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Diagnostic value of magnetic resonance and computed tomography colonography for the diagnosis of colorectal cancer
A systematic review and meta-analysis

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Abstract
Background: Surgical resection is the recommended procedure for colorectal cancer (CRC), but majority of the patients were diagnosed with advanced or metastatic CRC. Currently, there were inconsistent results about the diagnostic value of magnetic resonance colonography (MRC) and computed tomography colonography (CTC) in early CRC diagnosis. Our study conducted this meta-analysis to investigate the diagnostic value of MRC and CTC for CRC surveillance.

Methods: A comprehensive literature search was conducted in PubMed, Embase, and the Cochrane library to select relevant studies. The summary sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), diagnostic odds ratio (DOR), and the area under the receiver operating characteristic curves (AUC) were calculated to evaluate the diagnostic value of MRC and CTC, respectively.

Result: Twenty-five studies including 2985 individuals were selected in the final analysis. Eight studies evaluated the diagnostic value of MRC, and 17 studies assessed CTC. The summary sensitivity, specificity, PLR, NLR, DOR, and AUC in MRC for early detection of CRC were 0.98 (95% confidence interval, CI: 0.80–1.00), 0.94 (95% CI: 0.85–0.97), 15.48 (95% CI: 6.30–38.04), 0.02 (95% CI: 0.00–0.25), 115.09 (95% CI: 15.37–862.01), and 0.98 (95% CI: 0.97–0.99), respectively. In addition, the sensitivity, specificity, PLR, NLR, DOR, and AUC of CTC for diagnosing CRC were 0.97 (95% CI: 0.88–0.99), 0.99 (95% CI: 0.99–1.00), 154.11 (95% CI: 67.81–350.22), 0.03 (95% CI: 0.01–0.13), 642.51 (95% CI: 145.05–2846.02), and 1.00 (95% CI: 0.99–1.00). No significant differences were found between MRC and CTC for DOR in all the subsets.

Conclusion: The findings of meta-analysis indicated that MRC and CTC have higher diagnostic values for early CRC diagnosis. However, the DOR for diagnosing CRC between MRC and CTC showed no significance.

Abbreviations: AUC = the area under the receiver operating characteristic curves, CC = conventional colonoscopy, CIs = confidence intervals, CRC = colorectal cancer, CTC = computed tomography colonography, DOR = diagnostic odds ratio, FOBT = fecal occult blood test, MRC = magnetic resonance colonography, NLR = negative likelihood ratio, PLR = positive likelihood ratio.

Keywords: colorectal cancer, computed tomography colonography, magnetic resonance imaging, meta-analysis

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1. Introduction

Colorectal cancer (CRC) is the fourth leading cause of cancer-related mortality in both men and women worldwide, causing a major public health issue.[1] The high morbidity population included patients aged ≥75 years, but the cancer-related mortality rates appear to decline.[2] Mortality in most of the CRC patients occurs due to metastasis, which was consistent with other common cancers. Due to poor diagnosis of clinical symptoms, a relatively high proportion of CRC patients were diagnosed in the advanced stages. According to the data, nearly 25% of CRC patients with metastases were diagnosed initially, and approximately 50% of these patients will develop into metastases stages.[3] Surgical resection remains the mainstay of treatment in nonmetastatic CRC patients, while curative resection was appropriate in a very low percentage of patients.[4] Conventional colonoscopy (CC) is the best method for diagnosis and differentiation of CRC from other lesions. However, CC was considered to be invasive and completely safe in patients undergoing examination.[5] Therefore, additional simpler screening methods should be explored, and compared with colonoscopy, which is a more selective and efficient tool.[6]

Currently, virtual colonoscopy including magnetic resonance colonography (MRC) and computed tomography colonography (CTC) have already been studied as alternative methods for the diagnosis of CRC and other colonic pathologies. These 2 approaches have been demonstrated as well tolerated, feasible, and safe methods.[7–9] However, the impact of ionizing radiation burden could not be neglected.[10,11] Previous meta-analyses studies mainly focused on single virtual colonoscopy compared with CC, and comparison of the diagnostic value between MRC and CTC was not evaluated.[12,13] It is particularly important to clarify the best diagnostic procedure in individuals who are at high risk of CRC, as it has not been determined before. Therefore, we systematically examined published studies to evaluate the diagnostic values of MRC and CTC for diagnosing early CRC, and compared their effectiveness.

2. Materials and methods

2.1. Data sources, search strategy, and selection criteria

This review was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement issued in 2009 (Checklist S1).[14] Published studies investigating the diagnostic ability of MRC or CTC in the diagnosis of CRC were eligible for inclusion in this meta-analysis, and there was no language restriction. We searched PubMed, Embase, and Cochrane Library electronic databases for articles published through February 2018 and the following search terms were used ("computed tomography colonography" OR "magnetic resonance colonography" OR "virtual colonoscopy") AND ("colorectal" OR "colon" OR "rectal") AND ("cancer" OR "tumor" OR "neoplasm"). Manual search of the reference lists was performed for identifying any potentially eligible studies.

Literature search and study selection process were conducted by 2 reviewers independently, and any disagreement was resolved by group discussion until a consensus was reached. The inclusion criteria of this meta-analysis were as follows: participants: patients with high or moderate risk of progression into CRC; intervention or exposure: patients undergoing MRC/CTC examination; control: studies that employed CC as gold standard; outcomes: the study should report true and false positive, true and false negative, or other data that could transform into the above results; and study design: studies with prospective design.

2.2. Data collection and quality assessment

Two reviewers independently collected the characteristics of the studies and participants who are using a standardized approach, and any inconsistencies were examined and adjudicated independently by an additional author by referring to the original studies. The collected information included the first author's surname, publication year, region, sample size, mean age, percentage male, inclusion criteria, imaging modality, true and false positive, and true and false negative. For studies that published on similar populations more than once, data from the recently published studies was chosen. Quality assessment was performed by Quality Assessment Tool for Diagnostic Accuracy Studies, version 2.0, which included 14 items that are answered by "yes," "no," and "unclear." The answer "yes" was considered as satisfied with the criteria, while "no" and "unclear" were considered as the study was not satisfied with the criteria or the study was partially satisfied with the criteria or could not provide sufficient information.[15]

2.3. Statistical analysis

The summary sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), diagnostic odds ratio (DOR), and the area under the receiver operating characteristic curves (AUC) with their 95% confidence intervals (CIs) were calculated based on true positive, false positive, false negative, and true negative. The summary sensitivity, specificity, PLR, NLR, and DOR were calculated by using bivariate random effects, and the AUC was calculated by hierarchical regression.[16,17] Heterogeneity between studies was investigated by using I^2 and Q statistic, and we considered $P < .10$ as indicative of significant heterogeneity.[18,19] Subgroup analyses were performed for DOR in MRC and CTC diagnosis of CRC based on sample size, mean age, and percentage male. Furthermore, P values between subgroups were also calculated by using chi-squared test and meta-regression.[20] Funnel plots and Deeks asymmetry tests were employed to evaluate publication biases for MRC and CTC.[21] The significant level (α) was 0.05 for pooled diagnostic parameters. The meta-analysis was performed by using STATA software (version 10.0; Stata Corporation, College Station, TX).

