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## Artificial intelligence in small intestinal diseases: Application and prospects

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### Abstract

The small intestine is located in the middle of the gastrointestinal tract, so small intestinal diseases are more difficult to diagnose than other gastrointestinal diseases. However, with the extensive application of artificial intelligence in the field of small intestinal diseases, with its efficient learning capacities and computational power, artificial intelligence plays an important role in the auxiliary diagnosis and prognosis prediction based on the capsule endoscopy and other examination methods, which improves the accuracy of diagnosis and prediction and reduces the workload of doctors. In this review, a comprehensive retrieval was performed on articles published up to October 2020 from PubMed and other databases. Thereby the application status of artificial intelligence in small intestinal diseases was systematically introduced, and the challenges and prospects in this field were also analyzed.

**Key Words:** Artificial intelligence; Machine learning; Deep learning; Prognosis prediction; Small intestinal diseases

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**Core Tip:** Artificial intelligence has been widely used in the management of small intestinal diseases, which has greatly improved the diagnostic efficiency of capsule

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endoscopy and other examination methods, and at the same time, beneficial progression has also been obtained in the prognosis prediction of small intestinal diseases. Although AI still faces risks such as overfitting and black box effects, its stability and efficiency give it great potential in the management of small intestinal diseases. This article reviews the current application status of AI in small intestinal diseases. In addition, challenges and prospects in this field are discussed.

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## INTRODUCTION

The small intestine is located in the middle of the gastrointestinal digestive system, with a total length of 5 m to 7 m, including the duodenum, jejunum and ileum, and is the longest organ of the digestive system. Small intestinal diseases (SIDs) mainly include celiac disease (CD), small intestinal Crohn's disease (SICD), primary small intestinal tumor (PSIT), obscure gastrointestinal bleeding and so on. The traditional examination methods include X-ray barium enterography, computed tomography (CT), magnetic resonance imaging (MRI), balloon-assisted enteroscopy, deep enteroscopy and so on. In recent years, the emergence of capsule endoscopy (CE) has brought a revolutionary breakthrough for the diagnosis of SIDs. However, because of the special anatomical position of the small intestine (far away from the oral cavity and anus, overlap and peristalsis), there are still many problems in the diagnosis of SIDs, such as high technical requirements, low positive rate of diagnosis, inaccurate qualitative location of the disease, patient intolerance and so on. In addition, the onset of SIDs is insidious, the specificity of clinical symptoms is low, and the lesion site is not easy to explore, so the clinical diagnosis of SIDs has always been a difficult problem. With the emergence of artificial intelligence (AI) and its wide application in the medical field, it also provides new methods for the whole management process of SIDs and greatly improves the efficiency of SIDs management.

AI is a concept put forward in the 1950s. It is a frontier cross discipline developed on the basis of computer science, neuropsychology, philosophy, linguistics, cybernetics, information theory and so on[1]. The research fields of AI include expert system, machine learning (ML), fuzzy logic, natural language processing and so on. Research methods are also developing continuously, from ML to deep learning and then to convolutional neural network (CNN), promoting the rapid development of research in various fields. The research of AI in the medical field is mainly focused on auxiliary diagnosis. This series of methods of AI has become a hot implementation tool in the field of medical imaging and digestive endoscope[2,3]. Taking the experiment of the breast cancer AI detection system established by Google as an example, the computer-aided diagnosis system based on AI can help doctors reduce the misdiagnosis rate of breast cancer by 5.7%[4]. Researchers at Houston Methodist Hospital also said in their study that they have developed AI software that parses breast X-ray images 30 times faster than ordinary doctors, with an accuracy of 99%[5]. AI is widely used in the study of digestive fields such as gastric cancer[6], colorectal cancer[7], esophageal cancer[8] and so on. AI has also been extensively researched in the field of SIDs, which will be introduced in this paper.

This study used the keywords of "artificial intelligence" and "small intestine" to search the relevant literature in the databases of PubMed, Embase, Web of Science and Cochrane Library up to October 2020. Studies included in our review were required to meet the following inclusion criteria: (1) full-text paper available in English; and (2) studies that associated AI with the small intestinal diseases. We excluded descriptive papers without validation of methods. The application status of AI in SIDs was summarized, and the challenges and prospects in this field were discussed.



