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Diagnostic performance of noninvasive imaging using computed tomography, magnetic resonance imaging, and positron emission tomography for the detection of ovarian cancer: a meta-analysis

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Abstract

Objective The aim of this meta-analysis was to compare the diagnostic value of noninvasive imaging methods computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) in the detection of ovarian cancer (OC).

Methods PubMed, Embase, and Ovid were comprehensively searched from the date of inception to 31st, March, 2022. Pooled sensitivity, specificity, positive likelihood ratio (+LR), negative likelihood ratio (- LR), diagnostic odds ratio (DOR), and area under the curve (AUC) of summary receiver operating characteristic (SROC) with their respective 95% confidence intervals (CIs) were calculated.

Results Sixty-one articles including 4284 patients met the inclusion criteria of this study. Pooled estimates of sensitivity, specificity, and AUC of SROC with respective 95% CIs of CT on patient level were 0.83 (0.73, 0.90), 0.69 (0.54, 0.81), and 0.84 (0.80, 0.87). The overall sensitivity, specificity, SROC value with respective 95% CIs of MRI were 0.95 (0.91, 0.97),0.81 (0.76, 0.85), and 0.90 (0.87, 0.92) on patient level. Pooled estimates of sensitivity, specificity, SROC value of PET/CT on patient level were 0.92 (0.88, 0.94), 0.88 (0.83, 0.92), and 0.96 (0.94, 0.97).

Conclusion Noninvasive imaging modalities including CT, MRI, PET (PET/CT, PET/MRI) yielded favorable diagnostic performance in the detection of OC. Hybrid implement of different tools (PET/MRI) is more accurate for identifying metastatic OC.

Keywords Ovarian cancer · CT · MRI · PET · Diagnostic performance · Meta-analysis

Abbreviations

OC	Ovarian cancer
EOC	Epithelial ovarian cancer
CT	Contrast-enhanced computed tomography
MRI	Magnetic resonance imaging
PET	Positron emission tomography
^{18}F-FDG	2-Deoxy-2-[^{18}F]fluoro-D-glucose
PRISMA-DTA	The Preferred Reporting Items for a Systematic Review and Meta-analysis of Diagnostic Test Accuracy Studies
TP	True positive
FP	False positive
TN	True negative
FN	False negative
QUADAS	The quality assessment of diagnostic accuracy studies
+LR	Positive likelihood ratio
−LR	Negative likelihood
DOR	Diagnostic odds ratio

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SROC	Summary receiver operating characteristic
CI	Confidence interval

Introduction

Ovarian cancer (OC) is the seventh most common cancer worldwide in the female with the highest mortality rate among gynecologic malignant tumors affecting the female reproductive system [1, 2]. According to available statistics, more than 180 thousand women die of ovarian cancer every year worldwide [3]. Histogenetically, OC is classified into three major subtypes, including epithelial, stromal, or germ cell tumors [4]. Approximately, 90% of ovarian cancers have been found to be epithelial ovarian cancer (EOC) subtypes [5]. Surgical resection and chemotherapy are the standard treatment options [6]. The International Federation of Gynecology and Obstetrics (FIGO) or Union for International Cancer Control (UICC) TNM classifications are referred to as the staging standard of ovarian cancer [7, 8]. Nevertheless, due to the vague and nonspecific symptoms and alike gastrointestinal, genitourinary, and gynecological findings, OCs are difficult to diagnose at early stage, and are often metastatic at the time of presentation, and are involved in a high likelihood of recurrence and poor prognosis [4, 9]. With regard to this, accurate preoperative evaluation, namely the differentiation of benign or malignant diseases, or the detection of nodal, peritoneal or distant diseases, is indispensable to achieve an optimized treatment schedule [10].

A biopsy of tumor tissue from surgery or imaged-guided needle aspiration, to date, is the reference standard to confirm the disease [11]. Nevertheless, this procedure is invasive and carries potential risks of unwanted and unpredictable complications [12, 13]. Transvaginal ultrasonography (TVUS) or abdominal contrast-enhanced computed tomography (CT) is the first imaging modality for the detection of OC [9, 14, 15]. TVUS is currently used for screening of OC and may be associated with discomfort and risk to the vagina [16]. In clinical setting, CT is the most commonly employed imaging method before the staging laparotomy [9]. However, the diagnostic value of CT is limited to depict tumor implants that are 1 cm or smaller the sensitivities of 25–50% in peritoneal metastases [17, 18]. Other modalities are being increasingly used in the management of ovarian cancer including magnetic resonance imaging (MRI), positron emission tomography/computed tomography (PET/CT), or PET alone [9]. MRI provides superior soft-tissue contrast resolution, and it can identify indeterminate lesions seen on CT without exposure to radiation [15, 19]. PET, using 2-Deoxy-2-[^{18}F]fluoro-D-glucose (^{18}F-FDG) as radiotracer, if especially combined with CT, is beneficial for the staging gynecological malignant tumors, particularly lymph node metastasis or recurrent tumors, as both functional and anatomical information are available [20–23]. Furthermore, ^{18}F-FDG PET/CT is known to have a high sensitivity for detection of OC relapse with a reported pooled sensitivity of 89% when multidisciplinary standard of reference including histology, clinical and imaging follow-up have been utilized [24]. Moreover, reports demonstrated that the combination of ^{18}F-FDG PET and MRI also provided both high anatomical and functional resolution, and it had shown acceptably superior diagnostic performance than ^{18}F-FDG PET/CT in gynecologic malignancies [25, 26].

