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Clinical Value Study of Artificial Intelligence-Assisted Gastrointestinal Ultrasound Contrast Imaging in the Diagnosis of Gastric Mucosal Lesions

Tianyu She [1, *], Yina Zhao [1], Hangyan Qian [2], Hongmin Dang [3], Yuan Li [4], Tao Hou [5], Qiyi Hu [6], Ling Tu [7], Na Jing [8], Yunlong Gao [9], Lei Hua [10], Wei Bai [4], Xiaoxiao Zhao [11], Dan Yun [3], Xiaoying Tian [1], Yangyan Sun [1], Ruixia Yue [1], Yu Cao [1], Mei Liu [12], Jie Mei [12], Lu Xing [13]

[1] Department of Medical Imaging Function, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[2] Department of Nursing, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[3] Department of Proctology, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[4] Department of Health Management Center, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[5] Department of Community Health Service, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[6] Third People's Hospital of Beichuan Qiang Autonomous County, Mianyang, China
[7] Nanchang Institute of Technology, Nanchang, 330044, Jiangxi Province, China
[8] Department of Thyroid and Breast Surgery, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[9] Hepatobiliary, Pancreatic and Liver Transplantation surgery, The Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an. China
[10] Department of Ultrasound, Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an. China
[11] Department of Traditional Chinese Medicine, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[12] Department of Medical Imaging Radiology, Xi'an Electric Power Central Hospital, Xi'an 710032, Shaanxi, China
[13] Zokhiomj University, Ulaanbaatar, Mongolia

[*] **Corresponding author**: (Email: tianyu202210@126.com)

Abstract: Evaluating the diagnostic significance of AI-assisted contrast-enhanced ultrasonography in diagnosing gastric mucosal lesions among 200 cases diagnosed with suspected gastric mucosal diseases through conventional imaging and subsequently confirmed via histopathology under MRI guidance was determined to be an adequate method for comparison. Diagnosis by this system achieved a score above 83 percent, which is statistically significantly lower than 73 per cent for regular ultrasound examination results ($p < 0.01$). Using AI algorithms to precisely define lesions and microcirculatory vessels to red uce interscanner variability. According to the above research results, an artificial intelligent assist gastroint estinal CEUS examination system has already been developed; therefore, its clinical diagnosis applications are highly necessary.

Keywords: AI-assisted diagnosis, gastric mucosal lesions, contrast-enhanced ultrasound, diagnostic accuracy, clinical value.

1. Introduction

1.1. Background and Significance of AI in Gastrointestinal Ultrasound

Ultrasound examinations of the gastrointestinal system for detecting various inflammatory conditions, such as ulcers and gastric cancer, within the stomach; but they have their own deficiencies. The results of image analysis are influenced by individual differences; there is instability in observation under conditions such as details such as morphological changes on the surface layer of gastric lesions or enhancement effects [1]. Diagnostic indirectness often causes delayed diagnosis and missed treatment opportunities [2].

Artificial intelligence, especially deep learning algorithms, provides a solution to these problems [3]. AI can process massive pixel data more accurately than humans, extract subtle features of gastric mucosal lesions (e.g., echogenicity changes, contrast enhancement timing, vascular disorder) from annotated ultrasound images that are difficult for human observation [4], and provide objective and measurable diagnostic data [5]. Existing studies have shown that AI algorithms achieve diagnostic accuracy comparable to or even higher than experienced radiologists in mammography microcalcification detection and chest X-ray pulmonary nodule recognition [6], and have shown preliminary potential in gastrointestinal imaging [7]. CEUS has been proven effective in gastric cancer staging and submucosal lesion identification, providing rich data for AI analysis [8], and the combination of the two is expected to construct a more efficient imaging analysis system [9].

AI-assisted gastrointestinal CEUS has multiple clinical merits: it improves the accuracy of abnormality identification, reduces false positives and missed diagnoses [10]; accelerates the diagnostic process, reduces the workload of medical staff, and is suitable for large-scale screening and primary medical institutions [11]; standardizes diagnosis, reduces inter-observer differences, and improves diagnostic credibility [12]; and detects and measures complex imaging biomarkers to lay a foundation for individualized treatment [13].

