Front. Med. 2020, 14(4): 511–517
https://doi.org/10.1007/s11684-020-0742-4

COMMENTARY

Artificial intelligence in gastroenterology: where are we heading?

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Abstract **Artificial intelligence (AI) is coming to medicine in a big wave. From making diagnosis in various medical conditions, following the latest advancements in scientific literature, suggesting appropriate therapies, to predicting prognosis and outcome of diseases and conditions, AI is offering unprecedented possibilities to improve care for patients. Gastroenterology is a field that AI can make a significant impact. This is partly because the diagnosis of gastrointestinal conditions relies a lot on image-based investigations and procedures (endoscopy and radiology). AI-assisted image analysis can make accurate assessment and provide more information than conventional analysis. AI integration of genomic, epigenetic, and metagenomic data may offer new classifications of gastrointestinal cancers and suggest optimal personalized treatments. In managing relapsing and remitting diseases such as inflammatory bowel disease, irritable bowel syndrome, and peptic ulcer bleeding, convoluted neural network may formulate models to predict disease outcome, enhancing treatment efficacy. AI and surgical robots can also assist surgeons in conducting gastrointestinal operations. While the advancement and new opportunities are exciting, the responsibility and liability issues of AI-assisted diagnosis and management need much deliberations.**

Keywords artificial intelligence; endoscopy; robotics; gastrointestinal diseases

Background

The era of artificial intelligence (AI) has arrived in medicine, penetrating various specialties. Deep learning algorithms enable highly sensitive and specific diagnosis of diabetic retinopathy [1]. Breast cancer screening using mammography can be performed by machine-learning devices, saving much time for radiologists [2]. Automated classification of skin conditions using convoluted neural network (CNN) program in smart phones enables dermatologists to make vital diagnosis from a distance [3]. Neural network algorithms can detect polyps during colonoscopy, reducing the chance of missing such potentially malignant lesions [4]. AI may also facilitate physician–care manager–patient partnership in educating patients, checking compliance, and enhancing self-management in chronic diseases [5]. Increasingly, machine-learning devices can replace several time-consuming, labor-intensive, repetitive, and mundane tasks of clinicians.

Gastroenterology is a field that AI can make a significant impact. This is because diagnosis of gastrointestinal conditions relies much on image-based investigations (endoscopy and radiology). Taking digestive tract cancer as an example, AI-assisted image analysis aids the detection of gastrointestinal neoplasia during endoscopy, provides optical biopsy to determine the nature of lesions, integrates genomic and epigenetic data to provide new classification of cancers, and provides evidence-based suggestions for optimal therapies. Furthermore, AI-assisted surgical operations, through semi-automated and automated robotic surgery, will obviate some part of surgical procedures to be performed by surgeons.

AI-assisted endoscopy

AI has been proved to work well in assisting endoscopic examination of the gut with high sensitivity and specificity in detecting lesions such as polyps, bleeding, and

Received July 29, 2019; accepted December 18, 2019
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inflammatory lesions. Machines make less intra- and inter-observer variations and do not suffer from fatigue during visual examination, and their results often out-perform those of human endoscopists.

AI-assisted colonoscopy has already been used in clinical practice to identify and characterize polyps (Fig. 1). Byrne *et al*. demonstrated that their AI model for assessment of endoscopic video images of colorectal polyps can differentiate between hyperplastic polyps from adenomatous polyps with sensitivity of 98% and specificity of 83% [6]. Urban *et al*. designed and trained deep CNNs to detect polyps in archived video with a receiver operating characteristic (ROC) curve of 0.991 and accuracy of 96.4%. The total number of polyps identified is significantly higher than that of human endoscopists. However, most of the additional polyps found by CNN are small adenomas measuring 1–3 and 4–6 mm in size [7]. Wang *et al*. conducted an open, non-blinded trial with over 1000 patients prospectively [8]. By randomizing these patients to undergo diagnostic colonoscopy with or without AI assistance, they found that AI system increased adenoma detection rate from 20.3% to 29.1% and the mean number of adenomas per patients from 0.31 to 0.53. However, a higher number of diminutive polyps were found with no statistical difference in detecting advanced adenoma.