3. Results

3.1. Literature search

A flowchart of literature selection process was shown in Figure 1. Based on the predefined search strategy, 690 studies (443 from PubMed, 193 from Embase, and 54 from the Cochrane library) were identified during the initial electronic search, and 51 studies were excluded due to duplications. Furthermore, 571 articles were excluded due to irrelevant, reviews, letters, and meta-analysis studies. A total of 68 potentially eligible studies were selected, and after detailed evaluations, 25 prospective studies were selected for
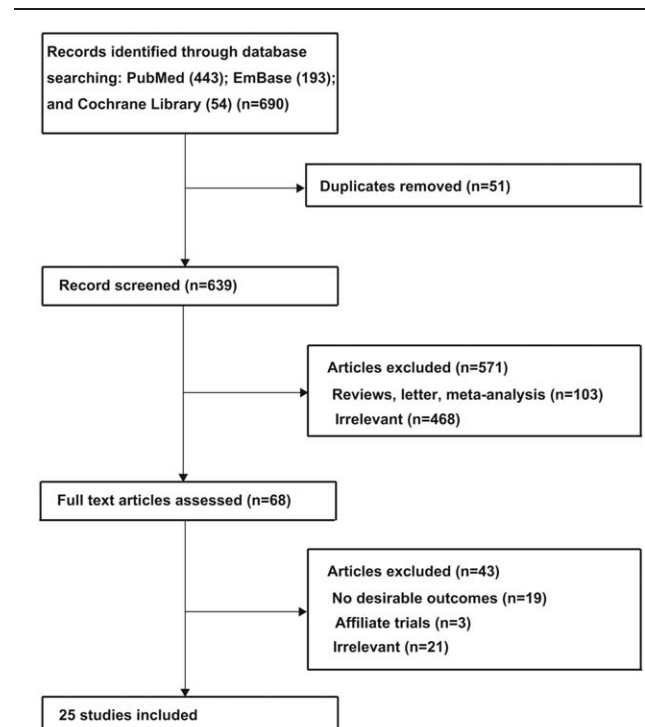

Figure 1. Flow diagram of the literature search and trial selection process.

Table 1

Baseline characteristics of the included studies.

References	Region	Sample size	Mean age (years)	Percentage male (%)	Inclusion criteria	Imaging modality	True positive	False positive	True negative	False negative
[22]	USA	100	62.0	60.0	50 years of age or older and if they had a history of adenomatous polyps, recent sigmoidoscopic evidence of 1 or more polyps, a positive finding on FOBT, or a history of colorectal cancer in 1 or more first-degree relatives.	CTC	3	0	97	0
[23]	Italy	70	59.0	60.0	colonic endoluminal lesions	MRC	53	2	14	1
[24]	Switzerland	132	60.0	57.6	Possible presence of a mass	MRC	27	11	48	29
[25]	UK	201	71.0	41.3	Colorectal symptoms or requiring surveillance	CTC	13	0	186	2
[26]	USA	34	64.2	58.8	Colorectal masses, benign obstructing colorectal strictures, and prior colorectal resection	CTC	16	0	16	2
[27]	Germany	6	NA	NA	Suspected colorectal tumors	MRC	4	0	2	0
[28]	Germany	17	66.0	64.7	Colorectal mass lesions	MRC	12	2	3	0
[29]	Italy	96	NA	NA	NA	CTC	7	1	88	0
[30]	USA	300	62.6	97.0	Hematochezia, stools with positive hemoccult test results, iron deficiency anemia, or personal or family history of colonic neoplasms	CTC	8	0	292	0
[31]	Germany	24	57.0	50.0	Rectal bleeding, positive FOBT, or altered bowel habits	MRC	13	2	9	0
[32]	Italy	165	62.0	47.9	Suspected colorectal lesions	CTC	30	0	135	0
[33]	China	71	62.0	53.5	Abdominal pain, iron deficiency anemia, hematochezia or positive FOBT, tumor search, colonic polyps follow up, and diarrhea/alteration of bowel habit	CTC	5	0	66	0
[34]	Germany	120	60.2	46.7	Suspected colorectal disease	MRC	11	2	107	0
[35]	China	156	55.2	47.4	Symptoms suggestive of colorectal neoplasm, positive FOBT, history of CRC, and asymptomatic individuals >50.0 years	MRC	3	32	118	3
[36]	UK	54	69.0	40.7	Rectal bleeding with change in bowel habit, change in bowel habit alone, age over 60, rectal bleeding without anal symptoms, abdominal mass, iron deficiency anemia	CTC	5	1	48	0
[37]	UK	80	68.0	56.3	Change in bowel habit, rectal bleeding, abdominal pain, loss of weight, and a rectal mass	CTC	28	1	50	1
[38]	Germany	55	59.0	54.5	Positive family history of CRC, a positive FOBT, or chronic diarrhea	MRC	8	1	46	0
[39]	USA	600	61.0	45.0	Aged 50 years or older	CTC	6	2	592	0
[40]	Switzerland	100	66.0	62.0	Hematochezia, positive hemoccult test result, iron deficiency anemia, or person or family history of colonic neoplasms	CTC	7	1	92	0
[41]	Korea	51	63.0	62.7	History of altered bowel habits, anemia of unknown cause, abdominal pain, positive FOBT, and hematochezia	CTC	20	0	31	0
[42]	Australia	38	NA	NA	Aged 50 years or older	CTC	10	1	27	0
[43]	USA	150	60.9	48.7	Age >40 years, bright/dark red PR bleed or unexplained anemia and altered bowel habit/family history of CRC	CTC	17	2	130	1
[44]	Italy	49	60.5	61.2	Positive FOBT from a regional screening program	CTC	20	2	14	13
[45]	Brazil	85	61.0	37.6	Age over 40 years and bright/dark red fecal bleed or unexplained anemia and altered bowel habit/family history of CRC	CTC	13	0	71	1
[46]	USA	231	58.5	60.3	0–III CRC	CTC	16	9	163	43

CRC = colorectal cancer, CTC = computed tomography colonography, FOBT = fecal occult blood test, MRC = magnetic resonance colonography, NA = not available.

final meta-analysis.[22–46] No additional eligible study was observed by manual searching of the reference lists. Table 1 summarized the baseline characteristics of the studies and participants.

3.2. Study characteristics

Twenty-five prospective studies including a total of 2985 individuals were enrolled in this meta-analysis, where 8 studies evaluated the diagnostic value of MRC, and the remaining 17 studies evaluated the diagnostic value of CTC. The published studies ranged from 1999 to 2017, while 6 to 600 patients were included in each study. Seven studies were conducted in the United States or Australia, 15 in Europe, and the remaining 3 studies were conducted in Asia. The details of study quality assessment are presented in Table 2.