Current research on AI-assisted gastrointestinal ultrasound is mostly retrospective, and there are still deficiencies: AI models have poor generalization, with algorithms trained on specific population, equipment and imaging protocols showing low reliability in other scenarios [14]; the lack of large, diverse and high-quality annotated datasets leads to high research costs [15]; advanced deep learning models have the "black box" problem, which is difficult to gain clinical trust [16]; multi-center prospective validation studies are insufficient, and the combination with other diagnostic tools needs further exploration [17]. Therefore, future research needs to enhance model explanationability through multiple centers, conduct cross-modality fusion, etc [18].

1.2. Objectives and Scope of the Study

Research on using Artificial Intelligence technology within the digestive system examination for US-guided endoscopic diagnosis of gastric mucosa disorders; Also to assess if this approach provides a scientific means based on measurable metrics like Diagnostic accuracy, Sensitivity & Specificity, etc., to evaluate its effectiveness relative to existing approaches. [19] This paper aims to solve the problem that traditional method has a low detection sensitivity, high observer variability and weak consistency in diagnosing mild or early gastric mucosal lesions [20]. Even though CEUS can observe microvascularisation for improving lesion characterisation; however, it has difficulty in interpreting complicated contrast dynamics and is therefore less practical [21].

Considering that mature applications have been made for deep-learning models, including convolutional-neural-networks (CNNs), in complex medical-image analysis [22], this paper employs high-level AI technologies to process spatiotemporal data from gastrointestinal-ceus-enhanced ultrasound examinations, objectively evaluate changes in the contrast features across various gastric-mucosal lesion sites [23], decrease observer bias, enhance inter-observer agreement, and improve abnormal-recognition accuracy. To determine the Value of artificial intelligence in CEUS imaging interpretation, investigate how it aids in diagnosis among various types of gastric mucosal lesions at different stages, thus offering proof for medical practice [24].

This paper uses an appropriate Design of the Prospective comparison type to compare AI-assisted CEUS diagnosis with conventional endoscopy plus biopsy-histopathology examination for reference criteria [25]. Enrolled patients participated in an organised gastrointestinal CEUS examination; automatically process generated dynamic CECT images using the built-in artificial intelligence system, and produce automatic diagnoses. To evaluate the diagnostic performance of the AI system, accuracy, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and area under the ROC curve (AUC) were calculated to compare them with those made by expert radiologists [26].

AI-aided CEUS has the potential to increase diagnosis speed, accuracy and selectivity for cancer through detection of different kinds of tumours such as malignancies, inflammations and benign lesions; Also it can be used to reduce examinations because it is capable of identifying precise quantitative markers that are not qualitative [27]. At the same time, the study also acknowledges its limitations: the generalization of results is affected by the selected AI algorithm and dataset, and the performance may fluctuate with different equipment and contrast agents [28]. In the future, we will build an even broader evaluation Index System for multimodal diagnosis Data Integration Algorithm Accuracy Transparency [29].

1.3. Methodology Overview

Using a prospective comparative study design, this paper evaluates the clinical effectiveness of AI-assisted gastrointestinal CEUS for diagnosing gastric mucosal lesions and verifies if incorporating AI technology helps enhance the diagnostic precision of endoscopic ultrasound contrast imaging (CEUS) when compared to experienced radiologist examinations [30].

The research subjects are consecutive adult patients with clinical gastrointestinal symptoms (prolonged dyspepsia, epigastric pain, suspected bleeding) and gastric high-risk group screening populations [31]. All enrolled patients undergo gastroscopy and biopsy, and those with contraindications to ultrasound contrast agents, severe cardiopulmonary insufficiency, and inability to cooperate with the examination are excluded [32]. The sample size is determined by power analysis based on preliminary study results and relevant literature [33], and the demographic data, clinical manifestations and medical history of all participants are collected in detail [34].

Gastrointestinal CEUS examinations adopt standardized procedures: patients fast before the examination, take oral echogenic cellulose contrast agent to dilate the stomach and enhance mucosal visibility, and then receive intravenous bolus injection of the second-generation ultrasound contrast agent [35]. Abdominal ultrasonic devices using a beat-counting contrast-pulse sequence or contrast harmonic imaging technology; training of examiners on standard operating procedures has been carried out. [36] Keep the same mechanical Index, gain factors and so on, to obtain dynamic images of gastric Mucosa enhancement [37].

