ORIGINAL RESEARCH

The Role of Preoperative CT Perfusion Imaging in Assessing Colorectal Cancer Angiogenesis and its Clinical Value

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ABSTRACT

Purpose • Angiogenesis, the formation of new blood vessels, plays a crucial role in tumor growth and metastasis. Understanding the vascular characteristics of colorectal cancer through preoperative computed tomography (CT) perfusion parameters can provide valuable insights into the tumor's aggressiveness and potential for spread. Additionally, exploring the correlation between these parameters and serum tumor marker levels may offer a comprehensive perspective on the disease's biological behavior.

Methods • In this retrospective study, we investigated 42 colorectal cancer patients. Based on microvascular density (MVD) measured by immunohistochemistry (IHC), participants were categorized into either a high-density group (n = 24) with MVD ≥ 35/field of view or a low-density group (n = 18) with MVD < 35/field of view. Additionally, a control group comprised 25 patients with pathologically confirmed benign colorectal lesions. This study design allowed us to assess the correlation between MVD and colorectal cancer, differentiating between high and low microvascular density groups, while also comparing results to a control group for comprehensive analysis.

Results • Colorectal cancer was associated with significantly higher levels of blood volume (BV; high-density group: 7.65±1.36 mL/100g; low-density group: 6.73±1.29 mL/100g), blood flow (BF; high-density group: 67.33±12.16 ml/(100g·min); low-density group: 52.84±11.43 ml/(100g·min)), permeability surface (PS; high-density group: 35.19±6.32 ml/(100g·min); low-density group: 22.27±4.85 ml/(100g·min)), serum glycoprotein antigen 19-9 (CA19-9; high-density group: 45.38±5.41 g/ml); low-density group: 23.43±3.59 g/ml), glycoprotein antigen 125 (CA125; high-density group: 27.56±3.73 g/ml); low-density group: 12.63±2.59 g/ml), and carcinoembryonic antigen (CEA; high-density group: 17.87±3.12 g/ml); low-density group: 8.51±2.87 g/ml) versus benign colorectal lesions, with more significant changes observed in the high-density group versus the low-density group ($P \leq .001$). The three groups showed similar mean transit time (MTT). The AUCs under the ROC curves for BV, BF, PS, and TTP were 0.901, 0.898, 0.963, and 0.983, respectively. Pearson correlation analysis showed a positive correlation of patients' serum CA19-9 with BV, BF, and PS., Serum CA125 and CEA were positively correlated with BF and PS, and the above indicators were negatively correlated with TTP.

Conclusions • In conclusion, our study highlights the potential of preoperative CT perfusion imaging as a valuable tool for evaluating angiogenesis in colorectal cancer and its correlation with serum tumor markers. The identified associations open avenues for further research to delve into specific aspects of angiogenesis and tumor markers. Future investigations could focus on elucidating the molecular mechanisms underlying the observed correlations, potentially identifying novel therapeutic targets. Additionally, exploring the dynamic changes in angiogenesis and tumor markers during different stages of colorectal cancer progression may provide a more comprehensive understanding. Moreover, assessing the prognostic value of these imaging and biomarker correlations in larger, diverse patient cohorts could enhance their clinical utility. Our findings lay the groundwork for these future research directions, emphasizing the need for continued exploration to advance our knowledge and improve clinical strategies for colorectal cancer management. (*Altern Ther Health Med.* 2024;30(10):157-163).

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INTRODUCTION

In the ever-evolving landscape of China's disease spectrum and dietary habits, the relentless rise in colorectal cancer incidence has become a poignant focal point in the realm of cancer prevention and treatment.[1] In 2020, colorectal cancer accounted for 10% of global cancer incidence and 9.4% of cancer-related fatalities, with around 2 million new cases and 1 million deaths reported.[2] Unhealthy lifestyles are associated with an increased risk, while adopting healthy habits is linked to a reduced colorectal cancer risk.[3] Despite surgical treatment being the primary approach for early-stage cases, many are diagnosed in advanced stages, often with distant metastases. Early diagnosis and treatment have been proven beneficial for patient prognosis.[4]

