ISSN 2644-3236 (online)

Artificial Intelligence in *Gastroenterology*

Quarterly Volume 5 Number 2 August 8, 2024

Published by Baishideng Publishing Group Inc

Artificial Intelligence in Gastroenterology

Contents

Quarterly Volume 5 Number 2 August 8, 2024

Contents

Artificial Intelligence in Gastroenterology

Quarterly Volume 5 Number 2 August 8, 2024

ABOUT COVER

Editorial Board Member of *Artificial Intelligence in Gastroenterology*, Jan Grosek, MD, PhD, Assistant Professor, Surgeon, Department of Abdominal Surgery, University Medical Centre Ljubljana, Ljubljana 1000, Slovenia. jan.grosek@kclj.si

AIMS AND SCOPE

The primary aim of *Artificial Intelligence in Gastroenterology* (*AIG*, *Artif Intell Gastroenterol*) is to provide scholars and readers from various fields of artificial intelligence in gastroenterology with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

AIG mainly publishes articles reporting research results obtained in the field of artificial intelligence in gastroenterology and covering a wide range of topics, including artificial intelligence in gastrointestinal cancer, liver cancer, pancreatic cancer, hepatitis B, hepatitis C, nonalcoholic fatty liver disease, inflammatory bowel disease, irritable bowel syndrome, and *Helicobacter pylori* infection.

INDEXING/ABSTRACTING

The *AIG* is now abstracted and indexed in Reference Citation Analysis, China Science and Technology Journal Database.

RESPONSIBLE EDITORS FOR THIS ISSUE

Production Editor: *Yu-Qing Zhao*; **Production Department Director:** *Xu Guo*; **Cover Editor:** *Jin-Lei Wang*.

NAME OF JOURNAL
Artificial Intelligence in Gastroenterology

ISSN
ISSN 2644-3236 (online)

LAUNCH DATE
July 28, 2020

FREQUENCY
Quarterly

EDITORS-IN-CHIEF
Rajvinder Singh, Ferruccio Bonino

EDITORIAL BOARD MEMBERS
https://www.wjgnet.com/2644-3236/editorialboard.htm

PUBLICATION DATE
August 8, 2024

INSTRUCTIONS TO AUTHORS
https://www.wjgnet.com/bpg/gerinfo/204

GUIDELINES FOR ETHICS DOCUMENTS
https://www.wjgnet.com/bpg/GerInfo/287

GUIDELINES FOR NON-NATIVE SPEAKERS OF ENGLISH
https://www.wjgnet.com/bpg/gerinfo/240

PUBLICATION ETHICS
https://www.wjgnet.com/bpg/GerInfo/288

PUBLICATION MISCONDUCT
https://www.wjgnet.com/bpg/gerinfo/208

ARTICLE PROCESSING CHARGE
https://www.wjgnet.com/bpg/gerinfo/242

STEPS FOR SUBMITTING MANUSCRIPTS
https://www.wjgnet.com/bpg/GerInfo/239

ONLINE SUBMISSION
https://www.f6publishing.com

Artificial Intelligence in Gastroenterology

Submit a Manuscript: https://www.f6publishing.com

Artif Intell Gastroenterol 2024 August 8; 5(2): 91336

DOI: 10.35712/aig.v5.i2.91336

ISSN 2644-3236 (online)

EDITORIAL

Will artificial intelligence reach any limit in gastroenterology?

Joseph Bou Jaoude, Rose Al Bacha, Bassam Abboud

Specialty type: Gastroenterology and hepatology

Provenance and peer review: Unsolicited article; Externally peer reviewed.

Peer-review model: Single blind

Peer-review report's classification

Scientific Quality: Grade C

Novelty: Grade C

Creativity or Innovation: Grade C

Scientific Significance: Grade C

P-Reviewer: Yu HG, China

Received: December 27, 2023

Revised: April 25, 2024

Accepted: June 7, 2024

Published online: August 8, 2024

Processing time: 225 Days and 1.3 Hours

Joseph Bou Jaoude, Rose Al Bacha, Department of Gastroenterology, Levant Hospital, Beirut 166830, Lebanon

Bassam Abboud, Department of General Surgery, Geitaoui Hospital, Faculty of Medicine, Lebanese University, Lebanon, Beirut 166830, Lebanon

Corresponding author: Bassam Abboud, MD, Professor, Department of General Surgery, Geitaoui Hospital, Faculty of Medicine, Lebanese University, Lebanon, Rmeil, Beirut 166830, Lebanon. dbabboud@yahoo.fr

Abstract

Endoscopy is the cornerstone in the management of digestive diseases. Over the last few decades, technology has played an important role in the development of this field, helping endoscopists in better detecting and characterizing luminal lesions. However, despite ongoing advancements in endoscopic technology, the incidence of missed pre-neoplastic and neoplastic lesions remains high due to the operator-dependent nature of endoscopy and the challenging learning curve associated with new technologies. Artificial intelligence (AI), an operator-independent field, could be an invaluable solution. AI can serve as a "second observer", enhancing the performance of endoscopists in detecting and characterizing luminal lesions. By utilizing deep learning (DL), an innovation within machine learning, AI automatically extracts input features from targeted endoscopic images. DL encompasses both computer-aided detection and computer-aided diagnosis, assisting endoscopists in reducing missed detection rates and predicting the histology of luminal digestive lesions. AI applications in clinical gastrointestinal diseases are continuously expanding and evolving the entire digestive tract. In all published studies, real-time AI assists endoscopists in improving the performance of non-expert gastroenterologists, bringing it to a level comparable to that of experts. The development of DL may be affected by selection biases. Studies have utilized different AI-assisted models, which are heterogeneous. In the future, algorithms need validation through large, randomized trials. Theoretically, AI has no limit to assist endoscopists in increasing the accuracy and the quality of endoscopic exams. However, practically, we still have a long way to go before standardizing our AI models to be accepted and applied by all gastroenterologists.

Key Words: Artificial intelligence; Digestive tract; Gastroenterology; Gastroscopy; Colo-scopy

Core Tip: The field of gastrointestinal endoscopy is an essential tool in the management of digestive diseases. Despite ongoing advancements in endoscopic technology, the incidence of missed pre-neoplastic and neoplastic lesions remains high. This is attributed to the operator-dependent nature of endoscopy, resulting in variability in detection rates and the characterization of lesions among endoscopists. To enhance endoscopic performance, it is imperative to minimize the "cognitive errors" made by the endoscopist. Artificial Intelligence, being operator-independent, could potentially serve as an unlimited solution.

Citation: Bou Jaoude J, Al Bacha R, Abboud B. Will artificial intelligence reach any limit in gastroenterology? *Artif Intell Gastroenterol* 2024; 5(2): 91336
URL: https://www.wjgnet.com/2644-3236/full/v5/i2/91336.htm
DOI: https://dx.doi.org/10.35712/aig.v5.i2.91336

INTRODUCTION

The field of gastrointestinal (GI) endoscopy (GE) is an essential tool in the management of digestive diseases. Technology is essential for the advancement of endoscopy. Presently, white-light endoscopy (WLE) with high resolution stands as the standard technology that enables endoscopists to detect and characterize lesions more accurately. However, despite this, even expert endoscopists can overlook several lesions, including small and flat ones.

To morphologically predict the malignant potential of digestive lesions in real-time, several classification systems have been endorsed by scientific societies. These systems categorize lesions based on morphology (sessile, slightly raised, or excavated) or through a detailed examination of vascular and mucosal patterns using optical image-enhancing technology known as virtual chromo-endoscopy. Consequently, the assessment of invasion depth or lymph node involvement plays a crucial role in clinical decision-making, determining whether the lesion is surgically or endoscopically resectable.

Despite the ongoing development of endoscopic technology, the incidence of missed pre-neoplastic and neoplastic lesions remains high. This is attributed to the operator-dependent nature of endoscopy, resulting in variability in detection rates and the characterization of lesions among endoscopists. The existence of this skills gap can be explained by the extended learning curve associated with adopting new technologies.

To enhance the performance of the endoscopic procedure, it is imperative to minimize the "cognitive errors" made by the endoscopist. Artificial intelligence (AI), being operator-independent, could potentially serve as an unlimited solution.

As endoscopy fundamentally depends on high-quality images, it presents an appealing domain for AI, which comprises computer processes performing complex tasks to simulate the human brain. Alan Turing, one of AI's founders, defined = itas "the ability of a computer to achieve human performance in cognitive tasks". Thus, this concept combined the fields of medical knowledge and machine tools. Deep learning (DL) was innovated as a major transformation of machine learning (ML), allowing machines to learn and make decisions independently. DL automatically extracts input features from targeted images, demonstrating the ability to explore all pixels without experiencing transitory lapses in attention or fatigue. As a result, DL emerges as a promising technology, serving as a reliable "second observer" independent of the endoscopist's performance. DL encompasses two primary tasks: real-time detection or computer-aided detection (CADe) and real-time characterization or computer-aided diagnosis (CADx). Given that navigation software enhances mucosal exposure, CADe assists endoscopists in reducing the miss rate of lesion detection. Simultaneously, CADx aims to predict the histologic and optical diagnosis of pre-neoplastic lesions without the need for biopsy, as well as estimating the depth of invasion in malignant lesions to facilitate optimal therapeutic decision-making.

Moreover, DL can reduce the cost and the procedure time by abandoning random biopsies in favor of targeted ones and avoiding unnecessary resection of non-neoplastic lesions. DL can also evaluate the quality of endoscopic procedures by identifying parameters such as land marks, blind spots, measurement of withdrawal speed and mucosal cleansing assessment, making surveillance protocols more effective.

Thus, AI allows human-machine interaction, transferring expert knowledge to the entire gastroenterological community.

AI APPLICATIONS IN DIAGNOSTIC GE

AI applications in clinical GI diseases are continuously expanding and evolving into new areas. AI is embraced for its robust self-learning capability and unbiased nature. Real-time AI assists endoscopists throughout the entire digestive tract, including the upper, middle, and lower parts, as well as the hepato-biliary tree and pancreatic gland.

LOWER GI TRACT

Colorectal polyps

In the GI field, the primary application of AI involves DL convolution neural network (CNN) models for detecting and diagnosing polyps during colonoscopy.

Detection of colorectal polyps using CADe: It has been established that the removal of pre-neoplastic polyps reduces the risk of colorectal cancer (CRC). However, endoscopy is operator-dependent, and the adenoma detection rate (ADR) varies widely from 7% to 53% among colonoscopists[1] while post-colonoscopy interval CRC constitutes nearly 8% of all diagnosed CRC[2]. The initial application of AI technology in GE was the detection of colorectal polyps, with most research focusing on the management of colorectal polyps. In 2018, Urban *et al*[3]and Misawa *et al*[4] reported the two earliest applications of CADe on video clips. Their algorithms demonstrated an accuracy of ≥90%. In 2019, Wang *et al*[5] conducted the first randomized controlled trial. Since then, numerous prospective randomized controlled trials[6-10], as well as meta-analyses[11], have been published, involving different AI systems and training. Consequently, CADe for polyp detection has been shown to increase the ADR, at least comparable to that assessed by experienced endoscopists, as recommended by the European Society of Gastrointestinal Endoscopy (ESGE) guidelines[12].

Characterization of colorectal polyps using CADx (polyp ≤ 5 mm): According to the current ESGE guidelines, polyps ≤ 5 mm with adenomatous structures need to be removed and sent for histopathological analysis. Diminutive polyps located in the recto-sigmoid, characterized as hyperplastic by virtual chromo-endoscopy, can either be "left in situ" or undergo the "resect and discard" approach. CADx tools, when combined with CADe, can assist endoscopists in real-time colonoscopy by distinguishing between neoplastic (adenoma or serrated) and non-neoplastic (hyperplastic) polyps. Consequently, in the case of non-neoplastic polyps, the "diagnose and leave" strategy reduces the need for polypectomy. Similarly, for neoplastic diminutive polyps, the "resect and discard" strategy minimizes the necessity for histopathological processing. In clinical practice, these two strategies, supported by CADe systems, contribute to reduced costs and procedure time. Indeed, many centers have developed CADx tools with WLE, narrow-band imaging (NBI), and endocystoscopy[13-15]. Their published results align with the parameters outlined by the American Society of Gastrointestinal Endoscopy Preservation and Incorporation of Valuable Endoscopic Innovation (PIVI).

Advanced subtle neoplastic (flat and serrated)

The increased detection of non-advanced adenomas alone cannot reduce the interval CRC. Consequently, developing AI systems to enhance the detection of advanced polyps is now considered a priority, as they pose the highest risk of developing CRC. Most CADx studies lack data about sessile serrated lesions (SSL) and flat polyps. When SSL are des-cribed, the majority is located in the recto-sigmoid and is diminutive. Only one recent prospective study, utilizing video datasets enriched with flat, SSL, and advanced colorectal polyps, evaluated AI performance against endoscopists. The AI-based algorithm achieves high per-polyp sensitivities for the diagnosis of advanced polyps[16].

Malignancy in colorectal polyps

Endoscopists must assess the level of submucosal invasion in T1 CRC without resorting to biopsy to decide whether to perform endoscopic or surgical resection. AI emerges as an ideal tool to offer valuable guidance to endoscopists. Two Japanese AI studies were conducted using CNN algorithms to differentiate between T1a and T1b. The initial study was a randomized one and achieved 94% of accuracy; however, the second one ranged only 81.4% of accuracy[17,18].

Computer-aided quality assessment of colonoscopy technique: AI, functioning as a virtual endoscopist, can complement the expertise of endoscopists in reducing the rate of missed polyps visible on the screen. However, the quality of a colonoscopy procedure relies on additional parameters such as incomplete mucosal exposure, blind spots, withdrawal speed, and the degree of bowel cleansing. Currently, AI is developing new systems to measure these parameters during the procedure, alongside CADe and CADx, to address exposure errors. Consequently, computer-aided quality assessment objectively evaluates the time spent exploring different segments of the colon, the quality of fold examination, and mucosal cleansing[19]. Therefore, in the future, we can objectively determine the quality of colonoscopy for the optimal surveillance protocol of CRC.

UPPER GI TRACT

Esophagus

In a recent multicenter study of upper GI endoscopies, a 6.4% esophageal cancer miss rate was reported[20]. Due to the capability of DL to explore images beyond the reach of the human eye, it has been employed in the analysis of endoscopic images related to esophageal and stomach diseases. Wu *et al*[21] utilized a DL model and demonstrated promising outcomes in the classification and segmentation of individual esophageal lesions. Consequently, several CADe systems have been recently tested in clinical settings.

