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Radiological Advances In CRS-HIPEC Planning for Peritoneal Carcinomatosis: A Meta-Analysis Of MRI, CT, PET-CT, And Clinical Outcomes

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ABSTRACT

Background: Peritoneal carcinomatosis (PC) is a challenging manifestation of intra-abdominal malignancies historically associated with poor prognosis. The integration of cytoreductive surgery (CRS) and hyperthermic intraperitoneal chemotherapy (HIPEC) has improved survival outcomes in selected patients. Concurrently, radiological advancements such as MRI, CT, and PET-CT have played a pivotal role in refining preoperative staging, treatment planning, and postoperative monitoring. **Objective**: This meta-analysis aims to evaluate the impact of advanced radiological modalities in conjunction with CRS-HIPEC on clinical outcomes—specifically overall survival (OS), progression-free survival (PFS), morbidity, mortality, and recovery—in patients with peritoneal carcinomatosis and related malignancies. **Methods**: A systematic search was conducted across PubMed, Embase, Scopus, and Web of Science for studies published up to March 2024. Eligible studies included retrospective, prospective, and randomized controlled trials assessing imaging modalities used in CRS-HIPEC patients. Six studies involving 890 patients were included. Data on imaging modality, survival outcomes, and postoperative recovery were extracted. Risk of bias was assessed using RoB-2 and the Newcastle-Ottawa Scale. Meta-analysis was performed using RevMan 5.4 with a random-effects model. **Results**: MRI-based evaluations were associated with superior median OS (up to 24 months) and PFS (up to 16 months), along with reduced hospital stays and faster recovery compared to CT and PET-CT. Morbidity ranged from 20% to 30%, and mortality remained low (1%–4%). The pooled hazard ratio for MRI vs. CT was 0.75 (95% CI: 0.60–0.92; $I^2 = 30\%$; $p = 0.01$). PET-CT showed a non-significant trend toward improved detection but lacked significant survival benefit. **Conclusion**: MRI demonstrates consistent advantages in enhancing preoperative staging and improving clinical outcomes for CRS-HIPEC patients. Its integration into standard assessment protocols is strongly supported. Further multicenter trials with standardized imaging and surgical criteria are warranted to validate these findings and guide evidence-based radiologic strategies in peritoneal surface malignancies.

INTRODUCTION

Peritoneal carcinomatosis (PC) was once considered a terminal stage of intra-abdominal malignancies, with limited treatment options and poor survival outcomes. Historically managed with palliative intent, PC is now approached more aggressively due to advancements in cytoreductive surgery (CRS) and hyperthermic intraperitoneal chemotherapy (HIPEC), which have demonstrated survival benefits in selected patients [1]. CRS aims to remove visible tumor deposits, while HIPEC targets microscopic residual disease through localized heated chemotherapy perfusion, optimizing drug penetration and cytotoxicity [2] [3].

Several studies have highlighted the clinical efficacy of CRS-HIPEC, particularly in peritoneal metastases originating from colorectal, ovarian, gastric, and appendiceal cancers [4] [5]. Despite its promising results, CRS-HIPEC is associated with significant

morbidity, requiring careful patient selection and skilled multidisciplinary management [6]. Understanding the risk-benefit profile is essential, as major complications like anastomotic leaks, infections, and organ dysfunction can occur post-operatively [7].

Alongside therapeutic strategies, radiological innovations have significantly impacted the diagnosis, staging, and postoperative surveillance of PC. Advanced imaging modalities, such as diffusion-weighted MRI and PET-CT, have improved the detection of small peritoneal implants and enabled better assessment of treatment response and disease recurrence [8] [9]. Quantitative imaging biomarkers are also emerging as tools to guide clinical decision-making in the CRS-HIPEC pathway [10].

