The applications and challenges of artificial intelligence in colonoscopy

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Abstract
It has been widely acknowledged that colonoscopy is the most effective method of preventing colorectal cancer because it can detect and remove precursor lesions, thereby reducing both incidence and mortality. Among these approaches, standardized colonoscopy stands out as the most efficacious method for early-stage colorectal cancer identification. Artificial intelligence is a rapidly expanding field in gastrointestinal endoscopy. This article presents a comprehensive review of the advantages and clinical evidence supporting the application of artificial intelligence in colonoscopy while also discussing prospects for utilizing artificial intelligence-assisted endoscopy in diagnosing colorectal cancer.

Keywords: artificial intelligence; colonoscopy
Background

The development of colorectal cancer occurs gradually over an extended period, emphasizing the significance of early diagnosis and prompt treatment [1]. Among them, standardized and high-quality colonoscopy, including high-quality intestinal preparation, standard anatomical site shooting, appropriate exit time, and standardized observation methods are the key points to detecting lesions [2]. However, the standard and quality of colonoscopy are heavily reliant on the professional expertise and operational experience of endoscopists, resulting in a certain degree of missed diagnoses and misjudgments. A large-scale meta-analysis indicates that the missed diagnosis rate for colonoscopy adenomas is as high as 26%, while serrated polyps have a missed diagnosis rate of up to 27%, and advanced adenomas have a missed diagnosis rate as high as 9% [3]. Therefore, we urgently need different assistive technologies to standardize colonoscopy operations and improve the quality of colonoscopy.

In recent years, artificial intelligence (AI) has made significant advancements across various domains, particularly in the realm of healthcare [4]. The integration of AI into colonoscopy has unveiled novel prospects for enhancing the precision, efficiency, and patient experience of this pivotal medical procedure [5]. During colonoscopy, real-time video feedback and identification of potential lesions can be facilitated through the application of AI algorithms [6]. These algorithms typically employ deep learning techniques to analyze the extensive visual data generated during inspections, thereby automating the process and enhancing lesion detection rates as well as diagnostic accuracy [7]. Six studies involving 67 endoscopists and 2085 patients have reported prospective investigations on the utilization of AI technologies. However, in the context of these AI studies, human accuracy for diagnosing colorectal neoplasia is found to be suboptimal [8]. The implementation of AI in gastroscopy is poised to revolutionize healthcare, making a profound impact. This article aims to provide an overview of the current limitations and future prospects for integrating AI into colonoscopy.

Evolution of AI in digestive endoscopy

Since its introduction in 1983, electronic endoscopy has ushered in a new era for the diagnosis and treatment of gastrointestinal diseases. Furthermore, digestive endoscopy has evolved into an indispensable technology for disease diagnosis and management [9]. Currently, digestive endoscopy has been demonstrated as the most efficacious approach for augmenting the early detection rate of gastrointestinal malignancies [10]. The advancements in AI, particularly the deep learning technology, offer a promising solution for mitigating human performance biases through assisted decision support during digestive endoscopy examinations [11]. AI leverages computational systems to emulate the cognitive processes of the human brain, facilitating corresponding decision-making and actions. By employing algorithms such as machine learning, deep learning, and computer vision, computers analyze extensive datasets to execute tasks like language recognition and image identification, ultimately achieving a simulation of human behavior. AI is extremely hot in the field of digestive endoscopy [12]. The objective of AI system development is to construct a mathematical model based on a pre-labeled dataset, facilitating the interpretation of novel information [13]. Among them, deep learning, as a pivotal branch of AI machine learning, is further categorized into deep neural networks, recurrent neural networks, and convolutional neural networks (CNN) [14]. Currently, state-of-the-art AI image algorithms, particularly in domains such as chest CT imaging, demonstrate the capability to match or even surpass the performance of human expert [15]. AI research covers almost all endoscopy in the digestive endoscopy. In the context of upper gastrointestinal endoscopy, AI can not only enhance the detection rate of early esophageal cancer lesions and improve diagnostic accuracy but also facilitate the identification of incipient-stage esophageal malignancies [16], and to evaluate the depth of esophageal lesion [17]. In the diagnosis of stomach diseases, AI can not only help improve the diagnosis rate of early gastric cancer [18], aided automatic labeling of the lesion area [19]. It can also assist in the diagnosis of helicobacter pylori infectious gastritis [20]. In capsule endoscopy, AI can assist in the identification of small intestinal lesions, lesion localization, and improve the quality and efficiency of the examination [21].

