Differentiating Complicated Acute Appendicitis From Non-complicated Acute Appendicitis Based on Ultrasound Characteristics

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AIM: This study aimed to identify key ultrasound (US) characteristics that differentiate complicated acute appendicitis (CAA) from non-complicated acute appendicitis (NCAA) and to develop and validate a US-based predictive model for preoperative diagnosis.
METHODS: A retrospective analysis was conducted on 178 patients with surgically confirmed acute appendicitis between June 2022 and May 2025. All patients underwent a standardized preoperative US examination. Clinical and sonographic variables were compared between the CAA (n = 63) and NCAA (n = 115) groups. Least Absolute Shrinkage and Selection Operator (LASSO) regression was used for variable selection, followed by multivariable logistic regression to construct a predictive model. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC), calibration plots, and decision curve analysis (DCA).
RESULTS: Compared to the NCAA group, the CAA group had significantly older age, longer symptom duration, higher white blood cell (WBC), and higher neutrophil percentage (NE%) ($p < 0.05$). Significant US-based predictors included greater appendiceal outer diameter (AOD), increased periappendiceal inflammatory fat thickness (PIFT), and higher incidences of periappendiceal fluid collection (PAFC), marginal indistinctness (MI), and altered bowel peristalsis (ABP). The final model identified eight independent predictors: age, symptom duration, WBC, NE%, PIFT, PAFC, MI, and ABP. The nomogram showed excellent discrimination (AUC = 0.890), good calibration (Hosmer–Lemeshow test, $p = 0.108$), and sustained performance during internal validation (AUC = 0.902). DCA confirmed high clinical utility.
CONCLUSIONS: The proposed US-based nomogram provides an accurate, non-invasive tool for preoperative differentiation of CAA from NCAA, potentially aiding in risk stratification and treatment decision-making.

Keywords: complicated acute appendicitis; non-complicated acute appendicitis; ultrasound characteristics; preoperative diagnosis

Introduction

Acute appendicitis (AA) is one of the most common diseases in the surgical acute abdomen [1]. According to global epidemiological reports, the standardized mortality rate of AA was 0.358 per 100,000 cases in 2021, and the disease burden caused by appendicitis remains considerable [2,3]. Approximately 20%–30% of the AA patients progress to complicated acute appendicitis (CAA) [4], which includes pathological types such as perforation, gangrene, abscess or diffuse peritonitis. Existing research indicates that over 20% of CAA patients experience postoperative complications at a rate significantly higher than that of non-complicated acute appendicitis (NCAA) [5]. The choice of treatment plan for acute appendicitis is highly dependent on the pathological severity of the disease. Existing research indicates that for patients with NCAA, standardized conservative antibiotic therapy, when strictly adhering to indications, can achieve short-term outcomes comparable to surgical intervention while effectively reducing surgery-related complications [6,7]. However, patients with CAA require prompt surgical intervention due to the destruction of the appendix wall structure and the extensive spread of inflammatory infiltration to avoid further deterioration of their condition [8]. Therefore, the early and accurate differentiation between CAA and NCAA is of paramount importance for formulating individualized clinical treatment plans and improving patient outcomes.

At present, computed tomography (CT) is regarded as the gold-standard imaging method for diagnosing AA, demonstrating high sensitivity and specificity [9]. However, adoption of the CT approach is constrained by several limitations such as the risk of ionizing radiation exposure and the relatively high costs [10]. As a non-invasive imaging technique, ultrasound (US) examination offers advantages such as ease of operation, low cost, and absence of radiation exposure, and has been widely adopted in the diagnosis of acute abdominal conditions [11]. In recent years, with the continuous improvement in the resolution of US equipment and the increasing sophistication of the relevant diagnostic techniques, the significance of US examinations in diag-

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nosing AA has gained further recognition [12]. Through US examination, the position and shape of the appendix can be clearly delineated, along with accurate identification of pathological changes such as fecalith of the appendix and periappendiceal effusion [13]. These US features are closely related to the pathological severity of AA. However, the sensitivity and specificity of these US characteristics vary significantly in different studies and are greatly influenced by the operator's experience and the resolution of the equipment. Furthermore, there is currently a lack of systematic research to identify the US characteristics with the highest discriminatory value and to establish reliable evaluation criteria in the context of AA.

