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Review

Enhancing endoscopic precision: the role of artificial intelligence in modern gastroenterology

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SUMMARY

Background: Endoscopy remains the gold standard for gastrointestinal (GI) diagnostics, enabling direct visualization and intervention within the GI tract. However, diagnostic accuracy and procedural outcomes vary significantly depending on the endoscopist's skill and experience, leading to potential missed lesions and inconsistent patient care. The integration of artificial intelligence (AI) into endoscopic practice offers a promising solution to address these limitations and enhance diagnostic precision. This review explores the current applications of AI in endoscopy, focusing on image analysis, lesion detection, classification, and workflow optimization, while evaluating the impact on clinical practice and identifying implementation challenges.
Methods: A literature search was conducted using PubMed, Google Scholar, and IEEE Xplore databases for studies published between January 2010 and December 2024. Keywords included "Artificial Intelligence," "Endoscopy," "Gastrointestinal Diseases," "Image Analysis," and "Lesion Detection." Studies were selected based on their focus on AI applications in endoscopy with quantitative or qualitative data on performance and clinical impact.
Results: AI demonstrates exceptional capabilities in polyp detection, achieving detection rates that often surpass those of human practitioners, with systems such as GI Genius showing high sensitivity and specificity. Convolutional neural networks excel in real-time lesion identification and classification, differentiating between benign and malignant growths with remarkable precision. AI also optimizes endoscopic workflows through automated reporting and advanced training tools.
Conclusion: Although AI integration shows promise for enhancing endoscopic diagnostic accuracy and procedural efficiency, successful implementation requires careful consideration of current limitations, including reliance on industry-sponsored studies, and addressing challenges in data quality, clinical workflow integration, and regulatory considerations. Future developments in advanced algorithms, personalized medicine, and telemedicine may further advance endoscopic practice and improve patient outcomes.

Introduction

Endoscopy, which involves the insertion of a flexible tube equipped with a light and camera into the digestive tract, is an indispensable tool in modern medicine [1]. It allows for direct visualization and intervention within the gastrointestinal (GI) tract, playing a crucial role in diagnosing and treating a wide range of conditions, including GI bleeding, inflammatory diseases, infections, and cancers [2]. By

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providing a direct view of the mucosal lining of the GI tract, endoscopy facilitates the detection of lesions, polyps, and other abnormalities that might not be visible through noninvasive imaging techniques [3]. This ability to directly visualize and, if necessary, biopsy suspicious areas makes endoscopy a cornerstone of GI diagnostics.

Despite its efficacy, the success of endoscopic procedures largely depends on the skill and experience of the endoscopist [4]. This dependency introduces a significant degree of variability in diagnostic accuracy and procedural outcomes [5]. An experienced endoscopist may detect subtle lesions or early-stage abnormalities that a less experienced practitioner might overlook [6]. Furthermore, the physical and cognitive demands of endoscopic procedures can lead to fatigue, potentially affecting performance and increasing the risk of missed lesions [7]. This inherent variability underscores the need for advancements that can support endoscopists, reduce the burden of procedural demands, and enhance the consistency of diagnostic outcomes.

The advent of artificial intelligence (AI) in medical imaging presents a promising solution to these challenges [8]. AI, particularly through machine learning and deep learning techniques, has shown exceptional capabilities in analyzing medical images with high precision [9]. In the context of endoscopy, AI algorithms can be trained to recognize and highlight abnormalities in real time, providing a second set of eyes to assist the endoscopist [10]. These systems can analyze vast amounts of data quickly, identifying patterns and features that might be missed by human observation alone. Thus, the integration of AI into endoscopy aims to enhance image analysis, improve lesion detection, and support decision-making processes, ultimately aiming to standardize and elevate the quality of care [11].

One of the most significant applications of AI in endoscopy is in the detection of polyps during colonoscopy [12]. Colorectal cancer prevention relies heavily on the early detection and removal of adenomatous polyps, which are precancerous lesions [13]. AI systems have been developed to assist endoscopists in identifying these polyps, often achieving detection rates that surpass those of human practitioners. By providing real-time alerts and highlighting suspicious areas, AI can help ensure that polyps are not overlooked, thereby reducing the incidence of interval cancers, cancers that develop between regular screening intervals owing to missed lesions.

