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Artificial Intelligence in Ultrasound Diagnosis of Bowel Diseases: Modern Possibilities

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Aim. Review of current achievements, opportunities and challenges in applying artificial intelligence (AI) for analyzing intestinal ultrasound images.

Key points. Ultrasound examination is a highly informative, safe, and widely accessible method for bowel pathology diagnosis. The integration of AI, particularly deep learning and radiomics methods, aims to overcome the operator-dependence of ultrasound, standardize diagnosis, and enhance its efficiency. This article reviews the development and validation of AI algorithms for key areas: inflammatory bowel diseases, acute appendicitis, bowel intussusception and colorectal cancer. Limitations and concerns that require resolution for the successful integration of AI into clinical practice are also discussed.

Conclusion. The integration of AI into ultrasound diagnosis of bowel diseases has significant potency for improving accuracy, reproducibility, and operational efficiency.

Keywords: inflammatory bowel disease, Crohn's disease, ulcerative colitis, artificial intelligence, intestinal ultrasound

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Искусственный интеллект для ультразвуковой диагностики заболеваний кишечника: современные возможности

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Цель. Обзор современных достижений, возможностей и проблем применения технологий искусственного интеллекта (ИИ) для анализа изображений ультразвукового исследования (УЗИ) кишечника.

Основные положения. Ультразвуковое исследование является высокоинформативным, безопасным и широкодоступным методом диагностики патологии кишечника. Внедрение ИИ, в частности методов глубокого обучения и радиомики, направлено на преодоление оператор-зависимости УЗИ, стандартизацию диагностики и повышение ее эффективности. В статье представлены данные о разработке и валидации ИИ-алгоритмов для ключевых направлений: воспалительные заболевания кишечника, острый аппендицит, инвагинация кишечника, колоректальный рак. Представлены ограничения и опасения, которые требуют решения для внедрения ИИ в клиническую практику.

Заключение. Интеграция ИИ в ультразвуковую диагностику заболеваний кишечника обладает значительным потенциалом для повышения точности, воспроизводимости и эффективности работы, особенно в условиях высокой нагрузки на специалистов.

Ключевые слова: воспалительные заболевания кишечника, болезнь Крона, язвенный колит, искусственный интеллект, УЗИ кишечника

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Ultrasound is one of the most commonly used diagnostic methods in medicine due to its numerous advantages, including high diagnostic value, safety, accessibility, non-invasiveness, and low cost. According to the report by I.E. Tyurin, Chief Freelance Specialist of the Russian Ministry of Health for Radiation and Instrumental Diagnostics, over 326 million radiation diagnostic examinations were performed in 2020, with ultrasound examinations predominating, accounting for 43 % of these studies [1]. In total, 151,693,220 diagnostic and preventive ultrasound examinations were conducted in 2020. According to the FDA (Food and Drug Administration), the use of ultrasound is preferred for diagnosing diseases as part of the "Initiative to Reduce Unnecessary Radiation Exposure from Medical Devices". Due to the heavy workload on ultrasound diagnostics and its significant contribution to diagnosis, there is a need to improve the efficiency of ultrasound examinations and optimize data management [2].