Furthermore, AI can assist in interpreting the image of polyps identified during endoscopy and can determine whether they are adenomatous or hyperplastic. Misawa *et al*. found that AI-assisted optical biopsy using the EndoBRAIN system can characterize polyps found with high accuracy by applying indigo carmine dye spray on the lesions and adding magnification to the endoscopic image [9]. If matching-assisted optical biopsy is found to be reliable, this technology will not only improve adenoma detection in colonoscopy but also reduces unnecessary polypectomy of lesions with no malignant potential, saving tremendous labor and cost. The advantage of AI-assisted polyp detection and characterization seems to be more prominent when used by inexperienced endoscopists [10]. This technology is now considered mature enough to be marketed for use in clinics and hospitals. The Japanese regulatory body is considering to grant approval for the use of AI-assisted colonoscopy in polyp detection and characterization in 2020 [11].

AI-assisted endoscopy has extended beyond detecting and characterizing colonic polyps. Using deep CNN, AI has been used to detect premalignant changes in the stomach and detect early gastric cancer, a diagnostic challenge that is even difficult for experienced endoscopists [12]. The average diagnostic time for AI in analyzing an endoscopic image is much shorter than that for human endoscopists, resulting in a higher sensitivity (65.6% vs. 31.9%) and positive predictive value (41.9% vs. 36.7%) in diagnosis of gastric cancers [13]. Furthermore, AI has been found to be useful in detecting gastroesophageal junction adenocarcinoma, a disease that is on the rise as a result of increasing prevalence of acid reflux disease [14]. Future development in AI-assisted endoscopy is on real-time detection and interpretation of such lesions.

Endoscopic assessment of depth of cancer invasion by AI-assisted programs is also starting to produce promising results. Tokai *et al*. used white light imaging and narrow-band imaging endoscopic picture to train the machine in differentiating superficial versus deep invasion of squamous cell carcinoma of the esophagus [15]. Their results showed that the CNN system can diagnose, within seconds, the invasion depth of esophageal cancers with accuracy of around 80%. The differentiation between malignant and non-malignant tissue has found another therapeutic application. By accurately defining the margin of endoscopic resection, Ichimasa *et al*. claimed that AI-assisted endoscopy will indicate the need for additional surgery after endoscopic resection of early colorectal cancers [16]. These studies, if validated, will greatly reduce the need for operative surgery in early cancers.

Fig. 1 AI-assisted colonoscopy is already used in daily clinical practice to find polyps.

The next frontier will be combining AI-assisted image analysis and surgical robots in surgery. Human–machine interface treatment research is undertaken in full gear. In the future, AI-assisted image analysis and surgical robots will work with human surgeons in carrying out sophisticated gastrointestinal operations (Fig. 2).

However, when AI-assisted endoscopy and surgery are put into daily use, who should take the responsibility of clinical decisions? When a malignant polyp is missed or misdiagnosed as benign hence left unresected, when the depth of invasion is assessed to be superficial and surgery is not offered, and when the resection margin of endoscopic dissection is wrongly assessed and follow-up operations are not performed, these scenarios might lead to disastrous outcomes or even medical–legal consequences. Where should medical liability rest on?

AI-assisted capsule endoscopy

Wireless capsule endoscopy (WCE) is a ground-breaking advancement allowing painless examination of the gut. WCE reaches the small intestine where conventional endoscopy is difficult. However, the reading of the WCE images is extremely time consuming, rendering the biggest obstacle in the use of this technology. Aoki *et al*. trained a deep CNN system based on Single Shot MultiBox Detector using thousands of WCE [17]. The trained CNN required only 233 s to evaluate 10 440 test images and found most of the erosions and ulcerations of the small bowels with an ROC curve of 0.958 (95% CI 0.947–0.968). The amount of time and energy saved for this procedure is remarkable, minimizing the chance of oversight and burden on the physicians. The use of CNN is now extended into identifying other lesions such as angioectasia, which might cause occult gastrointestinal bleeding [18].

