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Advances in Artificial Intelligence for Polyp Detection: A Comprehensive Review

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Abstract

The increasing worldwide prevalence of colorectal cancer (CRC) emphasizes how urgently precancerous polyps must be found by regular colonoscopy. But for reasons including size, form, and visibility restrictions, even experienced endoscopists sometimes miss polyps. Using deep learning and convolutional neural networks (CNNs), artificial intelligence (AI) has become a transforming solution helping in real-time polyp detection with amazing sensitivity and accuracy. Focusing on the ability of AI-based systems to improve Adenoma identification Rates (ADR) and lower polyp miss rates, especially for difficult small or flat polyps, this article offers a thorough examination of recent AI breakthroughs in polyp identification. Important research show that by raising diagnosis accuracy and lowering endoscopist fatigue, artificial intelligence could enhance clinical practice. We also look at the pragmatic issues linked to introducing artificial intelligence systems into colonoscopy procedures including ethical, legal, and data-related ones. Looking ahead, developments in tailored detection technologies and ongoing improvement of AI algorithms present exciting paths to enhance outcomes in CRC prevention. This paper emphasizes how important artificial intelligence is in raising polyp detection standards and determining the direction of endoscopic medicine.

Keywords: Polyp detection, CNN, Colorectal cancer (CRC), Artificial intelligence. Machine learning .

1. Introduction

One of the main causes of cancer-related morbidity and death globally, colorectal cancer is clearly seen to be much improved by early identification and removal of precancerous polyps [1]. Little, aberrant growths mostly found in the colon, polyps act as early indicators of colorectal cancer. Accurate identification and diagnosis of polyps is absolutely important since missed or delayed diagnosis can cause disease to advance [2]. Traditional detection techniques, such eye examination during colonoscopy or analysis of endoscopic images, however, provide difficulties because of great diversity in polyp appearance, operator dependency, and sensitivity to human error, xaresulting in either possible oversight or false-negative results [3].

Artificial intelligence (AI) integration in medical imaging has attracted great attention as a potential fix for these problems [4]. Recent developments in artificial intelligence particularly in the fields of machine learning (ML) and deep learning (DL) provide creative means to improve polyp detection accuracy. Offering significant benefits over conventional diagnostic methods, convolutional neural networks (CNNs), a deep learning framework especially suited for image identification, have been vital in automating the detection of polyps [5]. Even in cases of minor lesions or low-quality imagery, when human identification could fail, CNN-based models have shown the capacity to precisely separate polyps from surrounding tissue in endoscopic images [6]. Beyond CNNs, other artificial intelligence techniques, such as transfer learning, region-based networks, and hybrid model architectures-further improve detection skills, therefore enabling automated systems to generalize effectively across many patient groups and imaging situations [7].With an emphasis on the approaches, algorithms, and model architectures most influential in recent research, this review paper offers a thorough analysis of the most current artificial intelligence methods applied to automated polyp diagnosis. We investigate the technological underpinnings of several artificial intelligence models and contrast their performance throughout many datasets, imaging environments, and clinical scenarios. Though artificial intelligence has transforming power in this field, problems still exist. Widespread clinical use is greatly hampered by problems like model interpretability, variability in imaging equipment, anatomical variations unique to patients, and the necessity for large annotated datasets. This review highlights these difficulties, explores possible approaches to solve them, and suggests directions for next studies meant to improve AI techniques and their application in healthcare environments.

2. AI Methodologies for Polyp Detection

AI Methodologies for Polyp Detection refer to the diverse techniques and approaches in AI used to identify and analyze polyps in medical imaging, particularly in endoscopic procedures [8]. These methodologies leverage advanced algorithms, particularly in the field of machine learning and deep learning, to automate and improve the accuracy of detecting polyps—abnormal growths in the colon or rectum that can potentially lead to colorectal cancer.

The methodologies encompass various aspects such as image processing, real-time video analysis, and predictive modeling to assist clinicians in identifying polyps more effectively.

2.1 Deep Learning in Medical Imaging

In medical imaging, particularly within gastroenterology, the early detection of colorectal polyps is crucial for preventing colorectal cancer; thus, polyp detection has significantly advanced with the application of deep learning [9]. Although traditional colonoscopy is effective,

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it is limited by endoscopist tiredness, visual limitations, and human error, potentially leading to missed polyps, especially small or flat ones [10]. Deep learning methodologies, especially CNNs, have shown promise in addressing these limitations by improving the precision and dependability of colonoscopy procedures, as shown in figure1.

CNNs acquire intricate characteristics associated with various polyp kinds by training on extensive labeled datasets of colonoscopy images or videos for polyp detection [11]. Once trained, these programs assess photos in real-time to detect subtle polyp characteristics, including texture, color variations, and structural irregularities that may be challenging for human observers to consistently identify. Minimizing undetected polyps that may progress to cancer would enhance this automated, real-time capability to elevate ADR, a critical measure of colonoscopy efficacy [12].

