A I C Artificial Intelligence in Cancer

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Artificial intelligence in rectal cancer: What is the future?

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Abstract

Colorectal cancer (CRC) is the third most prevalent cancer in both men and women, and it is the second leading cause of cancer-related deaths globally. Around 60%-70% of CRC patients are diagnosed at advanced stages, with nearly 20% having liver metastases. It is noteworthy that the 5-year survival rates decline significantly from 80%-90% for localized disease to a mere 10%-15% for patients with metastasis at the time of diagnosis. Early diagnosis, appropriate therapeutic strategy, accurate assessment of treatment response, and prognostication is essential for better outcome. There has been significant technological development in the last couple of decades to improve the outcome of rectal cancer including Artificial intelligence (AI). AI is a broad term used to describe the study of machines that mimic human intelligence, such as perceiving the environment, drawing logical conclusions from observations, and performing complex tasks. At present AI has demonstrated a promising role in early diagnosis, prognosis, and treatment outcomes for patients with rectal cancer, a limited role in surgical decision making, and had a bright future.

Key Words: Rectal cancer; Artificial intelligence; Role in treatment; Current status; Future implications

Core Tip: Early diagnosis and treatment decision making in rectal cancer significantly affects the outcome, which is multidisciplinary team approach and not without errors and bias. Newer technology artificial intelligence, has been found to be useful in early diagnosis, accurate staging, treatment planning and assessment of treatment response, however its evolving. The present review focuses its current role and future implications in the management of rectal cancer.

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INTRODUCTION

Colorectal cancer (CRC) holds a significant place in global health, ranking as the third most prevalent cancer among men and the second most prevalent cancer among women. In 2020 alone, the world witnessed a staggering 1.93 million new cases of this ailment, underlining the urgent need for increased awareness, prevention, and effective treatment strategies.

CRC represents a distinctive challenge, transcending geographical boundaries and affecting diverse populations worldwide. Its impact is profound, not only in terms of physical health but also in the emotional and socioeconomic well-being of individuals and their families. Acknowledging the unique complexities of CRC is crucial in developing tailored approaches to combat this pervasive disease[1]. CRC not only ranks high in terms of its incidence but also represents a significant threat as the second leading cause of cancer-related deaths worldwide. In 2020 alone, an alarming number of 935173 lives were lost to this relentless disease. These figures highlight the urgent need to address CRC comprehensively, from prevention to advanced treatment modalities. One of the formidable challenges associated with CRC is the occurrence of liver metastasis. Approximately 50% of CRC patients will experience the spread of cancer to their liver during their illness. This complication further complicates treatment approaches and necessitates a multidisciplinary approach involving surgical interventions, chemotherapy, targeted therapies, and emerging modalities such as radioembolization or ablation techniques.

Disturbingly, future projections for 2040 paint a worrisome picture, indicating a surge in the global incidence of CRC. Estimates suggest a staggering 3.2 million new cases of this disease, emphasizing the need for immediate action on a global scale. This projected increase necessitates heightened efforts in primary prevention, early detection, and advancements in treatment options[2]. As we embrace the era of personalized medicine, the quest for more effective diagnostic tools, accurate risk prediction models, reliable prognostic indicators, and precise treatment response predictions becomes increasingly urgent. To meet these challenges, one innovative field that holds immense promise is artificial intelligence (AI), a burgeoning branch of computer science that empowers computer systems to replicate human-like intelligence, encompassing cognitive functions such as thinking and decision-making. The components of AI include machine learning, deep learning, natural language processing, computer vision, robotics, expert systems, knowledge representation, planning and decision-making, cognitive computing, and machine perception. The use of AI in medicine is progressively increasing and has already demonstrated its clinical impact in various areas, including dermatology, pathology, and endoscopy.

AI has its value in numerous aspects of daily life and human needs, encompassing healthcare through health tracking devices, automobiles with autopilot technology, banking and finance employing chatbots and robot traders, surveillance *via* CCTV cameras, social media, entertainment, education, space exploration, industries such as aluminum and dairy, as well as disaster management; an exemplification of this is the efficient production of facemasks during the coronavirus disease 2019 pandemic. Through the analysis of vast amounts of data, AI algorithms can identify patterns, extract meaningful insights, and generate actionable recommendations. The various applications of AI in cancer are as follows Figure 1.

In the realm of CRC, AI holds particular significance, offering opportunities for advancements in early detection, personalized treatment planning, and monitoring of treatment response.

Current diagnostic tools for rectal cancer have certain limitations (as compared to AI) some of these limitations include:

Subjectivity and variability: Diagnostic tools like visual inspection, endoscopy, and imaging techniques can be subjective and rely on the expertise of the clinician, leading to variability in interpretation and potential diagnostic errors.