The abnormal growth of malignant tumor cells requires specific nutrition and oxygenation, but deficiencies in the structural integrity of nascent blood vessels within tumor tissue compared to those of normal tissue result in a high probability of tumor cell permeation through blood vessels.[5] In the past, the main treatment methods for colon cancer were surgery, radiotherapy, and chemotherapy. In recent years, with the in-depth research on the mechanism of tumor immune microenvironment changes in the process of tumor occurrence, development, metastasis, and recurrence, some scholars have found that the immune function of patients in the tumor process shows a tendency to be dominated by inhibition, which drives the tumors evade immune surveillance and accelerate disease progression. Immunotherapy therefore has become a hot spot in colon cancer research in recent years, providing new hope for the clinical treatment of colon cancer.[6]

In the realm of traditional Chinese medicine (TCM), colon cancer is classified within the category of abdominal mass based on its clinical symptoms and signs. While contemporary medicine lacks a unified standard for the differentiation and classification of colon cancer, TCM offers a unique perspective. According to TCM principles, the pathogenesis of colon cancer is intricately linked to the concepts of "essence deficiency" and "cancer toxin." The disease's outcome is perceived as a result of the pathological entanglement between these elements, providing a holistic understanding within the framework of TCM.[7] In the context of our study, integrating TCM perspectives becomes essential as we explore the correlation between CT perfusion parameters and serum tumor markers in colorectal cancer. TCM's viewpoint on essence deficiency and cancer toxin adds depth to our investigation, offering insights into the intricate relationship between the physiological and pathological aspects of colon cancer.

Building upon the intricate understanding of traditional Chinese medicine's categorization of colorectal cancer as an abdominal mass and the existing challenges in its differentiation and classification, our study aims to delve into the rationale for exploring the correlation between CT perfusion parameters and serum tumor markers. In contemporary oncology, the evaluation of colorectal cancer status and prognosis holds pivotal significance for treatment decision-making. Both computed tomography (CT) and magnetic resonance imaging (MRI) play integral roles in assessing lymphatic metastasis and evaluating prognosis in colorectal cancer. CT perfusion imaging, utilizing time-density curves (TDC) and various perfusion parameters, emerges as a powerful technique for noninvasively obtaining crucial information during intravenous enhanced-contrast injection.[8] A wide variety of tumor markers and neovascular markers are dispersed in peripheral blood and can therefore be accurately detected by noninvasive means. Serum CA19-9 and serum CA125 are commonly used tumor markers in clinical practice.[9] While CA19-9 is indicative of cancer, especially when exceeding 1000U/mL and associated with peritoneal metastasis, CA125, recognized as the primary marker for ovarian and endometrial cancers, exhibits high accuracy in diagnosing stage III~IV cancer with a positive threshold of 65U/ml.[10] Notably, CA125 also proves valuable in the diagnosis of gastrointestinal tumors.

Despite the substantial exploration of the correlation between CT perfusion imaging parameters and microvascular density (MVD) by various researchers, the specific value of CT perfusion imaging parameters in assessing angiogenesis and their correlation with serum tumor markers remain understudied.[11] Our research seeks to fill this knowledge gap and contribute to the comprehensive understanding of colorectal cancer assessment by elucidating the interplay between CT perfusion parameters and serum tumor markers.

Moreover, preliminary evidence supporting the positive impact of humanistic nursing on reducing preoperative anxiety, enhancing postoperative pain relief, and improving the prognosis of colorectal cancer patients. Further research and larger-scale trials are warranted to confirm these findings and explore the long-term effects of humanistic nursing interventions on colorectal cancer outcomes.[12] Thus, this study aimed to investigate the specific research problem of determining the value of preoperative CT perfusion parameters in assessing angiogenesis in colorectal cancer. Additionally, we sought to understand the correlation between these perfusion parameters and serum tumor marker levels. By focusing on these interrelated aspects, our research addresses the broader objective of advancing the knowledge surrounding the role of CT perfusion in colorectal cancer evaluation.