Precursor lesion of esophageal squamous cell neoplasia: Intrapapillary capillary loops (IPCL) observed through virtual chromoendoscopy (NBI) have been classified as a precancerous lesion of esophageal squamous cell neoplasia (ESCC), correlating with depth invasion. Everson *et al*[22] demonstrated that a DL model was an efficient, accurate, and reliable tool for classifying IPCL patterns as normal or abnormal. In two separate studies, Zhao *et al*[23] and Yuan *et al*[24] compared the accuracy of AI systems to that of endoscopists. AI models significantly enhance the ability of junior endoscopists to diagnose IPCL abnormalities and depth invasion of ESCC.

ESCC: A recent literature review demonstrated high diagnostic accuracy for AI in ESCC[25]. Extensive datasets have supported the overall diagnostic performance of AI for both superficial and advanced esophageal squamous cancer. Numerous studies have indicated that, AI accuracy in detection was comparable to or even higher than that experienced endoscopists[26-28]. In therapeutic decisions for ESCC, which depend on the depth of invasion, Zhang *et al*[29] conducted a multicenter study using an AI-based CADx model that simulated radiologists' diagnoses of lymph node metastasis. The results from AI systems significantly outperformed those of human diagnostics. Additionally, Tokai *et al*[30] published a comparative study between a DL CNN model and endoscopists to determine ESCC depth invasion. The results demonstrated that AI algorithms surpassed the performance of all endoscopists. Given these promising results, AI-assisted diagnostic techniques should be considered for adoption in future clinical practice.

Barrett's esophagus-related neoplasia: It is established that Barrett's esophagus (BE) is a precursor of esophageal adenocarcinoma (EAC). BE represents an exemplary application of AI systems, showcasing their capability in lesion identification and determining the degree of malignancy. Pan *et al*[31] demonstrated the ability of an AI model in identifying and classifying BE according to the Prague classification. To enable endoscopists to successfully detect dysplasia or EAC in BE, several AI studies have achieved high sensitivity, specificity, and accuracy, meeting the parameters outlined by the PIVI[32-35]. Two meta-analyses have reached similar conclusions[36,37].

To choose the optimal treatment, the identification of sub-mucosal invasion of BE-related neoplasia is mandatory. A retrospective multicenter study evaluated the performance of DL algorithms in discriminating between T1a and T1b cancer[38]. The AI model demonstrated comparable performance to experienced endoscopists.

Stomach

Gastric precancerous lesions: *Helicobacter pylori* (HP) infection can produce chronic atrophic gastritis (CAG) and gastric intestinal metaplasia (GIM). CAG and GIM are precancerous lesions associated with an increased risk of gastric cancer (GC) development[39]. Thus, endoscopic surveillance of the precancerous lesions is mandatory to detect GC in an early stage, termed early GC (EGC). The diagnosis of EGC is difficult because the sensitivity of endoscopic diagnosis of CAG is only 42% in a large study and the overall rate of missed neoplasia at endoscopy varies between 8.3% and 10%[40].

AI models may improve the diagnostic accuracy and aid the endoscopist in the detection and staging of precancerous lesions.

AI in the detection of gastric precancerous lesions and HP infection: Regarding CAG, in two studies, AI models were compared to endoscopists. Zhang *et al*[41] used the CNN model to detect CAG in 1699 patients. It outperformed three expert endoscopists with a sensitivity, specificity, and accuracy of 95%, 94%, and 94% respectively. Guimaraes *et al*[42] reported a 93% accuracy with WLE images.

Concerning GIM, Yan *et al*[43] developed a CNN-CAD model with ME-NBI. It reached an accuracy of 89% compared to 84% accuracy for expert endoscopists.

Concerning HP infection, Zheng *et al*[44] developed a CADe system to detect HP infection status based on endoscopic images without the need for biopsies. The CNN systems reached an accuracy of 92%. Nakashima *et al*[45] used a DL model with WLE and blue light imaging (BLI). The DL model had an area under the curve (AUC) of 0.96 with BLI, and 0.66 with WLE.

AI in the detection of EGC: Li *et al*[46] developed a CNN model on images of benign lesions and EGC. The AI model has a diagnostic accuracy of 91% compared to an accuracy of 87% when used by experts and 70%-74% for non-expert endoscopists. Horiuchi *et al*[47] used a CADe system to detect EGC using NBI videos and compared to 11 expert endoscopists in NBI. Only two endoscopists were outperformed by the CADe systems.

AI in the prediction of invasion depth of EGC: Nagao *et al*[48] developed a CNN-CAD system by using images of GC that underwent endoscopic resection or radical surgery to evaluate the accuracy of AI to determine invasion depth. They found that the CADe system can predict the invasion depth with a sensitivity of 75%-84%, specificity of 80%-99%, and accuracy of 94% during WLE and NBI images, respectively. Yoon *et al*[49] analyzed images of GC (T1a and T1b) to predict invasion depth with AUC of 0.85. This accuracy was significantly lower in undifferentiated lesions.

SMALL BOWEL

Inflammatory bowel disease

Recently, the therapeutic goals for patients with inflammatory bowel disease (IBD) have shifted toward mucosal healing, defined by endoscopic evaluation. However, histologic evaluation is essential to predict the risk of relapse and colon cancer.

This GI field has emerged as a new area for AI, utilizing data from endoscopic images, video capsule endoscopy images, histology, magnetic resonance imaging images, laboratory studies, and genetics. Numerous studies with meta-analyses using ML and DL systems have aimed to detect Crohn's disease and ulcerative colitis with high sensitivity and accuracy[49]. Additionally, AI studies utilizing ML and DL CNN systems have achieved a high level of accuracy in predicting disease severity for IBD[50,51].

Villous atrophy

Celiac disease is the primary cause of villous atrophy and remains undiagnosed in 50% of cases. A study conducted by Gadermayr *et al*[52] achieved a high accuracy of 94%, but that requires water immersion. Also, studies with video capsule endoscopy showed an accuracy > 90%[52-54]. These studies were conducted under special conditions with high probability of suspicion. It is mandatory to make the diagnosis in routine endoscopy. A recent retrospective study done by Scheppach *et al*[55] compared AI algorithms to performance of fellows and experts on routine endoscopy. The results showed that AI significantly improved the performance of all endoscopists with stable performance.

PANCREAS

Endoscopic ultrasound (EUS) is a reliable tool for the detection and staging of pancreatic lesions, particularly pancreatic cancer (PC). EUS-FNB is a well-established diagnostic tool for PC, demonstrating a specificity and sensitivity greater than 90%. However, the EUS technique is operator-dependent, exhibiting inter-observer variability, making it an ideal platform for AI applications.

AI in EUS for detection of PC

Three retrospective studies were conducted using DL algorithms, demonstrating high sensitivity, specificity, and accuracy in diagnosing PC[56-58]. Additionally, Goyal *et al*[59] conducted a systematic review of 11 studies on the role of AI-assisted EUS models in diagnosing PC, revealing that AI algorithms had high potential for detecting PC.

AI in EUS differentiation PC from benign lesions

Chronic pancreatitis: Chronic pancreatitis still mimics PC in radiologic features and is also considered a risk factor for the development of PC. Five studies were conducted with DL algorithms, reporting high accuracy, sensitivity, and specificity [60-64]. However, these studies were heterogeneous with a small patient population. Hence, two recent prospective multicenter studies using DL models were published, validating the aforementioned findings[65,66]. Therefore, AI-assisted EUS can be a validated tool in clinical practice to differentiate PC from chronic pancreatitis with accepted results.

Autoimmune pancreatitis: Marya *et al*[67] conducted a unique study using a DL model to differentiate between PC and autoimmune pancreatitis. The high sensitivity and specificity encourage the use of AI to assist EUS endoscopists in this field.

LIMITATIONS

Input data

DL tasks rely on databases used to train AI algorithms, which must be manually annotated and propagated through frames using dedicated software. The development of DL may be affected by selection biases, which include the chosen disease, its prevalence, the endoscopic center's characteristics, the patient population, and the number of patients enrolled. Spectrum biases in DL performance can arise from variations in patient population, the number and skills of endoscopists, and the technical characteristics used, such as WLE, advanced imaging, and optical magnification. Consequently, a database from a single institution, lacking diversity and failing to capture all possible variations, can impact the quality of input data, as well as the reproducibility and generalizability of the results. To mitigate these biases, it is essential to establish a quality-monitored central data collection server that aggregates data from all institutions.

Algorithm

Studies utilize different AI-assisted models that require images prepared in specific ways. These algorithms may not consistently achieve a high degree of accuracy. Therefore, it is essential to establish a universal protocol for input data to enhance the efficacy and accuracy of AI-assisted models.

Validation

AI findings must undergo clinical validation before being introduced into clinical practice. AI has a valuable advantage when the reference standard is based on histologic verification. However, if not, the reference standard relies on expert endoscopist raters, introducing potential bias. Therefore, AI systems should be validated through randomized trials comparing the standard and new endoscopic modalities. Additionally, these algorithms must be tested on large and cross-institutional datasets. Long-term data on the accuracy of AI-assisted models is lacking. Consequently, there are no results regarding the impact of AI on reducing the incidence and mortality of GI cancer. Clinical efficacy evaluation must adhere to established guidelines. The two recommended guidelines are the PIVI statement as a guide for new imaging technology and the ESGE guidelines. For example, in cases requiring targeted biopsies, PIVI recommends a per-patient sensitivity of 90% or greater and a specificity of 80% or greater to allow a reduction in biopsies. Therefore, studies must meet these parameters to be approved for clinical practice. Additionally, according to ESGE, the results of AI studies must be comparable to those of experts.

Output

There are "black boxes" in the logic of DL algorithm decision-making processes that are not understood or controlled by humans[68]. Consequently, AI can make mistakes, and humans cannot explain or justify the computer's decisions. For instance, physicians have concerns regarding the number of false-positive signals generated by AI. This may cause distraction, prolong procedure time, and frustrate the endoscopist, making some users hesitant to use it. Therefore, humans must make the final decision and should not become entirely dependent on AI technology for both diagnostic and therapeutic endoscopies; otherwise, they risk losing their cognitive abilities.

CONCLUSION

In conclusion, because the GI field relies on imaging, AI-assisted algorithms continue to explore new GI organs and diseases. The growth and applications of AI increase exponentially with the development of computer science and may reach no limit. However, we must be careful about how we use it and preserve our independence in the final decision. Additionally, to achieve better results in AI studies in the future, collaboration between academic and private gastroenterologists and the industry must be closer, aiming to improve the quality, utility, ease of use, and accuracy of AI models. We hope that AI-assisted diagnostic techniques will be widely used in GI diseases because AI is an unavoidable tool in GI endoscopy.

FOOTNOTES

Author contributions: Abboud B designed the research; Bou Jaoude J and Al Bacha R performed the research; Bou Jaoude J, Al Bacha R and Abboud B analyzed the data; Bou Japude J, Al Bacha R and Abboud B wrote the paper.

Conflict-of-interest statement: The authors declare no conflicts of interest.

Country of origin: Lebanon

ORCID number: Joseph Bou Jaoude 0000-0002-9858-3309; Bassam Abboud 0000-0001-5268-2347.

S-Editor: Lin C
L-Editor: Filipodia
P-Editor: Zhao YQ

REFERENCES

1 **Corley DA**, Jensen CD, Marks AR, Zhao WK, Lee JK, Doubeni CA, Zauber AG, de Boer J, Fireman BH, Schottinger JE, Quinn VP, Ghai NR, Levin TR, Quesenberry CP. Adenoma detection rate and risk of colorectal cancer and death. *N Engl J Med* 2014; **370**: 1298-1306 [PMID: 24693890 DOI: 10.1056/NEJMoa1309086]

2 **Cooper GS**, Xu F, Barnholtz Sloan JS, Schluchter MD, Koroukian SM. Prevalence and predictors of interval colorectal cancers in medicare beneficiaries. *Cancer* 2012; **118**: 3044-3052 [PMID: 21989586 DOI: 10.1002/cncr.26602]

3 **Urban G**, Tripathi P, Alkayali T, Mittal M, Jalali F, Karnes W, Baldi P. Deep Learning Localizes and Identifies Polyps in Real Time With 96% Accuracy in Screening Colonoscopy. *Gastroenterology* 2018; **155**: 1069-1078.e8 [PMID: 29928897 DOI: 10.1053/j.gastro.2018.06.037]

4 **Misawa M**, Kudo SE, Mori Y, Cho T, Kataoka S, Yamauchi A, Ogawa Y, Maeda Y, Takeda K, Ichimasa K, Nakamura H, Yagawa Y, Toyoshima N, Ogata N, Kudo T, Hisayuki T, Hayashi T, Wakamura K, Baba T, Ishida F, Itoh H, Roth H, Oda M, Mori K. Artificial Intelligence-Assisted Polyp Detection for Colonoscopy: Initial Experience. *Gastroenterology* 2018; **154**: 2027-2029.e3 [PMID: 29653147 DOI: 10.1053/j.gastro.2018.04.003]

5 **Wang P**, Berzin TM, Glissen Brown JR, Bharadwaj S, Becq A, Xiao X, Liu P, Li L, Song Y, Zhang D, Li Y, Xu G, Tu M, Liu X. Real-time automatic detection system increases colonoscopic polyp and adenoma detection rates: a prospective randomised controlled study. *Gut* 2019; **68**: 1813-1819 [PMID: 30814121 DOI: 10.1136/gutjnl-2018-317500]

6 **Xu H**, Tang RSY, Lam TYT, Zhao G, Lau JYW, Liu Y, Wu Q, Rong L, Xu W, Li X, Wong SH, Cai S, Wang J, Liu G, Ma T, Liang X, Mak JWY, Xu H, Yuan P, Cao T, Li F, Ye Z, Shutian Z, Sung JJY. Artificial Intelligence-Assisted Colonoscopy for Colorectal Cancer Screening: A Multicenter Randomized Controlled Trial. *Clin Gastroenterol Hepatol* 2023; **21**: 337-346.e3 [PMID: 35863686 DOI: 10.1016/j.cgh.2022.07.006]

7 **Nehme F**, Coronel E, Barringer DA, Romero LG, Shafi MA, Ross WA, Ge PS. Performance and attitudes toward real-time computer-aided polyp detection during colonoscopy in a large tertiary referral center in the United States. *Gastrointest Endosc* 2023; **98**: 100-109.e6 [PMID: 36801459 DOI: 10.1016/j.gie.2023.02.016]