Beyond polyp detection, AI is also being used to classify and characterize detected lesions [14]. This includes differentiating between benign and malignant growths and identifying specific types of polyps that may require different management strategies [15]. For instance, AI algorithms can be trained to recognize the morphological features of various types of polyps, aiding in the immediate in-procedure decision-making process [14]. This capability not only improves diagnostic accuracy but also facilitates more tailored and effective patient management.

The integration of AI into endoscopic practice is not limited to lesion detection and classification but also to image analysis, as shown in Fig. 1, which illustrates the use of AI in GI endoscopy. AI systems are also being developed to optimize the entire workflow of endoscopic procedures [16]. This includes preprocedure planning, in which AI can analyze patient history and suggest optimal examination strategies, and postprocedure documentation, in which automated systems can generate detailed reports of findings and interventions [17]. In addition, AI-powered training tools are providing new opportunities for educating novice endoscopists, offering simulations that mimic real-life procedures and allow for skill development in a controlled, risk-free environment [18].

The rationale for integrating AI into endoscopy lies in the pursuit of enhanced diagnostic accuracy and procedural efficiency. Traditional endoscopic techniques, although effective, are prone to human error and subjectivity [19, 20]. AI can mitigate these issues by providing consistent, objective analysis and support. The novelty of AI applications in endoscopy is evident in its transformative potential, leveraging advanced computational techniques to achieve levels of precision and reliability that were previously unattainable [21]. This review aimed to comprehensively examine the current applications of AI in endoscopy, evaluate its impact on clinical practice, and identify the challenges and limitations associated with its adoption. By exploring these aspects, this review seeks to highlight the benefits of AI integration, discuss areas needing further research, and outline future directions for this burgeoning field. Ultimately, our objective is to provide a thorough understanding of how AI can advance endoscopic practice, while acknowledging current limitations and the need for more robust, real-world evidence to support widespread clinical implementation.

Methods

Literature search strategy

To conduct this narrative review on the application of AI in endoscopy, a comprehensive literature search was performed using several electronic databases, including PubMed, Google Scholar, and IEEE Xplore. The search aimed to identify relevant studies, reviews, and articles published between January 2010 and December 2024.

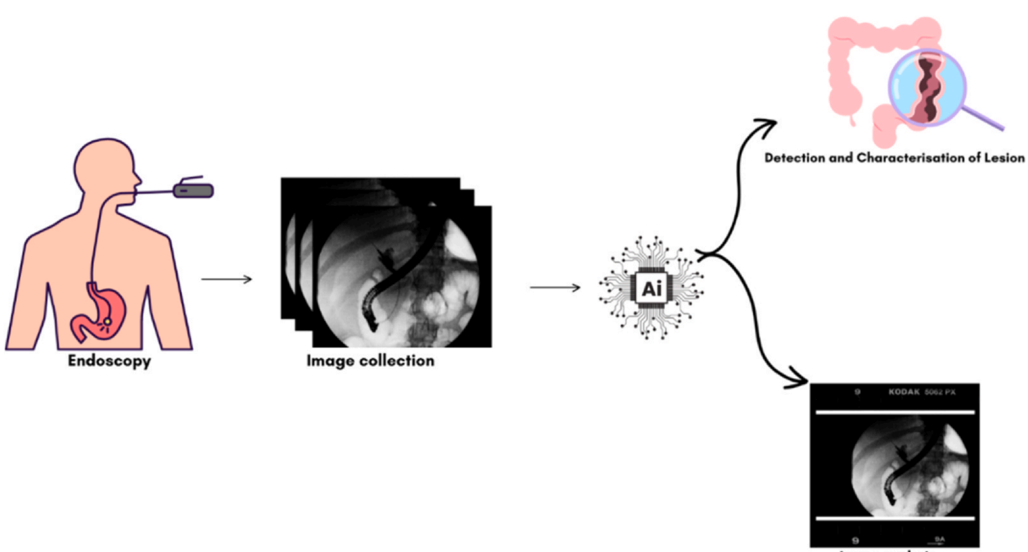

Figure 1. A diagram that illustrates the use of AI in gastrointestinal endoscopy. AI, artificial intelligence.

Keywords used in the search included “Artificial Intelligence,” “Endoscopy,” “Gastrointestinal Diseases,” “Image Analysis,” “Lesion Detection,” “Machine Learning,” “Deep Learning,” “Diagnostic Accuracy,” and “Workflow Optimization.” This broad search strategy ensured the inclusion of a wide range of studies related to AI applications in endoscopy.