For decades, a great number of studies on the diagnostic performance of noninvasive imaging modalities (CT, MRI, PET, PET/CT, and PET/MRI) aforementioned have been performed. The corresponding results varied on account of the study design, sample size, baseline characteristics, type of disease, and etc. The aim of this meta-analysis was to provide a broad overview of the diagnostic value of noninvasive imaging methods in the detection of ovarian cancer, and to come up with more evidenced-based findings for decision and strategy making on a clinical basis.

Materials and methods

This study was performed and reported in accordance with the Preferred Reporting Items for a Systematic Review and Meta-analysis of Diagnostic Test Accuracy Studies (The PRISMA-DTA Statement) [27].

Database search and study selection

Three electronic databases including PubMed, Embase, and Ovid were systematically searched from the date of inception to 31st, March, 2022. Only records in English language were considered for potential inclusion. Moreover, the bibliographies of reviews and studies included were manually screened in order to retrieve additional studies that met the inclusion criterion of the current study. The following medical subject headings and search terms were used for the database search: "magnetic resonance imaging", "positron emission tomography", "computed tomography", "MRI", "CT", "PET", "PET/CT", "PET/MRI" and "Ovarian cancer". The records searched from the aforementioned databases were altogether exported into Endnote software (Version 9.3.3; Thomson Corporation, Stanford, USA) for duplicates removing and further screening. The processes with regard to the literature search and study screening were performed by two independent investigators. Any disagreement was assessed by a third reviewer until the final consensus was achieved.

Studies were included if they met all the following criteria: (1) studies used MRI, CT, PET, PET/CT, or PET/MRI as detection modalities for the presence of ovarian cancer, regardless of tumor types; (2) reference standard was explicitly documented in the study; (3) absolute numbers of patients with true positive (TP), false positive (FP), true negative (TN), false negative (FN) outcomes, or they can be derived based on the presented data. Animal studies, case reports, reviews, comments, conference abstracts or records without extractable data were excluded in this study.

Data extraction and quality assessment

The following information in each study enrolled were identified and extracted in a predesigned table: name of the first author, year of publication, country or district where the study was conducted, absolute number of participants, age, gender, prevalence of OC, patient selection (suspected or confirmed OC), type of OC (primary, relapsed, or metastatic), reference standard, modality used, variables including TP, FP, FN, TN, and analytical level (patient-based or lesion based). Two reviewers independently performed the data extraction, and discrepancies were addressed through discussion with a third reviewer.

The revised tool for the quality assessment of diagnostic accuracy studies 2 (QUADAS-2) was utilized to evaluate the methodological quality of each included study [28]. This 14-item tool is comprised of 2 components, namely risk of bias and applicability concerns. As for the assessment of risk of bias, 4 aspects including patient selection, index test, reference standard, and flow and timing were considered. Patient selection, index test, and reference standard were assessed, respectively, in the evaluation of applicability concerns. Each item was rated as 'yes', 'no', or 'unclear'. Two independent authors scored the included studies using the Review Manager software (Version 5.3; Cochrane Collaboration, Oxford, UK). Disagreements were resolved by discussion with a third reviewer.

Statistical analysis

Based on the data extracted, pooled estimates for diagnostic indicators, such as sensitivity, specificity, positive likelihood ratio (+ LR), negative likelihood ratio (- LR), diagnostic odds ratio (DOR), and area under the curve (AUC) of summary receiver operating characteristic (SROC) with corresponding 95% confidence intervals (CIs) were synthesized using the random effects models. The I^2 static tests were used to test heterogeneity between the studies, the value of $I^2 > 50\%$ and p value < 0.05 were considered to be statistically significant heterogeneity [29, 30]. Furthermore, subgroup meta-analysis and meta-regression were performed to investigate the underlying source of heterogeneity [31–33]. We employed Deeks' asymmetry test and funnel plot to detect potential publication bias in included studies [34]. The Stata software (Version 16.0; StataCorp, College Station, TX, USA) and R (Version 4.1.2; Comprehensive R Archive Network) were used for data.