Against this background, the present study aims to retrospectively analyze US examination data from patients with surgically confirmed AA and systematically investigate the distribution differences of distinct US characteristics between CAA and NCAA. We further establish a US-based differential diagnosis model and validate its diagnostic efficacy. This endeavor provides objective and reliable clinical insights based on imaging evidence, which is beneficial for accurate preoperative determination of the pathological type of AA and rational selection of treatment strategies. Consequently, it aims to enhance the diagnostic and therapeutic standards for AA and improve patient outcomes.

Methods

Research Subjects

In this retrospective study, data of a total of 204 AA patients were retrieved from The People's Hospital of Yingshang's electronic medical record system from June 2022 to May 2025. After a stringent patient selection process based on a set of well-defined inclusion and exclusion criteria, the data of 178 patients were ultimately included in the analysis. Among them, 115 cases were confirmed as NCAA and 63 as CAA based on surgical findings and pathological features. This research was conducted in strict adherence to all the principles of the Declaration of Helsinki and was approved by the Ethics Committee of The People's Hospital of Yingshang (No. 202521).

Inclusion and Exclusion Criteria

The inclusion criteria for this study are as follows: (1) patients aged $\geq$12 years old; (2) patients diagnosed with AA following postoperative pathological examination; (3) patients experiencing their first episode, with symptoms lasting no longer than seven days; (4) patients undergoing a comprehensive US examination prior to surgery, with clear images and complete documentation; and (5) patients with complete clinical records.

The exclusion criteria for this study are listed as follows: (1) patients comorbid with other abdominal emergencies (such as acute cholecystitis, intestinal obstruction, intestinal perforation, etc.); (2) patients with a previous history of abdominal surgery; (3) pregnant female patients; and (4) patients with chronic appendicitis.

Diagnosis and Grouping

All the diagnoses in this study were jointly determined based on the intraoperative findings and postoperative pathological results, and were analyzed jointly by two physicians. According to previous research reports, AA primarily encompasses acute simple appendicitis, acute suppurative appendicitis, gangrenous and perforated appendicitis, and appendiceal abscesses [14]. In this study, gangrenous and perforated appendicitis, along with appendiceal abscesses, were categorized into the CAA group, whereas acute simple appendicitis and acute suppurative appendicitis were classified into the NCAA group.

Operating Standards for US Examination

All US examinations were performed by two certified sonographers following standardized protocols. The ultrasound equipment used was GE LOGIQ E9 (GE Healthcare, Chicago, IL, USA), equipped with a convex probe (Model: C1-6, frequency range: 2–5 MHz) and a linear probe (Model: ML6-15, frequency range: 8–15 MHz). The examination was initially conducted with the patient in the supine position, with the left lateral position adopted only if necessary to optimize the imaging effect. The convex probe was initially used to scan the entire abdomen to locate the appendix and evaluate the overall abdominal condition, including the presence of free fluid. Subsequently, the linear probe with a higher frequency was used for detailed observation of the appendix and its surrounding structures. The following US parameters were measured and recorded: appendiceal outer diameter (AOD), periappendiceal inflammatory fat thickness (PIFT), and the presence or absence of periappendiceal fluid collection (PAFC), appendiceal fecolith obstruction (AFO), marginal indistinctness (MI), ileocecal wall thickening (IWT), periappendiceal mesentery thickening (PAMT), and altered bowel peristalsis (ABP). In the event of discrepancies in judgment, a third senior US physician (with more than 10 years of experience) was consulted to make a final decision.

Data Collection

Data were retrospectively retrieved from electronic medical records by trained researchers. Clinical variables included demographics (age, gender), symptom duration (hours), physical signs (abdominal pain, rebound tenderness, emesis, fever), and laboratory results (white blood cell [WBC], neutrophil percentage [NE%]). US characteristics were recorded as binary (present/absent) or continuous variables (e.g., AOD in mm) based on probe-specific imaging.

Statistical Analysis

Data analyses were performed using SPSS 26.0 (IBM Corp., Armonk, NY, USA) and R 4.2.1 (R Foundation for

Table 1. Comparison of baseline characteristics between NCAA and CAA patients.