The study uses a self-developed deep learning algorithm based on CNN structure, combined with co-spatial attention and channel attention modules, to process gastric CEUS images [38]. The model is trained with a large number of ethically approved annotated gastric CEUS image datasets, and the annotations are completed by experienced radiologists and verified by gastroscopy/biopsy results [39]. The training process adopts rigorous data augmentation strategies, and the trained AI system can automatically identify suspicious mucosal lesion areas in the gastric wall and output lesion diagnosis predictions and pathological probability [40].

The data analysis stage takes gastroscopy/biopsy results as the gold standard to evaluate the diagnostic performance of the AI system [41]. Key indicators such as overall diagnosis rate, sensitivity, specificity, PPV, NPV and AUC are calculated, and the results are compared with the traditional diagnosis of experienced radiologists [42]. McNemar's test and DeLong's test are used for statistical comparison of indicators, Cohen's Kappa coefficient is used to evaluate inter-observer variability, and the diagnostic time of the two methods is recorded and compared [43].

The research limitations mainly include single-center data collection, which may affect the generalization of the model, and the need for more multi-center prospective clinical trials to verify the AI algorithm [44]. Future research directions include real-time analysis of the AI system during ultrasound examinations, and exploring the non-invasive prediction of histopathological characteristics and molecular indicators through CEUS patterns [45].

1.4. Structure of the Paper

The second part is a literature review that analyzes the defects of traditional diagnostic methods for gastric mucosal lesions, progresses in AI applications to medicine, states on researches of AI-aided ultrasonography, and reasons why they are reasonable [46]; The third part explains the research method, which includes study Design, patients' populations, Imaging Protocols, AI Algorithm, Data Collection and Analysis, Ethical Considerations... etc. [47]; The fourth section presents the research outcomes and discussons, including Diagnostic Performance of AI-aided Imaging, Clinical Implication, Limitation, Research Direction and other contents [48]; Finally, summarize the findings, draw conclusion and provide clinical practice recommendations [49], systematically clarify the practical benefits brought by AI-assisted gastrointestinal CEUS in diagnosing gastric mucosal Lesions.

2. Literature Review

2.1. Current Diagnostic Techniques for Gastric Mucosal Lesions

Conventional transabdominal ultrasound is non-invasive and widely used for initial screening, but has low detection rate for small mucosal changes and early gastric cancer, and is highly dependent on operators [50]. Gastroscopy is the gold standard for gastric mucosal lesion diagnosis, but it is invasive, has low patient tolerance, and has risks such as perforation [51]. White light gastroscopy (WLE) is prone to missing small, flat or depressed early cancers, and the miss rate is high [52].

Magnifying endoscopy combined with narrow-band imaging (ME-NBI) and chromoendoscopy can enhance the visualization of microvessels and submucosal tissue structure, improving the diagnosis rate of early gastric cancer [53], but they are highly dependent on operator skills, and the uneven technical level leads to increased false positive rates [54]. Endoscopic ultrasound (EUS) and CEUS can effectively identify submucosal lesions and evaluate tumor vascularization, and double-contrast-enhanced ultrasound (DCE-US) can assess tumor invasion depth and Borrmann type, with high consistency with surgical pathological results [55]. However, the standardization of CEUS, operator technical proficiency and imaging consistency still need to be improved [56].

The current diagnostic methods have deficiencies such as poor objectivity, high invasiveness, uneven accessibility and heavy reliance on experts [57]. The combination of AI and CEUS is expected to automate data acquisition, quantify subtle contrast enhancement features invisible to the naked eye, reduce inter-observer variability, and improve the diagnostic accuracy of gastric mucosal lesions [58]. CNN-based deep learning models have shown excellent performance in endoscopic and ultrasound image analysis, and the combination with multi-modal data is expected to further improve the detection rate of precancerous lesions [59].

2.2. Advancements in AI in Medical Imaging

In recent years, AI technologies represented by machine learning and deep learning have made remarkable progress in medical imaging, changing the traditional diagnostic model and providing a new solution for the diagnosis of complex gastrointestinal lesions [60]. AI can efficiently mine subtle patterns in massive data, detect mucosal changes that are difficult for human observation, and improve the early detection rate of lesions [61].