Results

Baseline information on included studies

A total of 2406 citations were yielded through original literature search. Altogether 368 duplicates were removed using both Endnote software and manual identification. After title and abstract screening of the remaining 2038 records, 1943 articles were excluded. Ninety-five citations were reviewed in full text. Finally, 61 records (83 studies) including 4284 patients were deemed eligible for this study. The flow of literature search is displayed in Fig. 1. Enrolled citations included 18 prospective and 39 retrospective studies, 4 studies did not clarify their study design. The numbers of studies with regard to imaging modalities including CT, MRI, PET, PET/CT, and PET/MRI were 22, 11, 5, 43, and 2, respectively. The radiotracer used in PET imaging was ^{18}F-FDG. Detailed information on the characteristics in provided in Supplementary Table 1. Most studies were rated as low risk of bias and low applicability concerns. High risk of bias or applicability concerns was not notified in included studies (Fig. 2 and Supplementary Fig. 1).

Diagnostic performance of CT

Pooled estimates of sensitivity, specificity, + LR, -LR, DOR, and AUC of SROC with respective 95% CIs of CT on patient level were 0.83 (0.73, 0.90), 0.69 (0.54, 0.81), 2.7 (1.8, 4.0), 0.25 (0.17, 0.37), 11 (6, 19), and 0.84 (0.80, 0.87) with substantial heterogeneity among studies ($I^2 = 91.87\%$ for sensitivity, $I^2 = 86.66\%$ for specificity) (Table 1, Supplementary Fig. 2). On lesion level, the pooled sensitivity, specificity, + LR, -LR, DOR, and AUC of SROC with corresponding 95% CIs of CT were 0.69 (0.51, 0.83), 0.88 (0.73, 0.95), 5.8 (2.7, 12.2), 0.35 (0.22, 0.55), 17 (8, 36), and 0.86 (0.82, 0.89), respectively. Heterogeneity was detected ($I^2 = 93.73\%$ for sensitivity, $I^2 = 96.84\%$ for specificity) (Table 1, Supplementary Fig. 3). Results of meta-regression and subgroup analysis manifested insignificant affection of baseline characteristics on the pooled results (Table 2).
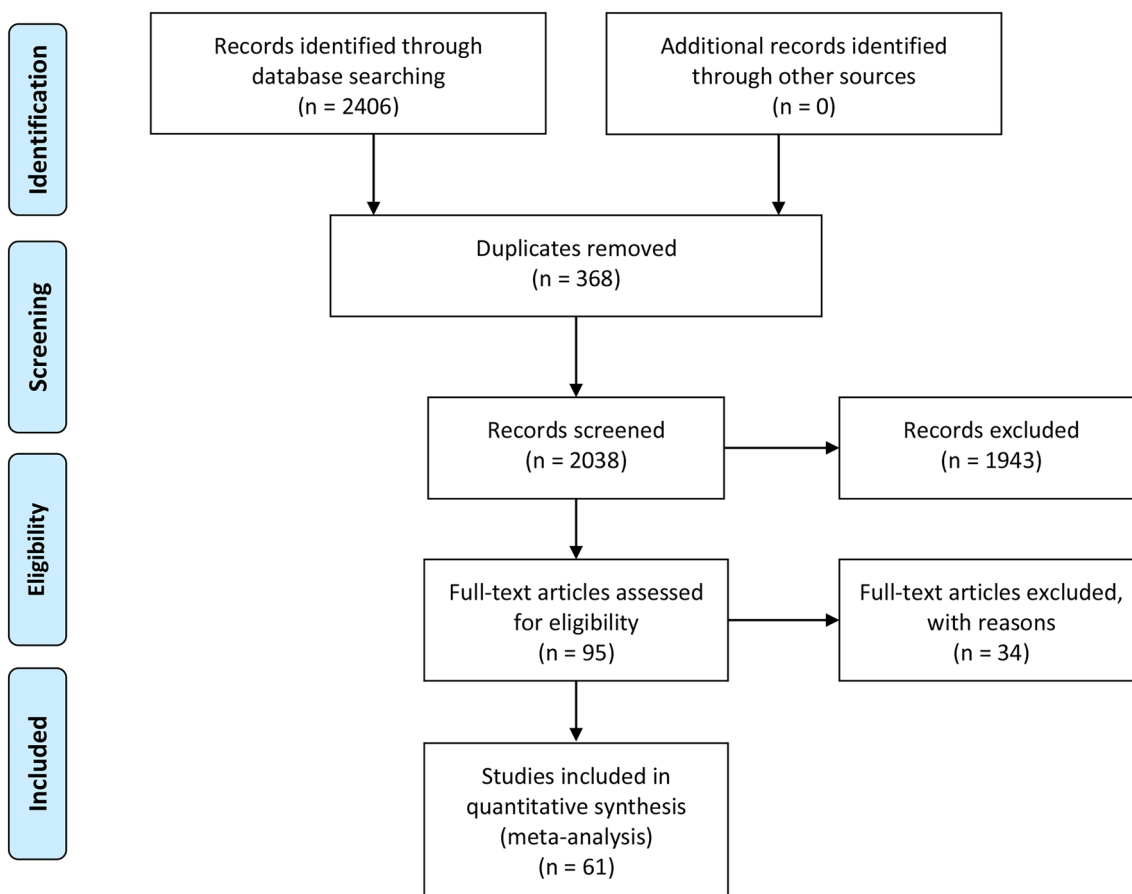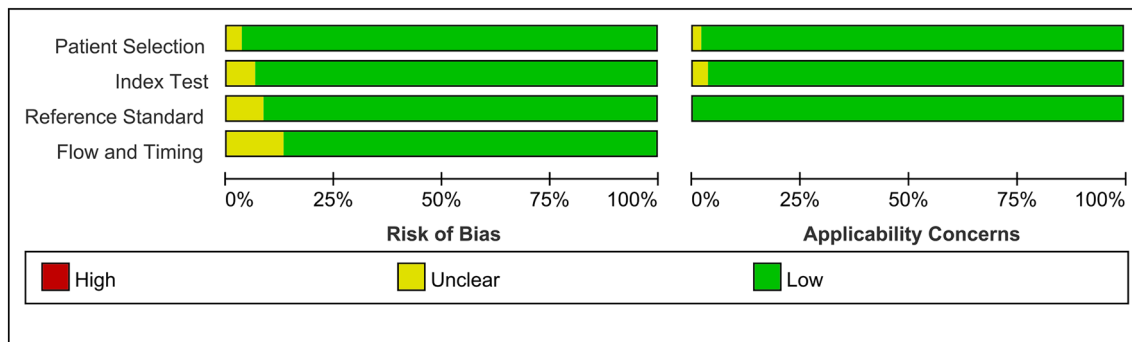
Fig. 1 Flow of literature search