Sensitivity and specificity: Conventional diagnostic tools may have limitations in terms of their sensitivity and specificity in detecting early-stage rectal cancer or distinguishing cancerous lesions from benign conditions. False negatives or false positives can occur, leading to missed or unnecessary interventions.

Interpretation challenges: The interpretation of diagnostic results can be complex and require experience and skill. Human interpretation may be influenced by biases, fatigue, or individual variations among clinicians.

Time and cost: Diagnosis using conventional tools can be time-consuming, requiring multiple tests and visits. This can delay the initiation of treatment and increase healthcare costs.

Limited quantitative analysis: Conventional diagnostic tools often lack advanced quantitative analysis capabilities. They may not be able to analyze large datasets or identify subtle patterns that could be indicative of rectal cancer.

In contrast, AI-based diagnostic systems have the potential to overcome these limitations. AI can analyze vast amounts of data with high precision, detect patterns that may be difficult for humans to perceive, and provide consistent and objective assessments. It can assist in early detection, risk assessment, and accurate diagnosis of rectal cancer, leading to improved patient outcomes and more efficient healthcare delivery. However, it's important to note that the development and deployment of AI systems must be carefully validated and integrated into clinical practice to ensure their safety, effectiveness, and ethical considerations.

Uses of AI in rectal cancer are progressively being used in the understanding of gastrointestinal diseases[3-5]. Imaging such as X-ray, computed tomography scanning, magnetic resonance imaging, or endoscopic imaging is being used for diagnosis[6-9]. The application of AI has led to early detection of intestinal malignancies or premalignant lesions, and inflammatory or other non-malignant diseases or lesions[10]. The Manipal Comprehensive Cancer Centre (Bangalore,

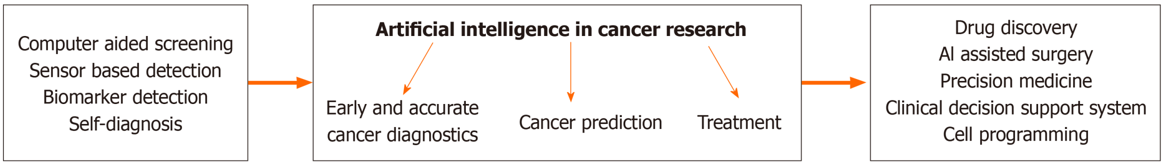

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Figure 1 The various applications of artificial intelligence in cancer. AI: Artificial intelligence.

India) has implemented WFO for treatment in 250 CRC patients[11]. There was a concordance in 92.7% of rectal and 81.0% of colon cancer patients between WFO and Mass Detection Tool recommendations.

By harnessing the power of AI, we can enhance the accuracy and efficiency of CRC diagnosis. AI algorithms trained on large datasets can analyze radiological images, pathology slides, and genetic profiles, aiding clinicians in identifying subtle markers of CRC and potentially reducing missed diagnoses. Furthermore, AI-based risk prediction models can integrate clinical, genetic, and lifestyle data to provide personalized assessments of an individual's likelihood of developing CRC, enabling targeted preventive strategies.

Prognostication is another critical aspect of CRC management where AI can make a profound impact. By assimilating patient-specific factors, including clinical data, genomic profiles, and treatment histories, AI algorithms can generate prognostic models that empower clinicians to estimate disease progression, recurrence risks, and survival outcomes. These tools enable personalized treatment planning and facilitate informed discussions between patients and healthcare providers. Moreover, AI has the potential to refine treatment selection and prediction of treatment response in CRC patients. By analyzing extensive databases of treatment outcomes, AI algorithms can identify molecular signatures and patient characteristics that correlate with therapeutic effectiveness. This knowledge can guide clinicians in tailoring treatment regimens to individual patients, optimizing outcomes, and minimizing unnecessary side effects.

While AI brings immense promise, its successful integration into clinical practice requires a collaborative approach. Experts in medicine, computer science, and data analytics must collaborate to develop robust AI models that are transparent, interpretable, and ethically sound. Data privacy and security considerations are paramount, ensuring the responsible use of patient information while advancing AI-driven healthcare innovations.

The application of AI in the medical field is gradually transforming how diseases are diagnosed and treated. While AI has made significant progress in certain types of cancer, such as lung and breast cancer, its use in CRC is still in the early stages. In CRC, AI has primarily been employed in screening and staging processes, while its use in intraoperative settings, specifically during surgery, is limited. This overview aims to introduce surgical professionals to key AI concepts and terms and provides a summary of the current state-of-the-art AI applications in rectal cancer and its future.

AI in rectal cancer: What is the future?

Role of AI in diagnosis: The diagnosis of cancer involves analyzing multiple sources of data and combining clinical experience. Due to the diverse symptoms, rapid progression, drug susceptibility, and individual variations in cancer, accurate diagnosis is challenging. However, AI has demonstrated its ability to assist clinicians in qualitative diagnosis and staging of CRC[12,13].