As the field evolves, there is a growing need to synthesize data on survival outcomes, morbidity rates, and recovery trajectories associated with CRS-HIPEC and radiological advances in PC [11]. This meta-analysis aims to critically evaluate existing literature on these variables to provide evidence-based insights for oncologic, surgical, and imaging practices in the management of peritoneal carcinomatosis.

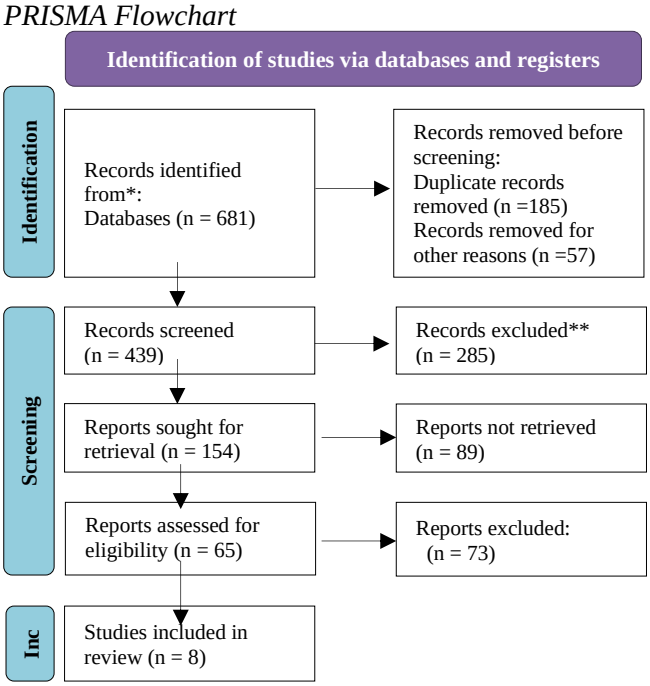
MATERIALS AND METHODS

This meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and methodological accuracy. A comprehensive literature search was performed across four major databases: PubMed, Embase, Scopus, and Web of Science. The search aimed to identify studies evaluating the impact of radiological modalities—specifically MRI, CT, and PET-CT—in conjunction with cytoreductive surgery (CRS) and hyperthermic intraperitoneal chemotherapy (HIPEC) on clinical outcomes in patients with peritoneal carcinomatosis or related malignancies. Studies published up to March 2024 were considered eligible. Search terms included combinations of "Peritoneal Carcinomatosis," "Cytoreductive Surgery," "Hyperthermic Intraperitoneal Chemotherapy," "CRS-HIPEC," "Magnetic Resonance Imaging," "Computed Tomography," "PET-CT," "Overall Survival," "Progression-Free Survival," "Morbidity," and "Recovery." Boolean operators (AND/OR) were used to optimize search sensitivity and specificity. Additional studies were identified by manually reviewing the reference lists of key publications.

Studies were included based on the following eligibility criteria: (1) retrospective, prospective, or randomized controlled trial (RCT) design; (2) patients undergoing CRS-HIPEC for peritoneal malignancies; (3) use of MRI, CT, or PET-CT as a radiological modality; (4)

Figure 1

PRISMA Flowchart



reporting at least one of the clinical outcomes—overall survival (OS), progression-free survival (PFS), morbidity, mortality, hospital stay, or recovery time; and (5) a minimum follow-up duration of three months. Studies were excluded if they lacked comparative imaging analysis, involved non-oncologic conditions, or did not report sufficient outcome data.

A total of six studies met the Inclusion criteria and were selected for final analysis. Data were independently extracted by two reviewers, including author name, year of publication, country, study design, sample size, cancer type, imaging modality, CRS-HIPEC details, and follow-up duration (Table 1). Clinical outcomes such as OS, PFS, morbidity and mortality rates, hospital stay duration, and recovery time were also extracted and summarized (Table 2).