AI-assisted prediction of clinical outcome

AI has another major potential in healthcare: to predict the clinical outcome of patients on the basis of clinical data set, genomic information, and medical images. Cardiologists have developed algorithms to assess the risk of cardiovascular disease and claimed that their prediction is superior to existing scoring systems [19]. By analyzing echocardiograms, deep CNN model claimed to predict the mortality of patients with heart failure [20]. Risk assessment and prediction of outcome have always been a challenge in public health and clinical medicine. Now, AI is offering a new direction to these challenges.

Hepatologists claim that one can predict which individual has developed non-alcoholic steatohepatitis (NASH) by using large data set from representative population. Bandaria *et al*. used a large electronic medical record data set that include extensive clinical claims data on patients seen in a variety of provider practice types across the United States [21]. They used a combination of sophisticated AI algorithms to characterize the likelihood that a patient who is not an ICD10 identified NASH is having such condition. The results seem remarkable.

Gastrointestinal bleeding still constitute one of the most common emergencies in hospitals that requires early endoscopy. Despite many clinical scoring systems being available, none of them have been widely used to predict clinical outcomes. Shung *et al*. developed and validated an AI model to predict the outcome of patients presenting

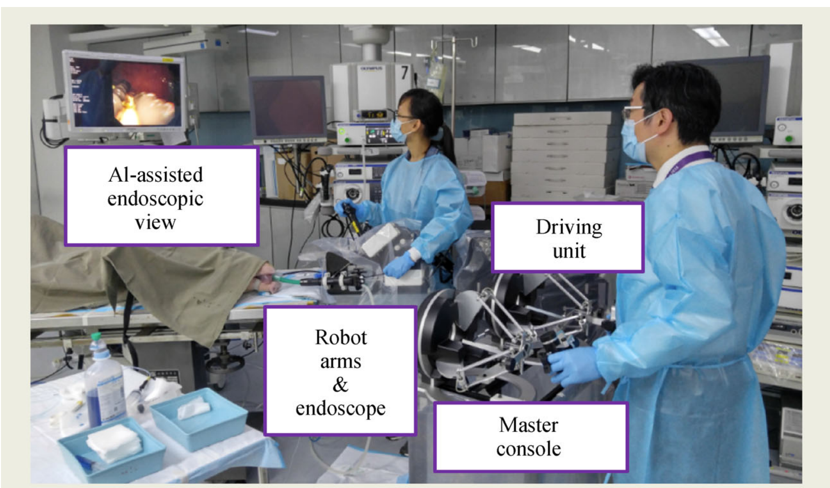

Fig. 2 Surgeon working with AI-assisted image and surgical robot in an animal model study.

with upper gastrointestinal bleeding [22]. They compared the machine learning score with the existing clinical risk scores in predicting clinical outcomes. Their machine learning model outperformed Glasgow–Blatchford score and Rockall score.

Combining genomic, epigenetic, and metagenomic data with biochemical parameters and lifestyle information will be a very powerful tool in medicine. The integration of various data sets in multi-layer informatics may be able to identify new insights into the prediction, prognostication, and prevention of diseases. This capability will offer new opportunities for personalized care. Precision medicine is no longer a concept or dream, it is a reality.

However, when a wrong diagnosis is made (and a patient is given inappropriate treatment) and when the prediction and prognostication are inaccurate (and a patient receives unnecessary or inappropriate therapy), who should take the responsibility? Should it be the manufacturer of the AI device, or should it be the physician who is supposed to be in charge of the patient [23]?

AI and robotics may be developed beyond human control

Traditionally, the attending clinician is the primary defendant in a clinical negligence or malpractice lawsuit. Up to now, AI-assisted image analysis and machine-learning neural network in diagnosis and prediction of disease progress merely offer an "opinion," facilitating decision-making in clinical management. The clinician still has full discretion on accepting or rejecting these diagnoses and opinions. Similarly, to date, endoscopic or surgical robots only perform relatively simple procedures and possess little autonomy and decision-making authority in an operation. The endoscopist or surgeon still has full control over the operation and is able to take over the operation from AI-assisted endoscopes or robots. Insofar as the decision-making process still rests upon the attending clinician, existing laws (common law tort of negligence, contract, and relevant legislative provisions) are adequate and sufficient to protect those who suffer from adverse outcomes.