MATERIALS AND METHODS

Baseline data

In this retrospective study, 42 patients with colorectal cancer between May 2019 and December 2021 assessed for eligibility were recruited and assigned via the degree of MVD measured by immunohistochemistry (IHC) to either a high-density group (n=24) with MVD≥35/field of view or a low-density group (n=18) with MVD<35/field of view, and 25 patients pathologically confirmed benign colorectal lesions were also included in a control group. The high-density MVD group was defined based on the rationale that higher MVD is often associated with increased angiogenesis and vascularization within the tumor microenvironment. High MVD may indicate a more extensive network of blood vessels, potentially supporting tumor growth and progression. Furthermore, the lower MVD group might signify reduced angiogenesis and a less extensive vascular network within the tumor tissue. Low MVD could indicate a potentially different tumor microenvironment compared to the high-density MVD group. The protocol of this study was ethically approved by the ethics committee of Tianjin Medical University (no. 2019/12-585). The Ethics Committee of Tianjin Medical University granted ethical approval for this study in December 2019, following a rigorous evaluation of the research protocol and ethical considerations. The study adhered to all relevant ethical guidelines and regulations to ensure the rights and well-being of the participants were protected throughout the research process.

Moreover, IHC for measuring MVD is a common laboratory technique used to quantitatively assess the number of microvessels in tissue. Here are the detailed steps for measuring MVD using IHC: (1)Tissue sample preparation: we obtained tissue samples from patients with colorectal cancer, and sectioned the tissue into thin slices (typically 4-5 micrometers thick) using a microtome. (2) Dehydration and rehydration: Dehydrate the tissue sections, which are embedded in paraffin, in xylene, and then rehydrate them through a series of graded alcohol solutions. (3) Antigen retrieval: Perform heat-induced epitope retrieval (HIER) to make antigens accessible for detection. This involves heating the tissue sections in a buffer solution, often using a microwave or pressure cooker, to facilitate antigen accessibility. (4) Blocking: Incubate the sections in a blocking solution containing serum or other blocking agents to reduce nonspecific binding. (5) Primary antibody incubation: Subsequently, incubate the sections with a primary antibody specific to the target antigen, in this case, the MVD marker. The primary antibody will specifically bind to the target antigen within the tissue. (6) Secondary antibody incubation: After washing away excess primary antibody, incubate the sections with a secondary antibody conjugated to an enzyme or fluorescent substance. The secondary antibody binds to the primary antibody, enhancing signal detection. (7) Visualization and contrast staining: In some cases, contrast stains (for bromocresol blue) are used to visualize the nucleus to provide contrast. (8) Microscopy: Microscopy of the stained tissue sections. MVD was assessed by counting or measuring the vessels in the selected field of view. (9) Data analysis: The MVD assessments by IHC were conducted by lab technician. Data obtained from IHC staining were analyzed to determine MVD in the high-density and low-density groups.

Inclusion and exclusion criteria

Inclusion criteria: 1) Primary colon cancer diagnosed by colonoscopy or pathological biopsy; 2) No other malignant tumor diseases; 3) With complete laboratory data and imaging data.

Exclusion criteria: 1) the clinicopathological information was incomplete; 2) more than one primary tumor; 3) no surgery or local tumor excision only; 4) Estimated survival time less than one month.

Patients with benign colorectal lesions included in the control group were selected based on the following criteria: 1) Pathological confirmation of benign colorectal lesions, which included conditions such as benign polyps, diverticulosis, or other non-malignant lesions. 2) Similar demographic characteristics, such as age and gender, were considered to minimize potential confounding variables in the analysis.

CT scanning and parameters

The patients fasted for 6 hours before scanning. The examination instrument used was the GERevolution CT machine from the USA. With the patient lying supine, plain scanning was initially performed to determine the target plane for perfusion scanning. Following this, an intravenous injection of 85 mL of iodine-based contrast agent was administered through the elbow vein using a double-barrel high-pressure syringe. This injection was administered at a controlled flow rate of 4.0 mL/s. Subsequently, enhanced-contrast scanning was carried out, acquiring one scan every 2 seconds, resulting in a total of 25 time phases.

The CT scanning parameters were precisely configured as follows: a tube voltage of 120 kV, tube current of 200 mAs, scanning layer thickness of 5.0 mm (measured in millimeters), reconstruction layer thickness of 5.0 mm (measured in millimeters), pitch of 1.0, and a matrix size of 512×512. Following the scanning process, the acquired axial scan images were subjected to additional processing. Coronal and sagittal images were reconstructed using an MSCT post-processing workstation. Beyond image reconstruction, specific image processing and analysis were conducted to derive perfusion parameters, including blood volume (BV, measured in milliliters), blood flow (BF, measured in milliliters), time to peak (TTP, measured in second), mean transit time (MTT, measured in second), and permeability surface (PS, measured in milliliters). This comprehensive workflow ensured a detailed assessment of colorectal cancer angiogenesis using advanced CT perfusion imaging.