Inclusion and exclusion criteria

Studies were included in the review if they were published in English and focused on the application of AI in endoscopy, particularly in image analysis, lesion detection, classification, characterization, workflow optimization, and clinical decision support. Studies providing quantitative or qualitative data on the performance, accuracy, or impact of AI technologies in endoscopic practices were also considered. Conversely, studies not related to AI applications in endoscopy, those focusing solely on theoretical aspects without practical applications or empirical data, and opinion pieces, editorials, or non–peer-reviewed articles were excluded. This ensured that the review focused on high-quality, relevant research.

Data extraction and synthesis

From the selected articles, relevant data were extracted, including the type of AI model or tool used, the specific application in endoscopy, key features, performance metrics (such as sensitivity, specificity, and accuracy), and impact on clinical practice. The extracted data were organized into tables and thematic categories to facilitate comparison and synthesis. This methodical approach allowed for a structured analysis of the various AI applications and their effectiveness in enhancing endoscopic procedures.

Evaluation of AI models and tools

The AI models and tools identified in the literature were evaluated based on several criteria. Technical performance was assessed using metrics such as sensitivity, specificity, accuracy, and the area under the receiver operating characteristic curve. These metrics provided insights into the effectiveness of AI in detecting and classifying lesions. Clinical impact was examined by evaluating the influence of AI on diagnostic accuracy, workflow efficiency, and patient outcomes, with particular emphasis on studies providing comparative data between AI-assisted and traditional endoscopic procedures.

Implementation feasibility was also a critical evaluation criterion, considering factors such as ease of integration into existing clinical workflows, user-friendliness, and compatibility with endoscopic equipment. This aspect of the evaluation focused on the practicality of AI systems in real-world clinical settings. Finally, regulatory and ethical considerations were assessed, including compliance with data protection regulations, obtaining necessary regulatory approvals, and addressing ethical concerns related to the use of AI in medical procedures. This comprehensive evaluation framework ensured a thorough understanding of the potential and limitations of AI applications in endoscopy.

AI in image analysis and lesion detection

AI has brought significant advancements to the field of endoscopy, particularly in the areas of image analysis and lesion detection [22]. The application of AI in these areas aims to address the limitations of traditional endoscopic practices, which rely heavily on the endoscopist’s expertise and experience. Variability in diagnostic accuracy and the potential for missed lesions are significant challenges that can affect patient outcomes [23]. AI algorithms, especially those based on deep learning, offer the potential to standardize and enhance the diagnostic process [24]. These algorithms can analyze endoscopic images with remarkable precision, providing real-time assistance and significantly improving the detection and classification of lesions [25]. The integration of AI into endoscopic procedures not only enhances diagnostic accuracy but also optimizes workflow efficiency, reducing the cognitive load on endoscopists and ensuring more consistent and reliable outcomes [26].

Automated image analysis

AI algorithms, particularly deep learning models, have demonstrated remarkable capabilities in analyzing endoscopic images, fundamentally transforming the landscape of GI diagnostics [27]. Convolutional neural networks (CNNs) are at the forefront of these advancements owing to their proficiency in recognizing patterns and features in visual data [28]. CNNs consist of multiple layers that process and learn from vast amounts of data, allowing them to identify complex structures and abnormalities with high accuracy. This capability is particularly beneficial in endoscopy, in which the identification of subtle lesions can significantly affect patient outcomes [28, 29].

Polyp detection

One of the most significant applications of AI in endoscopy is the early and accurate detection of polyps during colonoscopy, a critical factor in preventing colorectal cancer [30]. Colorectal cancer is one of the leading causes of cancer-related deaths worldwide, and early detection through polyp identification is essential for effective prevention and treatment [31]. AI models trained on large datasets of annotated endoscopic images have shown exceptional performance in detecting polyps [27]. These models can identify polyps with high sensitivity and specificity, often surpassing the detection rates of human endoscopists [32]. For instance, AI systems such as GI Genius can detect polyps with high sensitivity and specificity, significantly reducing the miss rate during colonoscopy. These systems increase the adenoma detection rate, highlighting the potential of AI to enhance the efficacy of colorectal cancer screening programs [33]. These findings underscore the potential of AI to serve as a powerful tool in improving early detection and, consequently, patient outcomes in colorectal cancer prevention [34].