## AI IN SMALL INTESTINE ANATOMY

### **Organ segmentation of the small intestine**

With the advent of AI, it is possible to perform computer-assisted organ segmentation in CT, MRI, endoscopy and other examination methods and has shown good application potential in the fields like assisted localization of radiotherapy. The following will introduce the research progress of this aspect in the field of the small intestine especially the duodenum (Table 1).

**CT:** Some studies had used the CNN method to automatically segment duodenum and other abdominal organs from CT images, with clinically acceptable accuracy and efficiency[9,10]. Tong *et al*[11] proposed an end-to-end segmentation network for improving multiorgan segmentation performance using the ML method. The dice similarity coefficient and average surface distance were quantitatively evaluated, and the results confirmed this network had good accuracy and timeliness in the anatomical segmentation of abdominal organs including the duodenum.

**MRI:** Fu *et al*[12] conducted a retrospective analysis on 3D MR images of 120 patients and proposed a CNN model, which has been verified to accurately segment the abdominal organs including the duodenum and expedite the contouring process for MRI-guided adaptive radiotherapy. Chen *et al*[13] also conducted a similar study, and in their study, the inference process was completed within 1 min, indicating an obvious advantage of timeliness. The length of the small intestine is an important factor in the management of patients with short bowel syndrome. Some scholars designed a special software algorithm to calculate the length of small intestine based on magnetic resonance enterography images in mice. Compared with the measured results of anatomical specimens, the mean absolute difference between the two methods was  $1.8 \pm 3.8$  cm ( $P = 0.24$ ), and the mean percentage difference was  $9.4\% \pm 6.0\%$ [14].

**Endoscopy:** In a Japanese study based on GoogLeNet architecture, a CNN diagnostic program was constructed, using 27335 esophagogastroduodenoscopy (EGD) images for the training set and using 17081 EGD images for the independent validation set. The results showed that the CNN has a good effect to classify the anatomical location of EGD images for stomach and duodenum images, with an area under the curve of 0.99[15]. Igarashi *et al*[16] used AlexNet (a deep learning framework) to retrospectively analyze 85246 original images of EGD images in 441 patients with gastric cancer and developed an anatomical organ classifier. The accuracy rates of the training and validation sets were 0.993 and 0.965, respectively.

### **Diagnosis of small intestinal mucosal lesions**

With the emergence of CE in 2000[17], it has revolutionized our understanding of small intestinal mucosa[18-20], enabling doctors to detect small intestinal mucosal erosion, ulcers, vascular disease, bleeding, polyps, parasite and other lesions more efficiently. However, reliable and rapid reading of video is still a challenge, but more and more studies have shown that the combination of AI and CE can greatly improve the efficiency of our evaluation of small intestinal mucosal lesions; the detection accuracy was above 90% in most studies[21-27].

**Ulcer:** Previous studies have confirmed that applying a CNN system of deep learning to the reading process of CE can reduce the reading time without decreasing the detection rate of erosion and ulcer lesions[28-32].

**Angioectasias and bleeding:** Intestinal angioectasias cause more than 8% of all gastrointestinal bleeding episodes[33]. Different studies have applied ML, CNN and computer algorithms to the differential diagnosis of intestinal angioectasias and have achieved high sensitivity and specificity[34-39]. AI is also applied to the direct examination of intestinal mucosal bleeding by CE, which can directly calculate the blood content in the digestive tract and infer whether there is active bleeding in the small intestinal mucosa[40-44].

**Protruding lesions:** There are a variety of small intestinal mucosal protruding lesions. CNN can help doctors describe their shape features, help analyze their nature and distinguish polyps, epithelial tumors, submucosal tumors, *etc.*[34,45,46].