However, scientists and engineers are making significant advancement in AI-assisted procedures: from no-autonomy robot assistant to task autonomy or conditional autonomy and, eventually, full automation. Self-learning machines will be able to directly process unpredictable and independent tasks. There may be circumstances where human clinicians are unable to control or override these procedures made by AI devices [24].

This technological shift will soon compel us to reconsider aspects of clinical liability in the event of inaccurate or delayed diagnosis. Neither the AI developer nor the attending clinician may be able to fully understand how the machine comes up with the diagnosis or prognosis decisions. On the other hand, following gradual stepping up of machine automation in endoscopy, interventional radiology, or surgical operations and correspondingly declining control of the endoscopist/radiologist/surgeon, the current legal position, whereby the clinician is primarily liable for inaccurate or delayed diagnosis or treatment caused by malfunctions of AI software, becomes more strained. However, legal academics and lawmakers have not reached common consensus on the allocation and scope of liability — between clinicians, healthcare organizations, and AI developers.

Who has the responsibility?

In the event of an adverse outcome involving the use of AI, a significant determinant under general tort law principles is the degree of control of the attending clinician and the AI-assisted device in the incident. Subject to legislative enactments, if the clinician or AI developer is found to possess the capacity to reasonably prevent the accident, legal liability will likely be concluded. The automobile industry of self-driving car is a good illustration of this [25].

Legal implications vary across different levels of autonomy in medicine. Traditionally, diagnosis is based on clinical skills of the physician who also determines the mode of therapy, hence naturally taking full responsibility of the case. When diagnosis and treatment decisions are made by machines on the basis of sophisticated self-learned algorithm and clinician approval is not required, liability will, at least partially, be attached to the AI developer. Upon the stage of fully automated endoscopic/robotic surgery, adverse events caused by a defect in the robot's configuration, design, and quality control of programs — matters that are outside the scope of clinician's expertise — it is likely to be the developer's responsibility in a product liability claim [26] (Fig. 3).

AI developers are usually best positioned to control risk and balance between benefits and cost of technology. Having said that, it will not make practical sense to hold the AI developer liable simply because their AI devices are not able to prevent harm in every single instance. In the past, courts are reluctant to extend product liability theories to software developers, particularly in the context of healthcare usage. Excessive liability will not only be against tort law principles but will also delay and discourage innovation and technological development.

The legal position is not at all straightforward. If it is found that the attending clinician should have taken reasonable steps to discharge his/her duty of care to the patients in the event of an AI failure, he/she may be held