Tumor identification

Beyond polyp detection, AI can significantly aid in the detection and classification of tumors in various parts of the GI tract [35]. Accurate differentiation between benign and malignant lesions is crucial for appropriate clinical management and treatment planning [36]. AI systems can analyze endoscopic images to identify tumors and classify them based on their visual characteristics, such as texture, morphology, and color patterns. AI algorithms have demonstrated high accuracy in differentiating between benign and malignant lesions [37]. For example, AI systems can achieve high accuracy in identifying early gastric cancer and esophageal squamous cell carcinoma, providing critical support for endoscopists in making timely and accurate diagnoses [38]. These results highlight the potential of AI to enhance the accuracy of cancer diagnoses, enabling more timely and appropriate interventions.

Real-time assistance

AI’s role in endoscopy extends beyond postprocedural analysis to providing real-time assistance during endoscopic procedures [39]. Real-time AI systems can analyze live endoscopic video feeds, alerting endoscopists to potential abnormalities that might be missed during manual inspection [40]. This real-time feedback is invaluable in enhancing diagnostic accuracy and reducing the likelihood of missed lesions [41]. For instance, a real-time AI system can continuously monitor the endoscopic video, identifying suspicious

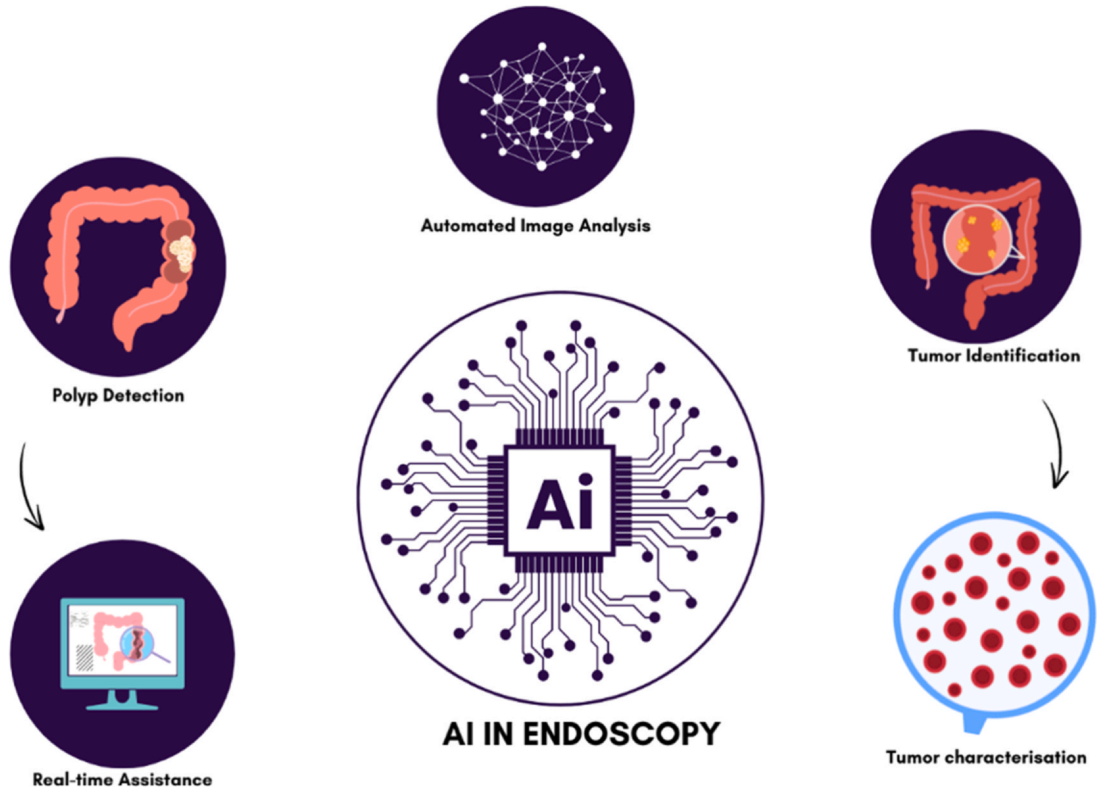

Figure 2. An overview of the application of AI in endoscopy. AI, artificial intelligence.

areas and flagging them for closer inspection by the endoscopist [42]. This functionality is particularly beneficial in detecting small or flat lesions that are easily overlooked. Real-time AI assistance can significantly improve lesion detection rates, demonstrating the impact of AI on enhancing the thoroughness of endoscopic examinations [43]. Moreover, real-time AI systems can provide consistent performance throughout the procedure, unaffected by the fatigue or cognitive load that can affect human endoscopists [44]. This consistency ensures that the quality of the examination remains high, potentially leading to better patient outcomes. In summary, the integration of AI into endoscopy, particularly through advanced image analysis and real-time assistance, holds great promise for improving diagnostic accuracy and efficiency, as shown in Fig. 2 below.