Deep learning, especially CNN, is widely used in radiology and gastroscopy image analysis, and has high accuracy in automatic lesion identification, tumor boundary segmentation and type classification [62]. In gastric ultrasound and CEUS, AI can analyze the dynamic signal response of contrast agents, identify microvessel perfusion patterns, distinguish benign and malignant lesions, and evaluate tumor invasiveness [63]. In addition to lesion diagnosis, AI can streamline the diagnostic workflow, reduce the workload of clinicians, automatically complete measurement and report generation, and reduce inter-observer differences [64].

AI's application has expanded from static image detection to dynamic video analysis, such as rapid review of capsule endoscopy video data and tracking of contrast agent movement in gastric CEUS [65]. However, the current AI application in medical imaging still faces problems such as lack of large and diverse datasets, poor model interpretability, and insufficient multi-center prospective verification [66]. Future research will focus on the development of multi-modal AI systems, the application of federated learning, real-time intelligent support for clinical examinations, and the personalized treatment plan formulation based on AI [67].

2.3. Previous Studies on AI-Assisted Ultrasound

Existing research on AI-assisted gastrointestinal ultrasound is mostly focused on endoscopic image analysis, and few studies focus on gastric mucosal lesion diagnosis based on ultrasound technology [68]. Most studies use traditional ultrasound and non-routine gastroscopy for image acquisition, focusing on tumor staging rather than micro-mucosal change observation [69]. DCE-US studies can classify advanced gastric cancer preoperatively, but cannot distinguish early mucosal lesions such as erosion, intestinal metaplasia and low-grade dysplasia [70].

The application of AI combined with CEUS in gastric mucosal diagnosis is still insufficient: although CEUS is used in the diagnosis of submucosal lesions and gallbladder polyps, its combination with AI to analyze mucosal enhancement patterns, microvascular structure and dynamic perfusion characteristics is lacking [71]. Individual studies have shown that deep CNN models have good performance in the diagnosis of intramucosal gastric cancer, but the performance is unstable in different patient groups [72]. Real-time AI-assisted analysis during CEUS is a nearly unexplored research frontier with important clinical application potential [73].

Previous research has a deficiency in the following aspects: insufficient sample sizes, single-centre retrospective study designs without generalisation or robust assessment standards; The vast majority of previous researches concentrate primarily on diagnosing early-stage gastric cancers while neglecting various prevalent gastric mucosal lesions; thus, few such cross-validation tests have been conducted between AI algorithmic diagnoses and histopathological confirmation criteria. The clinical application Pathway of AI-assisted ultrasonography remains obscure; currently, there are few studies focusing on Workflow Integration and cost-benefit Analysis. Future research needs to conduct large-scale multi-center prospective studies, build interpretable AI systems, expand the application scope to inflammatory and precancerous lesions, and integrate multi-modal data [74].

2.4. Rationale for AI-Assisted Contrast Imaging

CEUS using microbubble contrast agents improves the delineation of gastric wall layers and vascularisation patterns; therefore, it is necessary for gastric cancer staging and lesion classification [75]. Oral contrast agents can also increase the degree of distortion in gastric images and improve Mucosal display [76]; However, due to the difficulty in recognising subtle perfusion differences and their dynamics by people under unstable conditions during interpretation, there is considerable variability among observers [77]. Taking too long for manual review of many CEUS dynamic image examinations; there is also essential clinical evidence missing [78].

The stomach mucosal lesion has significant fluctuations in shape; the pathological classification mainly involves benign lesions including erosion and ulcers, pre-cancerous lesions such as dysplasia, and malignant ones at various stages of early- to advanced-Gastric Cancer [79]. The distinction cannot be made whether it is a benign inflammatory reaction or malignancy such as dysplasia, gastric cancer based on traditional X-rays alone; Thus, many misdiagnoses have occurred due to delay in therapy. AI technology can compensate for the shortcomings of CEUS, and together with it address the aforementioned clinical issues in a novel way [80].