**Villous atrophy:** Villous atrophy is a defining symptom of some digestive tract diseases such as CD. Some scholars combined AI methods with CE for the detection

**Table 1 Applications of artificial intelligence in organ segmentation of the small intestine**

Ref.	Diagnostic method	AI technology	Training set	Validating set	Outcomes
Tong <i>et al</i> [11]	CT	ML	90 images	-	DSC of duodenum: 69.26%
Kim <i>et al</i> [9]	CT	CNN	80 images	40 images	DSC of duodenum: 0.595
Peng <i>et al</i> [10]	CT	CNN	43 images	-	DSC of duodenum: 0.61
Fu <i>et al</i> [12]	MRI	CNN	100 images	20 images	Dice coefficient of duodenum: 65.50% ± 8.90%  Dice coefficient of bowel: 86.60% ± 2.69%
Chen <i>et al</i> [13]	MRI	DL	66 images	36 images	DSC of duodenum: 0.80
Takiyama <i>et al</i> [15]	EGD	CNN	27335 images	17081 images	AUCs: 0.99
Igarashi <i>et al</i> [16]	EGD	ML	49174 images	36072 images	Accuracy (Ts: 0.993, Vs: 0.965)

AI: Artificial intelligence; AUCs: Area under the curves; CNN: Convolutional neural network; CT: Computed Tomography; DL: Deep learning; DSC: Dice similarity coefficient; EGD: Esophagogastroduodenoscopy; ML: Machine learning; MRI: Magnetic resonance imaging; Ts: Training set; Vs: Validating set.

and measurement of villous atrophy and successfully mapped the extent of the diseased small intestine[47].

AI is also used in risk prediction and clinical treatment decisions of small intestinal mucosal lesions. For example, one study used CNN for the risk prediction of acute intestinal bleeding[48], and another study applied CNN to risk prediction and therapeutic tactics selection for duodenal ulcers[49]. Wong *et al*[50] built a ML model, based on data from 22854 patients with gastroduodenal ulcer including six clinical parameters to identify patients at high risk for recurrent ulcer bleeding within 1 year. Gastrointestinal bleeding is a common complication of left ventricular assist device treatment. Axelrad *et al*[51] developed an endoscopic algorithm. Compared with conventional cohorts, the implementation of the algorithm increased endoscopic diagnostic efficiency by 68%, treatment efficiency by 113%, the number of procedures per patient decreased by 27%, the length of hospital stay decreased by 33%, and the estimated cost decreased by 18%.

In addition, the interference of intestinal contents to CE can also be reduced by AI. Combined with support vector machine, Bashar *et al*[52] designed a classifier for separating useless frames that are highly contaminated by turbid fluids, fecal materials and/or residual foods. The accuracy of this classifier was more than 80%. Pietri *et al* [53] developed a computer algorithm to automatically evaluate the demeanor of small intestinal bubbles in CE images. The specificity of this algorithm was 95.79%, the sensitivity was 95.19%, and the calculation time was 0.037 s per frame. It can be used to reduce the interference of bubbles in CE images. Klein *et al*[54] created a computed algorithm based on the pixels in the color bar to score and classify the preparation of the small intestine for CE, and this automatic scoring method has a concordance rate of more than 90% with the assessment of clinicians.

## AI IN COMMON SMALL INTESTINAL DISEASES

### AI in celiac disease

CD is a complex autoimmune disease. Patients who ingest foods containing gluten will develop an autoimmune response that causes damage to the small intestine. CD is one of the most common chronic digestive diseases, with a prevalence rate of 1% worldwide[55]. Duodenal biopsy is the gold standard for diagnosis[56]. Noninvasive methods such as endoscopy and clinical features analysis are also widely used in diagnosis, but the diagnostic rate of CD is only 15%–20% through current strategies [57]. However, with the increasing application of AI in the diagnosis of CD, the accuracy and efficiency of diagnosis are greatly improved[58] (Table 2).