Fig. 2 Methodological quality graph

Diagnostic performance of MRI

The overall sensitivity, specificity, + LR, -LR, DOR, and AUC of SROC with respective 95% CIs of MRI were 0.95 (0.91, 0.97), 0.81 (0.76, 0.85), 4.9 (3.8, 6.3), 0.07 (0.04, 0.12), 72 (36, 147), and 0.90 (0.87, 0.92) on patient level ($I^2 = 62.82\%$ for sensitivity, $I^2 = 45.13\%$ for specificity) (Table 1, Supplementary Fig. 4). The pooled estimates on lesion-based MRI were not performed due to limited number of studies. Five included studies used DWI examination, 3 used conventional MRI, and 2 studies utilized either conventional or contrast-enhanced MRI. Results of meta-regression showed significant impact of characteristics including study design, type of examination, Tesla level, age, and number of patients on the overall outcomes (Table 3).

Table 1 Diagnostic performance of CT, MRI, and PET (PET/CT)

	No. of studies	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	-LR (95% CI)	DOR (95% CI)	SROC (95% CI)
Patient based							
PET	4	0.81 (0.71, 0.88)	0.81 (0.58, 0.93)	4.3 (1.7, 10.9)	0.23 (0.14, 0.39)	18 (5, 66)	0.82 (0.78, 0.85)
PET/CT	34	0.92 (0.88, 0.94)	0.88 (0.83, 0.92)	7.9 (5.5, 11.3)	0.09 (0.07, 0.13)	85 (53, 136)	0.96 (0.94, 0.97)
CT	20	0.83 (0.73, 0.90)	0.69 (0.54, 0.81)	2.7 (1.8, 4.0)	0.25 (0.17, 0.37)	11 (6, 19)	0.84 (0.80, 0.87)
MRI	10	0.95 (0.91, 0.97)	0.81 (0.76, 0.85)	4.9 (3.8, 6.3)	0.07 (0.04, 0.12)	72 (36, 147)	0.90 (0.87, 0.92)
Lesion based							
PET	2	NA	NA	NA	NA	NA	NA
PET/CT	21	0.82 (0.71, 0.89)	0.94 (0.88, 0.97)	12.6 (6.7, 23.9)	0.20 (0.12, 0.32)	64 (27, 152)	0.95 (0.92, 0.96)
CT	9	0.69 (0.51, 0.83)	0.88 (0.73, 0.95)	5.8 (2.7, 12.2)	0.35 (0.22, 0.55)	17 (8, 36)	0.86 (0.82, 0.89)
MRI	2	NA	NA	NA	NA	NA	NA

NA not applicable, *CT* contrast-enhanced computed tomography, *MRI* magnetic resonance imaging, *PET* positron emission tomography, +*LR* positive likelihood ratio, – *LR* negative likelihood, *DOR* diagnostic odds ratio, *SROC* summary receiver operating characteristic, *CI* confidence interval