The applications of AI in colonoscopy

Bowel preparation

Good intestinal preparation is an important examination basis for observing the colorectal mucosa and improving the detection rate of adenomas [22]. In the routine colonoscopy process, endoscopists usually record the Boston Bowel Preparation Scale (BBPS) based on their own memory after the colonoscopy is completed. Due to subjective factors such as different withdrawal times, personal experience, and patient status during the examination, there are differences in the basic understanding of intestinal preparation among different endoscopists, making the results of BBPS subjective. AI technology can intelligently control the preparation of the intestine based on BBPS, and perform real-time and objective evaluation of full intestinal coverage. The study is currently investigating an AI-assisted quality control system, which is based on the CNN model developed by Su et al. [23] can not only effectively improve the detection rate regarding the presence polyps and adenomas during colonoscopy withdrawal by endoscopists, but also evaluate the bowel readiness in real time. When the system score is unqualified (BBPS score < 2), the endoscopist is prompted via audio to clear the intestinal contents or suction pool. Artificial intelligence quality control system can effectively ensure that the time of exit examination is > 6 minutes, improve the pass rate of intestinal cleanliness, and dynamically identify and alarm polyps in real time, thus significantly improving the detection rate of colorectal adenoma and polyps. Lee et al. [24] developed a system based on CNN algorithm to evaluate whether intestinal preparation is suitable for BBPS score and provide an average BBPS score on this basis. The results show that the algorithm can evaluate intestinal cleanliness well, with an accuracy of 85.3%, which is similar to the expert evaluation results. The AI system, named ENDANGER and developed by Zhou et al. [25] is based on deep learning techniques. It autonomously assesses the intestinal readiness score at regular intervals of 30 seconds and presents the score during the exit phase of colonoscopy, ultimately delivering segment-specific results. The results showed that the system accurately classified intestinal preparation images with an accuracy of 93.33%, which was better than all the endoscopists involved in the study. The informative frames were classified into two categories, namely frames with remaining debris and frames without, using Support Vector Machine. To estimate BBPS scores, a CNN with two Net layers was proposed, incorporating a feature reuse mechanism before the soft max classifier. The technology demonstrated a remarkable accuracy of 90% when evaluated on the publicly available Nersus dataset [26]. The author believes that although optimizing the use of intestinal preparation drugs and strengthening the education of examination patients are fundamental to high-quality intestinal preparation, the feedback from AI-assisted evaluation of intestinal preparation can not only effectively improve the lesion detection rate of colonoscopy, but also compare the difference of intestinal preparation in different time of taking laxatives. According to the results of AI-assisted evaluation, personalized intestinal preparation drugs and medication time can be further developed for different types of patients.

Colonoscopy site identification

A high-quality colonoscopy encompasses adequate bowel preparation, a clear visualization of the entire colorectal mucosa, and optimal patient comfort. AI-assisted colonoscopy can automatically identify different parts such as the appendix opening, terminal ileum, ileocecal flap, ileocecal part, rectum, anal canal, and monitor and record the