Preoperative diagnosis (AI-based colonoscopy, magnetic resonance imaging, computed tomography, biopsy/histology): AI and computer-aided detection (CADe) systems have been utilized to improve the speed and accuracy of CRC detection during colonoscopy. These AI-based systems, often employing deep learning algorithms, enhance the adenoma detection rate (ADR), a reliable indicator for CRC detection. By assisting in real-time polyp detection, AI algorithms can effectively reduce missed lesions and improve ADR. However, it's important to note that some small, low-risk adenomas and polyps detected by AI systems may increase the overall CRC incidence. Optical biopsy techniques and CNN-based CADe systems have also shown potential in reducing the adenoma miss rate during colonoscopy. The integration of AI in colonoscopy has the potential to enhance CRC diagnosis and improve patient outcomes.

Endoscopy, which allows direct observation of lesions in the intestinal wall, has been advanced by AI technologies. Virtual colonoscopy based on computed tomography colonography has been introduced to detect CRC and its precursors [14]. Various AI methods have been developed to automatically detect colon polyps, distinguish neoplastic polyps from non-neoplastic ones, and improve adenoma recognition rate during colonoscopy. These AI systems have shown promising results, with high sensitivity, specificity, and accuracy in detecting and diagnosing CRC[15].

Pre-operative-staging: AI and machine learning techniques have shown promise in improving pre-operative staging for rectal cancer. These technologies can analyze various imaging modalities, such as magnetic resonance imaging (MRI) or computed tomography (CT) scans, to accurately assess tumor characteristics, lymph node involvement, and local tumor invasion. By leveraging large datasets and advanced algorithms, AI can provide more precise and consistent staging information, aiding in treatment planning and decision-making. AI-based models can help identify high-risk cases, predict outcomes, and guide personalized treatment strategies for patients with rectal cancer. These advancements in pre-operative staging can lead to improved patient management and better overall clinical outcomes.

AI has also been applied to other screening methods such as capsule endoscopy and plasma-based early screening[16]. Machine learning algorithms have been utilized to predict the onset of CRC by analyzing comprehensive patient information. Additionally, AI has been employed in histopathology analysis, genetic studies, and tumor classification based on histopathology alone. The integration of AI techniques with these approaches has shown the potential in improving diagnostic accuracy and prognosis[17].

Role of AI in imaging: Deep learning is a subset of ML that employs neural networks with multiple layers of processing to analyze and learn similarly to humans[18]. One of the exciting applications of AI has been in the field of radiology, which involves the use of imaging to diagnose and treat illnesses, and especially radiomics. Radiomics is a process that refers to the extraction of mineable data from medical images[19]. The significance of radiomics lies in its ability to extract a multitude of features from medical images, such as entropy patterns, skewness, and kurtosis, which are often imperceptible to the human eye. These extracted features play a crucial role in informing clinical decision-making, quantifying tumor phenotype, predicting treatment response, and determining prognosis. Their hidden nature underscores the importance of leveraging AI to effectively analyze these features.

The influence of AI in radiology extends beyond CRC. Its applications have permeated several medical fields, leveraging its potential to enhance diagnostic accuracy, refine treatment planning, and streamline patient care. The marriage of AI and radiomics opens new frontiers for precision medicine, with the potential to revolutionize not only oncology but also other areas of healthcare.

This breakthrough has revolutionized the field of radiology, particularly in oncology, and its relevance to CRC.

In conclusion, radiomics, with its ability to extract hidden features from medical images, combined with the power of AI, has ushered in a new era in radiology. Its impact on CRC and other medical fields is significant, enhancing clinical decision-making, treatment planning, and prognostication. By harnessing the potential of AI in radiomics, we can unlock new possibilities for improving patient outcomes and driving advancements in precision medicine[20]. The management of patients with CRC is multifaceted and involves various dimensions of care, such as screening, diagnosis, treatment, and follow-up. Because of these multiple components of care and the vast capabilities of AI, these technologies have an incredibly important role in the management of CRC, anywhere from polyp detection to the prediction of response to chemoradiotherapy. Various applications are currently being developed and validated to improve the detection and workup of CRC treatment[21].

AI is viewed by many researchers as a promising approach to enhance our understanding of diseases and improve their management[22]. It is believed that the gradual implementation of AI techniques can lead to more accurate and precise diagnosis and treatment of cancer[23]. Deep learning has shown potential in improving medical imaging and detecting cancer through various tools and technologies such as faster image interpretation, enhanced workflow, improved image quality, and 3D imaging[24].

Late diagnosis of CRC remains a challenge, but AI can contribute to addressing this issue. Machine learning algorithms can help improve accuracy in prognosis, particularly for stage II cancers, by analyzing textures, spatial relationships, and morphology[25]. Fuzzy systems, which allow for flexible parameters between 0 and 1, offer another tool for diagnosing CRC and predicting the likelihood of cancer-based on specific parameters[26].