Table 2 Subgroup analysis of diagnostic performance of CT

	No. of studies	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	– LR (95% CI)	DOR (95% CI)	SROC (95% CI)	*p* value
Study design								
Prospective	7	0.82 (0.69, 0.91)	0.52 (0.35, 0.68)	1.7 (1.2, 2.4)	0.34 (0.18, 0.65)	5 (2, 13)	0.73 (0.68, 0.76)	
Retrospective	13	0.83 (0.69, 0.92)	0.77 (0.60, 0.88)	3.6 (2.1, 6.0)	0.22 (0.13, 0.38)	16 (9, 29)	0.87 (0.84, 0.90)	0.17
Year of publication								
< 2010	4	0.87 (0.69, 0.95)	0.80 (0.69, 0.88)	4.3 (2.8, 6.7)	0.16 (0.06, 0.41)	27 (9, 77)	0.86 (0.82, 0.88)	
≥ 2010	16	0.82 (0.70, 0.90)	0.65 (0.46, 0.80)	2.3 (1.5, 3.6)	0.28 (0.18, 0.43)	8 (4, 16)	0.81 (0.78, 0.85)	0.17
Mean age (year)								
< 55	11	0.80 (0.66, 0.89)	0.65 (0.43, 0.83)	2.3 (1.3, 4.0)	0.31 (0.19, 0.51)	8 (3, 18)	0.81 (0.77, 0.84)	
≥ 55	9	0.85 (0.71, 0.93)	0.73 (0.56, 0.85)	3.2 (2.0, 5.0)	0.20 (0.11, 0.37)	16 (9, 28)	0.86 (0.83, 0.89)	0.84
No. of patients								
< 50	6	0.85 (0.76, 0.91)	0.57 (0.35, 0.77)	2.0 (1.1, 3.6)	0.26 (0.12, 0.55)	8 (2, 29)	0.84 (0.81, 0.87)	
≥ 50	14	0.82 (0.68, 0.91)	0.74 (0.58, 0.86)	3.1 (2.0, 5.0)	0.25 (0.15, 0.41)	13 (7, 23)	0.85 (0.81, 0.88)	0.81
Type of analysis								
Qualitative diagnosis	13	0.86 (0.78, 0.92)	0.57 (0.41, 0.72)	2.0 (1.4, 2.9)	0.24 (0.15, 0.39)	8 (4, 17)	0.82 (0.78, 0.85)	
Detection of metastases	7	0.75 (0.49, 0.90)	0.85 (0.66, 0.94)	4.8 (2.4, 9.9)	0.30 (0.14, 0.63)	16 (6, 41)	0.87 (0.84, 0.90)	0.07

OC ovarian cancer, *NA* not applicable, *CT* computed tomography, +*LR*, positive likelihood ratio, – *LR* negative likelihood, *DOR* diagnostic odds ratio, *SROC* summary receiver operating characteristic, *CI* confidence interval

Diagnostic performance of PET, PET/CT, PET/MRI

Results of studies investigating the diagnostic performance of PET/MRI were not pooled due to the limited number of studies included. The reported sensitivities and specificities were 91–97% and 86–87% in these studies. The overall sensitivity, specificity, SROC value of PET on patient level were 0.81 (0.71, 0.88), 0.81 (0.58, 0.93), and 0.82 (0.78, 0.85)

Table 3 Subgroup analysis of diagnostic performance of MRI

	No. of studies	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	–LR (95% CI)	DOR (95% CI)	SROC (95% CI)	p value
Study design								
Prospective	4	0.97 (0.94, 0.98)	0.78 (0.65, 0.87)	4.3 (2.7, 7.0)	0.04 (0.02, 0.08)	107 (42, 274)	0.96 (0.94, 0.98)	
Retrospective	6	0.90 (0.86, 0.94)	0.79 (0.73, 0.85)	4.4 (3.3, 5.8)	0.12 (0.08, 0.19)	36 (20, 67)	0.93 (0.90, 0.95)	0.02
Type of examination								
DWI	5	0.97 (0.94, 0.98)	0.83 (0.71, 0.91)	5.6 (3.2, 9.9)	0.04 (0.02, 0.08)	140 (51, 384)	0.98 (0.96, 0.99)	
Conventional/ conventional+contrast-enhanced	5	0.91 (0.86, 0.94)	0.76 (0.72, 0.80)	3.8 (3.2, 4.5)	0.12 (0.07, 0.18)	33 (19, 56)	0.92 (0.89, 0.94)	0.02
Tesla								
1.5 T	5	0.95 (0.90, 0.97)	0.87 (0.80, 0.91)	7.2 (4.8, 10.9)	0.06 (0.03, 0.12)	121 (52, 285)	0.97 (0.95, 0.98)	
3.0 T	4	0.95 (0.92, 0.97)	0.76 (0.69, 0.82)	4.0 (3.0, 5.4)	0.06 (0.04, 0.10)	65 (34, 126)	0.95 (0.93, 0.97)	<0.001
Year of publication								
<2010	3	0.92 (0.86, 0.96)	0.78 (0.70, 0.85)	4.1 (3.0, 5.8)	0.10 (0.06, 0.18)	45 (21, 97)	NA	
≥2010	7	0.95 (0.90, 0.98)	0.82 (0.76, 0.87)	5.2 (3.8, 7.1)	0.06 (0.02, 0.13)	92 (33, 261)	0.89 (0.86, 0.92)	0.13
Mean age (year)								
<55	4	0.89 (0.74, 0.96)	0.83 (0.75, 0.89)	5.3 (3.3, 8.6)	0.14 (0.05, 0.35)	39 (10, 142)	0.91 (0.88, 0.93)	
≥55	6	0.96 (0.93, 0.97)	0.77 (0.70, 0.83)	4.1 (3.1, 5.5)	0.06 (0.04, 0.09)	73 (40, 135)	0.95 (0.93, 0.97)	0.02
No. of patients								
<50	4	0.93 (0.87, 0.96)	0.86 (0.74, 0.93)	6.8 (3.4, 13.5)	0.08 (0.04, 0.16)	84 (29, 246)	0.96 (0.94, 0.97)	
≥50	6	0.95 (0.88, 0.98)	0.80 (0.75, 0.85)	4.8 (3.6, 6.3)	0.06 (0.02, 0.15)	80 (26, 247)	0.87 (0.84, 0.90)	0.02
Type of analysis								
Qualitative diagnosis	9	0.94 (0.90, 0.96)	0.80 (0.75, 0.85)	4.8 (3.8, 6.2)	0.08 (0.04, 0.13)	63 (31, 128)	0.90 (0.87, 0.92)	
Detection of metastases	1	0.98 (0.91, 1.00)	0.75 (0.19, 0.99)	3.9 (0.72, 21.5)	0.02 (0.00, 0.17)	177 (9, 795)	NA	NA