Serum tumor marker determination

Two milliliters of fasting peripheral venous blood were collected from each group of patients, rested at room temperature for 30 minutes, and centrifuged at low speed at 4°C to obtain the serum. Subsequently, the serum levels of specific tumor markers, including glycoprotein antigen 19-9 (CA19-9), glycoprotein antigen 125 (CA125), and carcinoembryonic antigen (CEA), were quantitatively determined utilizing enzyme-linked immunosorbent assay (ELISA) kits. All ELISA kits were provided by Elabscience Biotechnology Co., Ltd. The cat no. of CA19-9 was E-EL-H0637c, the cat no. of CA125 was PKSH033910, and the cat no. of CEA was E-EL-H6047. ELISA assays were performed following the manufacturer's instructions, and each assay included appropriate standards and controls to ensure accuracy and reliability. The measurements of CA19-9, CA125, and CEA were expressed in units of [measurement unit, e.g., ng/mL], and all steps were carried out in strict accordance with the provided instructions and quality control procedures.

Statistical analysis

SPSS 25.0 statistical software was used for data analyses. Count data were analyzed by the χ^2 test. This method is suitable for comparing categorical data between different groups. The measurement data are all normalized, and the data that do not conform to the normal distribution are normalized. Measurement data were analyzed by one-way ANOVA for comparison, and further group comparisons were performed by the LSD-T test. We employed receiver operating characteristic (ROC) curves to assess the value of CT perfusion parameters in angiogenesis evaluation. ROC curves are graphical representations that illustrate the trade-off between sensitivity and specificity across various thresholds. In our study, ROC curves were instrumental in evaluating how well CT perfusion parameters discriminate between different outcomes related to angiogenesis. They provide a comprehensive visualization of the diagnostic performance, allowing us to identify the optimal threshold for sensitivity and specificity in our analysis. Pearson

Table 1. Comparison of baseline data

Indices	High-density group	Low-density group	Control group	χ^2/F	*P* value
Male/female	18/6	14/4	17/8	0.575	.750
Age (year)	63.92±5.20	62.83±5.62	66.64±5.56	2.885	.063
Height (cm)	174.0±6.85	173.5±6.53	171.6±7.09	0.824	.443
Weight (kg)	63.29±6.46	63.94±6.58	63.61±6.53	0.051	.950

Table 2. Comparison of CT perfusion parameters

Groups	n	BV (mL/100g)	BF [ml/(100g·min)]	TTP (s)	MTT (s)	PS [ml/(100g·min)]
High-density group	24	7.65±1.36	67.33±12.16	20.42±4.37	11.54±2.22	35.19±6.32
Low-density group	18	6.73±1.29	52.84±11.43	29.74±5.32	11.64±2.09	22.27±4.85
Control group	25	4.80±1.28	38.42±10.42	42.61±5.38	12.02±2.51	12.21±4.63
F		30.242	39.850	120.589	0.297	113.324
P value		≤.001	≤.001	≤.001	.744	≤.001

Table 3. The value of CT perfusion parameters for angiogenesis assessment

Test result variables	Region	Standard error	Asymptotic Significance	Approaching 95% confidence interval Lower limit	Upper limit
BV	0.901	0.036	0.000	0.831	0.971
BF	0.898	0.038	0.000	0.823	0.973
PS	0.963	0.022	0.000	0.919	1.000
TTP	0.983	0.012	0.000	0.960	1.000

Table 4. Comparison of serum tumor markers

Groups	n	CA19-9 (g/ml)	CA125 (g/ml)	CEA(g/ml)
High-density group	24	45.38±5.41	27.56±3.73	17.87±3.12
Low-density group	18	23.43±3.59	12.63±2.59	8.51±2.87
Control group	25	8.36±1.25	8.16±1.83	1.94±0.43
F		582.103	308.700	272.422
P value		≤.001	≤.001	≤.001

Table 5. Correlation of CT perfusion imaging parameters with serum tumor markers

Indices		BV	BF	TTP	MTT	PS
CA19-9	r	0.319	0.484	-0.596	-0.021	0.640
	P value	.039	.001	.000	.897	.000
CA125	r	0.222	0.482	-0.672	0.064	0.671
	P value	.158	.001	.000	.685	.000
CEA	r	0.234	0.566	-0.515	0.011	0.609
	P value	.136	≤.001	≤.001	.946	≤.001

correlation analysis was utilized to examine correlations between specific variables in our study. We specifically explored the relationships between patients' serum CA19-9 and Serum CA125 and CEA with BV, BF, PS, and TTP. In all statistical analyses, the significance level (alpha) was set at .05, and results were considered statistically significant when the $P < .05$.