8 **Shaukat A**, Lichtenstein DR, Somers SC, Chung DC, Perdue DG, Gopal M, Colucci DR, Phillips SA, Marka NA, Church TR, Brugge WR;

SKOUT™ Registration Study Team. Computer-Aided Detection Improves Adenomas per Colonoscopy for Screening and Surveillance Colonoscopy: A Randomized Trial. *Gastroenterology* 2022; **163**: 732-741 [PMID: 35643173 DOI: 10.1053/j.gastro.2022.05.028]

9 **Wallace MB**, Sharma P, Bhandari P, East J, Antonelli G, Lorenzetti R, Vieth M, Speranza I, Spadaccini M, Desai M, Lukens FJ, Babameto G, Batista D, Singh D, Palmer W, Ramirez F, Palmer R, Lunsford T, Ruff K, Bird-Liebermann E, Ciofoaia V, Arndtz S, Cangemi D, Puddick K, Derfus G, Johal AS, Barawi M, Longo L, Moro L, Repici A, Hassan C. Impact of Artificial Intelligence on Miss Rate of Colorectal Neoplasia. *Gastroenterology* 2022; **163**: 295-304.e5 [PMID: 35304117 DOI: 10.1053/j.gastro.2022.03.007]

10 **Glissen Brown JR**, Mansour NM, Wang P, Chuchuca MA, Minchenberg SB, Chandnani M, Liu L, Gross SA, Sengupta N, Berzin TM. Deep Learning Computer-aided Polyp Detection Reduces Adenoma Miss Rate: A United States Multi-center Randomized Tandem Colonoscopy Study (CADeT-CS Trial). *Clin Gastroenterol Hepatol* 2022; **20**: 1499-1507.e4 [PMID: 34530161 DOI: 10.1016/j.cgh.2021.09.009]

11 **Hassan C**, Spadaccini M, Iannone A, Maselli R, Jovani M, Chandrasekar VT, Antonelli G, Yu H, Areia M, Dinis-Ribeiro M, Bhandari P, Sharma P, Rex DK, Rösch T, Wallace M, Repici A. Performance of artificial intelligence in colonoscopy for adenoma and polyp detection: a systematic review and meta-analysis. *Gastrointest Endosc* 2021; **93**: 77-85.e6 [PMID: 32598963 DOI: 10.1016/j.gie.2020.06.059]

12 **Messmann H**, Bisschops R, Antonelli G, Libânio D, Sinonquel P, Abdelrahim M, Ahmad OF, Areia M, Bergman JJGHM, Bhandari P, Boskoski I, Dekker E, Domagk D, Ebigbo A, Eelbode T, Eliakim R, Häfner M, Haidry RJ, Jover R, Kaminski MF, Kuvaev R, Mori Y, Palazzo M, Repici A, Rondonotti E, Rutter MD, Saito Y, Sharma P, Spada C, Spadaccini M, Veitch A, Gralnek IM, Hassan C, Dinis-Ribeiro M. Expected value of artificial intelligence in gastrointestinal endoscopy: European Society of Gastrointestinal Endoscopy (ESGE) Position Statement. *Endoscopy* 2022; **54**: 1211-1231 [PMID: 36270318 DOI: 10.1055/a-1950-5694]

13 **Mori Y**, Kudo SE, Misawa M, Saito Y, Ikematsu H, Hotta K, Ohtsuka K, Urushibara F, Kataoka S, Ogawa Y, Maeda Y, Takeda K, Nakamura H, Ichimasa K, Kudo T, Hayashi T, Wakamura K, Ishida F, Inoue H, Itoh H, Oda M, Mori K. Real-Time Use of Artificial Intelligence in Identification of Diminutive Polyps During Colonoscopy: A Prospective Study. *Ann Intern Med* 2018; **169**: 357-366 [PMID: 30105375 DOI: 10.7326/M18-0249]

14 **Rondonotti E**, Hassan C, Tamanini G, Antonelli G, Andrisani G, Leonetti G, Paggi S, Amato A, Scardino G, Di Paolo D, Mandelli G, Lenoci N, Terreni N, Andrealli A, Maselli R, Spadaccini M, Galtieri PA, Correale L, Repici A, Di Matteo FM, Ambrosiani L, Filippi E, Sharma P, Radaelli F. Artificial intelligence-assisted optical diagnosis for the resect-and-discard strategy in clinical practice: the Artificial intelligence BLI Characterization (ABC) study. *Endoscopy* 2023; **55**: 14-22 [PMID: 35562098 DOI: 10.1055/a-1852-0330]

15 **Hassan C**, Balsamo G, Lorenzetti R, Zullo A, Antonelli G. Artificial Intelligence Allows Leaving-In-Situ Colorectal Polyps. *Clin Gastroenterol Hepatol* 2022; **20**: 2505-2513.e4 [PMID: 35835342 DOI: 10.1016/j.cgh.2022.04.045]

16 **Ahmad OF**, González-Bueno Puyal J, Brandao P, Kader R, Abbasi F, Hussein M, Haidry RJ, Toth D, Mountney P, Seward E, Vega R, Stoyanov D, Lovat LB. Performance of artificial intelligence for detection of subtle and advanced colorectal neoplasia. *Dig Endosc* 2022; **34**: 862-869 [PMID: 34748665 DOI: 10.1111/den.14187]

17 **Takeda K**, Kudo SE, Mori Y, Misawa M, Kudo T, Wakamura K, Katagiri A, Baba T, Hidaka E, Ishida F, Inoue H, Oda M, Mori K. Accuracy of diagnosing invasive colorectal cancer using computer-aided endocytoscopy. *Endoscopy* 2017; **49**: 798-802 [PMID: 28472832 DOI: 10.1055/s-0043-105486]

18 **Ito N**, Kawahira H, Nakashima H, Uesato M, Miyauchi H, Matsubara H. Endoscopic Diagnostic Support System for cT1b Colorectal Cancer Using Deep Learning. *Oncology* 2019; **96**: 44-50 [PMID: 30130758 DOI: 10.1159/000491636]

19 **Liu W**, Wu Y, Yuan X, Zhang J, Zhou Y, Zhang W, Zhu P, Tao Z, He L, Hu B, Yi Z. Artificial intelligence-based assessments of colonoscopic withdrawal technique: a new method for measuring and enhancing the quality of fold examination. *Endoscopy* 2022; **54**: 972-979 [PMID: 35391493 DOI: 10.1055/a-1799-8297]

20 **Rodríguez de Santiago E**, Hernanz N, Marcos-Prieto HM, De-Jorge-Turrión MÁ, Barreiro-Alonso E, Rodríguez-Escaja C, Jiménez-Jurado A, Sierra-Morales M, Pérez-Valle I, Machado-Volpato N, García-Prada M, Núñez-Gómez L, Castaño-García A, García García de Paredes A, Peñas B, Vázquez-Sequeiros E, Albillos A. Rate of missed oesophageal cancer at routine endoscopy and survival outcomes: A multicentric cohort study. *United European Gastroenterol J* 2019; **7**: 189-198 [PMID: 31080603 DOI: 10.1177/2050640618811477]

21 **Wu Z**, Ge R, Wen M, Liu G, Chen Y, Zhang P, He X, Hua J, Luo L, Li S. ELNet:Automatic classification and segmentation for esophageal lesions using convolutional neural network. *Med Image Anal* 2021; **67**: 101838 [PMID: 33129148 DOI: 10.1016/j.media.2020.101838]

22 **Everson M**, Herrera L, Li W, Luengo IM, Ahmad O, Banks M, Magee C, Alzoubaidi D, Hsu HM, Graham D, Vercauteren T, Lovat L, Ourselin S, Kashin S, Wang HP, Wang WL, Haidry RJ. Artificial intelligence for the real-time classification of intrapapillary capillary loop patterns in the endoscopic diagnosis of early oesophageal squamous cell carcinoma: A proof-of-concept study. *United European Gastroenterol J* 2019; **7**: 297-306 [PMID: 31080614 DOI: 10.1177/2050640618821800]

23 **Zhao YY**, Xue DX, Wang YL, Zhang R, Sun B, Cai YP, Feng H, Cai Y, Xu JM. Computer-assisted diagnosis of early esophageal squamous cell carcinoma using narrow-band imaging magnifying endoscopy. *Endoscopy* 2019; **51**: 333-341 [PMID: 30469155 DOI: 10.1055/a-0756-8754]

24 **Yuan XL**, Liu W, Liu Y, Zeng XH, Mou Y, Wu CC, Ye LS, Zhang YH, He L, Feng J, Zhang WH, Wang J, Chen X, Hu YX, Zhang KH, Hu B. Artificial intelligence for diagnosing microvessels of precancerous lesions and superficial esophageal squamous cell carcinomas: a multicenter study. *Surg Endosc* 2022; **36**: 8651-8662 [PMID: 35705757 DOI: 10.1007/s00464-022-09353-0]

25 **Liu DY**, Gan T, Rao NN, Xing YW, Zheng J, Li S, Luo CS, Zhou ZJ, Wan YL. Identification of lesion images from gastrointestinal endoscope based on feature extraction of combinational methods with and without learning process. *Med Image Anal* 2016; **32**: 281-294 [PMID: 27236223 DOI: 10.1016/j.media.2016.04.007]

26 **Horie Y**, Yoshio T, Aoyama K, Yoshimizu S, Horiuchi Y, Ishiyama A, Hirasawa T, Tsuchida T, Ozawa T, Ishihara S, Kumagai Y, Fujishiro M, Maetani I, Fujisaki J, Tada T. Diagnostic outcomes of esophageal cancer by artificial intelligence using convolutional neural networks. *Gastrointest Endosc* 2019; **89**: 25-32 [PMID: 30120958 DOI: 10.1016/j.gie.2018.07.037]

27 **Cai SL**, Li B, Tan WM, Niu XJ, Yu HH, Yao LQ, Zhou PH, Yan B, Zhong YS. Using a deep learning system in endoscopy for screening of early esophageal squamous cell carcinoma (with video). *Gastrointest Endosc* 2019; **90**: 745-753.e2 [PMID: 31302091 DOI: 10.1016/j.gie.2019.06.044]

28 **Zhang YH**, Guo LJ, Yuan XL, Hu B. Artificial intelligence-assisted esophageal cancer management: Now and future. *World J Gastroenterol* 2020; **26**: 5256-5271 [PMID: 32994686 DOI: 10.3748/wjg.v26.i35.5256]

29 **Zhang ST**, Wang SY, Zhang J, Dong D, Mu W, Xia XE, Fu FF, Lu YN, Wang S, Tang ZC, Li P, Qu JR, Wang MY, Tian J, Liu JH. Artificial intelligence-based computer-aided diagnosis system supports diagnosis of lymph node metastasis in esophageal squamous cell carcinoma: A multicenter study. *Heliyon* 2023; **9**: e14030 [PMID: 36923854 DOI: 10.1016/j.heliyon.2023.e14030]

30 **Tokai Y**, Yoshio T, Aoyama K, Horie Y, Yoshimizu S, Horiuchi Y, Ishiyama A, Tsuchida T, Hirasawa T, Sakakibara Y, Yamada T,

Yamaguchi S, Fujisaki J, Tada T. Application of artificial intelligence using convolutional neural networks in determining the invasion depth of esophageal squamous cell carcinoma. *Esophagus* 2020; **17**: 250-256 [PMID: 31980977 DOI: 10.1007/s10388-020-00716-x]

31 **Pan W**, Li X, Wang W, Zhou L, Wu J, Ren T, Liu C, Lv M, Su S, Tang Y. Identification of Barrett's esophagus in endoscopic images using deep learning. *BMC Gastroenterol* 2021; **21**: 479 [PMID: 34920705 DOI: 10.1186/s12876-021-02055-2]

32 **Ebigbo A**, Mendel R, Probst A, Manzeneder J, Prinz F, de Souza LA Jr, Papa J, Palm C, Messmann H. Real-time use of artificial intelligence in the evaluation of cancer in Barrett's oesophagus. *Gut* 2020; **69**: 615-616 [PMID: 31541004 DOI: 10.1136/gutjnl-2019-319460]

33 **de Groof AJ**, Struyvenberg MR, van der Putten J, van der Sommen F, Fockens KN, Curvers WL, Zinger S, Pouw RE, Coron E, Baldaque-Silva F, Pech O, Weusten B, Meining A, Neuhaus H, Bisschops R, Dent J, Schoon EJ, de With PH, Bergman JJ. Deep-Learning System Detects Neoplasia in Patients With Barrett's Esophagus With Higher Accuracy Than Endoscopists in a Multistep Training and Validation Study With Benchmarking. *Gastroenterology* 2020; **158**: 915-929.e4 [PMID: 31759929 DOI: 10.1053/j.gastro.2019.11.030]

34 **Abdelrahim M**, Saiko M, Maeda N, Hossain E, Alkandari A, Subramaniam S, Parra-Blanco A, Sanchez-Yague A, Coron E, Repici A, Bhandari P. Development and validation of artificial neural networks model for detection of Barrett's neoplasia: a multicenter pragmatic nonrandomized trial (with video). *Gastrointest Endosc* 2023; **97**: 422-434 [PMID: 36283443 DOI: 10.1016/j.gie.2022.10.031]

35 **Hashimoto R**, Requa J, Dao T, Ninh A, Tran E, Mai D, Lugo M, El-Hage Chehade N, Chang KJ, Karnes WE, Samarasena JB. Artificial intelligence using convolutional neural networks for real-time detection of early esophageal neoplasia in Barrett's esophagus (with video). *Gastrointest Endosc* 2020; **91**: 1264-1271.e1 [PMID: 31930967 DOI: 10.1016/j.gie.2019.12.049]

36 **Arribas J**, Antonelli G, Frazzoni L, Fuccio L, Ebigbo A, van der Sommen F, Ghatwary N, Palm C, Coimbra M, Renna F, Bergman JJGHM, Sharma P, Messmann H, Hassan C, Dinis-Ribeiro MJ. Standalone performance of artificial intelligence for upper GI neoplasia: a meta-analysis. *Gut* 2020 [PMID: 33127833 DOI: 10.1136/gutjnl-2020-321922]

37 **Tan JL**, Chinnaratha MA, Woodman R, Martin R, Chen HT, Carneiro G, Singh R. Diagnostic Accuracy of Artificial Intelligence (AI) to Detect Early Neoplasia in Barrett's Esophagus: A Non-comparative Systematic Review and Meta-Analysis. *Front Med (Lausanne)* 2022; **9**: 890720 [PMID: 35814747 DOI: 10.3389/fmed.2022.890720]