3.3. Magnetic resonance colonography

Eight studies reported the diagnostic value of MRC for detecting CRC. The summary sensitivity and specificity of MRC were 0.98

Table 2

Quality evaluation of the included studies using the Quality Assessment of Diagnostic Accuracy Studies tool.

| References	Representative patient spectrum	Reporting of selection criteria	Reference standard	Absence of disease progression bias	Absence of partial verification bias	Absence of differential verification bias	Absence of incorporation bias	Description of index text execution	Description of reference standard execution	Reference standard blinded	Index test blinded	Absence of clinical review bias	Reporting of uninterpretable/ intermediate results	Withdrawal
							Question about study design characteristic							
[22]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[23]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[24]	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[25]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[26]	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[27]	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[28]	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[29]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[30]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[31]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[32]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[33]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[34]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[35]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[36]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[37]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[38]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[39]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
[40]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
[41]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[42]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[43]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
[44]	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[45]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
[46]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
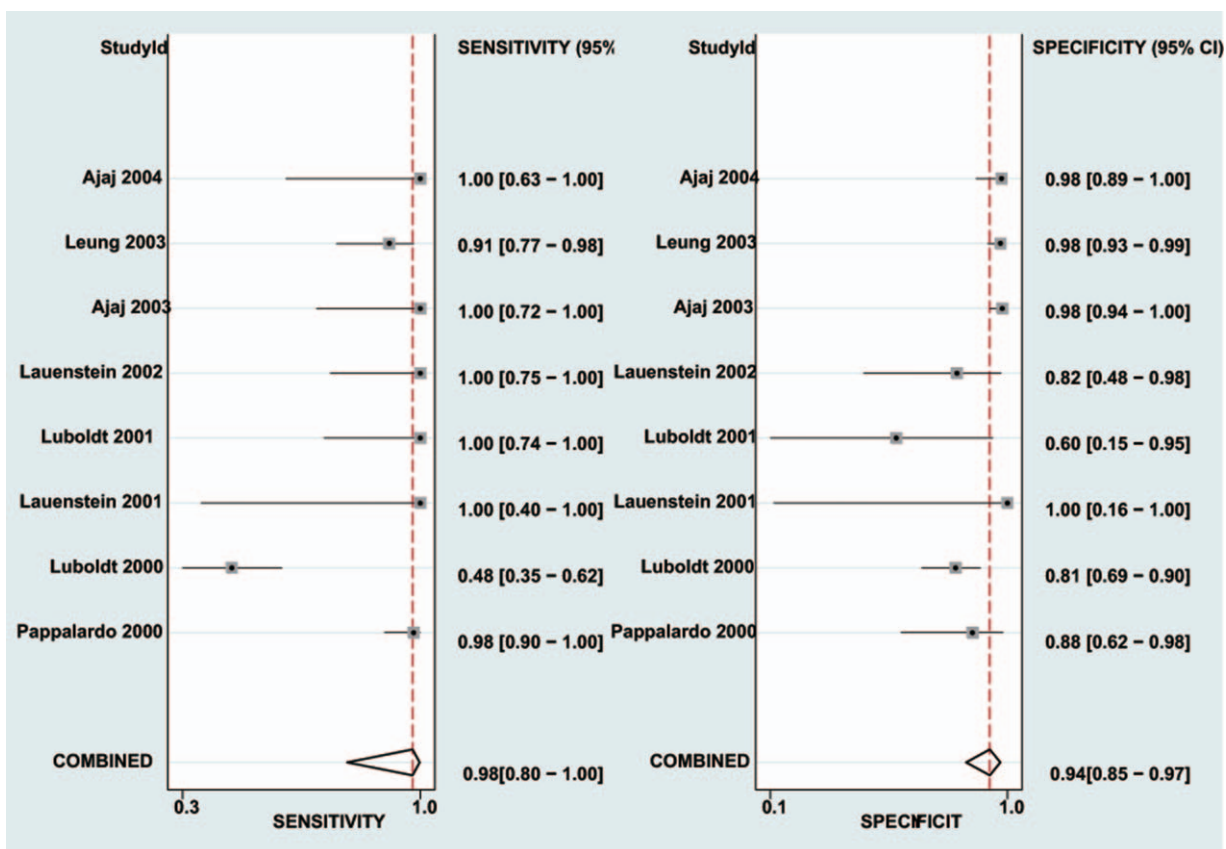
Figure 2. The summary sensitivity and specificity for magnetic resonance colonography. CIs=confidence intervals.

(95% CI: 0.80–1.00), and 0.94 (95% CI: 0.85–0.97), respectively (Fig. 2). Furthermore, the PLR and NLR in patients who received MRC were 15.48 (95% CI: 6.30–38.04), and 0.02 (95% CI: 0.00–0.25), respectively (Fig. 3). The DOR of MRC for diagnosing early CRC was 115.09 (95% CI: 15.37–862.01; Fig. 4). Finally, the summary AUC in MRC for diagnosing CRC was 0.98 (95% CI: 0.97–0.99; Fig. 5).

3.4. Computed tomography colonography

Seventeen studies reported the diagnostic value of MRC for detecting CRC. The summary sensitivity and specificity of MRC were 0.97 (95% CI: 0.88–0.99), and 0.99 (95% CI: 0.99–1.00), respectively (Fig. 6). Furthermore, the PLR and NLR in patients who received MRC were 154.11 (95% CI: 67.81–350.22), and 0.03 (95% CI: 0.01–0.13), respectively (Fig. 7). The DOR of MRC for diagnosing early CRC was 642.51 (95% CI: 145.05–2846.02; Fig. 8). Finally, the summary AUC was 1.00 (95% CI: 0.99–1.00) in patients using CTC for diagnosing CRC (Fig. 9).

3.5. Subgroup analysis

Subgroup analyses for DOR of MRC and CTC are shown in Table 3. The DOR in patients using MRC and CTC showed statistically significant differences in all the subsets. However, no significant differences between MRC and CTC for DOR in all the subsets were found. Furthermore, sample size and percentage male were important factors with significant DOR of MRC.

Finally, the sample size, mean age, and percentage male affected the DOR of CTC.

3.6. Publication bias

Publication biases of MRC and CTC for CRC detection are presented in Figure 10. There were no significant publication biases for MRC (P value for Deeks funnel plot asymmetry test: .59) and CTC (P value for Deeks funnel plot asymmetry test: .13).

4. Discussion

Due to varied diagnostic parameters of MRC and CTC for diagnosing CRC, the present study summarized the diagnostic value of MRC and CTC in the detection of CRC in patients with high risk. In this comprehensive quantitative meta-analysis, 25 prospective studies including 2985 individuals were recruited, and the results showed that both MRC and CTC demonstrated an excellent diagnostic accuracy in diagnosing CRC with a summary AUC of 0.98 and 1.00, respectively. Furthermore, there was no significant difference between MRC and CTC for DOR in all the subsets based on the predefined factors (such as sample size, mean age, and percentage male).