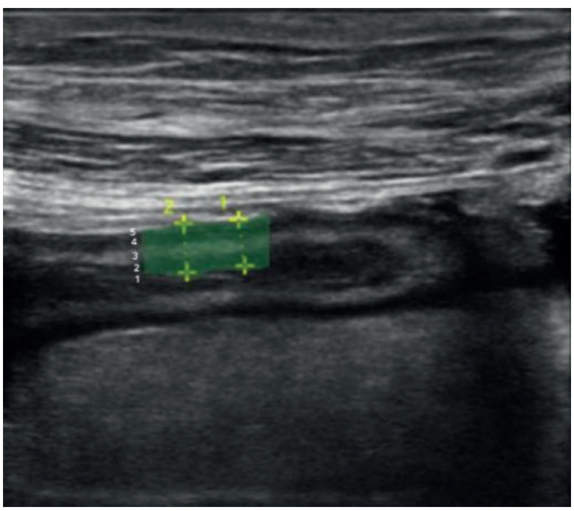


Figure 1. Ultrasound imaging of a 25-year-old patient with Crohn's disease ileitis. Intestinal wall thickness is about 4 mm. A five-layered intestinal wall in longitudinal section: *1* — hyperechoic layer of the border of the contents of the intestine and mucous, *2* — hypoechoic, muscularis mucosae, *3* — hyperechoic, submucosa, *4* — hypoechoic, muscular propria, *5* — hyperechoic, border of the serosa and surrounding fiber

Note: ultrasound imaging from the personal archive of the authors.

Рисунок 1. Эхограмма пациента 25 лет с илеитом болезни Крона. Отмечается утолщение кишечной стенки до 4 мм. Пятислойное строение кишечной стенки в продольном сечении: *1* — гиперэхогенный слой границы содержимого кишки и слизистой оболочки, *2* — гипоэхогенный — мышечная пластинка слизистой оболочки, *3* — гиперэхогенный — подслизистый слой, *4* — гипоэхогенный — мышечный слой, *5* — гиперэхогенный — граница серозной оболочки и окружающей клетчатки

Примечание: эхограмма из личного архива авторов.

Intestinal ultrasound allows for imaging of the bowel wall in longitudinal and transverse sections. When examined using high-frequency probes (5–15 MHz), the wall presents as a five-layer structure, which is defined particularly clearly in pathology (Fig. 1). The method also allows for the assessment of wall thickness and vascularization. According to the EFSUMB (European Federation of Societies for Ultrasound in Medicine and Biology) clinical guidelines, normal bowel wall thickness is less than 2 mm when measured in a state of normal filling, while the thickness of the duodenal bulb and rectum is less than 3 mm. In a healthy bowel wall, more than 1 or 2 vascular signals are rarely detected using color or power Doppler [3].

According to the First Global Summit on Artificial Intelligence (AI) in Gastroenterology and Endoscopy, gastroenterology is a leading field for the early adoption of AI. In this field, AI is rapidly transitioning from the experimental stage to clinical application. Over the next decade, the integration of AI into gastroenterology is expected to have a significant impact on the monitoring of patients with gastrointestinal diseases [4].

Basic Concepts of AI

Despite the longstanding application and extensive study of the method, performing ultrasound remains a complex, operator-dependent technique requiring years of training and extensive practical experience, which often makes results difficult to reproduce. This fact served as the impetus for the development of Computer-Aided Detection (CAD) systems. The majority of CAD systems are based on the principles of machine learning — a field of AI that involves training a computer algorithm to solve specific tasks using a multitude of examples where the correct answer is already known (the training set). CAD arises at the intersection of statistics, which seeks to study relationships based on data, and computer science, with a focus on efficient computational algorithms [2].

In recent years, artificial neural networks (ANNs) have gained particular popularity; they are a subset of machine learning algorithms modeled after the organization of biological neural networks. Unlike classical learning methods, where the researcher must manually define the object features used to train the machine learning algorithm, neural networks learn to extract these features independently. Artificial neural networks consist of interconnected neurons — computational units that receive input information, perform simple computational operations on it, and transmit it further. Three types of layers are distinguished in neural networks: the input layer, whose neurons distribute input information to the remaining neurons; the hidden layer, whose neurons transform input data into intermediate results; and the output layer, whose neurons transform signals from the hidden layers and generate the solution to the task [5].

Significant improvements in the performance of many machine learning tasks have been achieved thanks to deep neural networks (DNNs) — artificial neural networks with multiple hidden layers that enable feature extraction from complex data such as images, speech, and others [5]. Deep convolutional neural networks (CNNs) are widely used for image and video analysis. In convolutional neural networks, images are repeatedly processed using various filters during a process called convolution, resulting in the creation of feature maps [6]. Training a convolutional neural network consists of selecting the best filters. CNNs have gained widespread adoption in medicine for medical image analysis [7].