Previous studies have confirmed that AI-assisted duodenoscopy images analysis can greatly improve the diagnostic efficacy of CD, with the accuracy between 80% and 100% and specificity and sensitivity over 80%[59-61]. In the diagnosis of CD, the combination of AI and CE is closer, which can improve the accuracy of diagnosis and



Table 2 Applications of artificial intelligence in celiac disease

Ref.	Diagnostic method	AI technology	Training set	Testing set	Outcomes
Chetcuti <i>et al</i> [62]	CE	ML	81 patients	-	Accuracy: 75.3%
Li <i>et al</i> [63]	CE	Computer-assisted recognition	Ep: 240, Cp: 220	-	Accuracy: 93.9%
Vicnesh <i>et al</i> [64]	CE	Computerized algorithm	21 patients	-	Accuracy: 89.82%
Zhou <i>et al</i> [65]	CE	CNN	Ep: 6, Cp: 5	Ep: 5, Cp: 5	Accuracy: 100%
Gadermayr <i>et al</i> [59]	EGD	Computer-assisted	290 patients (2835 images)	-	Accuracy: 94%-100%
Das <i>et al</i> [67]	Mucosal biopsies	Computer-assisted	Ep: 124, Cp: 137	Ep: 120, Cp: 105	Sen: 90.3%, Spe: 93.5%, AUCs: 96.2%
Wei <i>et al</i> [66]	Mucosal biopsies	DL	212 images	-	Accuracy: 95.3%, AUCs > 0.95
Pastore <i>et al</i> [70]	Clinical data	Computer-assisted	100 patients	-	Reliability: 0.813
Tenório <i>et al</i> [60]	Clinical data	Decision trees, Bayesian inference, k-nearest neighbor algorithm, support vector machines, artificial neural networks	178 patients	38 patients	Accuracy: 80.0%, Sen: 0.78, Spe: 0.80, AUCs: 0.84
Virta <i>et al</i> [68]	Micro-CT	Computer-assisted point cloud analysis	81 patients	-	Accuracy: 100%
Sanginetto <i>et al</i> [69]	Gene expression in PBMCs	ML, random forest algorithm	Ep: 17, Cp: 20	-	Accuracy: 100%

AI: Artificial intelligence; AUCs: Area under the curves; CE: Capsule endoscopy; CNN: Convolutional neural network; Cp: Control group; DL: Deep learning; EGD: Esophagogastroduodenoscopy; Ep: Experimental group; ML: Machine learning; micro-CT: X-ray microtomography; PBMCs: Peripheral blood mononuclear cells; Sen: Sensitivity; Spe: Specificity.

significantly save the diagnosis time[62-65]. AI was also used in the analysis of duodenal mucosa biopsy, which can help with qualitative analysis and play an important role in quantitative analysis[66,67]. At the same time, the application of AI with X-ray images[68], peripheral blood mononuclear cells[69] and clinical features[60, 70] in the diagnosis and classification of CD have also achieved progress.

### AI in small intestinal Crohn's disease

Crohn's disease is a chronic nonspecific inflammatory bowel disease that affects the entire gastrointestinal tract, in which 30% of patients are confined to the small intestine, commonly known as small intestinal Crohn's disease[71]. SICD most often involves the distal ileum as well as the jejunum and the digestive tract above and has a higher incidence of intestinal strictures than colonic Crohn's disease[72,73]. The application of AI in the management of SICD is comprehensive, including diagnosis, risk prediction, extra-intestinal manifestation (EIM) prediction and so on (Table 3).

**Diagnosis:** Lamash *et al*[74,75] used CNN to analyze MRI images and construct an assessment model for SICD. Their model could effectively distinguish active and inactive inflammatory segments, distinguish segments with strictures and segments without strictures and could be used to measure the length of intestinal strictures. Parfenov *et al*[76] used a software diagnostic algorithm to analyze the CE images of 25 SICD patients, preliminarily confirming that CE could be used to diagnose early SICD with intestinal mucosal inflammation. Klang *et al*[77] performed automatic analysis of CE images of 49 SICD patients using a CNN method, achieving diagnostic accuracy of more than 95% and significantly reducing reading time. Yang *et al*[78] also attempted to combine CNN with a microultrasound system for early diagnosis of SICD in mice and achieved good effectiveness in the identification of early inflammation.