We reviewed previous meta-analyses studies that investigated the diagnostic value of MRC and CTC for detecting CRC. Firstly, Porté et al[12] pooled 7 studies and found that CTC was feasible for CRC surveillance, which was correlated with 95% of sensitivity and 100% of specificity. Furthermore, they pointed
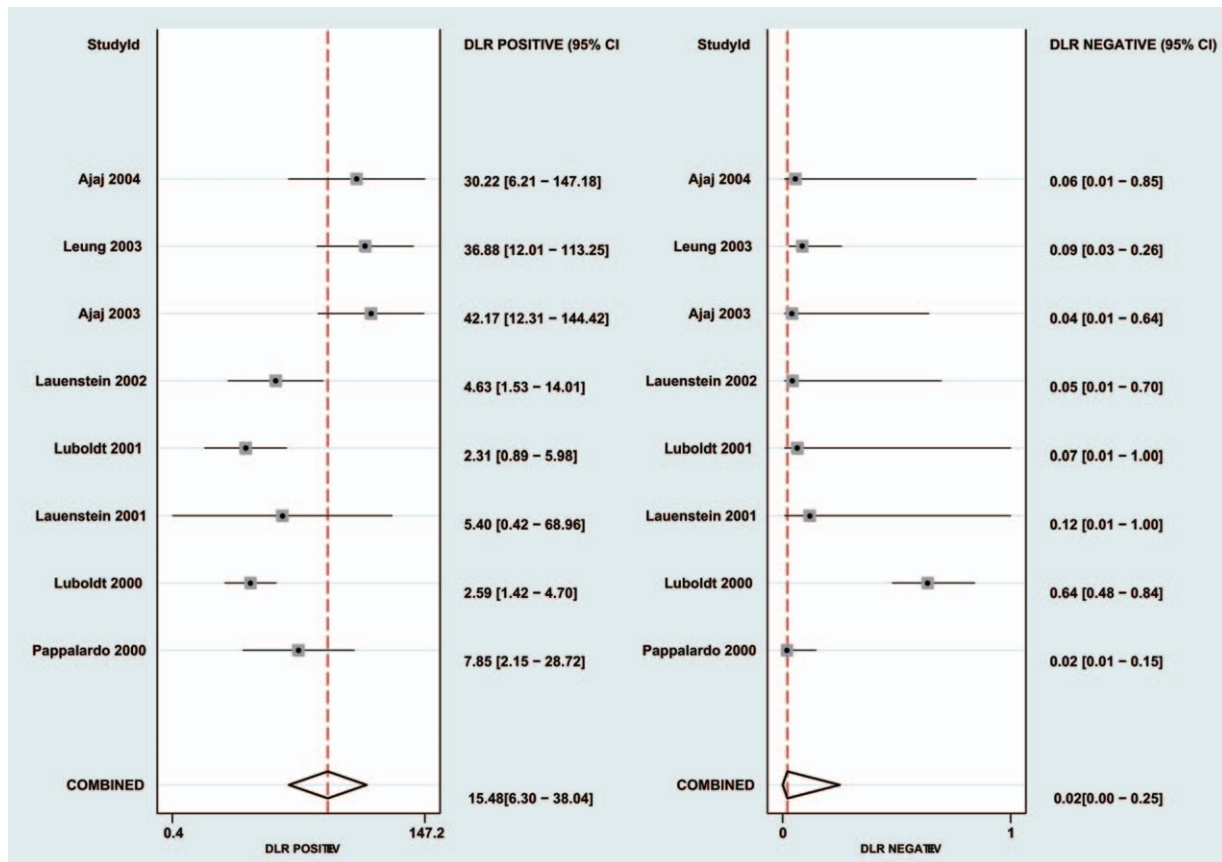
Figure 3. The summary positive likelihood ratio and negative likelihood ratio for magnetic resonance colonography. CIs = confidence intervals.
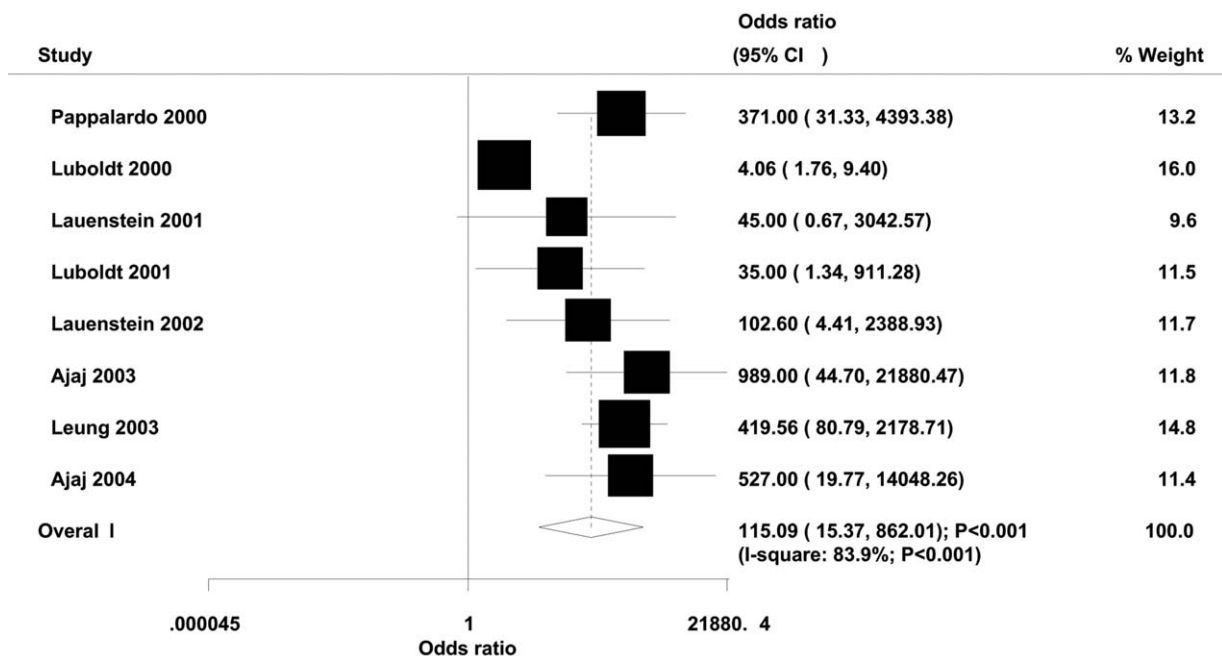

Figure 4. The summary DOR for magnetic resonance colonography. CIs = confidence intervals.
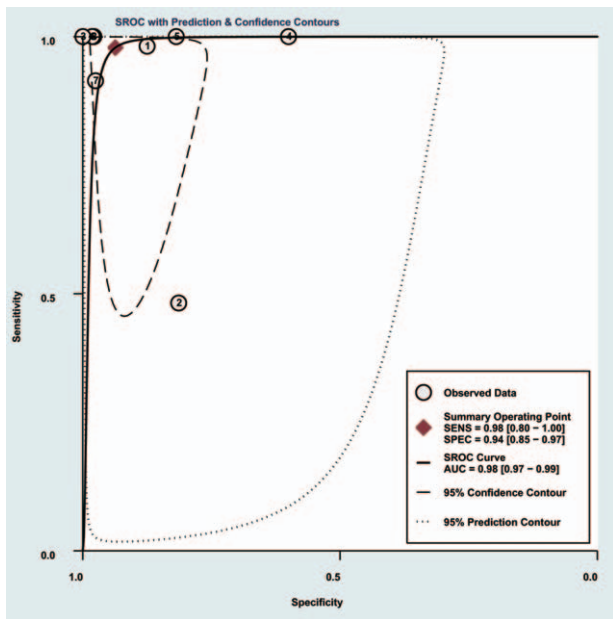
Figure 5. The summary receiver operating characteristic curves for magnetic resonance colonography.