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rate and observation time of different doctors. Gong et al. [27] investigated an AI-based quality control system for digestive endoscopy, which provides real-time monitoring of the speed and duration of advancement. Excessive retraction speed may result in missed diagnoses; hence, the system alerts endoscopists to be mindful of blind spots caused by insufficient retraction time. The arrival of the colonoscopy at the blind end serves as a crucial indicator for successful completion of the procedure, enabling assessment of the endoscopist’s proficiency level. In comparison to manual data extraction, an AI-assisted system can promptly detect and alert any instances of failure in reaching the cecum during colonoscopy. This AI-assisted detection system, significantly improved the detection rate of large (> 10 mm) colorectal polyps. The automatic quality control system developed by Su et al. [28] was based on deep convolutional neural networks, which employ algorithms to calculate the dropout time, monitor dropout stability, and evaluate intestinal preparation, detect colorectal polyps, and assess their potential for improving the detection rate of polyps and adenomas in clinical practice. This system significantly enhanced the detection rate of adenomas (0.289 compared to 0.165) and the average number of adenomas detected per colonoscopy (0.367 compared to 0.178), as well as the polyp detection rate (0.383 compared to 0.254) and the average number of polyps detected per colonoscopy (0.575 compared to 0.305). The cecum serves as the pivotal determinant for the entry and exit points of colonoscopy procedures. In their study, Cho et al. [29] employed deep learning techniques to analyze the recognition of cecum position in colonoscopy videos, achieving an impressive overall accuracy rate of 95.6%. Quantifying and utilizing endoscopic operational actions can effectively assess the proficiency levels of colonist. Furthermore, AI-assisted colonoscopy can also unify the endoscopic operation specifications, and it will automatically remind the parts required by the regulations if they are not photographed, providing effective real-time feedback for the standardized training of endoscopic operation for young physicians.

Detection rate of adenoma
The adenoma detection rate (ADR) is a quality index of colonoscopy. Improving the ADR and reducing the missed diagnosis of adenoma or early colon cancer is the key to the successful early diagnosis and treatment of colon cancer [30]. As an independent predictor of colorectal cancer risk, how to improve the detection rate of adenoma has become an urgent problem to be solved. The ADR serves as a crucial parameter for assessing the quality of colonoscopy, and in this study, ten general endoscopists (< 2000 colonoscopies) employed high-definition colonoscopy to screen for adenomas within a continuous cohort of subjects aged 40–80 years old. The investigation aimed to compare the disparity in ADR between AI-assisted and non-AI-assisted colonoscopy, ultimately demonstrating that AI-enhanced colonoscopy significantly enhances ADR [5]. The study conducted by Wang et al. [31] was a prospective cohort study that investigated the efficacy of an automatic polyp detection system based on deep learning. Their findings demonstrated that the utilization of AI-assisted technology significantly enhanced the detection rate of both polyps and adenomas, increasing them from 29% to 45% and from 20% to 29%, respectively. Importantly, this improvement in adenoma detection was primarily observed for small adenomas measuring between 0 mm and 5 mm, while no significant difference was found in the detection rate of large adenomas (> 5 mm). Furthermore, a separate study conducted by this research team demonstrated that AI-assisted colonoscopy had a significantly lower missed detection rate for polyps and adenomas compared to routine colonoscopy. Reducing the missed detection rate of adenomas during white light examination by endoscopists may potentially contribute to a decrease in the incidence of interval colon cancer [31]. Repici et al. [32] divided 685 patients into two groups, an AI-assisted group and a non-AI-assisted group. The study findings revealed that the AI-assisted group exhibited a significantly higher ADR compared to the non-AI-assisted group (54.8% vs. 40.4%). Furthermore, the investigated AI-assisted system not only enhanced the detection rate of small adenomas (0 mm–5 mm) but also improved the detection rate of adenomas sized between 6 mm and 9 mm. Alessandro Repici et al. [33] developed a deep learning-based AI assisted system, which was evaluated on 660 patients (62.3 ± 10 years old; male/female: 330/330) and compared with the performance of a general endoscopist. The AI assisted system demonstrated a significantly higher overall ADR compared to the control group (53.3% vs 44.5%). An analysis of randomized controlled trials reported that colonoscopies equipped with AI detection algorithms can effectively improve the detection rate of adenomas [34]. Ahmad et al. [35] aims to identify the research priorities for implementation, with a specific focus on harnessing the potential of AI to enhance adenoma detection rates. It is evident that AI-assisted endoscopists play a pivotal role in facilitating polypl and adenoma recognition.