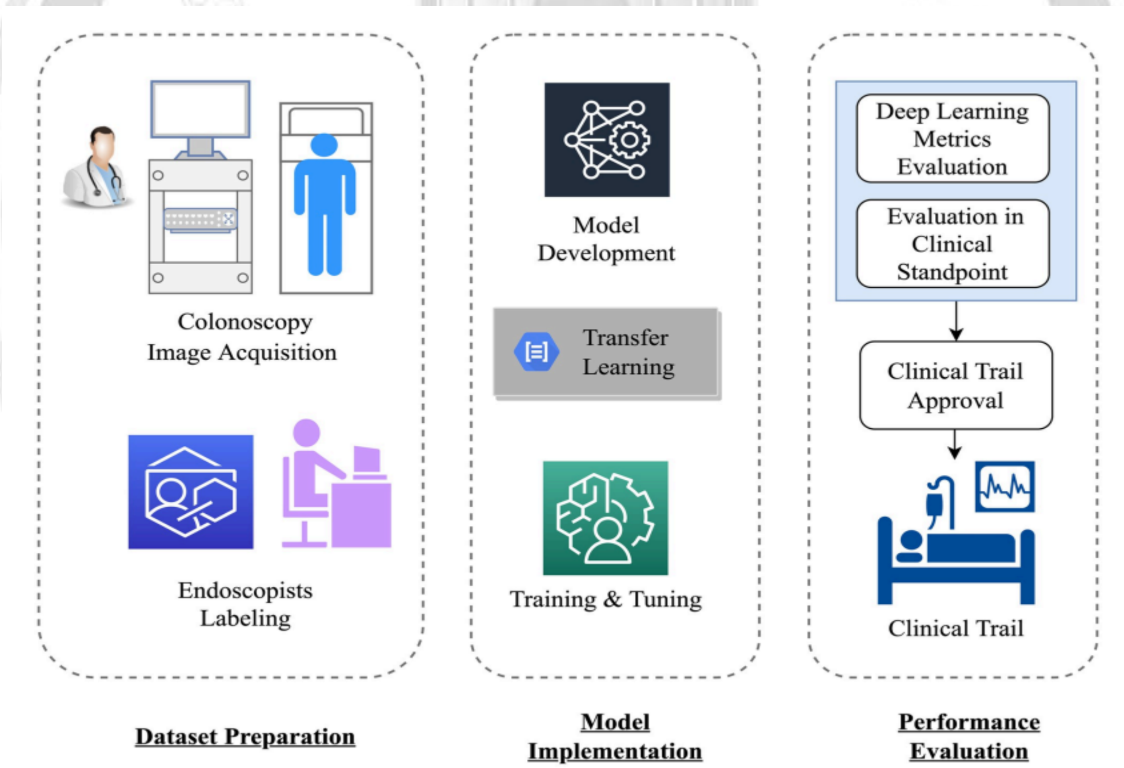

Fig.1. Overall of deep learning based polyp detection

Studies on polyp identification suggest that deep learning based algorithms have rather great sensitivity and specificity. Since real time AI can raise ADR by 30% or more over more conventional techniques, it aids colonoscopy to detect precancerous lesions. This has important consequences for clinical practice since lower frequency of interval cancers, which arise between consecutive tests, is linked with higher ADR. Early stage polyp detection using deep learning

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algorithms also promotes preventative treatment strategies, therefore reducing the general morbidity and death linked with colon cancer [13].

Particularly, deep learning into polyp recognition provides practical advantages for doctors, especially by lowering the cognitive burden and variability across endoscopists with different degrees of experience. Regularly pointing up concerning areas, AI driven algorithms free endoscopists to focus on intervention and decision making [14]. Notwithstanding these advances, challenges still exist including the need for large, diverse datasets to adequately train models and ensure model generalizability across several patient demographics and imaging equipment [15]. Deep learning algorithms' "black box" character, which can lack openness in how certain detections are achieved a vital component in gaining clinician confidence adds still another challenge. We summarize some of studies that discuses using Deep Learning techniques in table1.

Table.1 some of studies using Deep Learning techniques

Study	Title	Participants	Method	Results	Conclusion
Wang et al. (2019)[16]	Real-time automatic detection system increases colonoscopic polyp and adenoma detection rates: a prospective randomized controlled study	1058 patients undergoing colonoscopy	Randomized controlled trial comparing AI-assisted and standard colonoscopy	ADR increased by 30% (29.1% in AI vs. 20.3% in control); higher PDR in AI-assisted group	AI-assisted colonoscopy significantly improves detection rates of adenomas and polyps, aiding in CRC prevention
Urban et al. (2018)[17]	Deep Learning Localization of Polyps in Colonoscopy Videos	Colonoscopy video analysis	Real-time CNN-based system for polyp localization	Sensitivity: 94%; Specificity: 88%; Overall accuracy comparable to expert endoscopists	CNN-based AI can localize polyps with high accuracy, enhancing real-time support for endoscopists
Misawa et al. (2018)[18]	Development of a computer-aided detection system for colonoscopy and a publicly available large colonoscopy	Large colonoscopy video dataset	Computer-aided detection system based on deep learning algorithms	Improved polyp detection rate by ~20%; reduced miss rate for polyps <5mm	CAD system improves detection of small polyps, showcasing deep learning's role in enhancing