out that CTC could offer single-test luminal, serosal and extra-colonic assessment, and cost-saving alternative over standard surveillance procedures.[12] Secondly, Purkayastha et al[13] conducted a meta-analysis based on 8 studies involving 563 patients, and the results pointed out that the sensitivity of MRC for detecting all lesions was 75%, the specificity was 96%, and the AUC was 0.90. Furthermore, they indicated that the diagnostic accuracy of MRC for diagnosing CRC was superior in polyps.[13] Thirdly, Purkayastha et al[13] conducted another important meta-analysis and demonstrated similar diagnostic values between MRC and CTC for diagnosing CRC. The study also indicated that the study quality, size, and intravenous/intraluminal contrast agents could affect the diagnostic values of MRC and CTC.[47] However, previous studies did not calculate the stratified analyses, limiting their results. The latest published articles should be reevaluated into the pooled results. Therefore, we conducted this comprehensive quantitative meta-analysis to evaluate the accuracy of the diagnostic value of MRC and CTC for detecting CRC.

Several RCTs included in this systemic review have reported varied diagnostic parameters. The sensitivity of MRC from individual studies ranged from 0.48 to 1.00, while the specificity ranged from 0.60 to 1.00. Huge variability occurred due to the study by Luboldt et al in 2000 and 2001.[24,28] The study conducted in the year 2000 suggested that MRC was associated with lower sensitivity and appropriate specificity, while the study conducted in 2001 found higher sensitivity and lower specificity
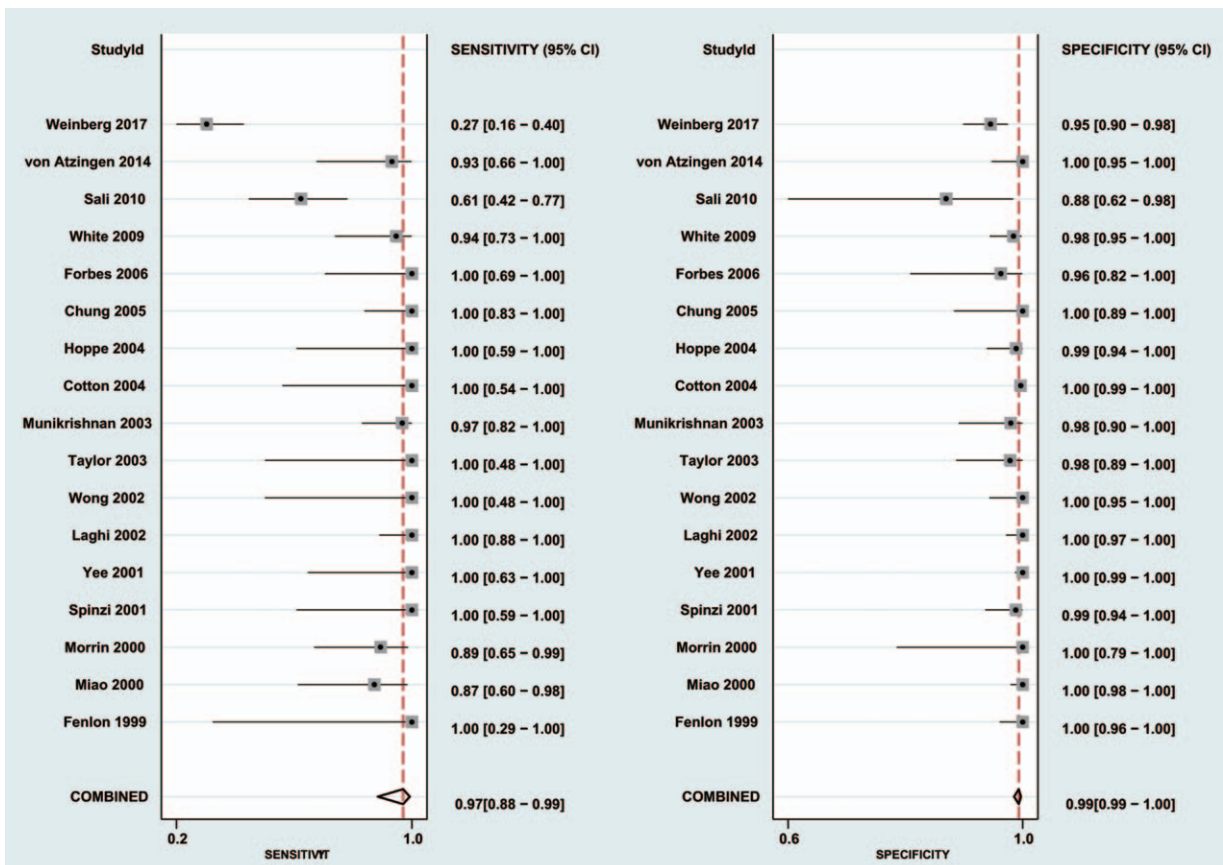