Diagnosis of colorectal cancer
Yamada et al. [36] developed an AI system capable of automatically detecting early colorectal cancer during colonoscopy, exhibiting a sensitivity and specificity of 97.3% and 99%, respectively. The validation set yielded an area under the curve value of 0.975. Furthermore, the sensitivity for the polyp subgroup was found to be 98%, while it was observed to be 93.7% for the non-polyp sub-group. The system can offer real-time prompts during endoscopy to prevent overlooking abnormalities, such as non-polypoid polyps, in colonoscopies. In the early detection of this disease, Takemura et al. [37] developed a computer system based on amplified colonoscopy images of narrow-band imaging to assist the diagnosis of colorectal neoplasia. The system demonstrated a diagnostic accuracy of 97.8%, with no significant difference between the diagnostic coincidence rate and that of endoscopic experts. Computer-aided diagnostic system can also be combined with amplified pigment endoscopy to automatically diagnose the malignant potential of colorectal lesions, which has a high sensitivity [38]. The implementation of AI-assisted colonoscopy is expected to significantly enhance the efficiency and accuracy of the procedure, thereby improving the screening rate for colorectal tumors and other lesions in the lower digestive tract.

Diagnosis other intestinal lesions
Al-assisted colonoscopy system can help solve problems such as uneven inspection quality and misdiagnosis of lower digestive tract lesions in endoscopy. Maeda Y et al. have highlighted the utilization of AI as an autonomous tool for ulcerative colitis diagnosis during colonoscopy, distinct from the endoscopists [39]. Moreover, inflammatory bowel disease is primarily categorized into ulcerative colitis and Crohn’s disease, with its diagnosis predominantly reliant on colonoscopy. AI can enhance the differentiation between inflammatory bowel disease and Crohn’s disease, evaluate the degree of inflammation, and assist clinical practitioners in early intervention for lesions [40].

Limitations and future perspective
The progress of AI in colonoscopy research is advancing rapidly and has yielded numerous significant findings, with the exception of a few medical device products that have yet to be widely implemented in clinical practice. The auxiliary application of AI in colonoscopy still requires further attention to unresolved issues. Firstly, the lack of multicenter, prospective randomized controlled trials poses a challenge. Uncertainty still exists regarding the efficacy of Al-assisted colonoscopy in real-world applications. Another obstacle lies in the requirement for large volumes of high-quality data to accurately train AI algorithms. Inadequate data may hinder the expected performance of AI algorithms. Moreover, due to the absence of unified inspection instrument standards and variations in image quality acquisition as well as individual differences, constructing datasets becomes more challenging [41]. Thirdly, the distinction between cancer and adenoma, particularly due to the limited availability of magnifying endoscopy data for early gastrointestinal cancer, significantly
influences treatment strategy decisions such as opting for endoscopic mucosal resection or endoscopic submucosal dissection, as well as determining whether to pursue endoscopic surgery or surgical interventions. Additionally, it should be noted that the algorithm solely analyzes provided images without always incorporating additional patient information into its analysis which can lead to biased interpretation of results. Furthermore, the inherent opacity of deep learning algorithms hinders interpretability in the obtained results. To ensure the safety and acceptance of AI-assisted diagnosis by clinical practitioners and patients, future research should prioritize elucidating the underlying rationale behind these outcomes [42]. Future research necessitates long-term, multicenter prospective randomized controlled trials of high quality that adhere to standardized regulatory protocols in order to authenticate the true efficacy of these computing systems. For physicians engaged in rapid endoscopic procedures, any delays in data transmission can pose significant challenges for recognition and should not be disregarded.

Conclusions

AI represents a highly promising tool with the potential to shape the future of colonoscopy, enhancing both the quality and efficiency of this examination, thereby ultimately benefiting patients. Presently, this technology is still undergoing continuous development, and despite existing challenges that need to be addressed, ongoing research and development in this field hold the potential to revolutionize the domain of colonoscopy in forthcoming years.

References