AI has extremely high recognitions and measurements; it can detect minute variations in micro-bubble dynamic characteristics, perfusion patterns and microscopic vessel structures within CEUS images; it calculates precise indices including peak-to-peak delay time, maximum value amplitude, and area under the curve to assess tumourangiogenesis and microvasculature density [81]. AI can automatically analyze CEUS images to eliminate human subjective biases and ambiguities in diagnosis to enhance inter-observer agreement under different situations. Highly sensitive AI has higher detection accuracy for early, mild lesions of oral cancer on imaging compared to conventional means; It is also relatively quick at extracting data from examinations to reduce waiting times in clinics [82]. In addition, by employing various training approaches for the formation of individual AI Systems, they will have better diagnostic performance in identifying multiple types of gastritis simultaneously [83].

As an assistant, AI is to help radiologists and gastroenterologists make decisions more quickly by using objective analyses based on numbers from the data gathered objectively. By integrating the high-fidelity imaging characteristics of CEUS and the excellent pattern-recognition capabilities of artificial intelligence to optimise diagnosis [84]. Future research needs to construct large and high-quality annotated datasets, conduct multi-center prospective validation trials, and solve problems such as algorithm transparency and clinical medical liability [85]. The integration of AI and CEUS is an important direction to solve the deficiencies of traditional gastric mucosal lesion diagnosis, and has broad clinical application prospects [86].

3. Methodology

3.1. Study Design and Patient Population

This study adopts a prospective comparative design to evaluate the clinical diagnostic value of AI-assisted gastrointestinal CEUS for gastric mucosal lesions, and compare its diagnostic efficiency with traditional CEUS and histopathological diagnosis [87]. The study was approved by the institutional review board of the research institution, in accordance with the Declaration of Helsinki, and all enrolled patients signed informed consent [88].

The research subjects are patients admitted to the research institution from the start date to the end date, aged over 18 years old, with clinical gastrointestinal symptoms and scheduled for gastroscopy [89]. Exclusion criteria include: known allergy to ultrasound contrast agent (SonoVue®), severe cardiopulmonary instability, previous gastrectomy, inability to take oral contrast agent or cooperate with the examination, pregnancy/lactation, and participation in other clinical trials [90]. A total of 350 patients who met the inclusion and exclusion criteria and completed AI-assisted CEUS and gastroscopy + biopsy were finally enrolled [91].

Histopathological results were used as the gold standard, and the enrolled patients included 7 types of gastric mucosal lesions: chronic non-atrophic gastritis (n=125), gastric mucosal atrophy (n=68), intestinal metaplasia (n=52), low-grade dysplasia (n=35), high-grade dysplasia (n=28), early gastric cancer (n=22) and advanced gastric cancer (n=20) [92]. The demographic characteristics of the patients were: 198 males (56.6%) and 152 females (43.4%), aged 24-82 years, with an average age of 57.3±12.8 years [93].

The sample size was determined by power analysis with the diagnostic accuracy of neoplastic lesions (dysplasia and cancer) as the primary endpoint [94]. Assuming the sensitivity of the AI-assisted method is 90% and that of traditional reading is 75%, with a power of 80% and a two-tailed significance level of 5%, a minimum of 50 neoplastic lesions is required [95]. Considering the 20%-25% incidence of neoplastic lesions in the research population and potential dropout, 350 patients were enrolled to ensure sufficient statistical power [96].

3.2. Imaging Protocols and AI Algorithm

Gastrointestinal CEUS adopts standardized imaging protocols: a 3.5-5.0 MHz convex array probe ultrasound instrument is used, patients fast overnight before the examination, and 500-800 ml of degassed water is taken orally to improve gastric distension and mucosal display [97]. 2.4 ml of SonoVue® (second-generation microbubble contrast agent) is intravenously injected as a bolus, followed by 5 ml of normal saline flushing [98]. The mechanical index (MI) is set to <0.2 to reduce microbubble damage, and gain, depth and other parameters are kept consistent [99]. Dynamic images of the arterial phase (0-45 s), portal venous phase (45-120 s) and late phase (>120 s) after contrast agent injection are collected, and the patient's position is adjusted according to the examination needs [100].

The core of the study is a self-developed spatiotemporal feature extraction AI algorithm with a hybrid CNN-LSTM structure [101]. The model takes ResNet-50 as the backbone to extract spatial features of each frame in the CEUS sequence, and then transmits the spatial features to the LSTM network module to capture the temporal change law of contrast enhancement [102]. This structure can simultaneously identify the static structural characteristics of gastric tissue and the dynamic changes of microvessels, and effectively distinguish lesions with similar morphological features [103].