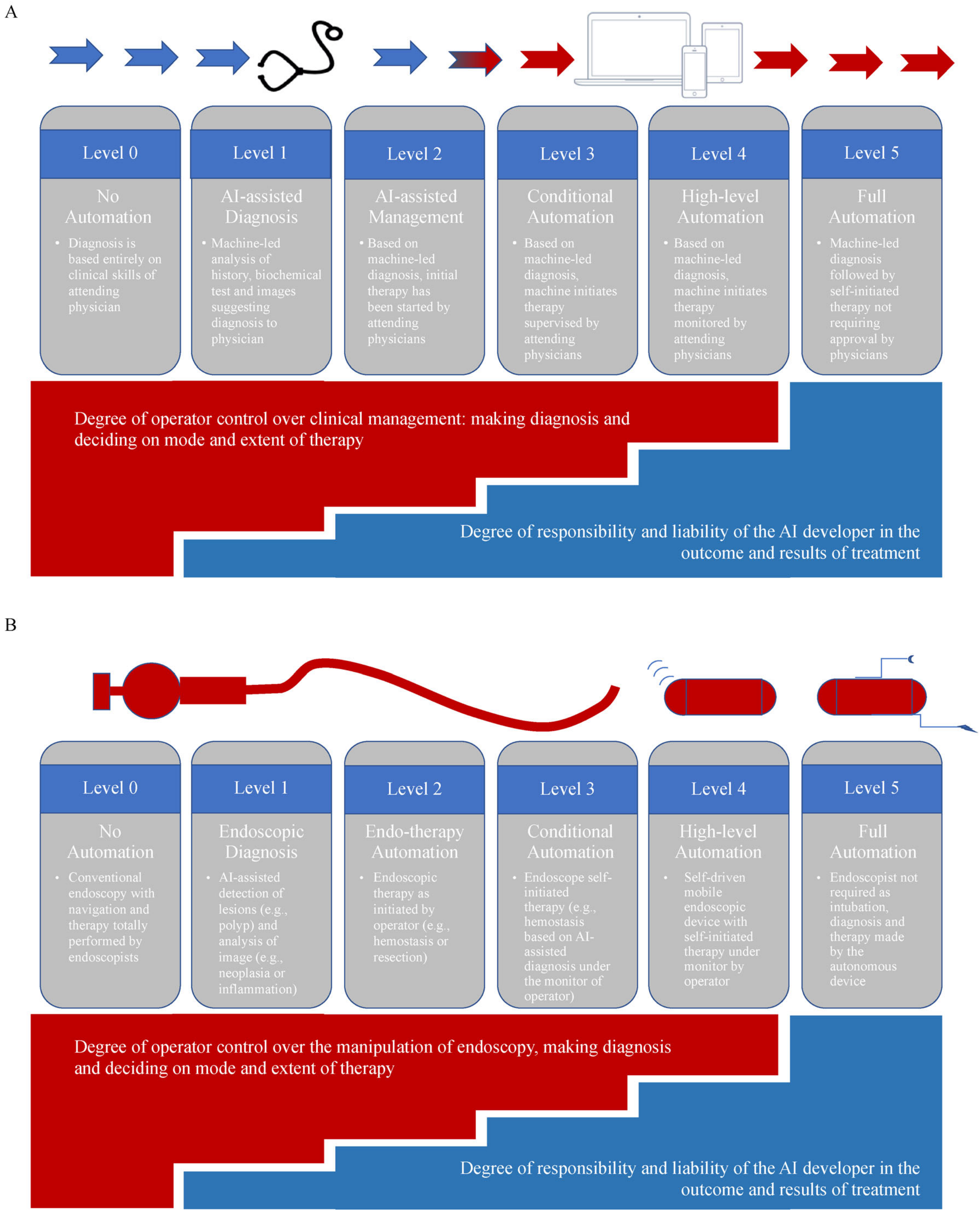

Fig. 3 Levels of AI-assisted decision in diagnosis and clinical management (A), AI automation in endoscopic procedures (B), and possible share of responsibility.

concurrently liable. Complete reliance on an AI device may be unreasonable. Appropriate amount of care of gastroenterologists in the context of using AI devices is required. A negligence assessment will focus on whether the clinician's act shows a lack of due care under such circumstances. It is a balancing task between protecting patients' well-being and ensuring efficiency and accuracy of medical outcomes.

In assessing liability, two major aspects of the case will be relevant for the court's deliberations, namely, the circumstances of the accident and the conditions of the AI device. Issues such as who is in control of the AI device and whether the users are provided with adequate information about the device and ask to take over the control when situation arises are crucial in the judgement. On the other hand, the conditions of the AI device, including the design and manufacturing process, quality control, maintenance, and undue modification of the device, would be examined.

Conclusions

AI will make a paradigm shift in medicine. This technological advancement is expanding rapidly in gastroenterology and gastrointestinal surgery. Researchers should continue to work on new AI technology and human–machine interface to improve diagnostic and prognostic accuracy. However, we should aim at developing AI-assisted medicine, instead of AI-driven medicine.

Compliance with ethics guidelines

Joseph JY Sung and Nicholas CH Poon declare that they have no conflict of interest. This manuscript is a commentary article and does not involve a research protocol requiring approval of a relevant institutional review board or ethics committee. The article does not contain any studies with human or animal subjects.

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