The application of AI in genetic testing for CRC can play a crucial role. Hu *et al*[27] conducted a study comparing the accuracy of three neural networks for cancer classification based on gene expression. They found that the S-Kohonen neural network achieved the highest accuracy in classifying cancer among 53 patients. In 2017, Xu *et al*[28] developed a SVM system to identify differentially expressed genes for distinguishing high-risk patients and predicting prognosis. They identified fifteen genetic markers as predictors of recurrence risk and prognosis for colon cancer patients. As per; Pham *et al*[29] investigated the predictive power of Ras homolog family member B protein in rectal cancer with the help of AI fusion in predicting survival and prognosis; which can be informative for clinical decision-making if the patient would be recommended for preoperative therapy. Zhang *et al*[30] developed a counter-propagation artificial neural network (ANN) to detect the BRAF gene mutation in CRC using near-infrared testing. Their model achieved high diagnostic sensitivity (100%), specificity (87.5%), and accuracy (93.8%), effectively distinguishing the BRAF V600E mutation from the wild type.

The use of methylated deoxyribonucleic acid (DNA) as a biomarker for early CRC diagnosis has gained significant attention in AI research. Coppedè *et al*[31] employed an ANN in 2015 to explore the relationship between CRC-related genes and environmental factors. They found that ANNs revealed the complex interconnections among factors associated with DNA methylation in CRC, including intricate networks between dietary and lifestyle factors and the methylation profiles of the studied genes. Shen *et al*[32] developed an analytical method for diagnosing early CRC by detecting methylated cytosine and guanine separated by a phosphate in blood and feces samples. This study involved 300 CRC patients and identified six potential epigenetic biomarkers of DNA methylation associated with rapid tumor development.

Assessment of treatment response: Choosing the most appropriate treatment is important in rectal cancer. A correct preoperative stage is important for the surgical and neoadjuvant CRT decision. Generally, pathological type, tumor differentiation, infiltration depth, and presence of lymph node metastasis determine the prognosis of the tumor. Therefore, understanding the pathological features of the tumor is very important for the clinical treatment decision. Treatment toxicity Effective toxicity estimation and evaluation schemes are required to limit RT-related side effects. High-tech devices and planning systems provide sub-millimetric precision. However, while giving the desired dose to the target volume, the OARs in their immediate neighborhood may be affected, leading to RT-induced toxicity. Acute toxicity occurs during treatment or within 3 mo of completion of treatment and usually, full recovery takes weeks to months. Late side effects such as fibrosis or RT-induced oncogenesis are generally irreversible and considered progressive over time. When planning RT, its potential benefits should be weighed against the possibility of damaging healthy organs and tissues to maximize the curative response while minimizing the possibility of normal tissue complications. AI and machine learning techniques have shown promise in improving pre-operative staging for rectal cancer. These technologies can analyze various imaging modalities, such as MRI or CT scans, to accurately assess tumor characteristics, lymph node involvement, and local tumor invasion. By leveraging large datasets and advanced algorithms, AI can provide more precise and consistent staging information, aiding in treatment planning and decision-making. AI-based models can help identify high-risk cases, predict outcomes, and guide personalized treatment strategies for patients with rectal cancer. These advancements in pre-operative staging can lead to improved patient management and better overall clinical outcomes. On the other hand, the target volume should not be compromised to preserve OARs. In addition to complex dosimetric data, AI provides the clinician with the ability to predict complications by integrating higher-level information such as detailed clinical and comorbidity data into a more comprehensive and quantitative model[33]. In 2019, Ferrari *et al*[34] reported promising results regarding the use of AI in the analysis of MR images to assess the complete therapeutic response of rectal cancer following neoadjuvant chemotherapy. Their AI model successfully distinguished between complete response and non-response to neoadjuvant treatment in rectal cancer patients. The role of AI in understanding drug metabolism and its impact on CRC treatment should not be overlooked. AI tools provide valuable insights into the transformation and metabolic pathways induced by drugs in cancer progression, enhancing our understanding of their biological behavior. The ANN algorithm is increasingly recognized for its predictive power in CRC. Its non-linear models offer flexibility and value in medical research and clinical practice. ANN has proven to be an accurate and reliable tool for clinical decision-making, with the added advantage of facilitating the dissemination of academic knowledge. A systematic review[25] of 27 studies utilizing ANNs as diagnostic or prognostic tools found that 21 of them demonstrated healthcare benefits, while the remaining studies showed results comparable to existing models. Furthermore, ANN applied to predicting distant metastasis of CRC has shown favorable outcomes. The prediction of the response to neoadjuvant treatment, particularly using MRI and AI, holds great potential in guiding personalized treatment strategies for cancer patients.

MRI is commonly used in the assessment of tumor response before and after neoadjuvant therapy. It provides detailed anatomical information and can capture changes in tumor size, morphology, and enhancement patterns. However, accurately predicting treatment response based solely on visual inspection of MRI images can be challenging and subjective.