By leveraging the capabilities of deep learning models such as CNNs, AI can enhance the detection and classification of polyps and tumors, providing invaluable support to endoscopists. These advancements not only improve the quality of endoscopic procedures but also have the potential to significantly affect patient outcomes, particularly in the early detection and treatment of GI cancers.

A comprehensive overview of specific AI models and tools used in image analysis and lesion detection in endoscopy, along with their descriptions, key features, and impact on diagnostic accuracy, is presented in Table 1 [45–50].

AI in classification and characterization

AI not only detects abnormalities but also classifies and characterizes them, providing a deeper level of analysis that is crucial for appropriate clinical decision making. This involves differentiating among various types of lesions, such as adenomas, hyperplastic polyps, and invasive carcinomas [51]. Advanced AI models can analyze the texture, morphology, and other features of lesions with remarkable precision, enabling more accurate and reliable classifications [52]. The differentiation of various types of lesions is a critical component of endoscopic diagnostics [53]. For example, distinguishing between adenomatous polyps, which have a higher risk of progressing to colorectal cancer, and hyperplastic polyps, which are typically benign, is essential for determining the appropriate clinical management and follow-up strategies [54]. AI systems can be trained using large datasets of labeled images to recognize the subtle differences in appearance that differentiate these lesions. By analyzing features such as size, shape, color, and surface patterns, AI models can provide accurate classifications that inform treatment decisions [55].

In addition to differentiating between benign and malignant lesions, AI can characterize the specific type and stage of tumors [56]. For instance, in the case of gastric and esophageal cancers, AI models can assess features such as the depth of invasion and the presence of lymphovascular invasion, which are critical for staging the disease and planning treatment [57]. These characterizations are based on the detailed analysis of image data, leveraging machine learning techniques to identify patterns and markers that may be invisible to the human eye [48]. By providing precise classifications and characterizations, AI enhances clinical decision support in endoscopy. For instance, AI can help determine whether a lesion should be biopsied, resected, or simply monitored [58]. This capability reduces uncertainty and variability in clinical practice, ensuring that patients receive the most appropriate care based on the specific characteristics of their lesions.

A comprehensive overview of specific AI models and tools used in classification and characterization in endoscopy, along with their descriptions, key features, and impact on clinical decision making, is presented in Table 2 [45,46,59–62].

Implementation challenges and technical considerations

Although AI holds great promise for enhancing endoscopic procedures, several implementation challenges and technical considerations must be overcome. By addressing issues related to data quality and quantity, ensuring seamless integration into clinical practice, and navigating regulatory and ethical considerations, the

Table 1
AI in image analysis and lesion detection.

Application	AI model/tool	Description	Key features	Impact on diagnostic accuracy
Polyp detection	GI Genius [45]	Real-time polyp detection system that highlights polyps during colonoscopy with high sensitivity and specificity	High sensitivity, real-time detection, reduces miss rates	Significantly improves polyp detection rates, reducing interval cancers
	EndoBRAIN [46]	AI tool that uses deep learning to detect colorectal polyps, enhancing adenoma detection rates	Enhanced adenoma detection rate, deep learning-based analysis	Increases adenoma detection rate, reducing the likelihood of missed lesions
Tumor identification	CNN Model for Gastric Cancer [47]	Convolutional neural network trained to identify early gastric cancer with high accuracy	High accuracy in early gastric cancer detection, deep learning model	Improves early detection and diagnosis of gastric cancer, aiding timely intervention
	AI for Esophageal SCC [48]	AI model designed to detect esophageal SCC, providing high sensitivity and specificity	High sensitivity and specificity, identifies esophageal SCC	Enhances detection of esophageal cancer, enabling appropriate clinical management
Real-time assistance	EndoAid [49]	Real-time AI system that monitors endoscopic video feeds and alerts endoscopists to potential abnormalities	Continuous monitoring, real-time alerts, improves diagnostic accuracy	Improves thoroughness of examinations, reduces missed lesions
	WISE VISION [50]	AI system providing real-time analysis and feedback, helping in the detection of small or flat lesions during endoscopy	Real-time feedback, detects small or flat lesions, consistent performance	Ensures high-quality examinations, potentially better patient outcomes

AI, artificial intelligence; SCC, squamous cell carcinoma.