RESULTS

General data

The baseline features of the high-density group were comparable with those of the low-density group and those of the control group ($P > .05$, no statistically significant). (Table 1)

CT perfusion parameters

Colorectal cancer was associated with significantly higher levels of BV, BF, PS, and a shorter time to peak (TTP) versus benign colorectal lesions, with more significant changes observed in the high-density group versus the low-density group ($P < .05$, statistically significant). The three groups showed similar mean transit time (MTT) ($P > .05$, no statistically significant). (Table 2)

The value of CT perfusion parameters for angiogenesis assessment

The AUC provides a quantitative measure of the discriminatory power of a diagnostic test. In our study, the AUCs under the ROC curves for BV, BF, PS, and TTP were 0.901, 0.898, 0.963, and 0.983, respectively. (Table 3) An AUC of 0.5 suggests no discriminatory power (similar to random chance), while an AUC of 1.0 indicates perfect discrimination. The AUC values obtained in our analysis indicate the ability of these CT perfusion parameters to effectively discriminate between different outcomes related to angiogenesis. Specifically, higher AUC values suggest a stronger discriminatory ability, emphasizing the potential clinical relevance of these parameters in assessing angiogenesis in colorectal cancer.

Serum tumor markers

Colorectal cancer was associated with significantly higher levels of serum CA19-9, CA125, and CEA versus benign colorectal lesions, with more significant changes observed in the high-density group versus the low-density group ($P < .05$, statistically significant). (Table 4)

Correlation of CT perfusion imaging parameters with serum tumor markers

Pearson correlation analysis showed a positive correlation of patients' serum CA19-9 with BV, BF, and PS ($P < .05$, statistically significant). Serum CA125 and CEA were positively correlated with BF and PS ($P < .05$, statistically significant), and the above indicators were negatively correlated with TTP ($P < .05$, statistically significant). (Table 5) Specifically, a positive correlation suggests that an increase in one variable is associated with an increase in the other, while a negative correlation indicates that as one variable increases, the other decreases. The significance level (alpha) for these tests was set at 0.05.

DISCUSSION

The results of the present study showed that colorectal cancer was associated with significantly higher levels of BV, BF, and PS, and a shorter TTP versus benign colorectal lesions, with more significant changes observed in the high-density group versus the low-density group, indicating that the high micro-vessel density in colorectal cancer patients is the main influencing factor for BV, BF, TTP, and PS. Building upon the findings of Shuford RA et al.[13], our study corroborates the positive correlation of BV and PS with MVD, emphasizing the robustness of these CT perfusion parameters in accurately reflecting microvessel density in colorectal cancer. This consistency across studies underscores the reliability and reproducibility of these parameters as indicators of angiogenesis.

Furthermore, our study adds to the growing body of literature by providing additional evidence of the diagnostic utility of CT perfusion parameters in colorectal cancer. The AUC values under the ROC curves for BV, BF, PS, and TTP

(0.901, 0.898, 0.963, and 0.983, respectively) in our study align with or even surpass those reported by Shuford et al., suggesting a consistent pattern of high diagnostic accuracy. These findings collectively strengthen the argument for the potential reference values of CT perfusion parameters in assessing micro-angiogenesis.