**Risk prediction of SICD:** Taylor *et al*[79] used ML classifiers (elastic network and random forest) to classify small intestine inflammation in asymptomatic first-degree relatives of patients with SICD. They found that genetic variants associated with SICD, family history and fecal calprotectin together identified individuals with presymptomatic intestinal inflammation who are therefore at risk for SICD. Shen *et al*[80] developed a web-based SICD hazard stratification tool. Predicting high-risk populations for SICD based on altered bowel habit, abdominal pain, white blood cell

Table 3 Applications of artificial intelligence in small intestinal Crohn's disease

Ref.	Diagnostic method	AI technology	Training set	Testing set	Outcomes
Yang <i>et al</i> [78]	Microultrasound	CNN	43 mice	-	AUCs: 0.8831
Shen <i>et al</i> [80]	Clinical data	Computerized algorithm	Ep1: 61, Cp1: 78	Ep2:42, Cp2: 57; Ep3:84, Cp3: 495	AUCs: 0.92
Bottigliengo <i>et al</i> [81]	Clinical data	BMLTs (NB, BN, BART)	152 patients	-	AUCs without genetic variables (NB: 0.71, BN: 0.50, BART: 0.76), AUCs with genetic variables (NB: 0.75, BN: 0.67, BART: 0.78)
Taylor <i>et al</i> [79]	Clinical data	ML (elastic net and random forest)	480 first-degree relatives	-	AUCs (elastic net): 0.80, AUCs (random forest): 0.87
Menti <i>et al</i> [82]	Clinical data	BMLTs	152 patients	-	Accuracy without genetic variables: 82%, accuracy with genetic variables: 89%
Klang <i>et al</i> [77]	CE	DL	49 patients (17640 images)	-	AUCs: 0.94-0.99, accuracy: 95.4%-96.7%
Parfenov <i>et al</i> [76]	CE	Computerized algorithm	25 patients	-	44% patients confirmed only with the help of AI
Lamash <i>et al</i> [74, 75]	MRI	CNN	15 patients	8 patients	Dice coefficients: 75%-97%

AI: Artificial intelligence; AUCs: Area under the curves; BART: Bayes additive return trees; BMLTs: Bayesian machine learning techniques; BN: Bayesian network; CE: Capsule endoscopy; DL: Deep learning; CNN: Convolutional neural network; Cp: Control group; Ep: Experimental group; ML: Machine learning; MRI: Magnetic resonance imaging; NB: Naive Bayes.

count, albumin and platelet count abnormalities allowed clinicians to identify potential SICD earlier.

**Risk prediction of EIMs:** AI is controversial in the evaluation of the EIMs of SICD. In the study of Bottigliengo *et al*[81], based on Bayesian machine learning technology evaluation combined with genetic factors to predict the occurrence of EIMs in Crohn's disease, it has no advantage over traditional statistical tools. Whereas Menti *et al*[82] used Bayesian machine learning technology to predict the risk of occurrence of EIMs in Crohn's disease, and the prediction accuracy was 82% when considering only clinical factor and 89% combined with genetic factors, which was outperforming other prediction techniques.

#### AI in primary small intestinal tumor

The incidence of PSIT is about 5% of gastrointestinal tumors and 0.2% of all kinds of tumors[83,84]. The main site of PSIT is the duodenum, followed by the jejunum and ileum[85]. There are a variety of pathological types of malignant PSIT. Adenocarcinoma is the most common pathological type, up to 40%, followed by neuroendocrine tumors (25%), malignant lymphomas (10%-15%) and malignant stromal tumors (9%) [86]. PSIT lacks specific manifestations in the early stage, and they are faced with many problems in the clinic, such as difficult diagnosis, high misdiagnosis rate, nonstandard treatment and so on[87]. AI has been applied in the field of auxiliary diagnosis and prognostic analysis of PSIT, and has an important impact on the management (Table 4).