38 **Ebigbo A**, Mendel R, Rückert T, Schuster L, Probst A, Manzeneder J, Prinz F, Mende M, Steinbrück I, Faiss S, Rauber D, de Souza LA Jr, Papa JP, Deprez PH, Oyama T, Takahashi A, Seewald S, Sharma P, Byrne MF, Palm C, Messmann H. Endoscopic prediction of submucosal invasion in Barrett's cancer with the use of artificial intelligence: a pilot study. *Endoscopy* 2021; **53**: 878-883 [PMID: 33197942 DOI: 10.1055/a-1311-8570]

39 **Pimentel-Nunes P**, Libânio D, Marcos-Pinto R, Areia M, Leja M, Esposito G, Garrido M, Kikuste I, Megraud F, Matysiak-Budnik T, Annibale B, Dumonceau JM, Barros R, Fléjou JF, Carneiro F, van Hooft JE, Kuipers EJ, Dinis-Ribeiro M. Management of epithelial precancerous conditions and lesions in the stomach (MAPS II): European Society of Gastrointestinal Endoscopy (ESGE), European Helicobacter and Microbiota Study Group (EHMSG), European Society of Pathology (ESP), and Sociedade Portuguesa de Endoscopia Digestiva (SPED) guideline update 2019. *Endoscopy* 2019; **51**: 365-388 [PMID: 30841008 DOI: 10.1055/a-0859-1883]

40 **Pimenta-Melo AR**, Monteiro-Soares M, Libânio D, Dinis-Ribeiro M. Missing rate for gastric cancer during upper gastrointestinal endoscopy: a systematic review and meta-analysis. *Eur J Gastroenterol Hepatol* 2016; **28**: 1041-1049 [PMID: 27148773 DOI: 10.1097/MEG.0000000000000657]

41 **Zhang Y**, Li F, Yuan F, Zhang K, Huo L, Dong Z, Lang Y, Zhang Y, Wang M, Gao Z, Qin Z, Shen L. Diagnosing chronic atrophic gastritis by gastroscopy using artificial intelligence. *Dig Liver Dis* 2020; **52**: 566-572 [PMID: 32061504 DOI: 10.1016/j.dld.2019.12.146]

42 **Guimarães P**, Keller A, Fehlmann T, Lammert F, Casper M. Deep-learning based detection of gastric precancerous conditions. *Gut* 2020; **69**: 4-6 [PMID: 31375599 DOI: 10.1136/gutjnl-2019-319347]

43 **Yan T**, Wong PK, Choi IC, Vong CM, Yu HH. Intelligent diagnosis of gastric intestinal metaplasia based on convolutional neural network and limited number of endoscopic images. *Comput Biol Med* 2020; **126**: 104026 [PMID: 33059237 DOI: 10.1016/j.compbiomed.2020.104026]

44 **Zheng W**, Zhang X, Kim JJ, Zhu X, Ye G, Ye B, Wang J, Luo S, Li J, Yu T, Liu J, Hu W, Si J. High Accuracy of Convolutional Neural Network for Evaluation of Helicobacter pylori Infection Based on Endoscopic Images: Preliminary Experience. *Clin Transl Gastroenterol* 2019; **10**: e00109 [PMID: 31833862 DOI: 10.14309/ctg.0000000000000109]

45 **Nakashima H**, Kawahira H, Kawachi H, Sakaki N. Artificial intelligence diagnosis of Helicobacter pylori infection using blue laser imaging-bright and linked color imaging: a single-center prospective study. *Ann Gastroenterol* 2018; **31**: 462-468 [PMID: 29991891 DOI: 10.20524/aog.2018.0269]

46 **Li L**, Chen Y, Shen Z, Zhang X, Sang J, Ding Y, Yang X, Li J, Chen M, Jin C, Chen C, Yu C. Convolutional neural network for the diagnosis of early gastric cancer based on magnifying narrow band imaging. *Gastric Cancer* 2020; **23**: 126-132 [PMID: 31332619 DOI: 10.1007/s10120-019-00992-2]

47 **Horiuchi Y**, Hirasawa T, Ishizuka N, Tokai Y, Namikawa K, Yoshimizu S, Ishiyama A, Yoshio T, Tsuchida T, Fujisaki J, Tada T. Performance of a computer-aided diagnosis system in diagnosing early gastric cancer using magnifying endoscopy videos with narrow-band imaging (with videos). *Gastrointest Endosc* 2020; **92**: 856-865.e1 [PMID: 32422155 DOI: 10.1016/j.gie.2020.04.079]

48 **Nagao S**, Tsuji Y, Sakaguchi Y, Takahashi Y, Minatsuki C, Niimi K, Yamashita H, Yamamichi N, Seto Y, Tada T, Koike K. Highly accurate artificial intelligence systems to predict the invasion depth of gastric cancer: efficacy of conventional white-light imaging, nonmagnifying narrow-band imaging, and indigo-carmine dye contrast imaging. *Gastrointest Endosc* 2020; **92**: 866-873.e1 [PMID: 32592776 DOI: 10.1016/j.gie.2020.06.047]

49 **Yoon HJ**, Kim S, Kim JH, Keum JS, Oh SI, Jo J, Chun J, Youn YH, Park H, Kwon IG, Choi SH, Noh SH. A Lesion-Based Convolutional Neural Network Improves Endoscopic Detection and Depth Prediction of Early Gastric Cancer. *J Clin Med* 2019; **8** [PMID: 31454949 DOI: 10.3390/jcm8091310]

50 **Aoki T**, Yamada A, Aoyama K, Saito H, Tsuboi A, Nakada A, Niikura R, Fujishiro M, Oka S, Ishihara S, Matsuda T, Tanaka S, Koike K, Tada T. Automatic detection of erosions and ulcerations in wireless capsule endoscopy images based on a deep convolutional neural network. *Gastrointest Endosc* 2019; **89**: 357-363.e2 [PMID: 30670179 DOI: 10.1016/j.gie.2018.10.027]

51 **Yao H**, Najarian K, Gryak J, Bishu S, Rice MD, Waljee AK, Wilkins HJ, Stidham RW. Fully automated endoscopic disease activity assessment in ulcerative colitis. *Gastrointest Endosc* 2021; **93**: 728-736.e1 [PMID: 32810479 DOI: 10.1016/j.gie.2020.08.011]

52 **Gadermayr M**, Kogler H, Karla M, Merhof D, Uhl A, Vécsei A. Computer-aided texture analysis combined with experts' knowledge: Improving endoscopic celiac disease diagnosis. *World J Gastroenterol* 2016; **22**: 7124-7134 [PMID: 27610022 DOI: 10.3748/wjg.v22.i31.7124]

53 **Stoleru CA**, Dulf EH, Ciobanu L. Automated detection of celiac disease using Machine Learning Algorithms. *Sci Rep* 2022; **12**: 4071 [PMID: 35260574 DOI: 10.1038/s41598-022-07199-z]

54 **Wang X**, Qian H, Ciaccio EJ, Lewis SK, Bhagat G, Green PH, Xu S, Huang L, Gao R, Liu Y. Celiac disease diagnosis from videocapsule endoscopy images with residual learning and deep feature extraction. *Comput Methods Programs Biomed* 2020; **187**: 105236 [PMID: 31786452 DOI: 10.1016/j.cmpb.2019.105236]

55 **Scheppach MW**, Rauber D, Stallhofer J, Muzalyova A, Otten V, Manzeneder C, Schwamberger T, Wanzl J, Schlottmann J, Tadic V, Probst A, Schnoy E, Römmele C, Fleischmann C, Meinikheim M, Miller S, Märkl B, Stallmach A, Palm C, Messmann H, Ebigbo A. Detection of duodenal villous atrophy on endoscopic images using a deep learning algorithm. *Gastrointest Endosc* 2023; **97**: 911-916 [PMID: 36646146 DOI: 10.1016/j.gie.2023.01.006]

56 **Kuwahara T**, Hara K, Mizuno N, Okuno N, Matsumoto S, Obata M, Kurita Y, Koda H, Toriyama K, Onishi S, Ishihara M, Tanaka T, Tajika M, Niwa Y. Usefulness of Deep Learning Analysis for the Diagnosis of Malignancy in Intraductal Papillary Mucinous Neoplasms of the Pancreas. *Clin Transl Gastroenterol* 2019; **10**: 1-8 [PMID: 31117111 DOI: 10.14309/ctg.0000000000000045]

57 **Zhang MM**, Yang H, Jin ZD, Yu JG, Cai ZY, Li ZS. Differential diagnosis of pancreatic cancer from normal tissue with digital imaging processing and pattern recognition based on a support vector machine of EUS images. *Gastrointest Endosc* 2010; **72**: 978-985 [PMID: 20855062 DOI: 10.1016/j.gie.2010.06.042]

58 **Ozkan M**, Cakiroglu M, Kocaman O, Kurt M, Yilmaz B, Can G, Korkmaz U, Dandil E, Eksi Z. Age-based computer-aided diagnosis approach for pancreatic cancer on endoscopic ultrasound images. *Endosc Ultrasound* 2016; **5**: 101-107 [PMID: 27080608 DOI: 10.4103/2303-9027.180473]

59 **Goyal H**, Sherazi SAA, Gupta S, Perisetti A, Achebe I, Ali A, Tharian B, Thosani N, Sharma NR. Application of artificial intelligence in diagnosis of pancreatic malignancies by endoscopic ultrasound: a systemic review. *Therap Adv Gastroenterol* 2022; **15**: 17562848221093873 [PMID: 35509425 DOI: 10.1177/17562848221093873]

60 **Das A**, Nguyen CC, Li F, Li B. Digital image analysis of EUS images accurately differentiates pancreatic cancer from chronic pancreatitis and normal tissue. *Gastrointest Endosc* 2008; **67**: 861-867 [PMID: 18179797 DOI: 10.1016/j.gie.2007.08.036]

61 **Norton ID**, Zheng Y, Wiersema MS, Greenleaf J, Clain JE, Dimagno EP. Neural network analysis of EUS images to differentiate between pancreatic malignancy and pancreatitis. *Gastrointest Endosc* 2001; **54**: 625-629 [PMID: 11677484 DOI: 10.1067/mge.2001.118644]

62 **Tonozuka R**, Itoi T, Nagata N, Kojima H, Sofuni A, Tsuchiya T, Ishii K, Tanaka R, Nagakawa Y, Mukai S. Deep learning analysis for the detection of pancreatic cancer on endosonographic images: a pilot study. *J Hepatobiliary Pancreat Sci* 2021; **28**: 95-104 [PMID: 32910528 DOI: 10.1002/jhbp.825]

63 **Zhu M**, Xu C, Yu J, Wu Y, Li C, Zhang M, Jin Z, Li Z. Differentiation of pancreatic cancer and chronic pancreatitis using computer-aided diagnosis of endoscopic ultrasound (EUS) images: a diagnostic test. *PLoS One* 2013; **8**: e63820 [PMID: 23704940 DOI: 10.1371/journal.pone.0063820]

64 **Săftoiu A**, Vilmann P, Dietrich CF, Iglesias-Garcia J, Hocke M, Seicean A, Ignee A, Hassan H, Streba CT, Ioncică AM, Gheonea DI, Ciurea T. Quantitative contrast-enhanced harmonic EUS in differential diagnosis of focal pancreatic masses (with videos). *Gastrointest Endosc* 2015; **82**: 59-69 [PMID: 25792386 DOI: 10.1016/j.gie.2014.11.040]

65 **Săftoiu A**, Vilmann P, Gorunescu F, Gheonea DI, Gorunescu M, Ciurea T, Popescu GL, Iordache A, Hassan H, Iordache S. Neural network analysis of dynamic sequences of EUS elastography used for the differential diagnosis of chronic pancreatitis and pancreatic cancer. *Gastrointest Endosc* 2008; **68**: 1086-1094 [PMID: 18656186 DOI: 10.1016/j.gie.2008.04.031]

66 **Săftoiu A**, Vilmann P, Gorunescu F, Janssen J, Hocke M, Larsen M, Iglesias-Garcia J, Arcidiacono P, Will U, Giovannini M, Dietrich CF, Havre R, Gheorghe C, McKay C, Gheonea DI, Ciurea T; European EUS Elastography Multicentric Study Group. Efficacy of an artificial neural network-based approach to endoscopic ultrasound elastography in diagnosis of focal pancreatic masses. *Clin Gastroenterol Hepatol* 2012; **10**: 84-90.e1 [PMID: 21963957 DOI: 10.1016/j.cgh.2011.09.014]

67 **Marya NB**, Powers PD, Chari ST, Gleeson FC, Leggett CL, Abu Dayyeh BK, Chandrasekhara V, Iyer PG, Majumder S, Pearson RK, Petersen BT, Rajan E, Sawas T, Storm AC, Vege SS, Chen S, Long Z, Hough DM, Mara K, Levy MJ. Utilisation of artificial intelligence for the development of an EUS-convolutional neural network model trained to enhance the diagnosis of autoimmune pancreatitis. *Gut* 2021; **70**: 1335-1344 [PMID: 33028668 DOI: 10.1136/gutjnl-2020-322821]

68 **Price WN**. Big data and black-box medical algorithms. *Sci Transl Med* 2018; **10** [PMID: 30541791 DOI: 10.1126/scitranslmed.aao5333]

A I G

Artificial Intelligence in Gastroenterology

Submit a Manuscript: https://www.f6publishing.com

Artif Intell Gastroenterol 2024 August 8; 5(2): 91550

DOI: 10.35712/aig.v5.i2.91550

ISSN 2644-3236 (online)

MINIREVIEWS

Expanding role and scope of artificial intelligence in the field of gastrointestinal pathology

Muhammed Mubarak, Rahma Rashid, Fnu Sapna, Shaheera Shakeel

Specialty type: Pathology

Provenance and peer review: Invited article; Externally peer reviewed.