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AI techniques, particularly machine learning and deep learning algorithms can aid in analyzing and interpreting MRI data for response prediction. These algorithms can learn from large datasets and identify complex patterns that may not be apparent to human observers. By extracting quantitative features from MRI images, AI models can assess tumor response more objectively and consistently.

Several studies have demonstrated the potential of AI in predicting the response to neoadjuvant treatment using MRI. These models can classify patients into different response categories (*e.g.*, complete response, partial response, or non-response) based on pre-treatment MRI features. AI algorithms can also incorporate clinical and molecular data to improve prediction accuracy.

The integration of AI and MRI-based response prediction can have several benefits. It can help clinicians identify patients who are likely to respond well to neoadjuvant therapy, enabling personalized treatment plans and avoiding unnecessary toxicities for non-responders. AI models can also assist in monitoring treatment response over time, allowing timely adjustments in therapy if needed.

However, it is important to note that further research and validation are needed to ensure the reliability and generalizability of AI models in this context. Large, multi-center studies are required to confirm the efficacy of AI-assisted prediction of neoadjuvant treatment response using MRI. Additionally, the implementation of AI systems in clinical practice should consider regulatory and ethical considerations to ensure patient safety and privacy.

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Role of AI in surgical decision making

Compared to AI applications in screening, radiology, and pathology, incorporating AI into surgical data and procedures presents additional challenges[35,36]. Surgical decision-making, such as whether to create an ileostomy or not, requires a comprehensive assessment of various factors specific to each patient's condition. These factors may include the type and location of the underlying disease, the extent of surgical intervention, overall patient health, and potential risks and benefits associated with ileostomy creation.

The decision-making process involves careful consideration of the potential short-term and long-term outcomes, the impact on quality of life, and the patient's preferences and goals. Factors that might favor the creation of an ileostomy include the presence of bowel obstruction, high-risk anastomosis, significant inflammation, or the need to divert stool temporarily to promote healing or manage complications. Conversely, factors that may discourage ileostomy creation include the absence of complications, good surgical outcomes, or the desire to preserve normal bowel function. Surgeons typically rely on their clinical expertise and knowledge of best practices to make these decisions. In complex cases, they may consult with a multidisciplinary team, including gastroenterologists, oncologists, and stoma therapists, to weigh the pros and cons and make an informed choice.

It's important to note that each patient's situation is unique, and decisions regarding ileostomy creation should be individualized. The goal is to optimize patient outcomes and quality of life by considering the specific circumstances and preferences of the patient while balancing the potential risks and benefits associated with the surgical procedure.

Surgical videos capture dynamic interactions between tools and tissues, involving complex deformations and reshaping of anatomical structures. Moreover, surgical workflows are difficult to standardize, especially in complex surgeries. Surgeons also rely on prior knowledge, experience, and intuition during operations. Addressing these challenges requires more and better data, consensus on annotation protocols, and the release of large, diverse, and well-annotated datasets. Collaboration among institutions is necessary to ensure data representativeness and enable external validation studies. Furthermore, the development of AI models capable of analyzing multimodal data and performing causal, probabilistic reasoning will be essential to replicate surgeons' mental models[37].

Currently, most AI algorithms in healthcare focus on individual aspects of medical care rather than replicating human cognitive behavior. In surgery, complex procedures like colorectal resections require the integration of multiple factors, including surgeons' skills, patient characteristics, and environmental factors[38]. Understanding how expert surgeons perform specific procedures and analyzing qualitative data and cognitive tasks could potentially generate AI algorithms that replicate expert behaviors.

Role of AI in prognostication

AI can aid in prognosticating rectal cancer by analyzing clinical and pathological data to predict patient outcomes. AI algorithms can identify patterns and correlations in large datasets, considering factors like tumor stage, histological features, genetic markers, and treatment regimens. By leveraging machine learning and deep learning techniques, AI models can provide more accurate and individualized prognostic assessments, assisting clinicians in treatment decision-making and follow-up strategies. However, further research and validation are necessary to establish the clinical utility and effectiveness of AI in this context.

DISCUSSION

Traditional treatment approaches for CRC involve a multimodal approach integrating surgery, chemotherapy, radiotherapy, and immunotherapy, aiming to provide comprehensive and more effective cures. AI can provide additional assistance to patients in selecting appropriate treatment methods, leading to more individualized and precise therapies, thereby improving treatment outcomes. AI is assisting in generating new approaches for cancer detection, screening of healthy subjects, diagnosis, classification of cancers using genomics, tumor microenvironment analysis, prognostication, follow-up, and new drug discovery[12-15].