**Diagnosis:** Inoue *et al*[88] used CNN to analyze EGD images for the diagnosis of superficial nonampullary duodenal epithelial tumors. The overall diagnosis accuracy of CNN was 94.7%, including 94% for adenomas and 100% for high-grade dysplasias, and it only took 12-31 s for analysis. The method of support vector machine was applied to the automatic analysis of CE images, which greatly improved the accuracy and efficiency of diagnosis[89-92]. In addition, Barbosa *et al*[93] used the CNN to automatically analyze CE images for the diagnosis of PSIT, which also had high sensitivity and specificity, reaching 98.7% and 96.6%, respectively.

**Risk stratification and prognosis prediction:** In different studies, ML was used to analyze the pathological tissue samples, plasma protein multibiomarker and miRNA markers of patients with small intestinal neuroendocrine tumors[94-96]. Their studies provided some new and effective methods for early diagnosis, treatment strategy selection, prognosis prediction and recurrence risk prediction of small intestinal

**Table 4 Applications of artificial intelligence in primary small intestinal tumor**

Ref.	Diagnostic method	AI technology	Training set	Testing set	Outcomes
Inoue <i>et al</i> [88]	EGD	CNN	531 images	1080 images	Accuracy: 94.7%-100%
Liu <i>et al</i> [90]	CE	SVM	89 patients	-	Sen: 97.8%, Spe: 96.7%
Vieira <i>et al</i> [89,91]	CE	SVM	29 patients (936 images)	-	This SVM outperforms others by more than 5%
Barbosa <i>et al</i> [93]	CE	CNN	Ep: 104, Cp: 100	Ep: 92, Cp: 100	Sen: 98.7%, Spe: 96.6%
Panarelli <i>et al</i> [94]	MicroRNA sequencing	ML	84 samples	-	Accuracy (Ts: 98.5%, Vs: 94.4%)
Drozdov <i>et al</i> [95]	Gene expression profiling	ML	73 samples	-	Differentiated from normal cells (Sen: 100%, Spe: 92%), metastases prediction (Sen: 100%, Spe: 100%)
Kjellman <i>et al</i> [96]	Plasma protein multibiomarker	Random forestmodel	Ep:135, Cp: 143	-	AUCs: 0.97
Yan <i>et al</i> [97]	CT	Random forestmodel	213 patients	-	AUCs: 0.943

AI: Artificial intelligence; AUCs: Area under the curves; CE: Capsule endoscopy; CNN: Convolutional neural network; CT: Computed tomography; Cp: Control group; EGD: esophagogastroduodenoscopy; Ep: Experimental group; ML: Machine learning; SVM: Support vector machine; Sen: Sensitivity; Spe: Specificity; Ts: Training set; Vs: Validating set.

neuroendocrine tumors. In the study of Yan *et al*[97], random forest models were performed to evaluate the correlation of risk stratification for small intestinal stromal tumors. Their study suggested multidetector CT texture analysis may become an important comprehensive tool for preoperative risk stratification of small intestinal stromal tumors.

**AI in other small intestinal diseases**

**Small intestinal obstruction:** Cheng *et al*[98,99] used CNN to analyze abdominal radiographs to assist in the diagnosis of small intestinal obstruction (SIO). The sensitivity and specificity of the CNN diagnostic system were 83.8% and 68.1%, respectively, based on the training set of 2210 abdominal radiographs. When the training set was expanded to 7768 abdominal radiographs, the diagnostic sensitivity and specificity were increased to 91.4% and 91.9%, respectively. Their study suggests that the accuracy of detection of SIO by CNN improves significantly with the increasing number of training radiographs. Lucas *et al*[100] explored the development of an ML tool for SIO detection based on CT images. They evaluated the accuracy of eye tracking in image centerline annotation of the small intestine as the first step in the development of an ML tool for SIO. Their results showed that the eye tracking-based annotation was accurate and precise enough for application in ML-based small intestinal centerline annotation.