	video database (ACE)				colonoscopy outcomes
Repici et al. (2020)[19]	Artificial intelligence-based detection of colorectal neoplasia in a multicenter, randomized trial (the AID trial)	700 patients across multiple centers	Comparison of AI-assisted and standard colonoscopy	ADR was 54.8% in AI group vs. 40.4% in control; higher detection of advanced adenomas	AI-based systems significantly increase ADR and advanced adenoma detection, critical for early cancer prevention
Haitao et al. (2023)	The investigation of constraints in implementing robust AI colorectal polyp detection for sustainable healthcare system	CVC-ColonDB, Kvasir-SEG dataset	YOLOv5 object detection model	The model achieved an improvement of 15.6% in average precision which Precision 0.81 and Recall 0.656	The integration of clinical feedback with computational metrics is essential for aligning AI tools with practical medical applications
Ahmed et al. (2024)[20]	Automated Detection of Colorectal Polyp Utilizing Deep Learning Methods With Explainable AI	The study utilized colonoscopy image datasets, involving a variety of cases with different polyp characteristics	convolutional neural networks (CNNs), integrated with explainable AI (XAI) techniques	high detection accuracy precision (0.946), recall (0.771), F1-score (0.85)	This study highlights the effectiveness of combining deep learning with explainable AI to enhance colorectal polyp detection

Table.1 provides a comprehensive overview of advancements in AI and CAD systems for colorectal polyp detection, highlighting various methods, results, and their implications for clinical practice. Wang et al. (2019) demonstrated the effectiveness of AI-assisted colonoscopy, showing a significant 30% increase in adenoma detection rates (ADR) and improved polyp detection rates (PDR) compared to standard colonoscopy. This underscores the potential of AI in enhancing CRC prevention through better diagnostic accuracy.

Urban et al. (2018) explored the use of CNN-based models for real-time polyp localization, achieving high sensitivity (94%) and specificity (98%), comparable to expert endoscopists. Their findings emphasize the potential of deep learning to support endoscopic workflows in real-time. Similarly, Misawa et al. (2018) focused on CAD systems with deep learning, demonstrating a 20% improvement in polyp detection rates and reduced oversight of small polyps (<5mm), further validating AI's role in improving diagnostic outcomes.

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In multicenter trials, Repici et al. (2020) showed that AI-assisted colonoscopy significantly increased ADR (54.8%) compared to standard methods (40.4%), proving the efficacy/ of AI in identifying advanced adenomas crucial for early cancer prevention.+ Haitao et al. (2023) employed YOLOv5 models, achieving notable improvements in precision (0.81) and recall (0.656), with a 15.6% increase in average precision. Their study highlighted the importance of integrating clinical feedback with computational metrics to align AI tools with practical healthcare needs.

Finally, Ahmed et al. (2024) integrated Explainable AI (XAI) techniques with CNNs, achieving high detection accuracy (precision: 0.946, recall: 0.771, F1-score: 0.85). This study emphasized the value of explainability in building trust in AI systems for clinical applications. Collectively, these studies demonstrate that AI, especially deep learning, significantly enhances colorectal polyp detection accuracy and efficiency. However, challenges remain in real-time integration, scalability, and ensuring alignment with clinical needs, making future research in interpretable and resource-efficient AI critical.

2.2 Computer-Aided Detection (CAD) Systems

To help radiologists and other medical professionals find anomalies in medical pictures, computer-aided detection (CAD) systems combine cutting-edge image analysis algorithms including deep learning techniques that By indicating possible areas of concern, CAD systems are meant to increase diagnosis accuracy and save time and effort needed to analyze medical pictures. Working with endoscopists, CAD systems scan colonoscopy images for polyps, therefore alerting the doctor to probable adenomas or precancerous lesions that could otherwise be missed.

Usually featuring several components, CAD systems include picture pre-processing, feature extraction, and anomaly detection. Deep learning more especially, CNNs is now included into many CAD systems to increase their adaptability and precision. Studies have shown that, particularly in cases of smaller or less obvious polyps—often disregarded-CAD systems can greatly raise polyp detection rates [21]. In hectic clinical environments, CAD systems have shown very helpful in helping doctors reduce diagnostic discrepancies, enhance early cancer detection outcomes, and assist in clinical decisions.

CAD systems are effective for simpler, well-defined tasks and in resource-constrained environments, while deep learning offers superior accuracy and adaptability for complex medical imaging tasks. However, the latter comes with higher demands for data, computation, and trust-building measures such as explainable AI. Both approaches have unique roles depending on the clinical and technical context. We summarize some of studies that discuses using CAD techniques in table 2.