Colorectal cancer is a malignant tumor of the gastrointestinal tract, and its etiology is related to dietary habits, familial genetic disorders, and ulcerative colitis. The disease can be classified according to pathology as adenocarcinoma, mucinous carcinoma, papillary carcinoma, adenosquamous carcinoma, mucinous carcinoma, and carcinoid carcinoma. Surgery is the main treatment for colorectal cancer.[14] Due to the lack of specificity of early symptoms of colorectal cancer, most patients are diagnosed with advanced cancer. Therefore, early diagnosis and screening are essential for the prevention and treatment of colorectal cancer.[15] During tumor invasion and migration, the rich vascular network provides sufficient nutrition and oxygen to the tumor population. CT perfusion imaging techniques can reveal pathological and anatomical changes in tumor tissues and can show hemodynamic changes in tumor tissues to identify the nature and staging of tumors and predict treatment outcomes.[16]

CT perfusion imaging is the selection of a specific slice for dynamic CT scanning after intravenous injection of contrast to obtain a fraction of the contrast concentration per pixel over time, followed by a gradual change in TDC apparent CT values.[17] Among the parameters related to CT perfusion imaging, BV represents the sum of red blood cells and plasma volume in a certain number of intravascular tissues, which is closely related to the number of capillary openings and lumen size, and BF is an indicator of blood flow in a certain number of tissue vascular structures to show the perfusion of selected tissues.[18] TTP can interpret the peak concentration of contrast filling the target tissue and thus reflect the capillary density and blood flow rate. MTT is the average time required for blood to pass through different paths of artery-capillary-venous sinus-vein, which can characterize the blood circulation in the capillary network, and PS can reflect the rate of blood passing through the capillary wall into the tissue interstitial space to evaluate the structural integrity of the vessel wall on a reliable basis [19]. Tumor tissue mainly originates from glands rich in the capillary network, and the longer residence time of the contrast agent in passing through the capillary network in tumor tissue leads to the increase of BF and BV levels. BF and BV are reliable parameters to evaluate the richness of blood vessels in tumor tissues, and their levels increase continuously with the vigorous growth of vascular structures in tumor tissues.[20] PS reflects the structural integrity of tumor neovascularization in tissues, and the level of PS is subsequently increased due to poor maturation of neovascularization, incomplete vessel wall structure, and high permeability in tumors.[21]

Beyond the scientific insights gained from our study, the practical implications of understanding CT perfusion parameters in colorectal cancer angiogenesis extend to the realm of patient care. The information derived from CT perfusion imaging has the potential to revolutionize clinical decision-making in several key aspects. Firstly, the assessment of BV and BF levels provides clinicians with valuable indicators of the richness and growth of blood vessels in tumor tissues. This information can be crucial in guiding surgical decisions, helping surgeons identify regions with higher vascularity that may require more intricate procedures or targeted interventions. Secondly, the evaluation of PS offers insights into the structural integrity of tumor neovascularization. The increased PS levels observed in our study may signify poor maturation of neovascularization, incomplete vessel wall structure, and heightened permeability in tumors. This knowledge can inform treatment strategies, particularly in the context of anti-angiogenic therapies, where targeting abnormal blood vessel formation is a key therapeutic approach.

Furthermore, understanding the dynamics of TTP and MTT provides a window into the blood circulation within the capillary network, offering additional information that could influence treatment planning and prognosis assessment. In essence, the integration of CT perfusion imaging into clinical practice has the potential to individualize treatment approaches, optimize surgical strategies, and enhance prognostic assessments for colorectal cancer patients. This holistic and personalized approach holds great promise for advancing the overall management of colorectal cancer, ultimately leading to improved patient outcomes.

CA19-9, CA125, and CEA are broad-spectrum tumor markers, and their aberrant expression is present in patients with various malignancies.[22] CEA is rarely present in normal adults, and elevated levels of CEA are often indicative of carcinogenesis in vivo, and the degree of CEA elevation is closely related to the proliferative capacity of the cancerous tissue.[23] CA19-9 and CA125 are tumor markers of glycoproteins, and their elevation commonly indicates malignancy in the gastrointestinal tract. According to previous studies,[24] CEA, CA19-9, and CA125 can mediate the shedding of cancer cells from the primary lesion and their attachment to adjacent tissues, thereby contributing to tumor metastasis or adjacent tissue invasion. However, the significance of our study extends beyond the confirmation of known associations. It provides crucial insights into the clinical utility of preoperative CT perfusion imaging for assessing angiogenesis in colorectal cancer. By demonstrating the correlations between CT perfusion parameters and serum tumor markers, we illuminate the potential for a non-invasive imaging technique to inform clinical practice.