AI in Ultrasound Diagnostics of Inflammatory Bowel Disease

According to the Russian clinical guidelines for the management of ulcerative colitis (UC) and Crohn's disease (CD), transabdominal bowel ultrasound is recommended for all patients with inflammatory bowel disease (IBD) to assess bowel wall thickness, the presence of defects in the affected area, and the degree of vascularization [8, 9]. Intestinal ultrasound is also included in the ESGAR (European Society of Gastrointestinal and Abdominal Radiology) and ECCO (European Crohn's and Colitis Organisation) guidelines for the diagnosis of IBD [10]. Recent meta-analyses comparing ultrasound, CT, and MRI for the diagnosis of IBD have found no significant differences in the diagnostic accuracy of these methods. However, since patients with IBD require frequent disease monitoring, a method free of radiation exposure is preferable [11–13].

Ultrasound signs of IBD include bowel wall thickening of more than 4 mm in adults and more than 3 mm in children; involvement of the mucosal and submucosal layers in the pathological process in UC, and transmural involvement in CD; additionally, Doppler imaging reveals increased blood flow within the bowel wall. Ultrasound also allows for the detection of IBD complications, such as toxic megacolon, the development of strictures and infiltrates, fistula formation, etc. [14]. Characteristic changes in the bowel wall in CD, accompanied by the development of complications in the form of strictures and infiltrate formation, are presented in Figure 2. Intestinal ultrasound is recommended for detecting IBD at disease onset, assessing the localization of the inflammatory process, and determining disease activity and possible complications in IBD [14].

Currently, there is no consensus regarding the use of AI for interpreting transabdominal bowel ultrasound images. Isolated studies have emerged involving the training of neural networks to detect bowel wall thickening. For instance, D. Carter et al. utilized a CNN-based AI model to detect thickened bowel walls. The study employed 1,008 ultrasound images: 805 were used for training, and 203 for testing the trained model. As a result, the model demonstrated an overall accuracy, sensitivity, and specificity for detecting bowel wall thickening of 90.1 %, 86.4 %, and 94 %, respectively. The trained neural network achieved a mean area under the ROC curve (AUC ROC) of 0.97, indicating the model's high accuracy in distinguishing between thickened and non-thickened bowel walls [15].

At present, there are no data on the real-time application of AI technologies in routine ultrasound diagnostic practice. The implementation of such solutions could potentially enhance the efficiency of detecting pathological changes, for example, by displaying indicators on the screen — similar to how it is implemented in certain software for the visualization of contrast studies (VCE) [16].

In recent years, there has also been a marked increase in interest in radiomics — a field where software is capable of extracting a vast array of potential quantitative features from images, which are then analyzed to determine their prognostic value [17]. Thus, radiomics is understood as the combination of radiology, mathematical modeling, and deep machine learning. The scientific literature already presents several machine learning models for the diagnosis of CD, developed based on radiomic data from CT and MRI [18, 19]. It is only relatively recently that work has been published on the use of radiomics in the analysis of transabdominal ultrasound images in patients