Figure 6. The summary sensitivity and specificity for computed tomography colonography. CIs = confidence intervals.
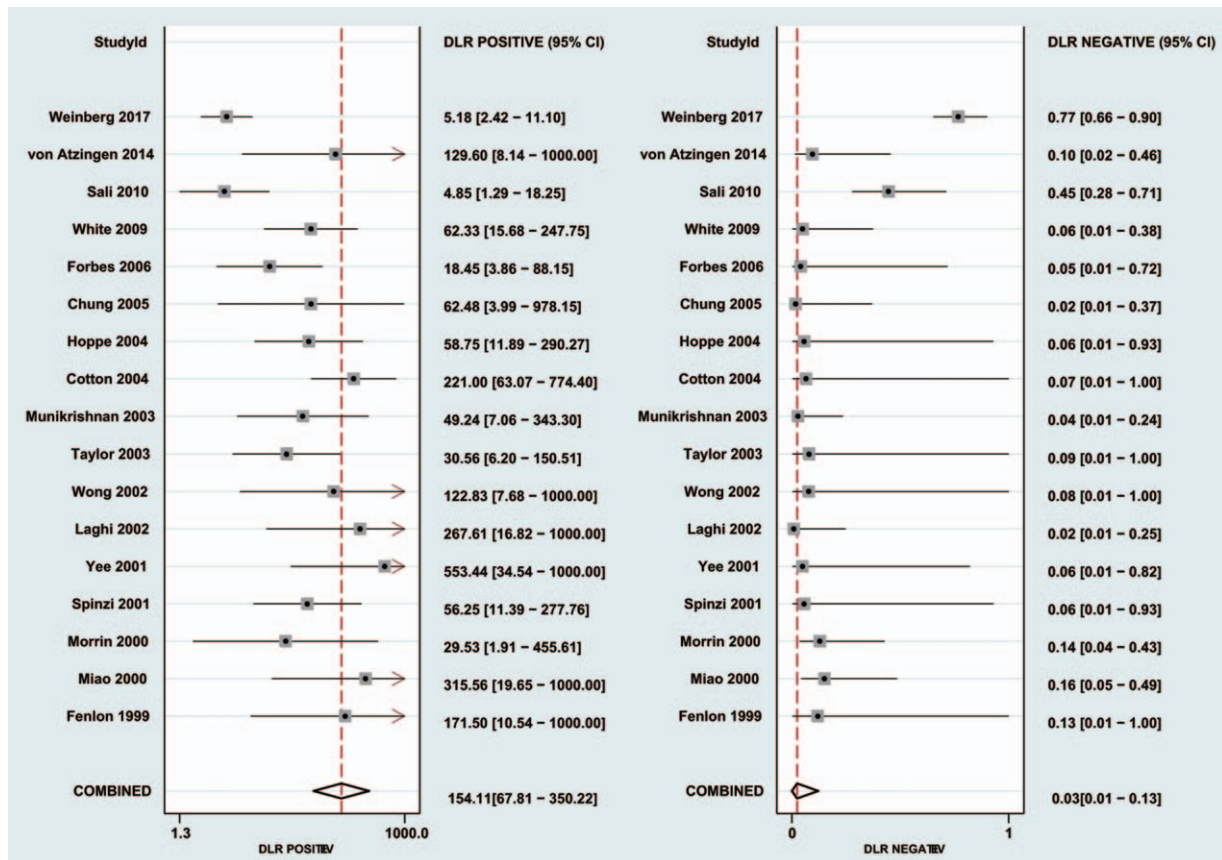
Figure 7. The summary positive likelihood ratio and negative likelihood ratio for computed tomography colonography. CIs=confidence intervals.
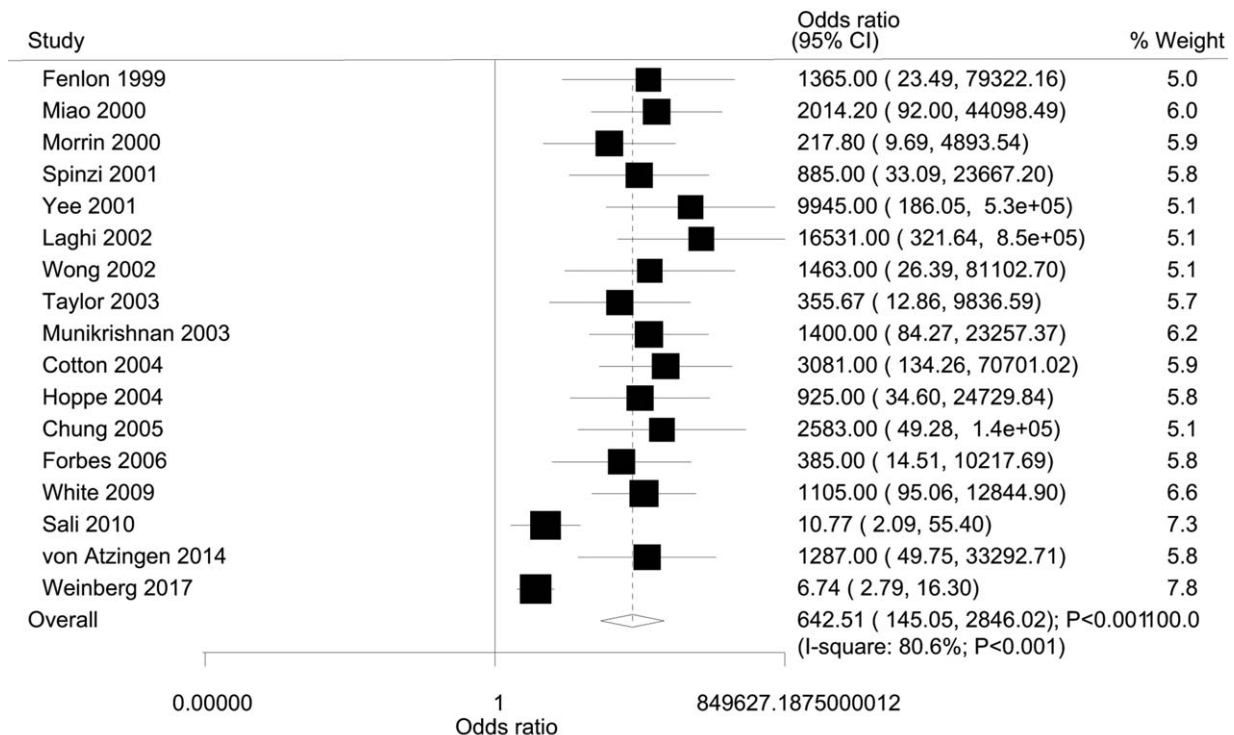

Figure 8. The summary diagnostic odds ratio for computed tomography colonography. CIs=confidence intervals.
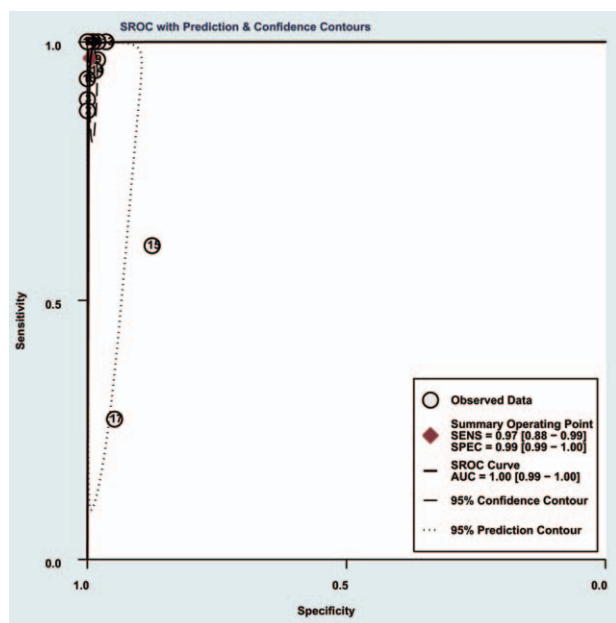
Figure 9. The summary receiver operating characteristic curves for computed tomography colonography.

Figure 10. Publication biases for magnetic resonance colonography (A) and computed tomography colonography (B).

in diagnosing CRC. Furthermore, the sensitivity of CTC in individual study ranged from 0.27 to 1.00, and the specificity ranged from 0.88 to 1.00. These differences were mainly focused in the study conducted by Sali et al[44] and Weinberg et al.[46] The reason for this was due to the inclusion of individuals with different risks. The type and size of colorectal lesions also affected the diagnostic accuracy of MRC and CTC. Finally, the expertise of the radiologist could also affect the accuracy of MRC and CTC, while this was not addressed in most of the included trials.