Table.2 some of studies using Computer-Aided Detection (CAD) techniques

Study	Title	Participants	Method	Results	Conclusion
Misawa et al. (2018)[18]	Development of a Computer-Aided Detection System for Colonoscopy and a Publicly Available Large Colonoscopy Video Database (ACE)	Large dataset of colonoscopy videos	CAD system using deep learning for real-time polyp detection	Increased polyp detection rate by 20%; reduced miss rate for polyps <5mm	CAD systems improve polyp detection and reduce oversight of smaller polyps
Repici et al. (2020)[19]	Artificial Intelligence-Based Detection of Colorectal Neoplasia in a Multicenter, Randomized Trial (the AID Trial)	700 patients	Multicenter randomized trial with AI-based CAD vs. standard colonoscopy	AI-assisted CAD group had a 54.8% ADR compared to 40.4% in the control	CAD systems improve ADR, aiding early identification of advanced adenomas
Nazarian, Scarlet, et al (2021)[22]	Diagnostic accuracy of artificial intelligence and computer-aided diagnosis for the detection and characterization of colorectal polyps	Colonoscopy images from multiple institutions	CAD system with hybrid deep learning for polyp classification	Achieved 90% classification accuracy for neoplastic vs. non-neoplastic polyps	CAD systems offer high accuracy in classifying polyps, supporting diagnostic decisions
Guetari1, et al (2023)[23]	Computer-aided diagnosis systems: a comparative study of classical machine learning versus deep learning-based approaches	The study focused on datasets of medical images used in diagnostic processes, evaluating different algorithms for CAD systems	Classical Machine Learning with CAD	CAD achieved a maximum accuracy of 94.28%	The study concluded that the choice between classical and deep learning approaches should depend on the dataset size and available computational resources.

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Table2 shows that deep learning significantly enhances CAD systems, enabling better real-time detection (e.g., Misawa et al. improved detection rates by 20%) and effective classification of neoplastic versus non-neoplastic polyps (Nazarian et al. achieved 90% accuracy). Comparative analysis (Guetari et al.) reveals that classical machine learning methods are effective but limited in scalability, whereas deep learning excels with larger datasets.

However, challenges such as high computational demands, the need for large annotated datasets, and integration into real-time workflows remain. Future research should focus on developing interpretable, cost-effective, and real-time AI systems to maximize their impact on sustainable healthcare systems.

3. Comparative Analysis of AI Systems for Polyp Detection

In terms of polyp and other abnormalities detection, colonoscopy and colorectal cancer screening efficacy are measured in terms of detection rates. Two important measurements taken in this sense are the PDR and the ADR. Both are important indicators of how well colonoscopy detects early precancerous lesions, therefore helping to avoid colorectal cancer.

3.1 Adenoma Detection Rate (ADR)

The proportion of colonoscopy patients in which at least one adenoma a kind of polyp capable of cancer development is identified is known as the ADR. Considered precursors of colorectal cancer, adenomas have to be discovered if we are to stop the cancer. Especially in those undergoing regular examinations, high ADR is associated with lower incidence of colorectal cancer.

A better ADR reveals that the colonoscopist is effectively spotting adenomas during the colonoscopy. ADR is affected by the experience of the endoscopist, bowel preparation quality, modern imaging technologies' use, and artificial intelligence (AI) or computer-aided detection (CAD) system application [24]. The goal in average-risk populations is an ADR of at least 25%–30%; more experienced practitioners or advanced screening techniques are targeted for higher rates (40%–45%).

Studies have demonstrated that enhancing ADR by means of improved training, technology, and procedural quality significantly lowers the risk of interval cancers—cancers identified between screening intervals resulting from missed lesions during past colonoscopies.

3.2 Polyp Detection Rate (PDR)

Regardless of kind e.g., adenomas, hyperplastic, or another type the PDR is another vital statistic indicating the percentage of colonoscopies in which at least one polyp, whatever type, is found. Though not all polyps are precancerous, the diagnosis of any polyp is crucial for estimating the risk of colorectal cancer [25]. Polyps are aberrant growths of different size and type. Since PDR includes all polyps rather than only adenomas, it is sometimes used as a more

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broad measure than ADR. One excellent sign that the colonoscopist is thorough in looking around the colon and spotting possible hazards is a high PDR. Usually depending on the population under study, PDR fluctuates; numbers in normal clinical practice usually range from 20% to 50%. By seeing more lesions which may subsequently be biopsied or removed for additional study increasing PDR can greatly help to prevent colorectal cancer [26].

3.3 The Role of AI in Improving ADR and PDR

By giving doctors real-time help during colonoscopies, artificial intelligence (AI) and CAD systems have demonstrated encouraging results in improving both ADR and PDR. Training on large databases of colonoscopy images, artificial intelligence algorithms-especially convolutional neural networks (CNNs) can automatically identify and highlight worrisome parts of the colon, therefore helping endoscopists to detect both adenomas (to improve ADR) and other polyps (to improve PDR) [27]. By ensuring that polyps, especially small or flat lesions, are not missed, artificial intelligence (AI) can also help lower the variability related with human elements including fatigue and attention span. Studies have shown that AI assisted colonoscopy systems can greatly raise PDR and ADR, therefore facilitating more comprehensive tests and maybe improved patient outcomes [28].

