{18}FDG PET-CT groups (I^2=0.81; P<0.05), and no heterogeneity existed in contrast-enhanced MRI groups (I^2=0; P>0.05).

The performance comparison of ^{18}FDG PET-CT and contrast-enhanced MRI in all of the 13 comparative studies (1,465 patients) suggested no differences in sensitivity or specificity between ^{18}FDG PET-CT and contrast-enhanced MRI (P>0.05).

SROC curves

The SROC curves for ^{18}FDG PET-CT and contrast-enhanced MRI from each of the 13 comparative studies are displayed in *Figure 2*. The overall weighted area under the SROC curves for ^{18}FDG PET-CT and contrast-enhanced MRI was 0.96 (95% CI, 0.94 to 0.97) and 0.98 (95% CI, 0.97 to 0.99), respectively.

Negative predictive values

With an assumed distant metastasis prevalence of 10%, 20%, and 30% on a per-patient basis, the NPVs of ^{18}FDG PET-CT were 0.98, 0.96, and 0.94, respectively, and those

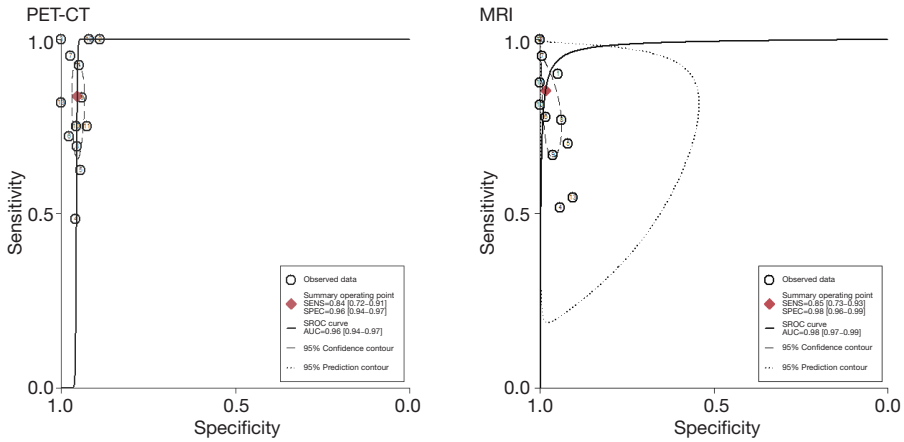

Figure 2 The forest plot of the SROC curves for ^{18}FDG PET-CT and contrast-enhanced MRI. SROC, summary receiver operating characteristic; ^{18}FDG PET-CT, ^{18}F-fluorodeoxyglucose positron emission tomography-computed tomography; MRI, magnetic resonance imaging.

for contrast-enhanced MRI were 0.98, 0.96, and 0.94, respectively.

Publication bias

In both the ^{18}FDG PET-CT (P=0.01>0.05) and the contrast-enhanced MRI groups (P=0.20>0.05) there was no significant publication bias identified. Each group had a symmetrical funnel plot, indicating publication bias to be statistically insignificant.

Subgroup analysis

Head and neck cancer

Four studies enrolled patients with tumours in the head and neck and performed both ^{18}FDG PET-CT and contrast-enhanced MRI on a total of 511 patients. The weighted overall estimates in relation to sensitivity, specificity, PLR, and NLR for ^{18}FDG PET-CT and contrast-enhanced MRI in patients with head and neck cancer were 0.82 (95% CI, 0.69 to 0.90) and 0.81 (95% CI, 0.64 to 0.90), 0.97 (95% CI, 0.94 to 0.98) and 0.98 (95% CI, 0.95 to 0.99), 23.9 (95% CI, 14.1 to 40.6) and 36.5 (95% CI, 13.7 to 97.5), and, 0.19 (95% CI, 0.11 to 0.34) and 0.20 (95% CI, 0.10 to 0.39), respectively (*Table 3*). This suggests ^{18}FDG PET-CT had similar sensitivity and specificity compared with contrast-enhanced MRI (*Table 3*).