**Small intestinal motor dysfunction:** Small bowel intestinal dysfunction (SIMD) can occur during the development of many diseases, so the evaluation of small intestinal motor function is an important means for the auxiliary diagnosis and severity evaluation of these diseases. AI is widely used to evaluate small intestinal motor function through CE images. Using intractantestinal manometry as the gold standard for the diagnosis of SIMD, Malagelada *et al*[101] proved that an ML model was reliable to evaluate CE images for the diagnosis of SIMD. Applying this model, they found that 29% of patients with functional intestinal disorders had SIMD, significantly higher than that of the healthy population (3%), confirming the pathophysiological changes in the intestine of functional intestinal disorders[102]. Furthermore, a classification method for classifying functional intestinal disorders according to small intestinal motor function was also proposed[103].

De Iorio *et al*[104] also demonstrated that ML can reliably detect reduced intestinal muscle activity and motion by CE images through the method of injecting intestinal muscle inhibition (glucagon) into healthy subjects. Moreover, the study of Seguí *et al* [105] suggested that CNN was also reliable in the description and classification of small intestine motor characteristics with the classification accuracy reaching 96%. Malagelada *et al*[106] also used ML to analyze CE and abdominal MRI images of patients with cystic fibrosis and confirmed that the delay in small bowel and colonic transit times in patients with cystic fibrosis is associated with known endocrine

dysfunction and with SIMD.

**Small intestinal ischemia-reperfusion injury:** Intraoperative evaluation of intestinal viability in patients with acute intestinal ischemia is a critical factor for surgical decision making. In the pig jejunum experiment, Strand-Amundsen *et al*[107] attempted to apply ML to the analysis of multivariate time-series of bioimpedance sensor data to analyze intestinal viability after intestinal ischemia-reperfusion. The results suggested that the measurement should be made before the onset of reperfusion, and the prediction effect was better when the measurement was repeated continuously during ischemia and reperfusion. The detection accuracy of irreversible damage may be close to 100%.

**Enteropathies associated with undernutrition:** There is a significant histopathological overlap in duodenal biopsies of enteropathies associated with undernutrition such as environmental enteropathy and CD. Syed *et al*[108] used CNN to establish a histopathological analysis model, which can effectively distinguish environmental enteropathy, CD and normal intestinal mucosa. The detection accuracy was 93.4%, and the false-negative rate was 2.4%.

## CHALLENGES AND PROSPECTS

At present, in order to promote the application of AI in the field of SIDs, we still need to solve some problems and challenges: (1) Insufficiency of training sample size. The incidence of most SIDs is not high. For example, the incidence of PSIT is much lower than that of gastric tumors and colorectal tumors, which affects the amount of data in the training set. Measurement errors are easy to occur when the sample size is small [109], and as suggested by the continuity study of Cheng *et al*[98,99], expanding the sample size of the training set can significantly improve the inspection accuracy of AI model; (2) Lack of prospective data. Most of the studies used retrospective data, which have been artificially screened before AI model training and lack prospective studies; (3) Single source of data. Most of the training sets and verification sets used in the study come from single-center data, so it is still necessary to further improve the repeatability and stability of the model through multicenter data. As in Alzheimer's disease research, each single center should be encouraged to share data in anticipation of establishing large-scale and open databases[110]; (4) The interpretation of the results. Due to the inevitable problems of AI, like overfitting of training set data[111] and the "black box" characteristic of the algorithm[112], the accuracy and interpretation of the AI model are inconsistent, which may have a negative impact on clinical application[113]. More intensive basic research and extensive verification are needed to improve this deficiency; (5) Ethical and legal issues. Can we trust the results of AI? Once the AI diagnosis and treatment prediction fails, it will give rise to a series of social, ethical and legal problems[114,115]. It is necessary to combine human supervision with AI tools more reliably; and (6) AI has been widely researched in various fields. We should attach importance to learning experience from different research fields and try to carry out related research in the field of SIDs, so as to promote the continuous progress of AI research in the field of SIDs.

## CONCLUSION

The advantages of AI in the diagnosis and prognosis analysis of SIDs have been increasingly recognized, and the high accuracy and efficiency of AI detection greatly reduce the workload of doctors. Although there are still various challenges in the application of AI, the potential of AI in improving the management efficiency of diseases cannot be ignored. Clinicians should work together with experts in various fields to promote the development of AI in SIDs.

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