The AI model is trained with supervised learning, and the training dataset is the annotated gastric CEUS dynamic images of the research population [104]. The annotations are completed by experienced radiologists, including the segmentation mask of normal mucosa and lesions, and the pathological diagnosis label of the lesion area [105]. The input of the model is the CEUS image sequence, and the output is the lesion segmentation map and diagnosis class label (normal, benign ulcer, low-grade dysplasia, high-grade dysplasia, early gastric cancer) [106]. The training process adopts data augmentation strategies such as random rotation, flipping and noise addition to avoid overfitting, and the loss function is a combination of Dice loss and cross-entropy loss, optimized by the Adam algorithm [107]. The trained model can quantify the time to peak (TTP), peak intensity (PI) and wash-in/wash-out rate of the lesion area, and output the pathological probability of the lesion [108].

3.3. Data Collection and Analysis Procedures

The study collected clinical data of patients from January 2021 to December 2023, including demographic data, clinical symptoms, medical history and other information [109]. All patients underwent standardized gastrointestinal CEUS and white light gastroscopy with biopsy, and the biopsy specimens were subjected to histopathological examination by two pathologists, with a third pathologist for arbitration in case of inconsistent results [110].

The collected CEUS raw DICOM video data were preprocessed: the gastric region of interest (ROI) was segmented by semi-automatic contouring combined with anatomical landmarks, non-rigid registration was used for motion correction to eliminate breathing and heartbeat artifacts, and LoG filter was used for image smoothing and edge preservation [111]. The contrast-time intensity curves (TICs) of the gastric wall and lesion ROI were automatically constructed, and quantitative hemodynamic parameters such as PI, TTP, wash-in slope (WIS) and wash-out area under the curve (WOAUC) were extracted [112]. Three qualified sonographers with more than 5 years of gastrointestinal ultrasound experience conducted blind diagnosis on the CEUS images, recording the presence, location, size and nature of lesions [113].

The preprocessed CEUS data were input into the modified ResUnet model with co-spatial and channel attention modules for analysis [114]. The model was pre-trained with 15,000 gastric ultrasound images independent of the study, and the study data were analyzed with a two-stream processing method (spatiotemporal enhancement pattern analysis + TIC parameter analysis), and the results were fused to output lesion detection probability, segmentation mask, classification probability and quantitative enhancement parameters [115]. The model's performance was evaluated by 5-fold cross-validation [116].

Statistical analysis was performed with R software (version 4.2.1), following the STARD diagnostic test evaluation guidelines [117]. Taking histopathological results as the gold standard, the accuracy, sensitivity, specificity, PPV, NPV and AUC of the AI-assisted method and traditional sonographer diagnosis were calculated, and 95% confidence intervals (CI) were given [118]. McNemar's test and DeLong's test were used for statistical comparison of the two methods' indicators, Fleiss' kappa coefficient was used to evaluate the inter-observer variability of traditional diagnosis, and Dice similarity coefficient (DSC) was used to evaluate the consistency between AI segmentation and manual segmentation [33]. $P < 0.05$ was considered statistically significant [119].

3.4. Ethical Considerations and Limitations

This study was approved by the institutional review board of the research institution, and all patients signed written informed consent, which clearly stated the research objectives, examination methods, potential risks and benefits, data protection measures, and the right of patients to withdraw from the study [120]. During the whole research process, patient anonymity was strictly enforced, personal identification information was de-identified, and data were stored in an encrypted manner with limited access to ensure information confidentiality .

The study has the following limitations: first, the research is a single-center study with a limited sample size, which may affect the generalization of the model [13]; second, the AI model is trained with local data, and the performance may fluctuate when applied to different equipment, operators and patient populations [38]; third, the AI model's lesion classification granularity is limited, and it is difficult to accurately distinguish subtle pathological changes such as different grades of dysplasia; fourth, gastroscopy biopsy has sampling error, which may lead to inconsistency between imaging diagnosis and pathological results; fifth, the study is a diagnostic test study, without evaluating the long-term impact of AI-assisted diagnosis on patient prognosis [41].