Lung cancer

Six studies enrolled only lung cancer patients and performed both ^{18}FDG PET-CT and contrast-enhanced MRI on a total of 779 patients. The weighted overall estimates in relation to sensitivity, specificity, PLR, and NLR for ^{18}FDG PET-CT and contrast-enhanced MRI in patients with lung cancer were 0.72 (95% CI, 0.53 to 0.85) and 0.83 (95% CI, 0.62 to 0.94), 0.95 (95% CI, 0.93 to 0.96) and 1.00 (95% CI, 0.86 to 1.00), 13.5 (95% CI, 9.4 to 19.5) and 400.8 (95% CI, 4.8 to 33130.6), and, 0.30 (95% CI, 0.17 to 0.53) and 0.17 (95% CI, 0.07 to 0.42), respectively. This suggests that there were no major differences between contrast-enhanced MRI and ^{18}FDG PET-CT, although the point estimates suggest that both specificity and sensitivity improved by 5-11% when contrast-enhanced MRI was used (*Table 3*).

Discussion

The correct staging of distant metastasis is crucial for cancer patients, as both prognosis and course of therapy are highly dependent on TNM stage. The concept of oncological whole-body imaging is not new; however, the possibility of routinely applying the procedure in a clinical setting is limited. Whole-body PET-CT and whole-body MRI are now increasingly used to replace the earlier multimodal staging strategies, but the findings between these two diagnostic modalities for distant metastasis are incongruent. In this updated meta-analysis of 13 studies (1,465 patients), we calculated summary estimates for ^{18}FDG PET-CT and contrast-enhanced MRI, and SROC curves were also constructed. This meta-analysis documents that ^{18}FDG PET-CT and contrast-enhanced MRI had high sensitivity (0.84 and 0.85) and specificity (0.96 and 0.98) for the detection of distant metastasis.

In cancer diagnosis, the negative predictive value acts as a a single indicator of the probability of distant metastasis being present in cases where the diagnostic result is negative (10). In this meta-analysis, if the prevalence of distant metastasis was assumed to be 10% and 20%, the negative predictive values for ^{18}FDG PET-CT/contrast-enhanced MRI were 0.98/0.98 and 0.96/0.96. At tumor staging, when the prevalence of distant metastasis was assumed to be 10–20%, ^{18}FDG PET-CT and contrast-enhanced MRI could provide valuable information, with the probability of distant metastasis being reduced to as low as 2–4% in cases of negative diagnostic results.

Contrast-enhanced MRI showed higher sensitivity than ^{18}FDG PET-CT in relation to lung cancer than in head and neck cancer (0.13 *vs.* 0.01). The reason for this phenomenon is that contrast-enhanced MRI and ^{18}FDG PET-CT have different advantageous qualities for detecting distant metastatic lesions in different organs. For patients with cancer of the head and neck, the skeleton and lungs are common sites for distant metastasis, accounting for 80% to 90% of cases of distant metastasis (16-19). Previous studies found contrast-enhanced MRI to have similar sensitivity to ^{18}FDG PET-CT in detecting bone and lung metastasis (14,23). The liver and brain are common distant-sites for lung cancer patients, involving 40% to 50% of patients with distant metastasis (3-5,13-15). Compared with ^{18}FDG PET-CT, contrast-enhanced MRI showed higher sensitivity in detecting metastasis in the brain and liver, because some metastatic lesions may be obscured by high physiological FDG uptake of brain and liver (24,25). For the detection of brain metastasis in particular, the sensitivity for ^{18}FDG PET-CT is only 21%, but for contrast-enhanced MRI it is 77% (25). Contrast-enhanced brain MRI could also offer more accurate diagnosis of metastatic brain lesions than ^{18}FDG PET-CT. Another study showed that the combination of ^{18}FDG PET-CT and brain MRI may enhance the sensitivity of only ^{18}FDG PET-CT (89.6% *versus* 83.0%) for distant metastasis staging in patients with lung adenocarcinoma (26). Therefore, the inclusion of the brain in the procedure for whole-body MRI is another advantage it holds over PET/CT.