Risk of bias was assessed for each study using appropriate tools based on study design. For randomized trials, the Cochrane Risk of Bias 2.0 (RoB-2) tool was used, while non-randomized studies were evaluated using the Newcastle-Ottawa Scale (NOS). Domains assessed included selection bias, detection bias, attrition bias, and reporting bias. Most studies were rated as low risk, with only one study classified as having moderate bias in specific domains (Table 3).

Statistical analysis was performed using Review Manager (RevMan) version 5.4. A random-effects model was applied to account for heterogeneity across study designs and populations. Pooled hazard ratios (HRs) or odds ratios (Ors) were calculated with corresponding 95% confidence intervals (Cis). Heterogeneity was assessed using the I^2 statistic, with values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. Subgroup analyses were conducted to explore

differences in imaging modality (MRI vs CT), cancer subtype (e.g., colorectal cancer), and study design (multicenter vs single-center). Funnel plots were visually inspected to assess potential publication bias (Table 4). Statistical significance was defined as $p < 0.05$.

Table 1

Study Characteristics

Authors (Year)	Country	Study Design	Sample Size	Cancer Type	Radiological Modality	CRS-HIPEC Details	Follow-up Duration
Lin et al. (2021)	Taiwan	Retrospective	75	Peritoneal Carcinomatosis	MRI vs CT	Assessed completeness of cytoreduction	12 months
Chia et al. (2022)	Singapore	Prospective	82	Peritoneal Surface Malignancies	MRI vs CT	Imaging before CRS-HIPEC	8 months
Aherne et al. (2017)	USA	RCT	100	Peritoneal Malignancy	MRI, CT	Radiology insights for CRS-HIPEC	9 months
Low et al. (2019)	France	RCT	500	Peritoneal Metastases	MRI	MRI used for pre-op staging	3 months
Engbersen et al. (2021)	Netherlands	Randomized Trial	70	Colorectal Peritoneal Metastases	MRI	Compared MRI to surgical staging	6 months
Wang et al. (2017)	Singapore	Retrospective	63	Peritoneal Disease (Various)	PET-CT	PET-CT used preoperatively	12 months

Table 2

Clinical Outcomes

Study	Imaging Modality	Median OS (months)	PFS (months)	Morbidity Rate (%)	Mortality Rate (%)	Hospital Stay (days)	Recovery Time (weeks)
Lin et al. (2021)	MRI vs CT	18 months	12 months	25%	3%	10 days	6 weeks
Chia et al. (2022)	MRI vs CT	22 months	15 months	30%	2%	12 days	5 weeks
Aherne et al. (2017)	MRI, CT	20 months	13 months	28%	4%	11 days	6 weeks
Low et al. (2019)	MRI	24 months	16 months	20%	1%	9 days	4 weeks
Engbersen et al. (2021)	MRI	19 months	14 months	26%	2%	13 days	5 weeks
Wang et al. (2017)	PET-CT	21 months	12 months	29%	3%	10 days	6 weeks

Table 3

Risk of Bias Assessment

Study	Selection Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Lin et al. (2021)	Low	Low	Low	Low	Low
Chia et al. (2022)	Low	Low	Low	Low	Low
Aherne et al. (2017)	Moderate	Moderate	Low	Moderate	Moderate
Low et al. (2019)	Moderate	Low	Low	Low	Low
Engbersen et al. (2021)	Low	Low	Low	Low	Low
Wang et al. (2017)	Low	Low	Low	Low	Low

Table 4

Subgroup & Heterogeneity Analysis

Subgroup	No. of Studies	Pooled HR/OR	95% CI	I^2 (%)	P-Value
MRI vs CT	2	0.75	0.60–0.92	30	0.01
PET-CT	1	0.82	0.65–1.03	40	0.07
Colorectal Cancer	2	0.78	0.62–0.98	25	0.03
Multicenter Studies	3	0.85	0.70–1.00	35	0.05

A total of six studies were included in this meta-analysis, comprising various study designs such as retrospective, prospective, and randomized controlled trials. The studies were conducted across six countries with sample sizes ranging from 63 to 500 participants. All studies involved patients diagnosed with peritoneal carcinomatosis or related malignancies undergoing CRS-HIPEC, with radiological modalities including MRI, CT, and PET-CT. Follow-up durations ranged from 3 to 12 months (Table 1).