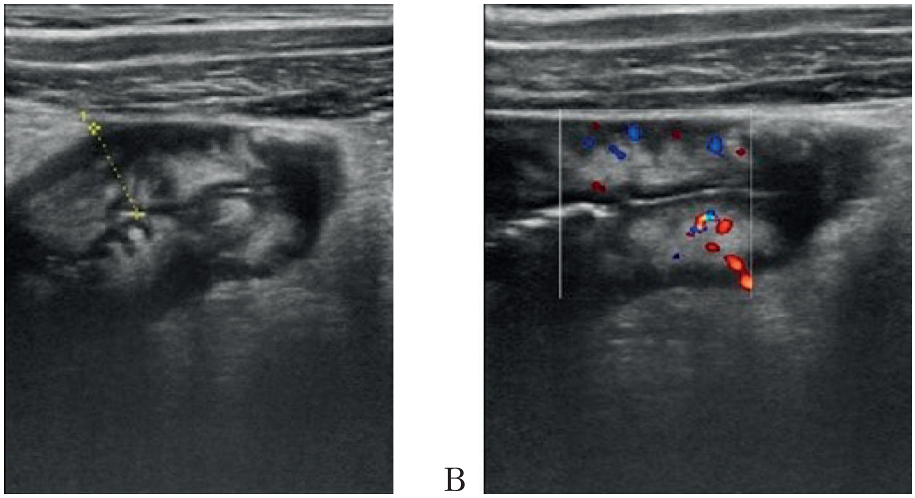


Figure 2. Ultrasound imaging of a 32-year-old patient with Crohn's disease sigmoiditis: A — in the sigmoid colon, wall thickening is about 11.6 mm (due to the submucosa and muscular propria), intestinal lumen is narrowed; along the periphery of the sigmoid colon, a hypoechoic rim and fixation of loops with surrounding hyperechoic tissue with the formation of an infiltrate are noted; B — dopplerography reveals increased blood flow

Note: ultrasound imaging from the personal archive of the authors.

Рисунок 2. Эхограмма пациента 32 лет с болезнью Крона сигмовидной кишки: A — утолщение стенки сигмовидной кишки до 11,6 мм (за счет подслизистой и мышечной оболочки), сужающее просвет кишки, по периферии сигмовидной кишки отмечается гипоэхогенный ободок и фиксация петель с окружающей гиперэхогенной клетчаткой с формированием инфильтрата; B — при доплерографии определяется усиление кровотока

Примечание: эхограмма из личного архива авторов.

with IBD. In a study by P. Gu et al., using a sample of 125 transabdominal ultrasound images from patients with IBD, various classical machine learning algorithms and a convolutional neural network were trained to distinguish between normal and abnormal images. The best classification quality was demonstrated by a classifier based on the gradient boosting algorithm. The mean values for ROC AUC, sensitivity, specificity, and accuracy on the test set were 0.98, 93.8 %, 93.8 %, and 93.7 %, respectively. Meanwhile, the CNN-based classifier achieved an ROC AUC value of only 0.75 [20].

Thus, although CNNs are successfully used in image-based pathology detection tasks, radiomics also offers the possibility of deep analysis of quantitative information from medical images — which is usually unrecognizable or indistinguishable to the naked human eye — and in certain tasks, it may prove not inferior to neural networks. Additionally, radiomics possesses a significant advantage in its ability to integrate with other clinical data, opening up possibilities for multimodal analysis capable of addressing a broader range of issues.

AI in Ultrasound Diagnostics of Acute Appendicitis

The appendix arises from the cecum approximately 3 cm below the ileocecal valve at the point where the three *teniae coli* converge. Normally, the diameter of the appendix rarely exceeds 4–5 mm [3]. Ultrasound signs of acute appendicitis include: a maximum outer diameter of more than 6 mm, maximal tenderness over the thickened appendix during transducer compression, rigidity of the inflamed appendix during transducer compression, hypervascularization on color Doppler imaging, pericecal abscess, hyperechoic periappendicular tissue, and mesenteric lymphadenopathy. The use of ultrasound imaging should be a routine procedure for every patient with suspected appendicitis [21].

The application of AI in abdominal ultrasound diagnostics shows promising preliminary results for the diagnosis of acute appendicitis [22]. A model developed by R. Marcinkevičs et al., analyzing 1,709 echograms from 579 patients, demonstrated an AUC of 0.80 for predicting appendicitis [23]. C. Stiel et al. developed a new AI-based diagnostic index for acute appendicitis based on four classic appendicitis scores: the Heidelberg Appendicitis Score, the Alvarado Score, the Pediatric Appendicitis Score, and the Tzanakis Score. As a result, the researchers achieved a positive predictive value (PPV) of 95.0 % and a negative predictive value (NPV) of 70.0 % for uncomplicated appendicitis, while for perforated appendicitis, the PPV was 34.4 % and the NPV was 93.8 % [24]. Later, W. Ghareeb et al. compared the predictive value of an AI-based acute appendicitis model with the Alvarado score, ultrasound criteria, and their combined assessment, with histopathological examination considered the standard. To develop the AI model, data from multiple variables—such as ultrasound results, patient characteristics, and clinical features—were pre-processed, enabling the effective use of machine learning methods. It was found that the AI predictive model demonstrated higher sensitivity (100 %) and accuracy (97.9 %); however, its specificity was 80 %, which was higher than that of the Alvarado score but lower than that of the combined Alvarado score and ultrasound criteria assessment (100 %) [25].