The introduction of new technologies such as AI often raises doubts and concerns among healthcare professionals who rely on verified and certain information for their work. However, in the era of big data, it becomes necessary to address these concerns and delve deeper into understanding the reliability and potential benefits of these methods. The next crucial step is the development of medical ethics guidelines to regulate the appropriate use of these new technologies. Understanding the data is essential to draw reliable conclusions. The limitation of such technologies lies in the scarcity of comprehensive and interpretable data that can lead to meaningful outcomes. For instance, when it comes to CT imaging and AI studies, the input data can vary significantly, which poses challenges in providing definitive diagnoses and treatments for the general population. Optimizing data through new technologies requires significant investments of time and resources. However, it enables the creation of systems that facilitate better data collection and more accurate decision-making processes. The accumulation of data by various institutions increases both its quantity and quality. Establishing public databases that include information such as symptomatology, imaging modalities, and geographic distribution can be an asset for researchers, providing them access to a wealth of information. Ensuring free access to this data represents another obstacle, as underdeveloped and impoverished countries may face difficulties in accessing such technology. As experimentation and application of AI progresses, costs are expected to decrease, and the benefits can be extended to a broader population, transcending geographical boundaries. It is crucial for the global health community that these countries have access to technology to enhance disease management and improve the quality of life in their local communities.

Shao *et al*[39] developed an AI model to identify the risk of anastomotic leakage (AL) after rectal cancer resection. Data from 2240 patients showed that the SVM model had good discernment of AL and could potentially increase the use of temporary ileostomy in patients with AL ($P < 0.001$). Several studies have utilized deep neural networks to recognize surgical phases and actions, offer intraoperative guidance, and automate skill assessment by analyzing surgical videos. Particularly encouraging results have been achieved in the recognition of surgical phases and actions, with accuracies exceeding 80% in some studies[40]. AI has also been employed to identify safe planes of dissection and interpret fluorescent signals for perfusion assessment during surgery. Additionally, a study by Park *et al*[41] demonstrated that AI can reliably assess surgical skills according to specific criteria. However, most of these studies have been conducted in a single center, making it unclear how well these models would perform in other healthcare settings. Furthermore, the lack of transparency in annotation protocols and the use of private datasets hinder the scrutiny of the validity of annotations and the representativeness of the data. Lastly, no studies have yet reported on the impact of AI on healthcare outcomes, such as surgical efficiency or clinical outcomes.

On the other hand, AI applications in CRC screening and staging are more advanced. In CRC screening, multiple studies have shown advantages over traditional endoscopic and radiological exams[21]. A recent meta-analysis[42] of randomized controlled trials (RCTs) demonstrated that combining AI algorithms with colonoscopy improved the detection rate of polyps and adenomas compared to colonoscopy alone. Similarly, AI has shown promise in assisting imaging techniques for CRC staging, including the assessment of lymph node status, prediction of pelvic lymph node involvement, and detection of liver metastasis. Although the clinical impact of these systems is yet to be investigated in RCTs, they have the potential to enhance disease staging and treatment allocation[43].

In the field of pathological staging, machine-learning models have been developed to accurately classify tumors and distinguish between malignant and normal colon samples. These models have demonstrated high accuracy in determining malignancy and grading CRC lesions based on histopathological images[44,45].

AI technology has emerged as a promising tool in the prediction, diagnosis, and treatment of CRC. By leveraging large datasets and advanced algorithms, AI systems can analyze complex patterns and provide valuable insights for clinicians.

In terms of prediction, AI models have been developed to assess the risk of developing CRC. These models utilize various data sources, including genetic information, lifestyle factors, and medical history, to generate personalized risk scores and aid in early detection.

For diagnosis, AI algorithms have shown remarkable capabilities in accurately detecting CRC from medical imaging, such as colonoscopy and radiological scans. Studies have demonstrated that AI-based systems can achieve comparable or even superior performance to human experts in identifying suspicious lesions and reducing missed diagnoses.

In the field of treatment, AI technology has the potential to optimize therapeutic strategies and improve patient outcomes. For instance, AI-driven algorithms can assist in determining the most appropriate treatment options, such as surgery, chemotherapy, or targeted therapy, based on individual patient characteristics and disease factors. Additionally, AI models can aid in predicting treatment response and prognosis, enabling personalized treatment plans and better patient management.

Overall, the integration of AI technology in CRC prediction, diagnosis, and treatment holds great promise for enhancing precision medicine approaches and improving patient care.

AI technology plays a pivotal role in the prediction, diagnosis, and treatment of CRC. By harnessing the power of AI algorithms and advanced data analysis techniques, significant advancements have been made in CRC research and clinical practice.

In the field of prediction, AI models have been developed to assess the risk of developing CRC. These models leverage various data sources, including genetic information, lifestyle factors, and medical history, to generate personalized risk scores and aid in early detection[35].

Regarding diagnosis, AI algorithms have demonstrated impressive capabilities in accurately detecting CRC from medical imaging, such as colonoscopy and radiological scans. Studies have shown that AI-based systems can achieve comparable or superior performance to human experts in identifying suspicious lesions and reducing missed diagnoses [46,47]. Some of the studies on the role of AI in rectal cancer have been shown in Table 1.