Peer-review model: Single blind

Peer-review report's classification

Scientific Quality: Grade B, Grade E

Novelty: Grade A, Grade D

Creativity or Innovation: Grade C, Grade D

Scientific Significance: Grade A, Grade D

P-Reviewer: Andreev DN; Zulkifli MH

Received: December 30, 2023

Revised: July 6, 2024

Accepted: July 29, 2024

Published online: August 8, 2024

Processing time: 190 Days and 21.5 Hours

Muhammed Mubarak, Rahma Rashid, Shaheera Shakeel, Department of Histopathology, Sindh Institute of Urology and Transplantation, Karachi 74200, Sindh, Pakistan

Fnu Sapna, Department of Pathology, Montefiore Medical Center, The University Hospital for Albert Einstein School of Medicine, Bronx, NY 10461, United States

Corresponding author: Muhammed Mubarak, MD, Full Professor, Department of Histopathology, Sindh Institute of Urology and Transplantation, Chand Bibi Road, Karachi 74200, Sindh, Pakistan. drmubaraksiut@yahoo.com

Abstract

Digital pathology (DP) and its subsidiaries including artificial intelligence (AI) are rapidly making inroads into the area of diagnostic anatomic pathology (AP) including gastrointestinal (GI) pathology. It is poised to revolutionize the field of diagnostic AP. Historically, AP has been slow to adopt digital technology, but this is changing rapidly, with many centers worldwide transitioning to DP. Coupled with advanced techniques of AI such as deep learning and machine learning, DP is likely to transform histopathology from a subjective field to an objective, efficient, and transparent discipline. AI is increasingly integrated into GI pathology, offering numerous advancements and improvements in overall diagnostic accuracy, efficiency, and patient care. Specifically, AI in GI pathology enhances diagnostic accuracy, streamlines workflows, provides predictive insights, integrates multimodal data, supports research, and aids in education and training, ultimately improving patient care and outcomes. This review summarized the latest developments in the role and scope of AI in AP with a focus on GI pathology. The main aim was to provide updates and create awareness among the pathology community.

Key Words: Gastrointestinal pathology; Digital pathology; Artificial intelligence; Machine learning; Deep learning; Precision diagnostics

Core Tip: Anatomic pathology remains largely subjective compared to other diagnostic laboratory fields. However, the digitization of tissue sections and the development of artificial intelligence-based technologies are rapidly advancing image-based diagnostics in anatomic pathology including gastrointestinal pathology. These technologies allow pathologists to make diagnoses more quickly and accurately, particularly for time-consuming and repetitive tasks, leading to higher volumes and faster turnaround times. Increasing awareness of the potential uses and benefits of these emerging technologies is essential for the pathology community.

Citation: Mubarak M, Rashid R, Sapna F, Shakeel S. Expanding role and scope of artificial intelligence in the field of gastrointestinal pathology. *Artif Intell Gastroenterol* 2024; 5(2): 91550
URL: https://www.wjgnet.com/2644-3236/full/v5/i2/91550.htm
DOI: https://dx.doi.org/10.35712/aig.v5.i2.91550

INTRODUCTION

Anatomic pathology (AP), particularly histopathology, represents the ground truth of medicine, providing the final and definitive test on which crucial treatment decisions are based, especially for cancer (Figure 1). Despite its critical role, AP has remained an analog enterprise, using processes developed in the early 20th century. Tissue preparation and diagnosis are still largely manual and subjective[1,2]. Diagnoses are based on the visualization and assessment of tissue sections on glass slides under a light microscope, making the process highly dependent on the pathologist's interpretation.

The diagnostic process is a complex mental exercise requiring multitasking and the coordination of observation, interpretation, and integration of information. This process yields continuous variables that pathologists use to drive classification systems, which clinicians use to make major therapeutic decisions (Figure 1). While cost-effective, this process is prone to significant inter- and intra-pathologist variation and diagnostic errors and is often time-consuming and tedious. The integration of multiple ancillary diagnostic tests, such as immunohistochemistry and molecular assays, adds to the complexity and demands on pathologists. Moreover, the shortage of pathologists globally exacerbates these challenges, highlighting the need for precision diagnostics, particularly in cancer treatment[3-5].

Traditionally, AP has been slow to embrace digital technology, but this is steadily changing. Many pathology laboratories worldwide have partially or completely transitioned to digital pathology (DP) workflows[6-10]. Advanced artificial intelligence (AI) techniques, such as machine learning (ML) and deep learning (DL), are set to transform AP into a more objective, efficient, and transparent discipline[11,12]. However, many pathologists, particularly in developing countries, have limited knowledge of AI and its vast potential[13,14].

This review aimed to provide a simplified overview of the latest developments in the role and scope of AI in pathology, with a specific focus on gastrointestinal (GI) pathology. It explored how AI can be used to diagnose and predict diseases, highlighting its benefits for routine histopathology practice. The goal was to update pathologists and other healthcare providers about these emerging diagnostic technologies and raise awareness.

LITERATURE REVIEW

A comprehensive search was conducted across multiple databases, including PubMed, Google Scholar, Scopus, and Web of Science, covering publications from 2010 to 2024. Keywords included "Artificial Intelligence," "Machine Learning," "Deep Learning," "Gastrointestinal Pathology," "Diagnosis," and "Histopathology." All types of studies in the English language were selected based on relevance, focusing on AI applications in GI pathology. The full texts of these articles were carefully read to extract the relevant points for writing this review article.

DEFINITION OF AI AND ITS APPLICATIONS

AI is a field of computer science that enables computers to perform tasks that typically require human intelligence, such as learning, pattern recognition, planning, problem-solving, and reasoning[15-17]. AI relies heavily on data for its operations, and the digitization of glass slides in DP workflows provides vast amounts of pixel data for AI applications. AI can be considered a part of data science[18-21].

Initially, AI comprised simple "if-then" algorithms but has since advanced to include complex algorithms that perform tasks akin to the human brain. The advent of DL has expanded the capabilities of AI, allowing systems to analyze data and images using multiple layers and learn from big data. ML and DL are subsets of AI (Figure 2), with DL being a more advanced form capable of solving complex problems using neural networks (Figure 3)[22-24].

AI represents a significant turning point for human society, comparable to the industrial revolution. It is a general purpose technology applicable in various fields, much like electricity. The role of AI in healthcare is growing rapidly, particularly in biomedical research and clinical practice. Modern techniques now generate vast amounts of data, which AI can analyze for patterns, enhancing diagnostics and treatment decisions[25-29]. AI can detect subtle pathological

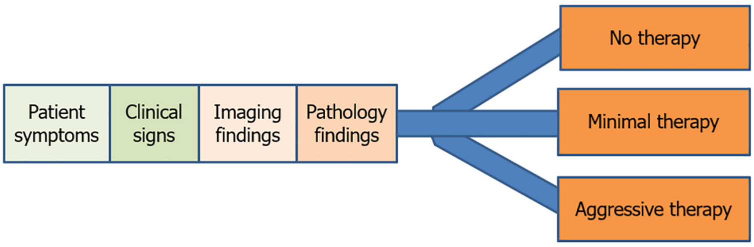

Figure 1 Pathological diagnosis is the final and definitive test that informs all subsequent therapy decisions by clinicians, particularly in oncology.

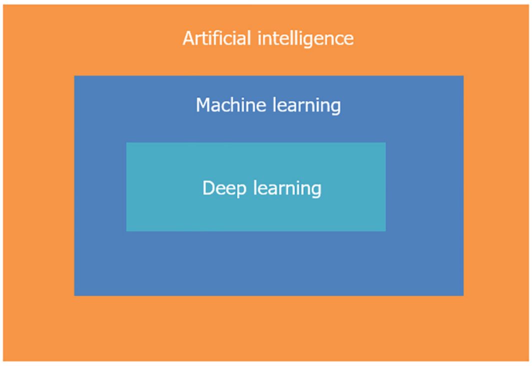

Figure 2 Relationship of artificial intelligence and its more advanced forms, machine learning and deep learning.

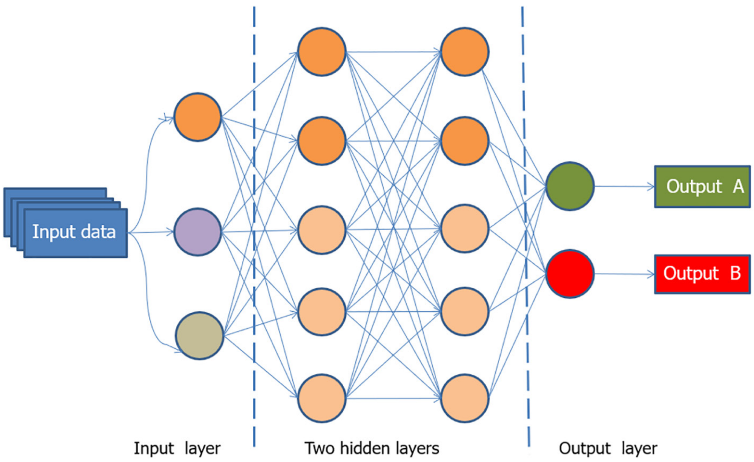

Figure 3 A simplified version of artificial neural network utilized in artificial intelligence algorithms.

alterations, predict therapy responses, and improve workflow efficiency in pathology[30].

In the diagnostics arena, radiologists have been early adopters of AI for image processing and interpretation[31,32]. Pathologists, facing greater visual data complexity in microscopic images, have been slower to adopt AI. However, the shift towards DP and whole slide imaging (WSI) is laying the groundwork for computational pathology technologies. With the recent advancements in AI for computer vision, it is expected that AI will soon support pathologists in various DP tasks. Concurrently, significant progress in DL has created a synergy with AI, enabling image-based diagnostics within the DP context. Efforts are underway to develop AI tools that save pathologists time and reduce errors[33]. Integrating AI systems into AP practices will require fully digital imaging platforms, updating outdated information technology infrastructures, modifying laboratory and pathologist workflows, establishing appropriate reimbursement models, and ensuring pathologists' active participation for buy-in and oversight. New regulations, designed to address the unique aspects and limitations of AI, are being developed to ensure its safe and effective use[34]. The recent Food and Drug Administration approval of WSI systems opens significant opportunities for AI-assisted pathological diagnosis, promising faster, more accurate, and cost-effective diagnostics[35-40].

ROLE OF AI IN ROUTINE AP DIAGNOSTIC WORKFLOW

AI is increasingly being integrated into AP to enhance diagnostic efficiency and accuracy, reduce turnaround times, and improve patient care[41,42]. AI algorithms can analyze DP images with high speed and accuracy, assisting pathologists in identifying and quantifying specific features such as cell structures, mitoses, tissue patterns, and abnormalities. This reduces subjectivity, minimizes diagnostic errors, and ensures consistent results[43-47].

AI-driven workflow management tools can streamline daily tasks, prioritize cases based on urgency, and help pathologists allocate their time effectively. AI can also integrate patient data, provide decision support tools, and assist in quality control and compliance with regulatory standards. AI tools can develop predictive models for disease outcomes and support research by analyzing vast datasets[48,49]. Although technical implementation has become less challenging, much work is needed to integrate AI into routine AP workflows. AI can also enhance the understanding of disease biology by analyzing DP images to identify patterns and features not visible to the human eye. This can aid in discovering new biomarkers and treatments, benefiting both diagnostics and research[50,51].

ROLE OF AI IN GI PATHOLOGY

AI technology is poised to revolutionize GI pathology, offering numerous current and potential applications (Figure 4). By processing digitized images of tissue samples, AI tools enhance the precise and effective identification of various GI disease processes, including inflammatory and neoplastic conditions such as colitis, Crohn's disease, and colorectal cancer (CRC). The integration of AI in GI pathology significantly improves the precision, speed, and quality of diagnostic and therapeutic decision-making processes, ultimately benefiting patient care. Additionally, AI can standardize quality control in GI pathology, ensuring accurate and consistent results across samples[52-55].

AI has been extensively studied for endoscopic diagnosis of GI tract disorders, demonstrating significant promise. It is expected that AI will primarily assist endoscopists with tasks such as detection, characterization, and segmentation. AI has the potential to enhance colonoscopy-based colorectal screening and monitoring by reducing unnecessary expenses and improving quality. Real-time computer-assisted polyp identification can enhance screening and monitoring quality, as measured by adenoma detection rates. Optical biopsies using computer-assisted diagnosis can identify low-risk polyps, supporting resect-and-discard or diagnose-and-leave strategies, thereby reducing unnecessary costs. Recent meta-analyses indicated that AI tools significantly increased colorectal neoplasia detection, regardless of initial adenoma features[56-58]. Furthermore, AI is useful in identifying upper GI pathological processes, including both neoplastic and non-neoplastic lesions[59,60].

In the GI tract, precancerous lesions and invasive tumors are routinely biopsied or excised for histopathological workup. Early and accurate diagnosis is a primary responsibility of pathologists, and AI can assist in achieving this objective. Numerous reports have documented AI-assisted diagnosis of both neoplastic and non-neoplastic GI diseases. For instance, Korbar *et al*[61] trained a model to distinguish between five prevalent types of colorectal polyps with an overall accuracy of 93% using a dataset of over 400 WSIs. Wei *et al*[62] demonstrated that neural networks trained to identify colorectal polyps on WSIs from one institution performed similarly to local pathologists when applied to WSIs from other institutions. Efforts have also been made to automate the diagnosis of preneoplastic and neoplastic lesions, such as Barrett's esophagus or gastric adenomas/adenocarcinomas[60].

AI models also show promise in predicting therapy response or prognosis from WSI analysis. Among all cancer types, GI and liver tumors have notably driven computational oncology forward. AI can extract complex information from digital images of GI and hepatic malignancies, providing clinical, biological, and molecular insights that are not accessible to the naked eye. By identifying the most predictive tissue areas, AI reduces the cognitive burden on pathologists, enhancing their efficacy in histopathological characterization and risk assessments of GI preneoplastic and neoplastic lesions. In biliary tract cancer, DL can identify tissue features predictive of clinical outcomes. DP images and tissue microarrays from CRC have shown the efficacy of DL in prognostic prediction across all tumor stages. The histomorphology of gastric cancer (GC) is more complex and variable than CRC, leading to fewer investigations using DL for GC. Most of this research has focused on tumor detection rather than prognostication[63-66].

Routine processing of surgical and biopsy specimens from various GI tract tumors involves investigating molecular biomarkers that predict responses to targeted therapy. Specific genetic events in GI and hepatobiliary cancers are linked to morphological features identified in hematoxylin and eosin sections. AI-based algorithms on WSIs have been successfully used as surrogate markers for these alterations[66-69]. For example, CRC serves as a model disease due to the abundance of pathology samples. Identifying microsatellite instability (MSI) is crucial because immune-modulating treatments significantly affect MSI tumors. MSI identification has major implications for patients and their families, necessitating further investigation to identify Lynch syndrome. Although immunohistochemistry techniques are typically used to identify MSI, not all patients are routinely screened. A study by Echle *et al*[70] examined 8836 CRC cases across all stages, developing an AI model that could identify MSI tumors from hematoxylin and eosin sections, maintaining performance even in biopsy samples with limited tissue and varying preprocessing methods. Other efforts have created models that accurately predict gene alterations from WSIs of hepatocellular carcinoma (HCC), GC, and other conditions.