AI in Ultrasound Diagnostics of Intussusception

Ultrasound is a reliable tool for the diagnosis of intussusception in children without the risk of radiation exposure. Previous studies with small sample sizes have demonstrated high efficacy for the ultrasound diagnosis of intussusception, achieving a sensitivity of over 92 % [26]. Given the reduced diagnostic sensitivity among ultrasound specialists with basic skills, the accuracy of intussusception detection depends largely on expert qualification; therefore, the implementation of AI could help improve diagnostic efficiency. X. Chen et al. developed and validated the CIDNet system for the diagnosis of intussusception in children, which showed an AUC of 0.9716 in the analysis of the study data. The CIDNet system demonstrated higher efficiency compared to the assessment by expert radiologists (AUC 0.97) [27]. In a study by Y. Pei et al., an algorithm recognized 1,086 images exhibiting three signs of ileocecal intussusception (AUC 0.97) and also diagnosed 184 patients — including those without intussusception, with non-surgical intussusception, and with surgical intussusception — across 184 ultrasound videos, achieving a mean AUC of 0.95. This improved the performance of ultrasound specialists with basic skills (mean AUC: 0.966 vs. 0.857, $p < 0.001$; median scanning time: 9.46 min vs. 3.66 min, $p < 0.001$). The performance was found to be comparable to that

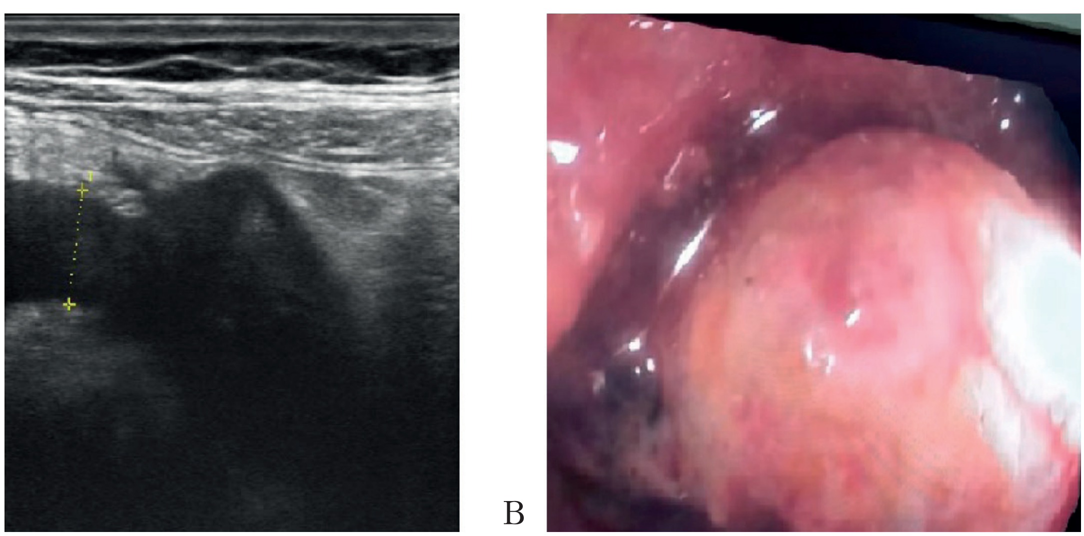
A

B

Figure 3. A 64-year-old patient: A — ultrasound imaging with a sigmoid tumor, where an uneven hypoechoic thickening of the intestinal wall up to 11 mm with a violation of its structure, narrowing the lumen, with increased vascularization in a Doppler are determined over a length of about 30 mm; B — endoscopy with subsequent morphological verification of adenocarcinoma

Note: ultrasound imaging from the personal archive of the authors.