OC ovarian cancer, *NA* not applicable, *MRI* magnetic resonance imaging, *DWI* diffusion-weighted imaging, *+LR* positive likelihood ratio, *–LR* negative likelihood, *DOR* diagnostic odds ratio, *SROC* summary receiver operating characteristic, *CI* confidence interval

(Table 4, Supplementary Fig. 5). Pooled estimates of sensitivity, specificity, and SROC value of PET/CT on patient level were 0.92 (0.88, 0.94), 0.88 (0.83, 0.92), and 0.96 (0.94, 0.97) (Table 4, Supplementary Fig. 6). The lesion-based overall sensitivity, specificity, and SROC value of PET/CT were 0.82 (0.71, 0.89), 0.94 (0.88, 0.97), and 0.95 (0.92, 0.96) (Table 4, Supplementary Fig. 7). Meta regression resulted in significant affection of study design, year of publication, and type of analysis on the pooled estimates of parameters.

Publication bias

Deeks' funnel plot asymmetry tests yielded *p* values of 0.83, 0.77, 0.31, and 0.53 for CT, MRI, PET, and PET/CT studies (Fig. 3).

Discussion

Ovarian cancer remains one of the leading causes of mortality of gynecologic malignancies [35]. Metastases are often presented at the time of OC diagnosis, and high rate of relapse and poor prognosis are involved regardless of optimized management [36]. Timely and accurate detection of

OC plays a significant role in treatment improvement and prognosis appraisal [21]. Imaging is critical for ovarian cancer management.

In the current study, we evaluated the most commonly utilized noninvasive imaging modalities in the detection of OC via the conduction of a meta-analysis. The diagnostic performance of CT, MRI, PET, along with hybrid imaging modalities, including PET/CT and PET/MRI were investigated. Results revealed that MRI manifested the highest overall sensitivity (0.95) and PET/CT showed the highest pooled specificity (0.88) on patient level. In general, PET/CT demonstrated the most superior diagnostic performance with an SROC value of 0.96 on a patient basis. Of note, only 2 PET/MRI studies were included in this study, the corresponding results were not meta-analyzed, sensitivities and specificities in these studies ranged from 91 to 97% and 86% to 87%, respectively. The combination of PET with CT or MRI can provide hybrid anatomical and functional imaging information so as to improve the detection accuracy [35, 37, 38]. Furthermore, results of meta-regression showed insignificant affection of baseline characteristics on the heterogeneity among CT studies. For MRI studies, study design, type of examination, Tesla level, age, and number of patients were detected to be potential sources of heterogeneity by meta-regression. Study design, year of publication,

Table 4 Subgroup analysis of diagnostic performance of PET (PET/CT)