AI-based pathology can predict gene expression and RNA sequencing data, holding great promise for clinical application. Developing DL models for prognostication that integrate clinical, biological, and genetic data is a promising approach. For example, Chaudhary *et al*[71] used RNA sequencing, microRNA sequencing, and methylation data to create a DL model predicting survival in HCC patients, demonstrating its efficacy across different HCC patient cohorts.

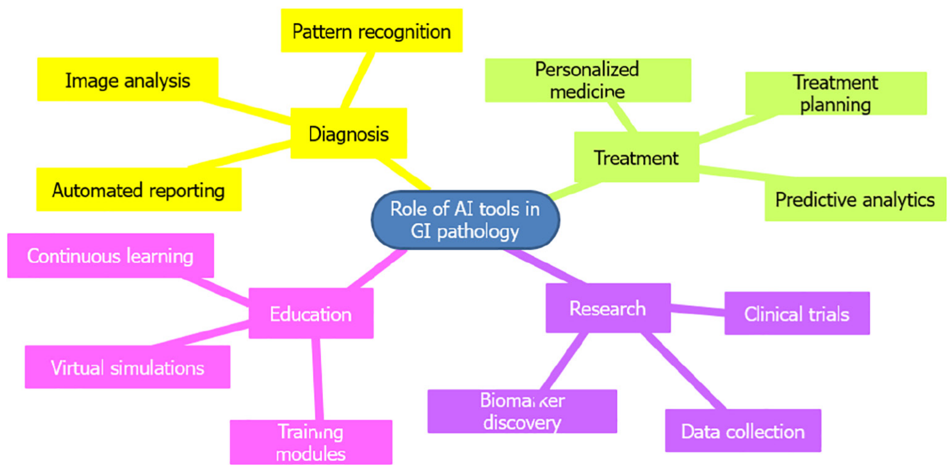

Figure 4 Four main roles of artificial intelligence-based tools in gastrointestinal pathology. AI: Artificial intelligence; GI: Gastrointestinal.

AI ALGORITHMS IN GI PATHOLOGY

AI algorithms, particularly those based on ML and DL, have shown substantial potential in analyzing complex pathological data and are central to the advancements in GI pathology (Table 1). ML algorithms such as support vector machines, random forests, and k-nearest neighbors have been employed to classify and predict various GI conditions. These include supervised, unsupervised, and reinforcement learning algorithms (Figure 5). Supervised learning algorithms, such as support vector machines and random forests, are widely used for classification tasks. These algorithms require extensive feature engineering and domain expertise to identify relevant features from pathology images and clinical data. They are relatively simpler to implement and interpret compared to DL algorithms. They are also effective for structured data analysis and smaller datasets and feature faster training times and lower computational requirements. The need for manual feature extraction limits their use, and ML algorithms may not perform as well as DL in recognizing complex patterns in unstructured data like histopathological images[72-75].

DL models, particularly convolutional neural networks, have revolutionized image analysis in GI pathology[76,77]. Convolutional neural networks can automatically learn hierarchical features from raw images, making them highly effective for tasks such as tumor detection and classification. They possess superior performance in image recognition tasks and are able to handle large and complex datasets. Automated feature extraction reduces the need for domain-specific knowledge. However, it requires substantial computational resources and large annotated datasets. It is difficult to interpret and explain the decision-making process (black-box nature). Recurrent neural networks, including their variants like long short-term memory networks, are used for sequential data analysis. They are particularly useful in analyzing time-series data from endoscopic videos to detect abnormalities[78-84]. While ML algorithms are generally more interpretable, DL algorithms often provide higher accuracy due to their ability to learn complex patterns from large datasets. However, DL models require substantial computational resources and large labeled datasets, which can be a limitation[73,75,79,85].

DATA SOURCES IN GI PATHOLOGY

The performance of AI algorithms heavily depends on the quality and diversity of data sources. Common data sources in GI pathology include: (1) Histopathological images in the form of WSIs and tissue microarrays as the primary data sources; (2) Clinical data, such as electronic health records, patient demographics, clinical history, and endoscopy images; and (3) Publicly available datasets such as The Cancer Genome Atlas and Gastrointestinal Image Data Collection. Each of these sources has merits and demerits. Integration of clinical data, including patient demographics, medical history, and laboratory results, enhances the contextual understanding of GI pathology and improves the predictive power of AI models. The availability of large, well-annotated datasets is a significant challenge. Variability in image quality and staining techniques and differences in pathological practices across institutions can affect the generalizability of AI models. Additionally, integrating clinical data requires sophisticated data management systems to handle patient privacy and data security concerns.

PERFORMANCE METRICS OF AI ALGORITHMS

Sensitivity measures the ability of an AI algorithm to correctly identify positive cases (*e.g.*, detecting cancerous lesions). Specificity measures the ability of an AI algorithm to correctly identify negative cases (*e.g.*, ruling out benign conditions). Achieving high sensitivity and specificity is challenging due to the inherent variability in pathological samples. DL

Table 1 Main artificial intelligence-based algorithms for use in the gastrointestinal pathology field

AI algorithms	Role in gastrointestinal pathology	Key uses	Examples
Machine learning	Assisting in diagnosis and classification of gastrointestinal diseases	Improved diagnostic accuracy, personalized treatment plans	Predictive models for colorectal cancer risk, classification of polyps in colonoscopy images
Deep learning	Analyzing endoscopic and histopathologic images	Enhanced image recognition, reduced human error	Convolutional neural networks for detecting and classifying lesions in endoscopic images
Natural language processing	Extracting relevant information from medical records and literature	Efficient data mining, real-time clinical decision support	Automated extraction of patient data from electronic health records for research and clinical use
Computer vision	Real-time analysis of endoscopic videos	Immediate feedback during procedures, increased detection rates of abnormalities	Detection of bleeding, polyps, and other abnormalities during live endoscopy procedures
Reinforcement learning	Optimizing treatment plans and clinical pathways	Adaptive learning from real-world outcomes, improved clinical decision-making	Personalized treatment strategies for inflammatory bowel disease based on patient response
Predictive analytics	Forecasting disease progression and patient outcomes	Proactive patient management, early intervention	Predicting flare-ups in Crohn's disease, forecasting outcomes after gastrointestinal surgeries
Robotics integration	Enhancing precision in minimally invasive surgeries	Increased surgical precision, reduced recovery time	AI-assisted robotic surgery for gastrointestinal procedures, such as robotic-assisted colectomy
Genomic data analysis	Identifying genetic markers associated with gastrointestinal diseases	Personalized medicine, targeted therapies	Analyzing genetic data to find markers for conditions like Lynch syndrome and hereditary pancreatitis

AI: Artificial intelligence.

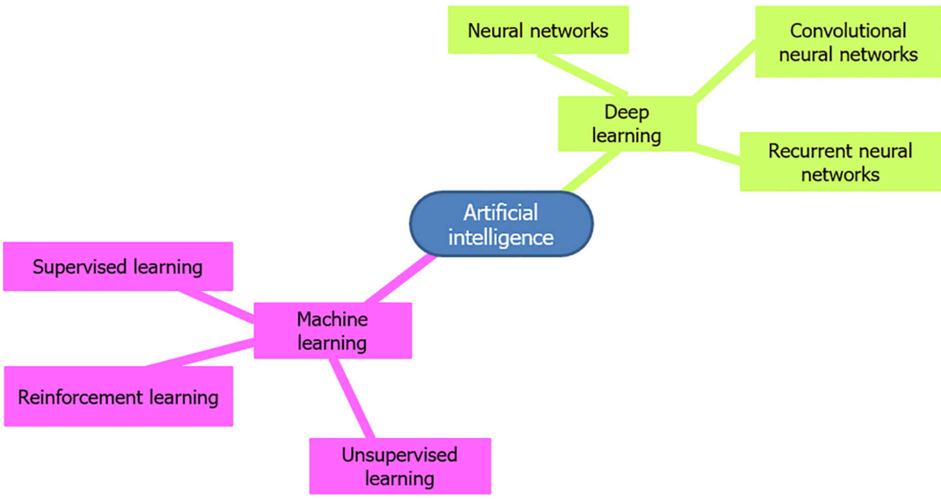

Figure 5 Main artificial intelligence-based algorithms for use in gastrointestinal pathology.

models often outperform traditional ML models in sensitivity and specificity due to their ability to learn intricate features from large datasets. However, there is a trade-off; models with high sensitivity might produce more false positives, reducing specificity. Balancing these metrics is essential to avoid misdiagnoses and unnecessary treatments[74,76,81,82].

CHALLENGES AND FUTURE PROSPECTS

AI is still in its early stages, and many pathology laboratories worldwide have yet to transition to a digital workflow to fully benefit from AI technologies. There are numerous obstacles to the widespread implementation of AI solutions in routine clinical practice, even in developed countries. Bringing an AI solution for pathology to market poses significant technological, business, and regulatory challenges. Although some clinical applications exist, the overall introduction of AI into medical practice has been slow and not without ethical concerns[86-90].

Despite significant research developments in AI-based techniques in recent years, only a few AI solutions have become commercial products for routine use. Consequently, much of the potential of AI remains untapped. Research models need further development, improvement, and integration into the information technology infrastructure of clinical laboratories before they can be used in routine pathology workflows. Additionally, commercial success requires a profitable business model in most countries, and pathologists need to be reimbursed for using the product. AI solutions are also classified as medical devices and thus require regulatory approval before they can be sold as products[91-94].

CONCLUSION

The role and scope of AI are expanding in GI pathology, with the potential to improve diagnostic accuracy, efficiency, and patient care. Increasing awareness among the pathology community about these emerging technologies is essential to realize their full potential and revolutionize diagnostics, prognostics, and theranostics in GI pathology.

FOOTNOTES

Author contributions: Mubarak M and Rashid R designed the research study and wrote the manuscript; Mubarak M, Rashid R, Sapna F, and Shakeel S performed the research; All authors contributed equally to this work, and read and approved the final manuscript.

Conflict-of-interest statement: All the authors report no relevant conflicts of interest for this article.

Country of origin: Pakistan

ORCID number: Muhammed Mubarak 0000-0001-6120-5884; Rahma Rashid 0000-0002-9332-2644; Fnu Sapna 0000-0002-7968-5027; Shaheera Shakeel 0000-0002-0142-6682.

S-Editor: Wang JJ
L-Editor: Filipodia
P-Editor: Yu HG

REFERENCES

1 **Mubarak M**. From Digital to Computational Pathology and Integrated Diagnostics: The Future of Histopathology. *J Coll Physicians Surg Pak* 2021; **31**: 2-3 [PMID: 33546524 DOI: 10.29271/jcpsp.2021.01.2]

2 **Pantanowitz L**, Sharma A, Carter AB, Kurc T, Sussman A, Saltz J. Twenty Years of Digital Pathology: An Overview of the Road Travelled, What is on the Horizon, and the Emergence of Vendor-Neutral Archives. *J Pathol Inform* 2018; **9**: 40 [PMID: 30607307 DOI: 10.4103/jpi.jpi_69_18]

3 **Kumar N**, Gupta R, Gupta S. Whole Slide Imaging (WSI) in Pathology: Current Perspectives and Future Directions. *J Digit Imaging* 2020; **33**: 1034-1040 [PMID: 32468487 DOI: 10.1007/s10278-020-00351-z]

4 **Boyce BF**. Whole slide imaging: uses and limitations for surgical pathology and teaching. *Biotech Histochem* 2015; **90**: 321-330 [PMID: 25901738 DOI: 10.3109/10520295.2015.1033463]

5 **Jahn SW**, Plass M, Moinfar F. Digital Pathology: Advantages, Limitations and Emerging Perspectives. *J Clin Med* 2020; **9** [PMID: 33217963 DOI: 10.3390/jcm9113697]

6 **Kiran N**, Sapna F, Kiran F, Kumar D, Raja F, Shiwlani S, Paladini A, Sonam F, Bendari A, Perkash RS, Anjali F, Varrassi G. Digital Pathology: Transforming Diagnosis in the Digital Age. *Cureus* 2023; **15**: e44620 [PMID: 37799211 DOI: 10.7759/cureus.44620]

7 **Yilmaz F**, Brickman A, Najdawi F, Yakirevich E, Egger R, Resnick MB. Advancing Artificial Intelligence Integration Into the Pathology Workflow: Exploring Opportunities in Gastrointestinal Tract Biopsies. *Lab Invest* 2024; **104**: 102043 [PMID: 38431118 DOI: 10.1016/j.labinv.2024.102043]

8 **Hanna MG**, Parwani A, Sirintrapun SJ. Whole Slide Imaging: Technology and Applications. *Adv Anat Pathol* 2020; **27**: 251-259 [PMID: 32452840 DOI: 10.1097/PAP.0000000000000273]

9 **Iyengar JN**. Whole slide imaging: The futurescape of histopathology. *Indian J Pathol Microbiol* 2021; **64**: 8-13 [PMID: 33433403 DOI: 10.4103/IJPM.IJPM_356_20]

10 **Jain E**, Patel A, Parwani AV, Shafi S, Brar Z, Sharma S, Mohanty SK. Whole Slide Imaging Technology and Its Applications: Current and Emerging Perspectives. *Int J Surg Pathol* 2024; **32**: 433-448 [PMID: 37437093 DOI: 10.1177/10668969231185089]

11 **Volynskaya Z**, Evans AJ, Asa SL. Clinical Applications of Whole-slide Imaging in Anatomic Pathology. *Adv Anat Pathol* 2017; **24**: 215-221 [PMID: 28590953 DOI: 10.1097/PAP.0000000000000153]

12 **Pantanowitz L**, Sinard JH, Henricks WH, Fatheree LA, Carter AB, Contis L, Beckwith BA, Evans AJ, Lal A, Parwani AV; College of American Pathologists Pathology and Laboratory Quality Center. Validating whole slide imaging for diagnostic purposes in pathology: guideline from the College of American Pathologists Pathology and Laboratory Quality Center. *Arch Pathol Lab Med* 2013; **137**: 1710-1722