Table 2
AI in classification and characterization.

Application	AI model/tool	Description	Key features	Impact on clinical decision making
Lesion differentiation	CAD-EYE [59]	AI tool designed to differentiate between adenomatous and hyperplastic polyps during colonoscopy	High accuracy in differentiating polyp types, real-time analysis	Improves accuracy in identifying adenomatous polyps, aiding prevention strategies
	EndoBRAIN [46]	Deep learning-based system for differentiating various types of colorectal polyps with high accuracy	Advanced deep learning algorithms, enhanced polyp classification	Enhances polyp classification, informs appropriate clinical management
Tumor characterization	GastroNet [60]	AI model used for characterizing gastric tumors, assessing features such as invasion depth and staging	Detailed characterization of gastric tumors, staging information	Provides accurate tumor staging, aiding in treatment planning
	ENDOANGEL [61]	AI system for characterizing esophageal cancers, evaluating tumor stage and presence of lymphovascular invasion	Characterizes esophageal cancers, assesses critical pathological features	Improves detection and staging of esophageal cancer, guides treatment decisions
	De Lange AI System [62]	AI for characterization of colorectal polyps in prospective multicenter study	Enhanced polyp characterization, multicenter validation	Provides robust polyp characterization across different clinical settings
Clinical decision support	GI Genius [45]	AI system providing decision support by suggesting biopsy or resection based on lesion classification	Real-time clinical decision support, reduces diagnostic uncertainty	Supports endoscopists in making biopsy and treatment decisions, enhances diagnostic confidence
	Medtronic AI platform	Platform that integrates AI analysis for lesion classification and offers treatment recommendations	Integrated platform, combines lesion classification with treatment recommendations	Offers comprehensive decision support, improves treatment planning and patient outcomes

AI, artificial intelligence.

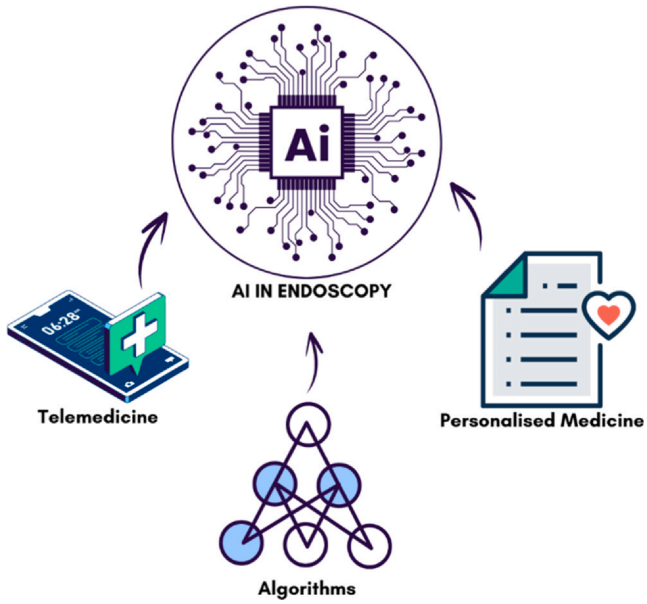

Figure 3. Integration of AI in endoscopy and its applications in a broader perspective. AI, artificial intelligence.

healthcare industry can harness the potential of AI to improve patient outcomes and the efficiency of endoscopic procedures [63].

Data quality and quantity

One of the primary challenges in developing effective AI models for endoscopy is the availability of high-quality, annotated datasets [64]. Training AI algorithms requires large amounts of data that accurately represent the variations seen in clinical practice [65]. However, acquiring such datasets is often difficult owing to several factors. Creating annotated datasets involves extensive manual work by expert endoscopists to label images and videos, which is time consuming and costly. The lack of sufficient annotated data limits the ability to train robust AI models [66]. In addition, endoscopic images can vary significantly in quality owing to differences in equipment, lighting, and operator technique [67]. These variations can affect the performance of AI models, given that algorithms trained on high-quality images may not perform well on lower-quality images commonly encountered in practice [68]. Addressing these data-related challenges requires collaborative efforts to create large, standardized, and annotated datasets [69]. Initiatives to share data across institutions and the development of sophisticated data augmentation techniques can help mitigate these issues.