	No. of studies	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	– LR (95% CI)	DOR (95% CI)	SROC (95% CI)	p value
Study design								
Prospective	11	0.91 (0.87, 0.94)	0.91 (0.84, 0.95)	10.2 (5.7, 18.3)	0.10 (0.07, 0.14)	102 (51, 206)	0.94 (0.91, 0.96)	
Retrospective	25	0.91 (0.87, 0.95)	0.88 (0.81, 0.92)	7.3 (4.9, 11.1)	0.10 (0.06, 0.15)	75 (41, 137)	0.95 (0.93, 0.97)	< 0.001
Acquisition								
PET	4	0.81 (0.71, 0.88)	0.81 (0.58, 0.93)	4.3 (1.7, 10.9)	0.23 (0.14, 0.39)	18 (5, 66)	0.82 (0.78, 0.85)	
PET/CT	34	0.92 (0.88, 0.94)	0.88 (0.83, 0.92)	7.9 (5.5, 11.3)	0.09 (0.07, 0.13)	85 (53, 136)	0.96 (0.94, 0.97)	0.46
Year of publication								
< 2010	14	0.87 (0.82, 0.90)	0.89 (0.84, 0.93)	8.0 (5.4, 11.6)	0.15 (0.11, 0.20)	53 (31, 92)	0.91 (0.88, 0.93)	
≥ 2010	24	0.93 (0.89, 0.95)	0.87 (0.80, 0.92)	7.4 (4.7, 11.6)	0.08 (0.05, 0.13)	89 (49, 164)	0.96 (0.94, 0.97)	< 0.001
Mean age (year)								
< 55	17	0.92 (0.85, 0.96)	0.90 (0.83, 0.95)	9.5 (5.4, 16.6)	0.09 (0.05, 0.16)	107 (51, 224)	0.96 (0.94, 0.98)	
≥ 55	20	0.90 (0.87, 0.93)	0.87 (0.80, 0.91)	6.9 (4.6, 10.4)	0.11 (0.08, 0.15)	62 (36, 105)	0.95 (0.92, 0.96)	0.53
No. of patients								
< 50	17	0.91 (0.86, 0.94)	0.86 (0.81, 0.91)	6.7 (4.7, 9.7)	0.11 (0.07, 0.16)	62 (35, 112)	0.92 (0.89, 0.94)	
≥ 50	21	0.91 (0.86, 0.94)	0.89 (0.82, 0.94)	8.4 (5.1, 13.7)	0.10 (0.07, 0.16)	83 (44, 156)	0.96 (0.94, 0.97)	0.06
Type of analysis								
Qualitative diagnosis	34	0.92 (0.89, 0.94)	0.87 (0.81, 0.91)	6.9 (4.8, 9.9)	0.10 (0.07, 0.12)	72 (46, 113)	0.95 (0.93, 0.97)	
Detection of metastases	4	0.76 (0.39, 0.94)	0.94 (0.89, 0.97)	12.6 (5.5, 29.0)	0.26 (0.07, 0.88)	49 (8, 323)	0.95 (0.92, 0.96)	0.01

OC ovarian cancer, *NA* not applicable, *PET* positron emission tomography, *+LR*, positive likelihood ratio, *– LR* negative likelihood, *DOR* diagnostic odds ratio, *SROC* summary receiver operating characteristic, *CI* confidence interval

and the detection of metastatic OC were deemed as causes of heterogeneity among PET (PET/CT) studies. Due to limited number of covariates extracted from each enrolled study and insufficient numbers of studies in certain subgroups, meta-regression was performed based on available parameters, other possible sources of heterogeneity among studies should be further explored in the future.

Subgroup analyses were carried out to investigate the diagnostic value of these imaging modalities in specific subgroups. CT revealed the highest sensitivity in the detection of primary OC and showed superior specificity in metastases. High-field MRI produces better image quality compared with the lower field strength 1.5 T magnetic resonance MRI machines because it has a better signal-to-noise ratio (SNR) [39]. However, MRI performed on 1.5 T showed better diagnostic performance than on 3.0 T in this study. The probable reasons may be the differences on characteristics of study population, prevalence of OC, and

the subjectivity of imaging reading between included studies. More well-designed relevant studies are warranted to further explore the impact of field strength on the diagnostic ability of OC. DWI examination demonstrated superior diagnostic ability than conventional or contrast-enhanced MRI. This combination of high contrast, millimeter level spatial resolution, robust performance, and short imaging time enables DWI to depict small tumor deposits in large volumes in a clinically timely manner [40]. PET/CT showed superior specificity but inferior sensitivity in the detection of metastasis compared to qualitative diagnosis. The possible reason may be the limited number of enrolled studies with regard to the detection of metastasis, more related studies are needed to verify the diagnostic performance of PET/CT in detecting metastasis. In addition, two reports enrolled in this study revealed that ^{18}F-FDG PET/MRI yielded better diagnostic accuracy for the detection of metastatic ovarian cancer but did not offer significant