The subgroup analysis indicated no significant differences between MRC and CTC for DOR in all subsets. The imbalances in the characteristics of included studies and participants might bias these results. Furthermore, the current comparisons of DOR between MRC and CTC were based on indirect comparisons, while the head-to-head comparisons regarding the diagnostic value of MRC and CTC for detecting CRC were not conducted.
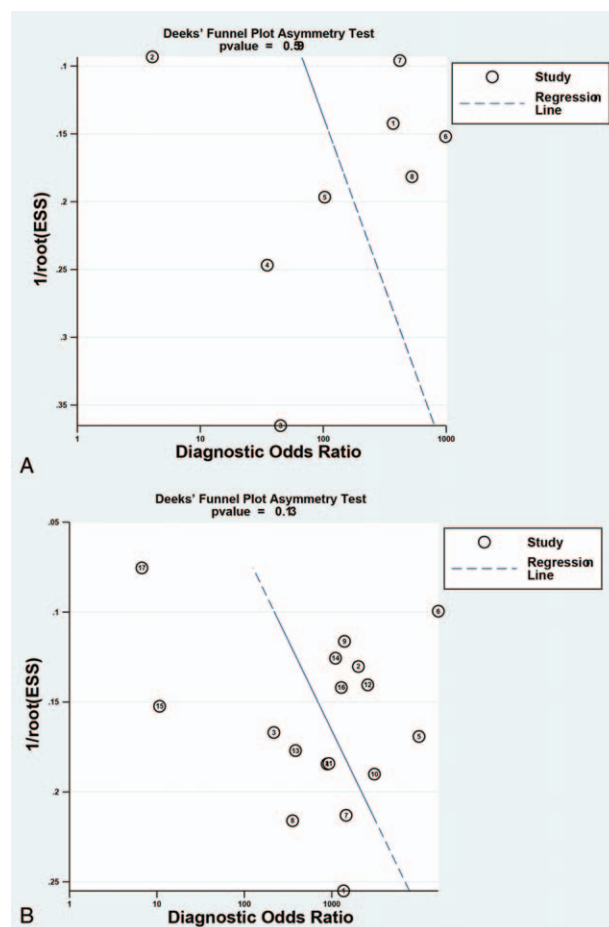
In addition, sample size and percentage male could affect the diagnostic value of MRC, while sample size, mean age, and percentage male could affect the DOR in CTC. The reason for this was due to the contribution of sample size for the weighted pooled results, mean age of the included patients was associated with the progression of CRC, and the percentage male was

Table 3

Subgroup analysis for diagnostic odds ratio in magnetic resonance colonography and computed tomography colonography.

Variable	Subgroups	Diagnostic tool	Number of studies	DOR and 95% CI	P value for heterogeneity	P value between MRC and CTC	P value between subgroups for MRC	P value between subgroups for CTC
Sample size	≥100	MRC	3	101.69 (2.18–4736.27)	<.001	.319	.003	.043
		CTC	8	1116.81 (73.19–1.7e+04)	<.001			
	<100	MRC	5	156.55 (38.48–636.91)	.693	.402		
		CTC	9	386.53 (79.52–1878.92)	.012			
Mean age (years)	≥65.0	MRC	1	35.00 (1.34–911.28)	−	.066	.920	<.001
		CTC	4	1037.08 (219.60–4897.95)	.891			
	<65.0	MRC	6	157.44 (13.43–1845.62)	<.001	.417		
		CTC	11	581.95 (80.84–4189.45)	<.001			
Percentage male (%)	≥50.0	MRC	5	65.85 (5.72–735.77)	<.001	.321	<.001	<.001
		CTC	9	325.46 (43.29–2446.88)	<.001			
	<50.0	MRC	2	506.91 (118.39–2170.37)	.632	.411		
		CTC	6	1659.83 (46.42–5894.39)	.787			

CIs = confidence intervals, CTC = computed tomography colonography, DOR = diagnostic odds ratio, MRC = magnetic resonance colonography.

correlated with differences in the lifestyle. Although mean age of the patients was not a significant factor for the DOR of MRC, the reason for this could be due to the evaluation of smaller number of studies on the diagnostic value of MRC for diagnosing CRC, and only 1 study included patients with mean age of >65.0 years.

Several advantages of this meta-analysis should be highlighted. First, only prospective studies were included for evaluation, which could avoid uncontrolled biases in the retrospective studies. Second, the current meta-analysis was based on large sample size, and the results were stable, providing the accurate assessment of the diagnostic ability of MRC and CTC. Third, comprehensive diagnostic parameters were calculated, which ensures guidance to further directions. Finally, subgroup analyses for DOR based on sample size, mean age, and percentage male were calculated, and the indirect comparisons for DOR between MRC and CTC were provided.

However, our study has few limitations which were as follows: substantial heterogeneity across the included studies was observed, indicating differences in the characteristics of the study and participants. However, stratified analyses based on most of the characteristics of patients were not conducted due to alterations in the inclusion criteria of patients in each individual study and these items were qualitative; the current meta-analysis was based on published studies, and the publication bias remained an inevitable problem; the analysis of this study was based on pooled data, and the individual data of patients' characteristics were not available, restricting us to conduct a more detailed analyses.

In conclusion, the results of this quantitative meta-analysis indicated that both MRC and CTC have relatively higher diagnostic values for detecting CRC. The DOR was relatively high in sample size of <100, mean age of <65.0 years, and percentage male <50.0% in patients who received MRC, while the DOR in CTC was higher if sample size ≥100, mean age ≥65.0 years, and percentage male <50.0%. Also no significant differences were found between MRC and CTC for DOR in all the subsets. Large-scale prospective head-to-head studies should be conducted to directly compare the diagnostic values of MRC and CTC for detecting CRC in future.

Author contributions

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Writing – review & editing: Lang Zhang.

References

[1] Ferlay J, Soerjomataram I, Dikshit R, et al. Cancer incidence and mortality worldwide: sources, methods and major patterns in GLOBO-CAN 2012. Int J Cancer 2015;136:E359–86.

[2] Gloeckler Ries LA, Reichman ME, Lewis DR, et al. Cancer survival and incidence from the Surveillance, Epidemiology, and End Results (SEER) program. Oncologist 2003;8:541–52.

[3] Heinemann V, Stintzing S, Modest DP, et al. Early tumour shrinkage (ETS) and depth of response (DpR) in the treatment of patients with metastatic colorectal cancer (mCRC). Eur J Cancer 2015;51:1927–36.

[4] Siegel R, Desantis C, Jemal A. Colorectal cancer statistics, 2014. CA Cancer J Clin 2014;64:104–17.

[5] Lieberman DA, Weiss DG, Bond JH, et al. Use of colonoscopy to screen asymptomatic adults for colorectal cancer. Veterans Affairs Cooperative Study Group 380. N Engl J Med 2000;343:162–8.

[6] Walsh JM, Terdiman JP. Colorectal cancer screening: clinical applications. JAMA 2003;289:1297–302.

[7] Xynopoulos D, Stasinopoulou M, Dimitroulopoulos D, et al. Colorectal polyp detection with virtual colonoscopy (computed tomographic colonography); the reliability of the method. Hepatogastroenterology 2002;49:124–7.

[8] Sosna J, Morrin MM, Copel L, et al. Computed tomography colonography (virtual colonoscopy): update on technique, applications, and future developments. Surg Technol Int 2003;11:102–10.

[9] Luboldt W, Bauerfeind P, Steiner P, et al. Preliminary assessment of three-dimensional magnetic resonance imaging for various colonic disorders. Lancet 1997;349:1288–91.

[10] Brenner DJ, Elliston CD. Estimated radiation risks potentially associated with full-body CT screening. Radiology 2004;232:735–8.