[PMID: 23634907 DOI: 10.5858/arpa.2013-0093-CP]
13 **Zehra T**, Parwani A, Abdul-Ghafar J, Ahmad Z. A suggested way forward for adoption of AI-Enabled digital pathology in low resource organizations in the developing world. *Diagn Pathol* 2023; **18**: 68 [PMID: 37202805 DOI: 10.1186/s13000-023-01352-6]
14 **Mubarak M**. Move from Traditional Histopathology to Digital and Computational Pathology: Are we Ready? *Indian J Nephrol* 2022; **32**: 414-415 [PMID: 36568597 DOI: 10.4103/ijn.IJN_508_20]
15 **Schüffler P**, Steiger K, Weichert W. How to use AI in pathology. *Genes Chromosomes Cancer* 2023; **62**: 564-567 [PMID: 37254901 DOI: 10.1002/gcc.23178]
16 **Bera K**, Schalper KA, Rimm DL, Velcheti V, Madabhushi A. Artificial intelligence in digital pathology - new tools for diagnosis and precision oncology. *Nat Rev Clin Oncol* 2019; **16**: 703-715 [PMID: 31399699 DOI: 10.1038/s41571-019-0252-y]
17 **Ahmad Z**, Rahim S, Zubair M, Abdul-Ghafar J. Artificial intelligence (AI) in medicine, current applications and future role with special emphasis on its potential and promise in pathology: present and future impact, obstacles including costs and acceptance among pathologists, practical and philosophical considerations. A comprehensive review. *Diagn Pathol* 2021; **16**: 24 [PMID: 33731170 DOI: 10.1186/s13000-021-01085-4]
18 **Yang YC**, Islam SU, Noor A, Khan S, Afsar W, Nazir S. Influential Usage of Big Data and Artificial Intelligence in Healthcare. *Comput Math Methods Med* 2021; **2021**: 5812499 [PMID: 34527076 DOI: 10.1155/2021/5812499]
19 **Försch S**, Klauschen F, Hufnagl P, Roth W. Artificial Intelligence in Pathology. *Dtsch Arztebl Int* 2021; **118**: 194-204 [PMID: 34024323 DOI: 10.3238/arztebl.m2021.0011]
20 **Berezowska S**, Cathomas G, Grobholz R, Henkel M, Jochum W, Koelzer VH, Kreutzfeldt M, Mertz KD, Rössle M, Soldini D, Zlobec I, Janowczyk A. Digital image analysis and artificial intelligence in pathology diagnostics-the Swiss view. *Pathologie (Heidelb)* 2023; **44**: 222-224 [PMID: 37987817 DOI: 10.1007/s00292-023-01262-w]
21 **Jiang Y**, Yang M, Wang S, Li X, Sun Y. Emerging role of deep learning-based artificial intelligence in tumor pathology. *Cancer Commun (Lond)* 2020; **40**: 154-166 [PMID: 32277744 DOI: 10.1002/cac2.12012]
22 **Serag A**, Ion-Margineanu A, Qureshi H, McMillan R, Saint Martin MJ, Diamond J, O'Reilly P, Hamilton P. Translational AI and Deep Learning in Diagnostic Pathology. *Front Med (Lausanne)* 2019; **6**: 185 [PMID: 31632973 DOI: 10.3389/fmed.2019.00185]
23 **Sultan AS**, Elgharib MA, Tavares T, Jessri M, Basile JR. The use of artificial intelligence, machine learning and deep learning in oncologic histopathology. *J Oral Pathol Med* 2020; **49**: 849-856 [PMID: 32449232 DOI: 10.1111/jop.13042]
24 **Sharma P**, Hassan C. Artificial Intelligence and Deep Learning for Upper Gastrointestinal Neoplasia. *Gastroenterology* 2022; **162**: 1056-1066 [PMID: 34902362 DOI: 10.1053/j.gastro.2021.11.040]
25 **Baxi V**, Edwards R, Montalto M, Saha S. Digital pathology and artificial intelligence in translational medicine and clinical practice. *Mod Pathol* 2022; **35**: 23-32 [PMID: 34611303 DOI: 10.1038/s41379-021-00919-2]
26 **Rajpurkar P**, Chen E, Banerjee O, Topol EJ. AI in health and medicine. *Nat Med* 2022; **28**: 31-38 [PMID: 35058619 DOI: 10.1038/s41591-021-01614-0]
27 **Polevikov S**. Advancing AI in healthcare: A comprehensive review of best practices. *Clin Chim Acta* 2023; **548**: 117519 [PMID: 37595864 DOI: 10.1016/j.cca.2023.117519]
28 **Rahman A**, Jahangir C, Lynch SM, Alattar N, Aura C, Russell N, Lanigan F, Gallagher WM. Advances in tissue-based imaging: impact on oncology research and clinical practice. *Expert Rev Mol Diagn* 2020; **20**: 1027-1037 [PMID: 32510287 DOI: 10.1080/14737159.2020.1770599]
29 **Corti C**, Cobanaj M, Dee EC, Criscitiello C, Tolaney SM, Celi LA, Curigliano G. Artificial intelligence in cancer research and precision medicine: Applications, limitations and priorities to drive transformation in the delivery of equitable and unbiased care. *Cancer Treat Rev* 2023; **112**: 102498 [PMID: 36527795 DOI: 10.1016/j.ctrv.2022.102498]
30 **Huang Z**, Shao W, Han Z, Alkashash AM, De la Sancha C, Parwani AV, Nitta H, Hou Y, Wang T, Salama P, Rizkalla M, Zhang J, Huang K, Li Z. Artificial intelligence reveals features associated with breast cancer neoadjuvant chemotherapy responses from multi-stain histopathologic images. *NPJ Precis Oncol* 2023; **7**: 14 [PMID: 36707660 DOI: 10.1038/s41698-023-00352-5]
31 **Chan HP**, Samala RK, Hadjiiski LM, Zhou C. Deep Learning in Medical Image Analysis. *Adv Exp Med Biol* 2020; **1213**: 3-21 [PMID: 32030660 DOI: 10.1007/978-3-030-33128-3_1]
32 **Bergquist M**, Rolandsson B, Gryska E, Laesser M, Hoefling N, Heckemann R, Schneiderman JF, Björkman-Burtscher IM. Trust and stakeholder perspectives on the implementation of AI tools in clinical radiology. *Eur Radiol* 2024; **34**: 338-347 [PMID: 37505245 DOI: 10.1007/s00330-023-09967-5]
33 **Kim I**, Kang K, Song Y, Kim TJ. Application of Artificial Intelligence in Pathology: Trends and Challenges. *Diagnostics (Basel)* 2022; **12** [PMID: 36428854 DOI: 10.3390/diagnostics12112794]
34 **Cheng JY**, Abel JT, Balis UGJ, McClintock DS, Pantanowitz L. Challenges in the Development, Deployment, and Regulation of Artificial Intelligence in Anatomic Pathology. *Am J Pathol* 2021; **191**: 1684-1692 [PMID: 33245914 DOI: 10.1016/j.ajpath.2020.10.018]
35 **Hanna MG**, Ardon O, Reuter VE, Sirintrapun SJ, England C, Klimstra DS, Hameed MR. Integrating digital pathology into clinical practice. *Mod Pathol* 2022; **35**: 152-164 [PMID: 34599281 DOI: 10.1038/s41379-021-00929-0]
36 **Kelleher M**, Colling R, Browning L, Roskell D, Roberts-Gant S, Shah KA, Hemsworth H, White K, Rees G, Dolton M, Soares MF, Verrill C. Department Wide Validation in Digital Pathology-Experience from an Academic Teaching Hospital Using the UK Royal College of Pathologists' Guidance. *Diagnostics (Basel)* 2023; **13** [PMID: 37443538 DOI: 10.3390/diagnostics13132144]
37 **Ardon O**, Klein E, Manzo A, Corsale L, England C, Mazzella A, Geneslaw L, Philip J, Ntiamoah P, Wright J, Sirintrapun SJ, Lin O, Elenitoba-Johnson K, Reuter VE, Hameed MR, Hanna MG. Digital pathology operations at a tertiary cancer center: Infrastructure requirements and operational cost. *J Pathol Inform* 2023; **14**: 100318 [PMID: 37811334 DOI: 10.1016/j.jpi.2023.100318]
38 **Codipilly DC**, Faghani S, Hagan C, Lewis J, Erickson BJ, Iyer PG. The Evolving Role of Artificial Intelligence in Gastrointestinal Histopathology: An Update. *Clin Gastroenterol Hepatol* 2024; **22**: 1170-1180 [PMID: 38154727 DOI: 10.1016/j.cgh.2023.11.044]
39 **Lujan GM**, Savage J, Shana'ah A, Yearsley M, Thomas D, Allenby P, Otero J, Limbach AL, Cui X, Scarl RT, Hardy T, Sheldon J, Plaza JA, Whitaker B, Frankel W, Parwani AV, Li Z. Digital Pathology Initiatives and Experience of a Large Academic Institution During the Coronavirus Disease 2019 (COVID-19) Pandemic. *Arch Pathol Lab Med* 2021; **145**: 1051-1061 [PMID: 33946103 DOI: 10.5858/arpa.2020-0715-SA]
40 **Shafi S**, Parwani AV. Artificial intelligence in diagnostic pathology. *Diagn Pathol* 2023; **18**: 109 [PMID: 37784122 DOI: 10.1186/s13000-023-01375-z]
41 **Janowczyk A**, Zlobec I, Walker C, Berezowska S, Huschauer V, Tinguely M, Kupferschmid J, Mallet T, Merkler D, Kreutzfeldt M, Gasic R,

Rau TT, Mazzucchelli L, Eyberg I, Cathomas G, Mertz KD, Koelzer VH, Soldini D, Jochum W, Rössle M, Henkel M, Grobholz R; Swiss Digital Pathology Consortium. Swiss digital pathology recommendations: results from a Delphi process conducted by the Swiss Digital Pathology Consortium of the Swiss Society of Pathology. *Virchows Arch* 2024; **485**: 13-30 [PMID: 38112792 DOI: 10.1007/s00428-023-03712-5]

42 **Boyce BF**. An update on the validation of whole slide imaging systems following FDA approval of a system for a routine pathology diagnostic service in the United States. *Biotech Histochem* 2017; **92**: 381-389 [PMID: 28836859 DOI: 10.1080/10520295.2017.1355476]

43 **Rakha EA**, Vougas K, Tan PH. Digital Technology in Diagnostic Breast Pathology and Immunohistochemistry. *Pathobiology* 2022; **89**: 334-342 [PMID: 34969036 DOI: 10.1159/000521149]

44 **Ibrahim A**, Gamble P, Jaroensri R, Abdelsamea MM, Mermel CH, Chen PC, Rakha EA. Artificial intelligence in digital breast pathology: Techniques and applications. *Breast* 2020; **49**: 267-273 [PMID: 31935669 DOI: 10.1016/j.breast.2019.12.007]

45 **Baydoun A**, Jia AY, Zaorsky NG, Kashani R, Rao S, Shoag JE, Vince RA Jr, Bittencourt LK, Zuhour R, Price AT, Arsenault TH, Spratt DE. Artificial intelligence applications in prostate cancer. *Prostate Cancer Prostatic Dis* 2024; **27**: 37-45 [PMID: 37296271 DOI: 10.1038/s41391-023-00684-0]

46 **Stenzinger A**, Alber M, Allgäuer M, Jurmeister P, Bockmayr M, Budczies J, Lennerz J, Eschrich J, Kazdal D, Schirmacher P, Wagner AH, Tacke F, Capper D, Müller KR, Klauschen F. Artificial intelligence and pathology: From principles to practice and future applications in histomorphology and molecular profiling. *Semin Cancer Biol* 2022; **84**: 129-143 [PMID: 33631297 DOI: 10.1016/j.semcancer.2021.02.011]

47 **da Silva LM**, Pereira EM, Salles PG, Godrich R, Ceballos R, Kunz JD, Casson A, Viret J, Chandarlapaty S, Ferreira CG, Ferrari B, Rothrock B, Raciti P, Reuter V, Dogdas B, DeMuth G, Sue J, Kanan C, Grady L, Fuchs TJ, Reis-Filho JS. Independent real-world application of a clinical-grade automated prostate cancer detection system. *J Pathol* 2021; **254**: 147-158 [PMID: 33904171 DOI: 10.1002/path.5662]

48 **Grobholz R**, Janowczyk A, Frei AL, Kreutzfeldt M, Koelzer VH, Zlobec I. National digital pathology projects in Switzerland: A 2023 update. *Pathologie (Heidelb)* 2023; **44**: 225-228 [PMID: 37987815 DOI: 10.1007/s00292-023-01259-5]

49 **McGenity C**, Randell R, Bellamy C, Burt A, Cratchley A, Goldin R, Hubscher SG, Neil DAH, Quaglia A, Tiniakos D, Wyatt J, Treanor D. Survey of liver pathologists to assess attitudes towards digital pathology and artificial intelligence. *J Clin Pathol* 2023; **77**: 27-33 [PMID: 36599660 DOI: 10.1136/jcp-2022-208614]

50 **Huang B**, Tian S, Zhan N, Ma J, Huang Z, Zhang C, Zhang H, Ming F, Liao F, Ji M, Zhang J, Liu Y, He P, Deng B, Hu J, Dong W. Accurate diagnosis and prognosis prediction of gastric cancer using deep learning on digital pathological images: A retrospective multicentre study. *EBioMedicine* 2021; **73**: 103631 [PMID: 34678610 DOI: 10.1016/j.ebiom.2021.103631]

51 **Iqbal MJ**, Javed Z, Sadia H, Qureshi IA, Irshad A, Ahmed R, Malik K, Raza S, Abbas A, Pezzani R, Sharifi-Rad J. Clinical applications of artificial intelligence and machine learning in cancer diagnosis: looking into the future. *Cancer Cell Int* 2021; **21**: 270 [PMID: 34020642 DOI: 10.1186/s12935-021-01981-1]

52 **Berbís MA**, Aneiros-Fernández J, Mendoza Olivares FJ, Nava E, Luna A. Role of artificial intelligence in multidisciplinary imaging diagnosis of gastrointestinal diseases. *World J Gastroenterol* 2021; **27**: 4395-4412 [PMID: 34366612 DOI: 10.3748/wjg.v27.i27.4395]

53 **Lino-Silva LS**, Xinaxtle DL. Artificial intelligence technology applications in the pathologic diagnosis of the gastrointestinal tract. *Future Oncol* 2020; **16**: 2845-2851 [PMID: 32892631 DOI: 10.2217/fon-2020-0678]

54 **Majidova K**, Handfield J, Kafi K, Martin RD, Kubinski R. Role of Digital Health and Artificial Intelligence in Inflammatory Bowel Disease: A Scoping Review. *Genes (Basel)* 2021; **12** [PMID: 34680860 DOI: 10.3390/genes12101465]