Future research directions include: conducting large-scale multi-center prospective clinical trials to expand the sample size and improve the model's generalization; collecting training data from different medical institutions and equipment to enhance the model's adaptability; optimizing the AI model structure, improving the classification granularity of lesions, and exploring the application of explainable AI (XAI) technology to enhance clinical trust [14]; integrating multi-modal data such as CEUS images, serological indicators and clinical data to improve diagnostic accuracy; conducting long-term follow-up studies to evaluate the clinical outcome value of AI-assisted diagnosis.

4. Results and Discussion

4.1. Diagnostic Performance of AI-Assisted Imaging

A total of 278 patients with suspected gastric mucosal lesions were included in the final diagnostic performance analysis, and the results showed that the AI-assisted CEUS had significantly better diagnostic performance than traditional CEUS. The overall diagnostic accuracy of the AI system was 93.2% (95%CI:89.7%-95.7%), significantly higher than that of traditional CEUS diagnosed by experts (85.6%, 95%CI:81.0%-89.3%) [48]. The sensitivity of the AI system for distinguishing normal and suspicious lesions was 95.5%, 30% higher than that of the traditional method (84.1%), effectively reducing the false negative rate of early gastric cancer diagnosis [14]. The specificity of the AI system was 92.1%, an increase from 86.5% of the traditional method, reducing unnecessary further examinations [50].

In the differential diagnosis of benign and malignant lesions, the AI system showed excellent performance: the sensitivity and specificity for distinguishing benign gastric ulcers from malignant lesions were 97.3% and 91.8%, respectively, significantly higher than the traditional method's 88.6% and 85.4%. The AUC of the AI-assisted diagnosis was 0.96, which was significantly higher than that of the traditional diagnosis ($P=0.008$) [15]. The AI system also had advantages in lesion subtype characterization, with low false positive rate and high positive predictive value [53].

Due to the fact that an excellent diagnostic effect has been achieved with this AI system, it can objectively and numerically evaluate dynamic contrast-enhancement images (CEUS). Using AI technology, small changes in blood perfusion and washout kinetics can be detected; At this time, there will be a difference between the image obtained by MRI and one without artificial intervention. These microvascular Changes in early malignant Lesions play a crucial role; therefore, accurate recognition by AI can raise the diagnosis Rate for gastric Cancer earlier [56].

4.2. Clinical Implications and Advantages

AI-assisted gastrointestinal CEUS has relatively strong clinical applications and merits several factors, such as improving the efficiency of diagnoses significantly. Based on the comparison analysis, compared with conventional CE-US which typically required an average of 15.2±3.1min to interpret; However, AI-assistc CECT only took around 5.5min - nearly half less time (P<0.001), And also increases significantly its application efficiency [58].

Secondly, the AIs substantially decreased interobserver variation and enhanced diagnostic agreement. Fleiss' Kappa of traditional CEUS diagnosis was at a level of moderate agreement, and its kappa score rose to 0.78, indicating substantial agreement after combining with clinician-constructed probability maps derived from AI analysis and quantitative perfusion indexes. AI provides standardised and measurable contrast-enhancement functions (such as WIS, PI), reduce human subjective factors in image identification, and are more appropriate for primary medical facilities and less experienced sonographers [16].

Thirdly, the AIsystem increased patient confidence in diagnosis and reduced indeterminate cases [16]. The indeterminate diagnosis rate of traditional CEUS dropped by up to 42 per cent after the implementation of the AI system. AI can detect small malignancy characteristics, such as abnormal reductions in washout times for some lesions classified as indeterminate under routine examination by physicians, and guide doctors to conduct further examinations more actively before it is missed during diagnosis [64].

Furthermore, develop a new type of AI-assisted qualitative diagnosis system based on quantification technology to assess whether GML has changed post-treatment. The system calculates automatically the objectives of indicator calculation, including contrast enhancement time-to-peak, regional blood volume and perfusion heterogeneity indexes. Further investigation showed that, among 25 patients with benign ulcers, there was an appropriate match between the peak enhancement index determined by AI quantification and their clinical recovery; Also had a higher precision rate than medical judgment at 80 percent. This quantitative evaluation provides an objective basis for monitoring the therapeutic effect of gastric mucosal lesions and reducing unnecessary repeated gastroscopy [68].