4. Enhancing Polyp Detection in Colonoscopy with AI Assistance

Multi-light technology presents the use of several light wavelengths (e.g., visible, infrared, and near-infrared light) to improve tissue differentiation, so improving the visualization of polyps and other anomalies in the colon, since colonoscopies are sometimes limited by lighting conditions that affect the clarity of images [29]. Even in demanding conditions with limited or inadequate lighting, this technology can greatly increase ADR and PDR when combined with AI-based detection algorithms [30].Multi-light technology allows more accurate and sharper images by enhancing the imaging circumstances, therefore facilitating the detection even minuscule or flat polyps that could otherwise be missed with conventional illumination sources by both human doctors and artificial intelligence algorithms. Using various light wavelengths such as visible light, narrow-band light, and even near-infrared or ultraviolet light Multi-Light Technology improves contrast and reveals unique tissue properties, hence enhancing tumor imaging [31]. Different tissues reflect and absorb light in different ways, so specific wavelengths can draw attention to specific characteristics separating benign from malignant tumors. For instance, narrow-band imaging (NBI) enhances frequently more irregular or denser vascular patterns in malignant tumors by using blue and green wavelengths that pass tissue more effectively. Small, flat, or early-stage tumors that might be missed on conventional imaging are especially well-served by this contrast enhancement. Practically speaking, Multi-Light Technology can be used dynamically during operations like endoscopy to enable real-time changes to grab the finest available pictures of problematic tissue [32]. By offering distinct visual difference without adding extra chemicals into the body, this method lessens the need for intrusive biopsies and contrast dyes. Moreover, the high-contrast images generated are perfect for integration with artificial intelligence systems, which can examine and categorize tumor characteristics, so enhancing the detection accuracy. Multi-Light Technology is a great tool in increasing non-invasive cancer detection and enhancing patient outcomes by supporting earlier

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and more exact diagnosis of both benign and malignant tumors.Comparative Analysis of Multi-Light Technology (MLT) and Artificial Intelligence Against Conventional Colonoscopy Methods. The gold standard for spotting colorectal polyps and avoiding colorectal cancer is a colonoscopy. Mucosal anomalies have been seen better using conventional imaging methods such narrow-band imaging (NBI) and chromoendoscopy (CE) [33]. Still, Multi-Light Technology (MLT) paired with AI has special benefits over these approaches in table.3 demonstrate the difference between these modes.

Table.3. difference between Light mode modes

Feature	Chromoendoscopy (CE)	Narrow-Band Imaging (NBI)	Multi-Light Technology (MLT) with AI
Visualization	Enhanced with dyes for mucosal and lesion detail.	Highlights vascular and mucosal patterns.	Uses multi-wavelength imaging for superior tissue differentiation.
Time Requirement	Time-intensive (dye application and cleanup).	Faster than CE but requires careful focus.	Real-time analysis with AI reduces procedure time.
Operator Dependency	Highly operator-dependent (manual dye application).	Moderate; requires significant training.	Minimal; AI assists in detection and classification.
Detection of Flat/Small Polyps	Improved but depends on dye application and skill.	Limited in some cases (misses faint lesions).	Superior; AI and multi-wavelength data highlight hard-to-detect polyps.
Training Requirement	Extensive training to master dye usage and patterns.	Requires expertise in interpreting vascular patterns.	Minimal training due to AI-guided decision support.
Cost	Relatively low (cost of dyes).	Moderate (specialized endoscopes required).	High; requires advanced hardware and AI integration.
Image Analysis	Manual interpretation.	Visual interpretation of patterns.	Automated and real-time with AI models.
Adaptability to New Settings	Limited adaptability (labor-intensive).	Adaptable but requires advanced equipment.	Scalable with further hardware optimization.
Overall Detection Rates	Improves ADR and PDR modestly in trained hands.	Moderate improvement in ADR and PDR.	Significant improvement in ADR and PDR, especially for subtle lesions.

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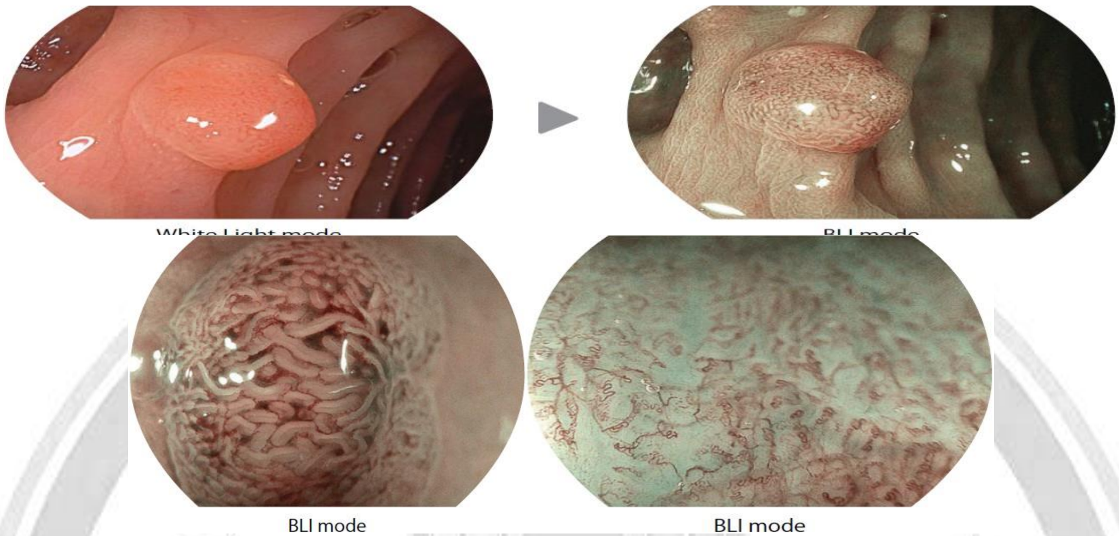