Integration with clinical practice

Integrating AI systems into existing clinical workflows without disrupting standard practices is another significant challenge [70]. Several factors contribute to this difficulty. AI tools must be intuitive and easy to use for endoscopists, who may have varying levels of comfort and experience with new technologies. Complex interfaces or workflows can hinder adoption and reduce the perceived value of AI tools [71]. Furthermore, AI systems need to be compatible with a wide range of endoscopic equipment used in different healthcare settings [14]. Ensuring seamless integration with various hardware and software platforms is essential for widespread use. Endoscopists and other healthcare professionals require training to effectively use AI tools [72]. Ongoing technical support is also crucial to address any issues that arise and ensure that AI systems are used to their full potential. Successful integration of AI into clinical practice involves designing user-friendly interfaces, ensuring compatibility with existing equipment, and providing comprehensive training and support to healthcare providers [16].

Regulatory and ethical considerations

The use of AI in medical procedures raises several regulatory and ethical concerns that must be addressed to ensure safe and effective implementation. Protecting patient privacy and ensuring the security of medical data are paramount [73]. AI systems must comply with strict data protection regulations, such as the General Data Protection Regulation in Europe and the Health Insurance Portability and Accountability Act in the United States. Robust measures must be in place to prevent data breaches and unauthorized access [74]. AI tools for medical use must obtain regulatory approvals from relevant authorities, such as the U.S. Food and Drug Administration or the European Medicines Agency [75]. The approval process can be lengthy and complex, involving rigorous testing and validation to demonstrate safety and efficacy. Ensuring that AI is used ethically in endoscopy involves addressing potential biases in AI algorithms, maintaining transparency in AI decision-making processes, and safeguarding against the misuse of AI [76]. It is crucial to develop guidelines and frameworks to govern the ethical use of AI in healthcare [77]. To address these regulatory and ethical challenges, continuous dialogue among developers, clinicians, regulatory bodies, and ethicists is necessary. Establishing clear regulations and ethical standards will help build trust in AI technologies and facilitate their adoption in clinical practice.

Future directions

The future of AI in endoscopy shows considerable promise, with significant advancements in algorithms, personalized medicine, and telemedicine on the horizon [78]. These developments may enhance endoscopic practice, making it more accurate, efficient (see Fig. 3 for better illustration), and accessible [10]. As AI continues to evolve, it could play an increasingly important role in improving patient outcomes and advancing the field of gastroenterology [79]. The ongoing collaboration among clinicians, researchers, and technologists will be essential to fully harness the potential of AI and bring these future directions to fruition.

An overview of the integration of AI in endoscopy and its applications in a broader perspective is shown in Fig. 3. AI in endoscopy leverages advanced algorithms to enhance diagnostic capabilities and is connected to applications in telemedicine and personalized medicine. This combination aims to improve patient outcomes and streamline healthcare delivery.

Advanced algorithms

Continued advancements in AI algorithms, particularly in areas such as reinforcement learning and unsupervised learning, could further enhance the capabilities of AI in endoscopy. Reinforcement learning, which involves training algorithms through trial and error to optimize decision making, could improve the precision of endoscopic procedures by continuously learning from new data and adapting to complex clinical scenarios [80]. Unsupervised learning, which identifies patterns in data without prelabeled outcomes, could be instrumental in discovering new biomarkers and understanding disease mechanisms, thus aiding in early detection and diagnosis [81]. These advanced algorithms could lead to more accurate, efficient, and adaptable AI systems, capable of providing even greater support to endoscopists in real time.

Personalized medicine

AI could play a significant role in personalized medicine by tailoring endoscopic procedures and treatments to individual patient profiles based on genetic, phenotypic, and clinical data. By integrating AI with genomic data and electronic health records, it is possible to develop highly personalized diagnostic and therapeutic strategies [82]. For example, AI can analyze a patient's genetic predisposition to certain GI diseases and suggest targeted surveillance and intervention protocols. Personalized AI models could also predict patient-specific responses to treatments, enabling more precise and effective management of conditions such as inflammatory bowel disease or colorectal cancer. This move toward personalized medicine promises to enhance patient outcomes by providing customized care that addresses the unique needs of each individual.