While our study contributes valuable insights into the potential utility of CT perfusion parameters and serum tumor markers for assessing colorectal cancer angiogenesis, it is crucial to acknowledge and address certain limitations. Firstly, the relatively small sample size in this study raises concerns about the generalizability of our findings. A larger and more diverse cohort would enhance the robustness and external validity of our results, providing a more comprehensive understanding of the relationships between CT perfusion parameters, serum tumor markers, and microvascular density. Additionally, the heterogeneity of colorectal cancer, encompassing various histological subtypes and stages, may introduce variability in CT perfusion parameters and serum tumor markers. This clinical and histopathological diversity should be considered when interpreting our results.

Furthermore, the absence of long-term follow-up data in our study represents another limitation. Future investigations incorporating extended follow-up periods could explore the impact of CT perfusion parameters and serum tumor markers on patient outcomes and survival. Addressing these limitations will not only strengthen the current study but also guide the design of more robust research endeavors in the future.

In the current study, by demonstrating the association between CT perfusion parameters and serum tumor markers, our study contributes to the growing body of evidence supporting the use of non-invasive imaging techniques in oncology. The ability to evaluate tumor angiogenesis through CT perfusion imaging provides clinicians with valuable insights into the vascular characteristics of colorectal tumors. Furthermore, the correlation with serum tumor markers enhances our understanding of the molecular and physiological aspects of cancer progression.

In summary, our study unravels the critical significance of preoperative CT perfusion imaging in the assessment of angiogenesis within colorectal cancer. The non-invasive nature of this imaging technique not only enhances its diagnostic value but also opens up promising avenues for transforming clinical practice and ultimately improving patient outcomes. Moreover, The quantitative insights into tumor vascularization provided by CT perfusion parameters empower oncologists with a valuable and precise tool. This tool enables the tailoring of treatment strategies, accurate prediction of tumor behavior, and optimization of surgical planning. Our findings contribute to the evolving landscape of colorectal cancer diagnosis and management, emphasizing the potential for personalized and targeted approaches that can significantly impact patient care.

CONCLUSION

In this study, we have unveiled the direct and practical implications of preoperative CT perfusion imaging as an invaluable tool for assessing angiogenesis in colorectal cancer. The substantial correlations identified between CT perfusion parameters and microvascular density (MVD) within colorectal tumor tissues offer clinicians pivotal insights into the intricate vascular characteristics of tumors.

Furthermore, our study uncovers compelling associations between CT perfusion parameters and serum tumor markers, specifically CA19-9, CA125, and CEA. These correlations establish a crucial link between non-invasive imaging and systemic biomarkers, providing a holistic understanding of the intricate biological behavior of colorectal tumors.

The multifaceted clinical benefits of these findings extend beyond colorectal cancer. Firstly, the correlations between CT perfusion parameters, MVD, and serum tumor markers lay the groundwork for more informed treatment decisions. The ability to tailor therapeutic strategies based on specific vascular and molecular characteristics identified through CT perfusion imaging holds promise not only for colorectal cancer but also for various other cancer types. Secondly, the immediate relevance of our study in surgical planning is noteworthy. The strong correlations between CT perfusion parameters and MVD suggest a broader applicability across different cancer types. Surgeons can potentially utilize preoperative imaging to identify regions of heightened vascularity, thereby guiding the extent and precision of surgical interventions in diverse malignancies. Lastly, the predictive value of CT perfusion imaging in assessing tumor behavior has implications for patient prognosis that transcend colorectal cancer. Integrating non-invasive imaging data with serum tumor markers allows clinicians to better stratify patients, anticipate disease progression, and individualize follow-up care plans, contributing to a paradigm shift in cancer management across various medical fields.

In conclusion, the next steps in this research trajectory involve conducting larger and more diverse studies, developing predictive models, and embarking on clinical trials to validate the transformative potential of CT perfusion imaging. These endeavors promise to enhance our understanding of tumor angiogenesis and foster the development of more effective and personalized cancer care strategies. And the envisioned endeavors are not only about advancing scientific understanding but also about translating these insights into tangible improvements in patient care. The transformative potential of CT perfusion imaging holds the key to more precise, personalized, and effective strategies in the management of colorectal cancer, ultimately contributing to advancements in the field and better outcomes for patients.

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AUTHORS' CONTRIBUTIONS

All authors contributed equally to this article.

DATA AVAILABILITY STATEMENT

The datasets used during the present study are available from the corresponding author upon reasonable request.

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