[11] Debatin JF, Luboldt W, Bauerfeind P. Virtual colonoscopy in 1999: computed tomography or magnetic resonance imaging? Endoscopy 1999;31:174–9.

[12] Porte F, Uppara M, Malietzis G, et al. CT colonography for surveillance of patients with colorectal cancer: systematic review andmeta-analysis of diagnostic efficacy. Eur Radiol 2017;27:51–60.

[13] Purkayastha S, Tekkis PP, Athanasiou T, et al. Magnetic resonance colonography versus colonoscopy as a diagnostic investigation for colorectal cancer: a meta-analysis. Clin Radiol 2005;60:980–9.

[14] Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6:e1000097.

[15] Whiting P, Rutjes AW, Reitsma JB, et al. The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. BMC Med Res Methodol 2003;3:25.

[16] DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials 1986;7:177–88.

[17] Walter SD. Properties of the summary receiver operating characteristic (SROC) curve for diagnostic test data. Stat Med 2002;21:1237–56.

[18] Deeks JJ, Higgins JPT, DG. A. Analyzing data and undertaking meta-analyses. In: Higgins, J., Green, S., e, editors. Cochrane Handbook for Systematic Reviews of Interventions. 5.0.1 ed. Oxford, UK2008

[19] Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ 2003;327:557–60.

[20] Deeks JJ, Altman DG, MJ. B. Statistical methods for examining heterogeneity and combining results from several studies in meta-analysis. In: Egger, M., Davey Smith, G., Altman, DG., e, editors. Systematic Reviews in Health Care: Metaanalysis in Context. 2nd ed. London 2001. 285-312

[21] Deeks JJ, Macaskill P, Irwig L. The performance of tests of publication bias and other sample size effects in systematic reviews of diagnostic test accuracy was assessed. J Clin Epidemiol 2005;58:882–93.

[22] Fenlon HM, Nunes DP, Schroy PC3rd, et al. A comparison of virtual and conventional colonoscopy for the detection of colorectal polyps. N Engl J Med 1999;341:1496–503.

[23] Pappalardo G, Polettini E, Frattaroli FM, et al. Magnetic resonance colonography versus conventional colonoscopy for the detection of colonic endoluminal lesions. Gastroenterology 2000;119:300–4.

[24] Luboldt W, Bauerfeind P, Wildermuth S, et al. Colonic masses: detection with MR colonography. Radiology 2000;216:383–8.

[25] Miao YM, Amin Z, Healy J, et al. A prospective single centre study comparing computed tomography pneumocolon against colonoscopy in the detection of colorectal neoplasms. Gut 2000;47:832–7.

[26] Morrin MM, Farrell RJ, Raptopoulos V, et al. Role of virtual computed tomographic colonography in patients with colorectal cancers and obstructing colorectal lesions. Dis Colon Rectum 2000;43:303–11.

[27] Lauenstein T, Holtmann G, Schoenfelder D, et al. MR colonography without colonic cleansing: a new strategy to improve patient acceptance. AJR Am J Roentgenol 2001;177:823–7.

[28] Luboldt W, Luz O, Vonthein R, et al. Three-dimensional double-contrast MR colonography: a display method simulating double-contrast barium enema. AJR Am J Roentgenol 2001;176:930–2.

[29] Spinzi G, Belloni G, Martegani A, et al. Computed tomographic colonography and conventional colonoscopy for colon diseases: a prospective, blinded study. Am J Gastroenterol 2001;96:394–400.

[30] Yee J, Akerkar GA, Hung RK, et al. Colorectal neoplasia: performance characteristics of CT colonography for detection in 300 patients. Radiology 2001;219:685–92.

[31] Lauenstein TC, Goehde SC, Ruehm SG, et al. MR colonography with barium-based fecal tagging: initial clinical experience. Radiology 2002;223:248–54.

[32] Laghi A, Iannaccone R, Carbone I, et al. Detection of colorectal lesions with virtual computed tomographic colonography. Am J Surg 2002;183:124–31.

[33] Wong BC, Wong WM, Chan JK, et al. Virtual colonoscopy for the detection of colorectal polyps and cancers in a Chinese population. J Gastroenterol Hepatol 2002;17:1323–7.

[34] Ajaj W, Pelster G, Treichel U, et al. Dark lumen magnetic resonance colonography: comparison with conventional colonoscopy for the detection of colorectal pathology. Gut 2003;52:1738–43.

[35] Leung WK, Lam WW, Wu JC, et al. Magnetic resonance colonography in the detection of colonic neoplasm in high-risk and average-risk individuals. Am J Gastroenterol 2004;99:102–8.

[36] Taylor SA, Halligan S, Saunders BP, et al. Use of multidetector-row CT colonography for detection of colorectal neoplasia in patients referred via the Department of Health "2-Week-wait" initiative. Clin Radiol 2003;58:855–61.

[37] Munikrishnan V, Gillams AR, Lees WR, et al. Prospective study comparing multislice CT colonography with colonoscopy in the detection of colorectal cancer and polyps. Dis Colon Rectum 2003;46:1384–90.

[38] Ajaj W, Lauenstein TC, Pelster G, et al. MR colonography: how does air compare to water for colonic distention? J Magn Reson Imaging 2004;19:216–21.

[39] Cotton PB, Durkalski VL, Pineau BC, et al. Computed tomographic colonography (virtual colonoscopy): a multicenter comparison with standard colonoscopy for detection of colorectal neoplasia. JAMA 2004;291:1713–9.

[40] Hoppe H, Netzer P, Spreng A, et al. Prospective comparison of contrast enhanced CT colonography and conventional colonoscopy for detection of colorectal neoplasms in a single institutional study using second-look colonoscopy with discrepant results. Am J Gastroenterol 2004;99:1924–35.

[41] Chung DJ, Huh KC, Choi WJ, Kim JK. CT colonography using 16-MDCT in the evaluation of colorectal cancer. AJR Am J Roentgenol 2005;184:98–103.

[42] Forbes GM, Mendelson RM, Edwards JT, et al. A comparison of colorectal neoplasia screening tests: a multicentre community-based study of the impact of consumer choice. Med J Aust 2006;184:546–50.

[43] White TJ, Avery GR, Kennan N, et al. Virtual colonoscopy vs conventional colonoscopy in patients at high risk of colorectal cancer: a prospective trial of 150 patients. Colorectal Dis 2009;11:138–45.

[44] Sali L, Falchini M, Della Monica P, et al. CT colonography before colonoscopy in subjects with positive faecal occult blood test. Preliminary experience. Radiol Med 2010;115:1267–78.

[45] von Atzingen AC, Tiferes DA, Deak E, et al. Using computed tomography colonography in patients at high risk of colorectal cancer: a prospective study in a university hospital in South America. Clinics (Sao Paulo) 2014;69:723–30.

[46] Weinberg DS, Pickhardt PJ, Bruining DH, et al. Computed tomography colonography vs colonoscopy for colorectal cancer surveillance after surgery. Gastroenterology 2018;154:927.e4–34.e4.

[47] Purkayastha S, Athanasiou T, Tekkis PP, et al. Magnetic resonance colonography vs computed tomography colonography for the diagnosis of colorectal cancer: an indirect comparison. Colorectal Dis 2007;9:100–11.