Moreover, the limited sensitivities of ^{18}FDG PET-CT imaging in patients with primary hepatocellular carcinomas, carcinomas of the gastrointestinal tract, renal cell carcinoma, pheochromocytomas, and many neuroendocrine tumors of the pancreas have also been identified (27-30). Another disadvantage of ^{18}FDG PET-CT is its low r dosage of radiation, which amounts to about 22 mSv for the PET-CT for the area from the head to the thighs (14).

The joint anatomical and functional capabilities of MRI may provide new insight for distant metastasis staging in patients with malignant tumors. Ohno *et al.* (18) stated that sensitivity and specificity of whole-body MRI without DWI for M1 staging of lung cancer was 60%, and 92% of whole-body MRI with DWI was 70.0% and 92.0%, respectively. The addition of DWI could improve the sensitivity of whole-body MRI for distant metastasis staging. This meta-analysis involved studies with basic sequences of T_1 and contrast-enhanced T_1 for whole-body MRI. Due to the limited number of studies with a DWI sequence, we excluded whole-body MRI studies in which the DWI sequence was used. Large, multicenter, and prospective studies which involve strict standardization of MRI protocols remain essential for evaluating the diagnostic capacity of whole-body MRI with DWI as a tool for effective distant metastasis staging in cancer patients. Until recently, the availability of whole-body MRI has been low. Negative aspects in terms of its practicability have included long examination times, time-consuming repositioning procedures, and the difficulty of combining the various steps of examination into a single imaging procedure. The development of concomitant data acquisition from several surface coils, new and fast sequences, and moving table platforms have contributed to an improvement in the practicability of whole-body MRI for assessing distant metastasis staging in patients who have malignant tumors (31-33).

Our meta-analysis had several limitations that must also be considered. First, publication bias is one well-described drawback of diagnostic meta-analyses because studies with meaningful results have a higher likelihood of being published than those with nonsignificant results. Furthermore, we also excluded non-original articles (conference abstracts, comments, letters to editors, etc.) that could have resulted in publication bias. However, the publication bias for ^{18}FDG PET-CT and contrast-enhanced MRI groups in our meta-analysis was insignificant (P>0.05). Second, we could did not carry out subgroup analyses based on each primary tumor location as individual patient data would have been needed. The primary tumor locations could influence the organ-sites of distant metastases. ^{18}FDG PET-CT and contrast-enhanced MRI have various advantageous qualities in the detection of malignant lesions in different organs (14,21-25). Therefore, the locations of primary tumors could have an impact on the diagnostic accuracy of ^{18}FDG PET-CT and contrast-enhanced MRI. Third, the qualitative manners for interpreting ^{18}FDG PET-CT and contrast-enhanced MRI were used in most of the included studies, and there could have been a risk of subjective interpretation. Fourth, the histopathologic

examination from biopsies for confirmation of distant metastatic lesions was not obtained from all the positive lesions. However, follow-up results from renewed imaging examinations also served as a benchmark in the absence of histologic confirmation. The establishment of a well-accepted reference standard is a challenging aspect of all diagnostic studies which assess different imaging procedures for the identification of distant metastasis.

Conclusions

^{18}FDG PET-CT and contrast-enhanced MRI both have high diagnostic performances in relation to distant metastasis staging in patients with malignant tumors. The subgroup analysis highlights that ^{18}FDG PET-CT and contrast-enhanced MRI may hold different advantages for distant metastasis staging in patients with various types of tumor. Both ^{18}FDG PET-CT and contrast-enhanced MRI may be utilized as first-line imaging techniques for detecting distant metastasis in patients with malignant tumors.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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