Telemedicine and remote diagnosis

AI-powered endoscopic systems could enable remote diagnosis and consultations, expanding access to specialized care, especially in underserved regions [83]. Telemedicine, supported by AI, can facilitate real-time analysis of endoscopic images and videos from remote locations, allowing expert endoscopists to provide guidance and second opinions without the need for a physical presence [84]. This capability is particularly valuable in rural or low-resource settings in which access to specialized medical care is limited. AI-driven remote diagnosis can also play a critical role in global health by providing scalable solutions to address disparities in healthcare access [85]. By leveraging AI and telemedicine, healthcare providers can ensure that patients receive timely and accurate diagnoses, regardless of their geographical location.

Limitations of the review

This narrative review has several limitations that should be acknowledged when interpreting the findings. First, as a narrative rather than a systematic review, the study selection process was less rigorous than would be used in a formal systematic review or meta-analysis. Although a comprehensive search strategy was used across multiple databases, the absence of a standardized protocol for study selection and quality assessment may have introduced selection bias and limited the reproducibility of the findings.

The heterogeneity of AI applications and technologies reviewed presents another significant limitation. The included studies used diverse AI models, ranging from CNNs to machine learning algorithms, applied across different endoscopic procedures and patient populations. This diversity makes direct comparison of results challenging and limits the ability to draw definitive conclusions about the overall effectiveness of AI in endoscopy.

The rapidly evolving nature of AI technology means that some findings may become outdated quickly, particularly given the review's inclusion of studies from 2010 onward. More recent developments in AI may not be fully captured, and the technological landscape continues to advance at an unprecedented pace.

Publication bias represents another potential limitation, given that studies demonstrating positive outcomes for AI applications are more likely to be published than those showing neutral or negative results. This bias may lead to an overly optimistic portrayal of AI's effectiveness in endoscopic practice.

The review's focus on English-language publications may have excluded relevant research published in other languages, potentially limiting the global perspective on AI applications in endoscopy. In addition, many of the studies reviewed were conducted in controlled research environments, and their findings may not translate directly to real-world clinical settings in which factors such as equipment variability, operator experience, and patient complexity can significantly affect outcomes.

The lack of standardized outcome measures across studies further complicates the interpretation of results. Different studies used varying metrics for assessing AI performance, making it difficult to establish consistent benchmarks for success.

Finally, the review did not assess the cost-effectiveness of AI implementation, which is a crucial consideration for healthcare systems contemplating the adoption of these technologies. Economic evaluations would provide valuable insights into the practical feasibility of widespread AI integration in endoscopic practice.

Conclusion

AI shows significant potential to enhance endoscopy by improving diagnostic accuracy, procedural efficiency, and patient outcomes. Through the application of advanced algorithms, AI enhances the detection and classification of GI lesions, offering real-time assistance that can mitigate the limitations of human observation. This promising technology not only aids in early and accurate diagnosis but also optimizes endoscopic workflows, reducing procedure times and administrative burdens. However, several challenges and limitations must be addressed to fully realize AI's potential in endoscopy. High-quality, annotated datasets are crucial for training robust AI models, and the scarcity of such data remains a significant hurdle. In addition, seamlessly integrating AI systems into existing clinical workflows without disrupting standard practices requires the development of user-friendly interfaces and ensuring compatibility with diverse endoscopic equipment. Regulatory and ethical considerations, including patient privacy, data security, and obtaining necessary approvals, are critical for the safe and effective implementation of AI in clinical settings.

An important limitation of current evidence is the predominance of industry-sponsored studies and controlled research environments, which may not fully represent real-world clinical performance. The reliance on "directed studies" rather than independent, real-world data necessitates cautious interpretation of current findings and emphasizes the need for more robust, unbiased validation studies.

Despite these challenges, the future of AI in endoscopy seems promising. Ongoing research and development in AI technologies, coupled with efforts to address regulatory and ethical concerns, may facilitate the successful integration of AI into endoscopic practice. Advanced algorithms, personalized medicine, and telemedicine represent significant future directions that could further enhance the capabilities and reach of AI in endoscopy. The continued collaboration among clinicians, researchers, and technologists is essential to harness the potential of AI. By working together, these stakeholders can ensure that AI technologies are developed, validated, and implemented in ways that maximize their benefits while minimizing risks. As AI continues to evolve, it may play an increasingly important role in advancing the field of endoscopy, potentially leading to improved patient care and outcomes while requiring careful consideration of current limitations and the need for more comprehensive real-world evidence.

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Declaration of competing interest

The authors declare no competing interests.

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