In the realm of treatment, AI technology has the potential to optimize therapeutic strategies and improve patient outcomes. AI-driven algorithms can assist in determining the most appropriate treatment options, such as surgery, chemotherapy, or targeted therapy, based on individual patient characteristics and disease factors[48]. Additionally, AI models can aid in predicting treatment response and prognosis, enabling personalized treatment plans and better patient management.

The integration of AI technology in rectal cancer prediction, diagnosis, and treatment holds immense promise for enhancing precision treatment approaches and advanced patient care.

Current and future role of AI in the management of rectal cancer

The role of AI in various diagnostic tools and management of rectal cancer is evolving. Good research has been done in the field of the detection of malignant polyps and AI algorithms have been added to CT, MRI, and positron emission tomography for better staging and treatment decision-making. Radiomics is a new field of AI where computer algorithms analyze medical images, such as MRI scans, to identify features that may be unique to cancer. Currently, European Society for Medical Oncology has come up with guidelines which are based on pre-operative MRI, for treatment planning. Hence, AI-based radiomics can then be used to help doctors plan treatment and predict the risk of recurrence [49]. Precision medicine is another newer concept where a patient's genetic mutation is used to plan perioperative treatment. A sub-field of AI, machine learning can be used to identify genetic data and patient records to predict prognosis[50]. Intra-operative role of AI in assisting the surgeon in obtaining adequate resection margin, avoidance of injury to surrounding organs (Ureter, urethra, urinary bladder, pre-sacral venous plexus, prostate, iliac vessels, *etc.*), and

Table 1 Published studies on artificial intelligence and machine learning in rectal carcinoma

S.No.	Ref.	No. of patients in AI-based study	Methods	Result	Conclusion
1	Pham *et al* [29], 2023	*N* = 53, rectal cancer biopsy	CNN based extraction of IHC images	SVMs extraction; total accuracy = 85%, Prediction of survival rate of more than 5 yr = 90%, and less than 5 yr = 75%	Use of AI can be informative for clinical decision making- whether required preoperative therapy or not
2	Kim *et al*[67], 2023	*N* = 39, mid to lower rectal cancer patients who underwent chemoradio-therapy	Deep learning-based imaging reconstruction (DLR) effect on MRI quality	Compared to conventional MRI DLR-MRI showed significantly higher specificity values (P < 0.036)	Compared to conventional MRI, DLR significantly increased the specificity of MRI for identifying pathological complete response (pCR)
3	Wang *et al* [68], 2023	*N* = 1651, machine learning model used for predicting major LARS following laparoscopic surgery of rectal cancer and their quality of life	The trained random forest (RF) model performed, and clinical utility of the model was tested by decision curve analysis	Compared to the conventional preoperative LARS score model, current machine learning model exhibited superior predictive performance in predicting major LARS	This model could potentially be used in the clinic to identify patients with a high risk of developing major LARS and then improve the quality of life
4	Qiu *et al*[69], 2023	*N* = 27180, used eight machine learning Model for predicting chances lung metastasis in rectal cancer patients	They used DCA and calibration analysis to test all the models to predict risk of lung metastasis in patients with rectal cancer	XGB model had better clinical decision making and prediction ability than other models	XGB model based on clinicopathological information to predict the risk of lung metastasis in patients with rectal cancer, which may help physicians make clinical decisions
5	Shao *et al*[39], 2023	*N* = 2469, consecutive patients with stage I-III rectal adenocarcinoma who received anterior resection and did not receive neoadjuvant therapy	Five AI algorithms, (SVM), logistic regression (LR), Naive Bayes (NB), stochastic gradient descent (SGD) and random forest (RF), were employed to generate five models	In summary, the present study developed a high-performance AI model based on clinical preoperative and intraoperative les, which may be supportive for the guidance of the intraop-erative decision-making by calculating the risk of AL	The application of this app can predict the risk of AL in patients with rectal cancer who have undergone anterior resection
6	Xia *et al*[70], 2023	172 rectal cancer patients were used for model training, and 18 patients were used for model validation. Another 40 rectal cancer patients were used for an end-to-end evaluation for both auto-segmentation and treatment planning	The PTV and OAR segmentation was compared with manual segmentation	The PTV DICE similarity coefficient was greater than 0.85 for all 40 patients in the evaluation dataset while the DICE indices of the OARs also indicated good performance	Deep learning-based automatic solution for rectal cancer treatment that can improve the efficiency of treatment planning

AI: Artificial intelligence; AL: Anastomotic leak; CNN: Artificial Neural Network; DLR: Deep learning; SVM: Linear support vector machine; LARS: Low anterior resection syndrome; XGB: Extreme gradient boosting; DICE: Diverse counterfactual explanation; OAR: Object attribute relation; PTV: Particle tracking velocimetry; IHC: Immunohistochemistry.