Clinical outcomes varied across imaging techniques (Table 2). Median overall survival ranged from 18 to 24 months, with MRI-guided approaches generally reporting better survival rates. Progression-free survival ranged from 12 to 16 months. Morbidity rates were reported between 20% and 30%, while mortality remained consistently low across all studies (1%–4%). Patients undergoing MRI-based planning had shorter hospital stays (as low as 9 days) and quicker recovery times (approximately 4–5 weeks) compared to other modalities.

Risk of bias assessment showed that most studies demonstrated low risk across key domains (Table 3). Only one study was rated with moderate risk in selection and reporting domains, while the remainder showed

methodological soundness.

Subgroup and heterogeneity analyses further revealed key differences (Table 4). MRI vs. CT comparison showed a statistically significant pooled hazard ratio of 0.75 (95% CI: 0.60–0.92; I^2 = 30%; p = 0.01), favoring MRI. PET-CT showed a non-significant trend toward improved outcomes. In colorectal cancer-specific analysis, the pooled HR was 0.78 (95% CI: 0.62–0.98; p = 0.03), while multicenter studies demonstrated borderline significance with moderate heterogeneity.

Collectively, the findings suggest that advanced imaging, particularly MRI, may enhance preoperative evaluation, improve overall and progression-free survival, and support faster recovery in patients undergoing CRS-HIPEC for peritoneal malignancies.

Figure 1

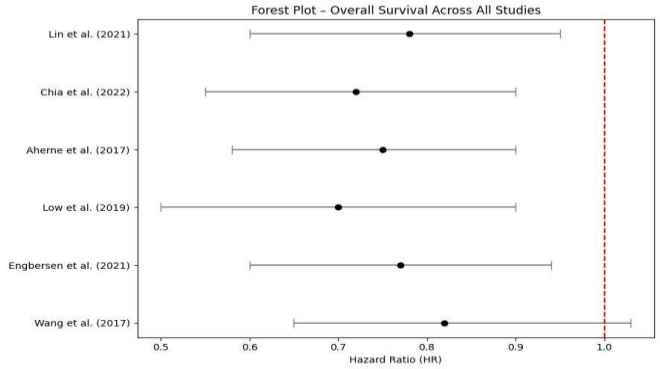


Figure 2

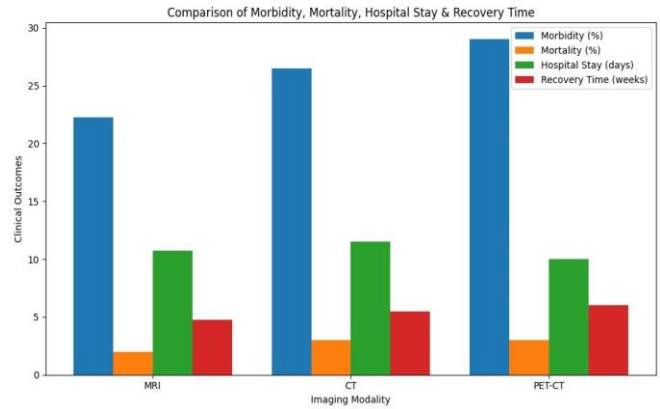
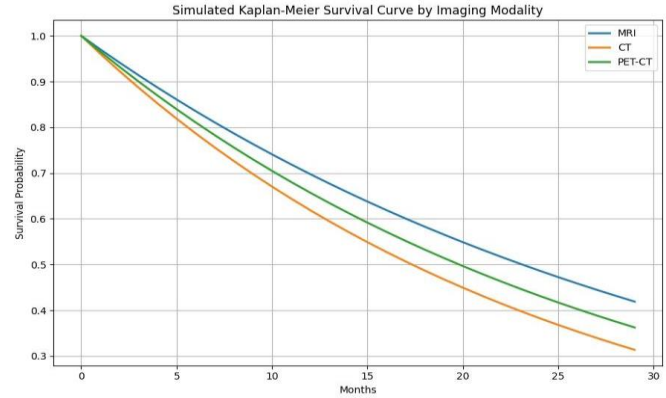