Fig.2. Represent BLI Technology compared with White Light

From figure 2 High contrast images suitable for observing microvascular and microsurface pattern are provided. Magnifying endoscopy is exellent with BLI.

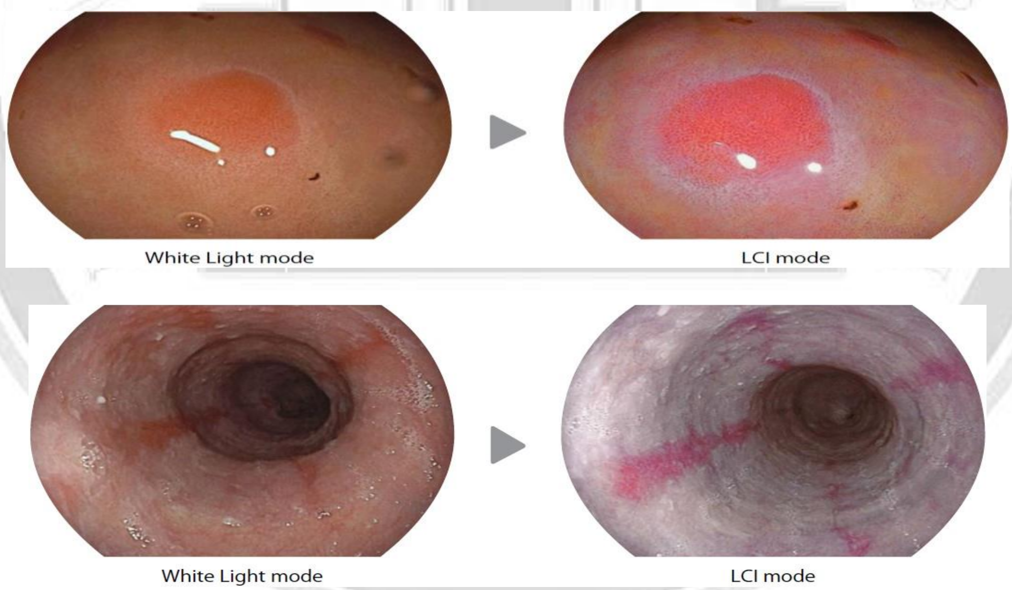

Fig.3. Represent LCI Technology compared with White Light

From figure 3 LCI would be helpful for detection with surface pattern and vessels. Slight color difference is visualized with natural tone, using “Red” component.

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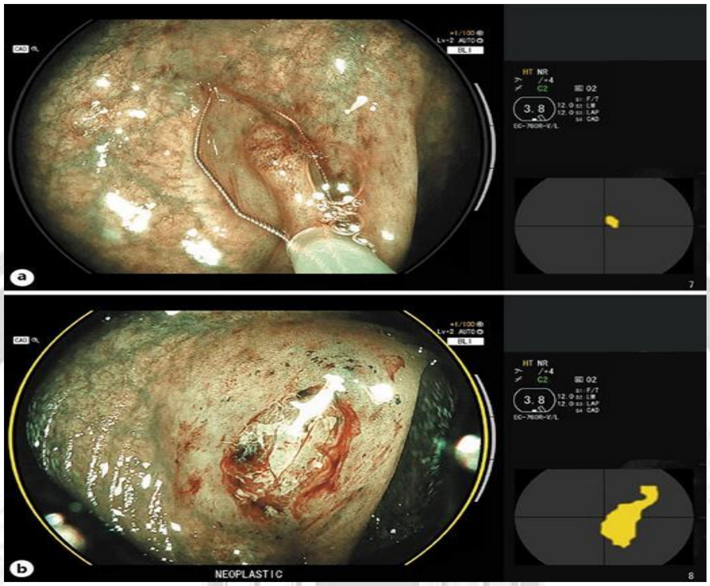

Fig.4. Polyp removal procedure using CADEYE

From figure 4. Its represent how the light technology BLI and LCI improve the detection and the characterization in the polyp detection.