autonomic nerve preservation is still in its infancy but seems promising. Virtual reality is another domain of technology that creates a realistic simulation of surgery, which can be of help to train surgeons for difficult and challenging surgeries. The use of AI can help intra-operative identification of safe resection plane (conventional mesorectal plane *vs* extended mesorectal plane), and surrounding organs. Virtual reality can also be used to deliver pain relief and relaxation therapy [51]. As commonly discussed today in every sphere of life, a Chatbot (ChatGPT) can help a patient with rectal cancer to alleviate anxiety, regulate hospital visits, and check compliance with the treatment plans as it can simulate conversation with humans. Chatbots are being used to provide information and support to patients with rectal cancer, as well as to collect data that can be used to improve treatment[52]. As oncologists have found a growing interest in the role of immunotherapy in rectal cancer, due to fewer side effects and better efficacy (Dostarlimab in mismatch repair deficient locally advanced rectal cancer), theragnostic which is a combined approach to diagnosis and treatment, AI can be used to develop personalize therapies (immunotherapy)[53]. Robotic surgery is a boon of AI in intra-operative assistance, with margin assessment, preventing injury to surrounding organs, such that rectal cancer surgeries are being done with greater precision and less risk of complications. AI is being used to develop robotic surgical systems that are even more precise and efficient[54]. Further combination of clinical profile, and genetic mutation can help to prognostication and plan adjuvant treatment or a robust follow-up[55]. Furthermore, AI-powered cytopathology in the detection of cancer cells[56], newer more effective drug discovery[57], personalized medicine[58], surgical decision-making[59], rehabil-itation[60] can improve patient outcome in rectal cancer.

Rectal cancer, AI and Ethical implications

Today AI has infiltrated into everyone's day to day life in some or other form and its role in the medicine is immense. However, AI poses a risk to the basic tenets of patient care “right to health’ by compromising patients' privacy, and autonomy[61] and therefore is not beyond the ethical issues. Over the years, the potential risk of AI in terms of ethical, legal, and social implications include 1) neutral values reflected by AI algorithms (in carcinoma rectum, the neutral value *i.e.* not a bad or good risk doesn't add to treatment planning, rather add to anxiety and concern), explain ability or interpretability of Al algorithms, data concerns (authenticity of a large volume of data provided for training of AI)[62,63]. In rectal cancer, data may be obtained from populations from different geographical locations, ethnicities, and genetic makeup, which prevents any algorithm unification. An AI algorithm can perform better in one population than another. Other drawbacks include professional responsibility, bias, and legal risk[64]. Though AI can perform many tasks of the human brain, however, a patient-doctor relationship is essential for the psychological alleviation of anxiety and concern of any patient. The legal impact of AI may be categorized into- differential access to high-quality health care, transparency to doctors and patients, social bias, deviation from patient's well-being, risk of automation, de-skilling and change in liability, and risk to privacy. To regulate the patient-doctor relationship, the "Oviedo Convention-European Convention on Human Rights and Biomedicine- 1997" has been amended[65]. In rectal cancer, the patient holds a key position, as its multimodality management needs multiple doctors treating one patient and it cannot be made by a single algorithm.

As with any newer technology, AI also comes with some legal implications that need regulation. Currently, an international regulation system is lacking, however a few documents available are the Okinawa Charter on Global Information Society (G8 Kyushu-Okinawa Summit Meeting 2000, Kyushu-Okinawa Japan), OECD Council Recommendation on Artificial Intelligence (adopted by the Council at Ministerial Level on 22 May 2019), G20 Ministerial Statement on Trade and Digital Economy (2019, Japan), *etc.* The goals of legal regulation include the creation of a unified digital space in AI, harmonization of national and international legal regimens, non-discriminatory access to AI, and ensuring legal liability of AI developers, administrators, and operators[66]. A good preoperative and perioperative deliberations between patient, relatives and treating team of doctors, about the benefits/pros and cons/technicality along with difference in the treatment outcomes which may arise out of AI based treatment *vs* pure classical clinical decision-based treatment. May resolve the patient-doctor conflict to great extent.

CONCLUSION

The integration of AI technology in the prediction, diagnosis, staging, and treatment of rectal cancer holds significant promise. However, its role in surgical decision-making is very limited. AI-driven algorithms can minimize missed diagnosis, and optimize therapeutic strategies by assisting in treatment selection and predicting treatment response, leading to personalized and improved patient care. The new technology driven treatment is not free of ethical and medicolegal issues but can be resolved with currently available ethical guideline and doctor – patient's dialogues. Currently, its role in rectal cancer is in its infancy and evolving. The continued advancement and implementation of AI technology in rectal cancer management has the potential to enhance precision medicine approaches and contribute to better patient outcomes and has a promising future.

FOOTNOTES

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