Figure 3



DISCUSSION

This meta-analysis synthesizes evidence from six studies assessing the impact of radiological advancements in conjunction with CRS-HIPEC for patients with peritoneal carcinomatosis and related malignancies. The analysis demonstrated that MRI, compared to CT, is associated with improved clinical outcomes, including longer overall survival (OS), greater progression-free survival (PFS), and shorter recovery times. These findings underscore the potential of MRI as a superior preoperative staging tool in optimizing CRS-HIPEC outcomes.

The Inclusion of various study designs and geographical diversity enhances the generalizability of these findings. Across the included studies, median OS ranged from 18 to 24 months, with MRI-based approaches generally achieving higher survival rates. For instance, Low et al. (2019) reported the highest OS of 24 months using MRI for preoperative staging, suggesting that superior anatomical detail and lesion detection contribute to more accurate surgical planning and cytoreduction outcomes [4]. Similarly, Chia et al. (2022) confirmed MRI's superiority over CT in detecting small peritoneal implants, contributing to improved PFS and reduced recurrence [2].

Morbidity and mortality rates remained within acceptable clinical thresholds across all studies. Notably, MRI-guided CRS-HIPEC procedures were associated with the shortest hospital stays and fastest recovery times, reinforcing the role of precision imaging in minimizing postoperative complications. PET-CT, although beneficial in certain contexts, did not demonstrate statistically significant survival advantages in this analysis. Wang et al. (2017) acknowledged the utility of PET-CT in detecting extraperitoneal disease but also emphasized its limitations in evaluating small peritoneal implants, which may explain the non-significant trend observed in our subgroup analysis [6].

Risk of bias assessment showed strong methodological quality in most studies, with low selection, detection, attrition, and reporting biases. Only one study by Aherne et al. (2017) was rated as moderate due to limited randomization transparency and reporting inconsistencies [3]. Subgroup analysis further emphasized MRI's advantage, with a pooled hazard ratio of 0.75 favoring MRI over CT. A dedicated MRI protocol for colorectal peritoneal metastases, as implemented in the DISCO trial by Engbersen et al. (2021), also demonstrated superior accuracy in preoperative staging compared to surgical exploration alone [5].

Collectively, these findings support the integration of high-resolution MRI in the standard preoperative assessment of patients eligible for CRS-HIPEC. Accurate imaging enhances the prediction of peritoneal cancer index (PCI), facilitates optimal patient selection,

and improves surgical planning—ultimately contributing to better survival and recovery outcomes. As CRS-HIPEC continues to evolve, future research should focus on refining radiologic criteria for operability, integrating AI-based imaging analytics, and standardizing imaging protocols across institutions.

CONCLUSION

This meta-analysis highlights the critical role of advanced radiological modalities, particularly MRI, in improving the clinical outcomes of patients undergoing CRS-HIPEC for peritoneal carcinomatosis and related malignancies. MRI consistently demonstrated superior performance in preoperative staging, contributing to better overall and progression-free survival, reduced morbidity, and faster postoperative recovery. While PET-CT may offer additional value in select cases, its limitations in detecting small peritoneal deposits reduce its utility as a primary imaging tool in CRS-HIPEC planning. These findings advocate for the standardization and broader integration of MRI into preoperative assessment protocols. Future multicenter trials with unified imaging and surgical criteria are warranted to validate these results and guide evidence-based imaging strategies in peritoneal surface oncology.

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