A
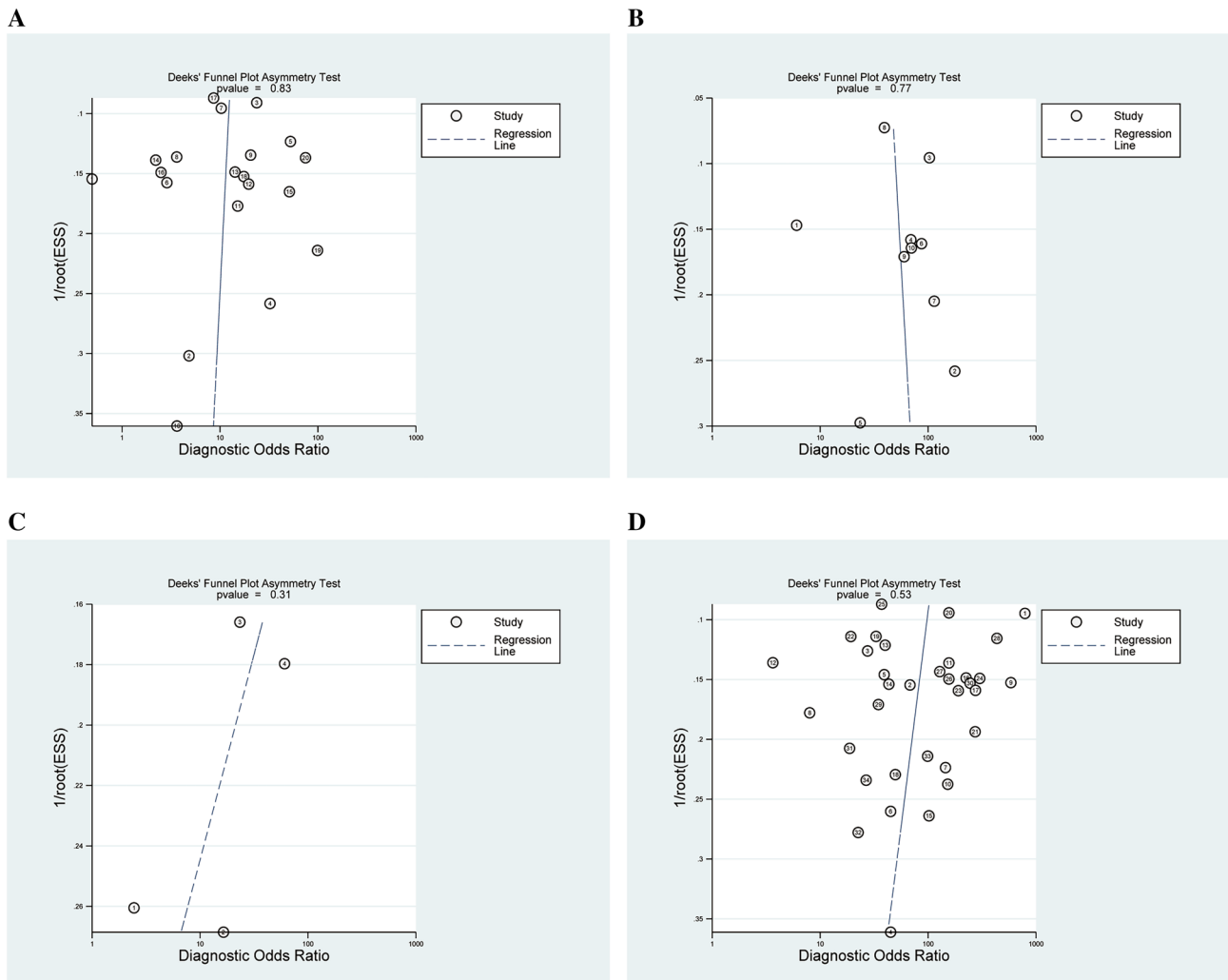

B

C

D

Fig. 3 Deeks' funnel plot asymmetry tests of CT, MRI, PET, and PET/CT studies. **A** Deeks' funnel plot asymmetry tests of CT studies. **B** Deeks' funnel plot asymmetry tests of MRI studies. **C** Deeks' fun- nel plot asymmetry tests of PET studies. **D** Deeks' funnel plot asymmetry tests of PET/CT studies

additional information for the diagnosis primary OC [10, 41].

The current meta-analysis focused on the assessment of diagnostic performance of noninvasive imaging modalities on OC detection despite the cancer stages. It also provided considerable updates to previous meta-analyses on individual OC stage or imaging technique [11, 24, 42–44]. First, electronic database was systematically searched using relevant keywords and comprehensive search strategies; second, the processes of the literature screening, quality assessment, and data extraction were performed by two independent reviewers to minimize objective bias. Finally, statistical approaches were employed to detect potential heterogeneity and publication bias in included records. Publication bias of included studies was not indicated by the Deeks' funnel plot asymmetry test. Nevertheless, as similar to any meta-analysis, heterogeneity is inevitable and the

source of this heterogeneity is not sorted out thoroughly. The results should be interpreted with caution.

Conclusion

This meta-analysis revealed that noninvasive imaging modalities including CT, MRI, PET (PET/CT, PET/MRI) yielded favorable diagnostic performance in the detection of OC. A combination of different tools (PET/MRI) was deemed to be more accurate for identifying metastatic OC. Professional and economic issues should be considered by practitioners in the real-world clinical setting.

Data availability All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declarations

Conflict of interest All the authors declared no conflict of interest.

Ethical approval Not applicable.

Consent for publication Not applicable.

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