55 **Robertson AR**, Segui S, Wenzek H, Koulaouzidis A. Artificial intelligence for the detection of polyps or cancer with colon capsule endoscopy. *Ther Adv Gastrointest Endosc* 2021; **14**: 26317745211020277 [PMID: 34179779 DOI: 10.1177/26317745211020277]

56 **Antonelli G**, Gkolfakis P, Tziatzios G, Papanikolaou IS, Triantafyllou K, Hassan C. Artificial intelligence-aided colonoscopy: Recent developments and future perspectives. *World J Gastroenterol* 2020; **26**: 7436-7443 [PMID: 33384546 DOI: 10.3748/wjg.v26.i47.7436]

57 **Parasher G**, Wong M, Rawat M. Evolving role of artificial intelligence in gastrointestinal endoscopy. *World J Gastroenterol* 2020; **26**: 7287-7298 [PMID: 33362384 DOI: 10.3748/wjg.v26.i46.7287]

58 **Correia FP**, Lourenço LC. Artificial intelligence application in diagnostic gastrointestinal endoscopy - Deus ex machina? *World J Gastroenterol* 2021; **27**: 5351-5361 [PMID: 34539137 DOI: 10.3748/wjg.v27.i32.5351]

59 **Visaggi P**, de Bortoli N, Barberio B, Savarino V, Oleas R, Rosi EM, Marchi S, Ribolsi M, Savarino E. Artificial Intelligence in the Diagnosis of Upper Gastrointestinal Diseases. *J Clin Gastroenterol* 2022; **56**: 23-35 [PMID: 34739406 DOI: 10.1097/MCG.0000000000001629]

60 **Suzuki H**, Yoshitaka T, Yoshio T, Tada T. Artificial intelligence for cancer detection of the upper gastrointestinal tract. *Dig Endosc* 2021; **33**: 254-262 [PMID: 33222330 DOI: 10.1111/den.13897]

61 **Korbar B**, Olofson AM, Miraflor AP, Nicka CM, Suriawinata MA, Torresani L, Suriawinata AA, Hassanpour S. Deep Learning for Classification of Colorectal Polyps on Whole-slide Images. *J Pathol Inform* 2017; **8**: 30 [PMID: 28828201 DOI: 10.4103/jpi.jpi_34_17]

62 **Wei JW**, Suriawinata AA, Vaickus LJ, Ren B, Liu X, Lisovsky M, Tomita N, Abdollahi B, Kim AS, Snover DC, Baron JA, Barry EL, Hassanpour S. Evaluation of a Deep Neural Network for Automated Classification of Colorectal Polyps on Histopathologic Slides. *JAMA Netw Open* 2020; **3**: e203398 [PMID: 32324237 DOI: 10.1001/jamanetworkopen.2020.3398]

63 **Zha Y**, Xue C, Liu Y, Ni J, De La Fuente JM, Cui D. Artificial intelligence in theranostics of gastric cancer, a review. *Med Rev (2021)* 2023; **3**: 214-229 [PMID: 37789960 DOI: 10.1515/mr-2022-0042]

64 **Fraggetta F**, L'Imperio V, Ameisen D, Carvalho R, Leh S, Kiehl TR, Serbanescu M, Racoceanu D, Della Mea V, Polonia A, Zerbe N, Eloy C. Best Practice Recommendations for the Implementation of a Digital Pathology Workflow in the Anatomic Pathology Laboratory by the European Society of Digital and Integrative Pathology (ESDIP). *Diagnostics (Basel)* 2021; **11** [PMID: 34829514 DOI: 10.3390/diagnostics11112167]

65 **Calderaro J**, Kather JN. Artificial intelligence-based pathology for gastrointestinal and hepatobiliary cancers. *Gut* 2021; **70**: 1183-1193 [PMID: 33214163 DOI: 10.1136/gutjnl-2020-322880]

66 **Kather JN**, Calderaro J. Development of AI-based pathology biomarkers in gastrointestinal and liver cancer. *Nat Rev Gastroenterol Hepatol* 2020; **17**: 591-592 [PMID: 32620817 DOI: 10.1038/s41575-020-0343-3]

67 **Murchan P**, Ó'Brien C, O'Connell S, McNevin CS, Baird AM, Sheils O, Ó Broin P, Finn SP. Deep Learning of Histopathological Features for the Prediction of Tumour Molecular Genetics. *Diagnostics (Basel)* 2021; **11** [PMID: 34441338 DOI: 10.3390/diagnostics11081406]

68 **Acs B**, Rantalainen M, Hartman J. Artificial intelligence as the next step towards precision pathology. *J Intern Med* 2020; **288**: 62-81 [PMID: 32128929 DOI: 10.1111/joim.13030]

69 **Wang Y**, Hu C, Kwok T, Bain CA, Xue X, Gasser RB, Webb GI, Boussioutas A, Shen X, Daly RJ, Song J. DEMoS: a deep learning-based

ensemble approach for predicting the molecular subtypes of gastric adenocarcinomas from histopathological images. *Bioinformatics* 2022; **38**: 4206-4213 [PMID: 35801909 DOI: 10.1093/bioinformatics/btac456]

70 **Echle A**, Grabsch HI, Quirke P, van den Brandt PA, West NP, Hutchins GGA, Heij LR, Tan X, Richman SD, Krause J, Alwers E, Jenniskens J, Offermans K, Gray R, Brenner H, Chang-Claude J, Trautwein C, Pearson AT, Boor P, Luedde T, Gaisa NT, Hoffmeister M, Kather JN. Clinical-Grade Detection of Microsatellite Instability in Colorectal Tumors by Deep Learning. *Gastroenterology* 2020; **159**: 1406-1416.e11 [PMID: 32562722 DOI: 10.1053/j.gastro.2020.06.021]

71 **Chaudhary K**, Poirion OB, Lu L, Garmire LX. Deep Learning-Based Multi-Omics Integration Robustly Predicts Survival in Liver Cancer. *Clin Cancer Res* 2018; **24**: 1248-1259 [PMID: 28982688 DOI: 10.1158/1078-0432.CCR-17-0853]

72 **Liao H**, Long Y, Han R, Wang W, Xu L, Liao M, Zhang Z, Wu Z, Shang X, Li X, Peng J, Yuan K, Zeng Y. Deep learning-based classification and mutation prediction from histopathological images of hepatocellular carcinoma. *Clin Transl Med* 2020; **10**: e102 [PMID: 32536036 DOI: 10.1002/ctm2.102]

73 **Schmauch B**, Romagnoni A, Pronier E, Saillard C, Maillé P, Calderaro J, Kamoun A, Sefta M, Toldo S, Zaslavskiy M, Clozel T, Moarii M, Courtiol P, Wainrib G. A deep learning model to predict RNA-Seq expression of tumours from whole slide images. *Nat Commun* 2020; **11**: 3877 [PMID: 32747659 DOI: 10.1038/s41467-020-17678-4]

74 **Huang Z**, Johnson TS, Han Z, Helm B, Cao S, Zhang C, Salama P, Rizkalla M, Yu CY, Cheng J, Xiang S, Zhan X, Zhang J, Huang K. Deep learning-based cancer survival prognosis from RNA-seq data: approaches and evaluations. *BMC Med Genomics* 2020; **13**: 41 [PMID: 32241264 DOI: 10.1186/s12920-020-0686-1]

75 **Pandey D**, Onkara Perumal P. A scoping review on deep learning for next-generation RNA-Seq. data analysis. *Funct Integr Genomics* 2023; **23**: 134 [PMID: 37084004 DOI: 10.1007/s10142-023-01064-6]

76 **Wei JW**, Wei JW, Jackson CR, Ren B, Suriawinata AA, Hassanpour S. Automated Detection of Celiac Disease on Duodenal Biopsy Slides: A Deep Learning Approach. *J Pathol Inform* 2019; **10**: 7 [PMID: 30984467 DOI: 10.4103/jpi.jpi_87_18]

77 **Tomita N**, Abdollahi B, Wei J, Ren B, Suriawinata A, Hassanpour S. Attention-Based Deep Neural Networks for Detection of Cancerous and Precancerous Esophagus Tissue on Histopathological Slides. *JAMA Netw Open* 2019; **2**: e1914645 [PMID: 31693124 DOI: 10.1001/jamanetworkopen.2019.14645]

78 **Iizuka O**, Kanavati F, Kato K, Rambeau M, Arihiro K, Tsuneki M. Deep Learning Models for Histopathological Classification of Gastric and Colonic Epithelial Tumours. *Sci Rep* 2020; **10**: 1504 [PMID: 32001752 DOI: 10.1038/s41598-020-58467-9]

79 **Sharma H**, Zerbe N, Klempert I, Hellwich O, Hufnagl P. Deep convolutional neural networks for automatic classification of gastric carcinoma using whole slide images in digital histopathology. *Comput Med Imaging Graph* 2017; **61**: 2-13 [PMID: 28676295 DOI: 10.1016/j.compmedimag.2017.06.001]

80 **Xiao Y**, Wang S, Ling R, Song Y. Application of artificial neural network algorithm in pathological diagnosis and prognosis prediction of digestive tract malignant tumors. *Zhejiang Da Xue Xue Bao Yi Xue Ban* 2023; **52**: 243-248 [PMID: 37283110 DOI: 10.3724/zdxbyxb-2022-0569]

81 **Noorbakhsh J**, Farahmand S, Foroughi Pour A, Namburi S, Caruana D, Rimm D, Soltanieh-Ha M, Zarringhalam K, Chuang JH. Deep learning-based cross-classifications reveal conserved spatial behaviors within tumor histological images. *Nat Commun* 2020; **11**: 6367 [PMID: 33311458 DOI: 10.1038/s41467-020-20030-5]

82 **Kuntz S**, Krieghoff-Henning E, Kather JN, Jutzi T, Höhn J, Kiehl L, Hekler A, Alwers E, von Kalle C, Fröhling S, Utikal JS, Brenner H, Hoffmeister M, Brinker TJ. Gastrointestinal cancer classification and prognostication from histology using deep learning: Systematic review. *Eur J Cancer* 2021; **155**: 200-215 [PMID: 34391053 DOI: 10.1016/j.ejca.2021.07.012]

83 **Huang G**, Wang C, Fu X. Bidirectional deep neural networks to integrate RNA and DNA data for predicting outcome for patients with hepatocellular carcinoma. *Future Oncol* 2021; **17**: 4481-4495 [PMID: 34374301 DOI: 10.2217/fon-2021-0659]

84 **Qi L**, Liang JY, Li ZW, Xi SY, Lai YN, Gao F, Zhang XR, Wang DS, Hu MT, Cao Y, Xu LJ, Chan RCK, Xing BC, Wang X, Li YH. Deep learning-derived spatial organization features on histology images predicts prognosis in colorectal liver metastasis patients after hepatectomy. *iScience* 2023; **26**: 107702 [PMID: 37701575 DOI: 10.1016/j.isci.2023.107702]

85 **Wang JG**. Application and future perspectives of gastric cancer technology based on artificial intelligence. *Tzu Chi Med J* 2023; **35**: 148-151 [PMID: 37261305 DOI: 10.4103/tcmj.tcmj_305_22]

86 **Caputo A**, L'Imperio V, Merolla F, Girolami I, Leoni E, Della Mea V, Pagni F, Fraggetta F. The slow-paced digital evolution of pathology: lights and shadows from a multifaceted board. *Pathologica* 2023; **115**: 127-136 [PMID: 37387439 DOI: 10.32074/1591-951X-868]

87 **Tizhoosh HR**, Pantanowitz L. Artificial Intelligence and Digital Pathology: Challenges and Opportunities. *J Pathol Inform* 2018; **9**: 38 [PMID: 30607305 DOI: 10.4103/jpi.jpi_53_18]

88 **Browning L**, Jesus C, Malacrino S, Guan Y, White K, Puddle A, Alham NK, Haghighat M, Colling R, Birks J, Rittscher J, Verrill C. Artificial Intelligence-Based Quality Assessment of Histopathology Whole-Slide Images within a Clinical Workflow: Assessment of 'PathProfiler' in a Diagnostic Pathology Setting. *Diagnostics (Basel)* 2024; **14** [PMID: 38786288 DOI: 10.3390/diagnostics14100990]

89 **Yoshida H**, Kiyuna T. Requirements for implementation of artificial intelligence in the practice of gastrointestinal pathology. *World J Gastroenterol* 2021; **27**: 2818-2833 [PMID: 34135556 DOI: 10.3748/wjg.v27.i21.2818]

90 **Wong ANN**, He Z, Leung KL, To CCK, Wong CY, Wong SCC, Yoo JS, Chan CKR, Chan AZ, Lacambra MD, Yeung MHY. Current Developments of Artificial Intelligence in Digital Pathology and Its Future Clinical Applications in Gastrointestinal Cancers. *Cancers (Basel)* 2022; **14** [PMID: 35954443 DOI: 10.3390/cancers14153780]

91 **Giansanti D**. The Regulation of Artificial Intelligence in Digital Radiology in the Scientific Literature: A Narrative Review of Reviews. *Healthcare (Basel)* 2022; **10** [PMID: 36292270 DOI: 10.3390/healthcare10101824]

92 **Yao L**, Lu Z, Yang G, Zhou W, Xu Y, Guo M, Huang X, He C, Zhou R, Deng Y, Wu H, Chen B, Gong R, Zhang L, Zhang M, Gong W, Yu H. Development and validation of an artificial intelligence-based system for predicting colorectal cancer invasion depth using multi-modal data. *Dig Endosc* 2023; **35**: 625-635 [PMID: 36478234 DOI: 10.1111/den.14493]

93 **Abels E**, Pantanowitz L. Current State of the Regulatory Trajectory for Whole Slide Imaging Devices in the USA. *J Pathol Inform* 2017; **8**: 23 [PMID: 28584684 DOI: 10.4103/jpi.jpi_11_17]

94 **García-Rojo M**, De Mena D, Muriel-Cueto P, Atienza-Cuevas L, Domínguez-Gómez M, Bueno G. New European Union Regulations Related to Whole Slide Image Scanners and Image Analysis Software. *J Pathol Inform* 2019; **10**: 2 [PMID: 30783546 DOI: 10.4103/jpi.jpi_33_18]

Published by **Baishideng Publishing Group Inc**
7041 Koll Center Parkway, Suite 160, Pleasanton, CA 94566, USA
Telephone: +1-925-3991568
E-mail: office@baishideng.com
Help Desk: https://www.f6publishing.com/helpdesk
https://www.wjgnet.com