4. Research and Development in Multi-Light Technology and AI for Polyp Detection

Multi-Light Technology (MLT) and Artificial Intelligence (AI) combined in polyp detection mark a convergence of computational creativity with sophisticated imaging. Research in this field aims to improve colorectal cancer screening by using deep learning algorithms and multi-spectral imaging strengths [34].

4.1 Imaging Technology Development

Using several wavelengths of light such as visible, near-infrared, and UV Multi-Light Technology captures minute tissue features. By means of their spectral characteristics, researchers are honing optical devices to produce high-resolution images distinguishing between normal tissue and anomalies, such polyps. Improving imaging depth and accuracy depends critically on developments in light source technology like tuned lasers and LED arrays. These advancements help to better visualize sometimes ignored mild or flat polyps by conventional methods [35].

4.2 AI Algorithm Research

Deep learning models especially CNNs are being enhanced to investigate the various, multi-channel data generated by MLT. These models are taught to identify across numerous light spectrum patterns connected with polyps, including color, texture, and vascular architecture [36]. Efforts are also under progress to improve AI interpretability, thereby helping doctors to understand the algorithmic decision-making process. This transparency builds trust and clinical adoption.

4.3 Dataset Creation and Standardization

To train and validate artificial intelligence models, big annotated datasets of multi-light colonoscopy images are being created. Dealing with data variability, researchers are making sure models generalize effectively over demographics and clinical settings. Projects aiming at standardizing multi-light imaging data collection and labeling techniques guarantee uniformity in AI training and evaluation [37].

4.5 Clinical Trials and Validation

In real-world environments, multi-center clinical studies are assessing the effectiveness of MLT mixed with artificial intelligence. These studies evaluate changes in important benchmarks including procedural efficiency, Polyp Detection Rate (PDR), and Adenoma Detection Rate (ADR) [38].

Researchers are also looking at how these technologies might lower false positives and negatives, important determinants of patient safety and process accuracy.

4.6 Hardware and Integration Development

Designs for small and moderately priced multi-light imaging systems are aimed to permit integration into present colonoscopy instruments. Making these systems scalable and adaptable enough for implementation in different healthcare scenarios, including resource-limited ones, is the key objectives of efforts.

Integration with clinical processes is being strengthened to ensure that MLT and artificial intelligence addition does not cause interruption of current operations [39]. Perfect integration with electronic medical records (EMRs) and user-friendly interfaces come first.

5. Advantages of AI in Polyp Detection

The integration of AI in polyp detection offers several benefits [40]:

- **Increased Detection Rates**: AI systems can continuously analyze colonoscopy images, reducing the likelihood of human error and fatigue.
- **Consistency and Reliability**: AI provides consistent performance, irrespective of the time of day or the endoscopist's experience level.
- **Real-Time Analysis**: AI can provide immediate feedback during colonoscopy procedures, aiding in the prompt identification and removal of polyps.

6. Challenges and Limitations

Despite the potential of combining Multi-Light Technology (MLT) and AI-based systems for polyp detection in colonoscopy, there are several challenges and limitations to consider as demonstrated in table.4. These barriers may affect the adoption, implementation, and efficacy of these technologies in clinical practice [41].

Table.4. the challenge using AI in the polyp detection.

Category	Challenge	Details
Technological Challenges	**Hardware Complexity**	Sophisticated hardware increases size, cost, and complexity of systems.
	Real-Time Integration	Requires powerful computational resources for real-time processing of multi-spectral images.
	Compatibility Issues	Existing endoscopy systems may require significant modifications or upgrades to support Multi-Light Technology.
Data and Algorithm Challenges	**Dataset Diversity**	Limited availability of diverse multi-light imaging datasets for AI training.
	Algorithm Complexity	Handling multi-channel (e.g., visible, infrared) imaging adds complexity to AI development.
	False Positives/Negatives	AI models may misclassify normal tissue or miss small/flat polyps, reducing reliability.
Clinical Challenges	**Training Requirements**	Clinicians need training to interpret multi-light images and effectively use AI systems.
	Acceptance and Trust	Resistance from healthcare professionals to adopt and trust new technologies.
	Procedure Disruption	Initial integration may disrupt workflows, requiring time and adjustments.
Cost and Resource Barriers	**High Implementation Costs**	Multi-light imaging systems and AI algorithms are expensive to develop and maintain.
	Economic Justification	Need to demonstrate cost-effectiveness to justify investment in new technologies.
Ethical and Regulatory Issues	**Data Privacy**	Handling patient data raises privacy concerns and compliance with regulations like GDPR or HIPAA.
	Regulatory Approval	Lengthy and costly approval processes for safety and efficacy certification.
	Bias in AI	Poor performance in underrepresented populations if training datasets are non-diverse.
Performance in Real-World Settings	**Suboptimal Conditions**	Reduced effectiveness in cases of poor bowel preparation, motion artifacts, or challenging anatomy.
	Generalizability	AI models trained in controlled environments may struggle to generalize to diverse clinical settings.