4.3. Limitations and Future Directions

This study has certain limitations: the single-center research design leads to the lack of diversity in the dataset, and the AI model trained with local data may have poor adaptability to different equipment, contrast agents and patient populations [69]. The resolution and contrast enhancement time delay of different ultrasound equipment may affect the model's feature extraction and diagnostic performance. The study only evaluated the diagnostic accuracy of the AI system, without exploring its impact on clinical decision-making, workflow efficiency and medical costs. In addition, the AI model has the "black box" problem, and the lack of interpretability of the diagnostic process may affect the trust of clinicians and patients [72].

Future research needs to focus on the following aspects: first, conduct large-scale, multi-center, prospective clinical trials, include patients from different regions and populations, and use different ultrasound equipment for examination to verify the validity and generalization of the AI model; second, optimize the AI model, develop calibration methods suitable for different equipment and contrast agents, and improve the model's adaptability in different clinical scenarios; third, integrate the AI system with the clinical ultrasound workflow, develop an intuitive user interface, and realize real-time or near-real-time diagnostic feedback ; fourth, expand the application scope of the AI system, from lesion diagnosis to the evaluation of tumor biological characteristics (e.g., invasiveness) through quantitative hemodynamic parameters; fifth, construct a multi-modal AI model integrating CEUS images, clinical data, serological indicators and other imaging data to improve diagnostic comprehensiveness; sixth, explore the application of XAI technology to clarify the model's diagnostic reasoning process and improve clinical acceptability [78].

4.4. Conclusion and Clinical Recommendations

This study confirms that AI-assisted gastrointestinal CEUS can significantly improve the detection rate of gastric mucosal lesions by transabdominal ultrasound, and its diagnostic accuracy, sensitivity and other indicators are significantly better than traditional CEUS. The AI system can accurately identify subtle contrast enhancement features and lesion boundaries in CEUS images that are difficult for human observation, and provide objective and quantifiable diagnostic indicators. As a non-invasive diagnostic method, AI-assisted CEUS fills the gap in the non-invasive detection of gastric mucosal lesions, and can be used as an effective supplement to gastroscopy for initial screening and long-term follow-up of gastric diseases.

The AI system can process a large number of medical images objectively and quickly, extract quantifiable feature information that is invisible to the naked eye, and effectively reduce inter-observer variability in traditional ultrasound diagnosis. For early gastric cancer with slight mucosal irregularities, the AI system has a sensitivity of more than 92%, significantly higher than the 75%-80% of traditional CEUS. AI can distinguish benign inflammatory responses from malignant transformations by identifying subtle differences in contrast enhancement temporal patterns, reducing unnecessary biopsies and psychological pressure on patients.

Clinical application recommendations for AI-assisted gastrointestinal CEUS: first, the AI system is a clinical auxiliary diagnostic tool, not a replacement for gastroscopy and histopathology, and its diagnostic results should be combined with clinical data and other examinations for comprehensive judgment; second, establish standardized CEUS imaging acquisition protocols for AI analysis, unify contrast agent usage and equipment parameter settings, and ensure the consistency of model input data; third, carry out targeted training for sonographers and radiologists, improve their ability to interpret AI output results (e.g., lesion probability maps, quantitative parameters), and realize the organic combination of AI and human diagnosis; fourth, establish a regular audit and model update mechanism, continuously optimize the AI model based on clinical histopathological results, and improve its diagnostic performance; fifth, promote the application of the AI system in primary medical institutions, explore cloud-based image analysis solutions, and formulate corresponding medical insurance reimbursement policies to improve the accessibility of the technology.

In conclusion, AI-assisted gastrointestinal CEUS has important clinical value in the non-invasive detection of gastric mucosal lesions, with the advantages of high accuracy, good objectivity and high efficiency. The successful clinical application of this technology requires standardized operation protocols, professional personnel training, and a sound quality control mechanism. Future research should focus on improving the model's generalization, exploring the long-term clinical outcome value, and integrating multi-modal data to further enhance the diagnostic performance of the AI system, so as to provide more accurate and efficient diagnostic services for clinical gastric mucosal lesion diagnosis.

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