Рисунок 3. Пациент 64 лет: А — эхограмма с опухолью сигмовидной кишки, где на протяжении около 30 мм определяется неравномерное гипоэхогенное утолщение кишечной стенки до 11 мм с нарушением ее структуры, сужающее просвет, с усиленной васкуляризацией при доплеровском исследовании; В — эндоскопическая картина с дальнейшей морфологической верификацией аденокарциномы

Примечание: эхограмма из личного архива авторов.

of experienced ultrasound specialists (mean AUC: 0.966 vs. 0.973, $p = 0.6$) [28].

Colorectal cancer (CRC) is one of the most common malignant neoplasms of the gastrointestinal tract worldwide [29]. A major challenge is the difficulty of diagnosing it at an early stage; therefore, early detection is crucial for the successful prevention and treatment of this pathology. Sonographically, features such as hypoechoic focal thickening of the bowel wall with irregular contours, loss of wall layer differentiation, and the absence of normal peristalsis may indicate malignancy [30]. An example of the sonographic appearance of sigmoid adenocarcinoma is presented in Figure 3.

Recently, a number of researchers have focused on tumor deposits during the morphological examination of rectal cancer; these represent foci of adenocarcinoma growth within the mesocolic or mesorectal adipose tissue distinct from lymph nodes. These lesions are discontinuous from the primary tumor and are not associated with lymph nodes. The presence of tumor deposits in a patient is a poor prognostic factor associated with a higher risk of recurrence and reduced disease-free and overall survival [31, 32].

L. Chen et al. developed a system utilizing ultrasound radiomics and clinical parameters for the diagnosis of tumor deposits (sensitivity: 72.7 %, specificity: 75.9 %, AUC: 0.743). The study demonstrated that ultrasound radiomics holds potential for the pretreatment prediction of tumor deposits [33]. D. Song et al. developed a model based on ERUS designed to detect malignant colorectal tumors. This system could significantly reduce the workload of ultrasound specialists and decrease the rate of diagnostic errors [34].

Limitations and Concerns

Generalizability, or the ability to find general patterns within data, remains a serious challenge for many machine learning algorithms, creating difficulties in translating computer science research into clinical practice. The data used for training, validating, and testing algorithms that have demonstrated impressive results in research often fail to sufficiently account for the variability found in real-world clinical practice [35].

Automation bias regarding the decisions of automated systems is a serious issue when implementing AI in clinical practice. This phenomenon implies that humans tend to uncritically trust and prefer solutions proposed by algorithms, even in the presence of contradictory information or their own doubts. Researchers believe that people will expect practically perfect performance from AI, yet algorithm failures will be judged less strictly than human errors [36]. There is also a risk of the diagnostician developing excessive dependence (or "blind trust") on automation, which could lead to a significant number of errors in the event of an AI algorithm failure.

Furthermore, a significant drawback of neural networks is the opacity of their operation, which makes it very difficult to establish trust in AI within the public consciousness [37]. The medical community may demand stricter regulatory standards for the implementation and approval of AI technologies. Issues of accountability and liability will be just as important to society as the accuracy and performance of the algorithms. Additionally, the use of AI will raise concerns regarding data privacy [36].

It is also worth noting the high cost of using AI, which may become an obstacle to the implementation of algorithms in real clinical practice. However, cost savings may be achieved through increased efficiency and a reduction in the number of missed pathological symptoms [36].

Conclusion

Experts at the First Global Summit on AI in Gastroenterology and Endoscopy concluded that gastroenterology could become one of the first specialties for the early adoption of AI in clinical practice [4]. Modern AI-assisted ultrasound approaches may further improve the diagnosis of gastrointestinal diseases, reduce healthcare costs, and optimize patient monitoring on the path to achieving disease remission [38].

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