8. Discussion

The integration of AI in the field of colorectal polyp detection has gained significant traction in recent years. As reviewed in this paper, numerous AI and CAD systems have shown promising results in enhancing the sensitivity and specificity of colonoscopy procedures. Through methods like deep learning, convolutional neural networks (CNNs), these systems are poised to revolutionize the early detection of colorectal cancer, particularly by detecting polyps that may be missed by human endoscopists.

One of the key advantages of AI systems is their ability to reduce human error, particularly in identifying smaller polyps that are often overlooked.

However, despite these advancements, there are several challenges that hinder the widespread adoption of AI in clinical settings. First, AI models typically require large, high-quality annotated datasets to achieve reliable performance, which can be difficult to obtain, especially in under-resourced settings. Moreover, the computational demands of deep learning models remain a barrier to real-time clinical deployment. Although AI models like CNNs have demonstrated impressive accuracy in research settings, their application in live clinical environments requires substantial processing power. Another challenge is the integration of AI systems into existing clinical workflows. Even though AI-assisted colonoscopy systems have demonstrated effectiveness, the integration of these tools into routine practice requires careful planning and coordination. Looking forward, the future of AI in colorectal polyp detection seems promising. As AI models continue to improve, the incorporation of hybrid approaches, such as combining AI with human expertise, could further enhance the accuracy and efficiency of CRC screening. Moreover, the development of more efficient models that require less computational power and smaller datasets could increase the accessibility and applicability of these systems across different healthcare settings.

9. Conclusion

This comprehensive review underscores the significant strides AI has made in advancing polyp detection in CRC screening. AI and CAD systems, particularly those utilizing deep learning algorithms such as convolutional neural networks (CNNs), have shown great promise in enhancing diagnostic accuracy, reducing oversight of small polyps, and increasing adenoma detection rates (ADR). Studies reviewed highlight the efficacy of AI-assisted colonoscopy systems in improving detection performance, particularly for challenging polyps, and in identifying advanced adenomas critical for early cancer prevention.

Despite the demonstrated success, challenges persist in ensuring real-time application, data scalability, and integration into clinical workflows. The need for large annotated datasets, computational resources, and the development of explainable AI (XAI) techniques to increase clinical trust are some of the barriers that require ongoing attention. However, the integration of AI systems in medical imaging is an exciting frontier, offering the potential to revolutionize CRC screening, enhance patient outcomes, and streamline healthcare processes.

As AI technologies continue to evolve, future research should focus on creating more efficient, interpretable, and resource-efficient systems while addressing regulatory and ethical concerns. The promise of AI in improving polyp detection is clear, and with continued innovation and collaboration between clinical practitioners and AI researchers, these systems will likely play an increasingly pivotal role in sustainable and effective healthcare delivery.

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التطورات في الذكاء الاصطناعي للكشف عن الأورام الحميدة: مراجعة شاملة

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الخلاصة :

يؤكد الانتشار المتزايد لسرطان القولون والمستقيم على مستوى العالم على مدى ضرورة اكتشاف الزوائد اللحمية قبل السرطانية من خلال تنظير القولون المنتظم. ولكن لأسباب تشمل الحجم والشكل والقيود على الرؤية، يخطئ حتى أطباء التنظير الداخلي ذوي الخبرة في بعض الأحيان في اكتشاف الزوائد اللحمية. باستخدام التعلم العميق والشبكات العصبية التلافيفية، أصبح الذكاء الاصطناعي حلاً تحويليًا يساعد في اكتشاف الزوائد اللحمية في الوقت الفعلي بحساسية ودقة مذهلتين. مع التركيز على قدرة الأنظمة القائمة على الذكاء الاصطناعي على تحسين معدلات تحديد الورم الغدي وخفض معدلات تفويت الزوائد اللحمية، وخاصة بالنسبة للزوائد اللحمية الصغيرة أو المسطحة الصعبة، تقدم هذه المقالة فحصًا شاملاً للاختراقات الحديثة للذكاء الاصطناعي في تحديد الزوائد اللحمية. تُظهر الأبحاث المهمة أنه من خلال زيادة دقة التشخيص وخفض إجهاد أطباء التنظير الداخلي، يمكن للذكاء الاصطناعي أن يعزز الممارسة السريرية. كما ننظر إلى القضايا العملية المرتبطة بإدخال أنظمة الذكاء الاصطناعي في إجراءات تنظير القولون بما في ذلك الأخلاقية والقانونية والمتعلقة بالبيانات. بالنظر إلى المستقبل، تقدم التطورات في تقنيات الكشف المخصصة والتحسين المستمر لخوارزميات الذكاء الاصطناعي مسارات مثيرة لتعزيز النتائج في الوقاية من سرطان القولون والمستقيم. تسلط هذه الورقة البحثية الضوء على مدى أهمية الذكاء الاصطناعي في رفع معايير اكتشاف الأورام الحميدة وتحديد اتجاه الطب التنظيري.

الكلمات الدالة : كشف الاورام الحميدة، CNN، سرطان القولون والمستقيم (CRC)، الذكاء الاصطناعي.