Variables	NCAA group (n = 115)	CAA group (n = 63)	t/Z/χ^2	p
Age (years)	34.00 (17.00, 47.00)	49.00 (26.00, 66.50)	–3.52	<0.001
Gender			0.18	0.675
Female	51 (44.35)	30 (47.62)		
Male	64 (55.65)	33 (52.38)		
DAS (h)	24.00 (17.00, 30.00)	27.00 (18.00, 37.00)	2.06	0.040
Abdominal pain			0.06	0.802
Negative	5 (4.35)	3 (4.76)		
Positive	110 (95.65)	60 (95.24)		
Rebound tenderness			0.28	0.594
Negative	20 (17.39)	13 (20.63)		
Positive	95 (82.61)	50 (79.37)		
Emesis			0.69	0.405
Negative	92 (80.00)	47 (74.60)		
Positive	23 (20.00)	16 (25.40)		
Fever			2.59	0.108
Negative	91 (79.13)	43 (68.25)		
Positive	24 (20.87)	20 (31.75)		
WBC ($\times 10^9$/L)	12.87 ± 3.25	14.59 ± 3.46	–3.30	0.001
NE%	80.74 (71.05, 84.54)	85.11 (79.10, 88.06)	–4.04	<0.001

Abbreviation: CAA, complicated acute appendicitis; DAS, duration of acute symptoms; NCAA, non-complicated acute appendicitis; NE%, neutrophil percentage; WBC, white blood cell.

Statistical Computing, Vienna, Austria). The Shapiro–Wilk test was used to evaluate the normality of data distribution for continuous variables (e.g., data of WBC and AOD follow a normal distribution). Continuous variables that conform to the normal distribution are expressed as mean ± standard deviation (SD), and t-tests were used for intergroup comparisons. Continuous variables that do not conform to the normal distribution are presented as median and interquartile range, and comparisons between groups were conducted using the Mann–Whitney U test. Chi-square or Fisher's exact test was employed to conduct comparative analyses of categorical variables, which are expressed as n (%). Least Absolute Shrinkage and Selection Operator (LASSO) regression (ten-fold cross-validation) was utilized to identify potential predictors, and multivariate logistic regression was subsequently performed to determine independent risk factors. A nomogram was constructed based on the final logistic regression model. Odds ratios (OR) with 95% confidence intervals (CI) were calculated. Model discrimination was assessed in terms of the area under the receiver operating characteristic (ROC) curve (AUC); calibration was evaluated using the Hosmer–Lemeshow test and calibration plot. Internal validity was tested using 1000 bootstrap resamples to obtain bias-corrected AUC, sensitivity, specificity and accuracy. Decision curve analysis (DCA) was used to estimate clinical net benefit. Two-sided $p < 0.05$ was considered statistically significant.

Results

General Characteristics of the Patients

A total of 178 AA patients were included in this study, among whom 115 (64.61%) were classified into the NCAA group and 63 (35.39%) into the CAA group (Table 1). The age (49.00 vs. 34.00, $p < 0.001$), DAS (27.00 vs. 24.00, $p = 0.040$), WBC count (14.59 vs. 12.87, $p = 0.001$), and NE% (85.11 vs. 80.74, $p < 0.001$) in the CAA group were significantly higher than those in the NCAA group. No significant differences in other characteristics were found between the two groups of patients.

Comparison of US Examination Characteristics

The results of the US examination showed that the AOD (12.57 vs. 11.36, $p < 0.001$) and PIFT (5.00 vs. 4.00, $p < 0.001$) of patients in the CAA group were significantly higher than those in the NCAA group (Table 2). In addition, the proportion of patients with PAFC (26.98% vs. 7.83%, $p < 0.001$), AFO (30.16% vs. 13.91%, $p = 0.009$), MI (28.57% vs. 9.57%, $p = 0.001$), IWT (23.81% vs. 8.70%, $p = 0.006$), PAMT (33.33% vs. 17.39%, $p = 0.016$), and ABP (22.22% vs. 5.22%, $p < 0.001$) in the CAA group was also significantly higher than that in the NCAA group.

LASSO Regression Analysis

Nineteen candidate variables were entered into the LASSO regression with ten-fold cross-validation to perform the initial variable screen. The coefficient profile plot (Fig. 1A) and the cross-validated error plot (Fig. 1B) illustrate how the coefficients and the number of non-zero predictors

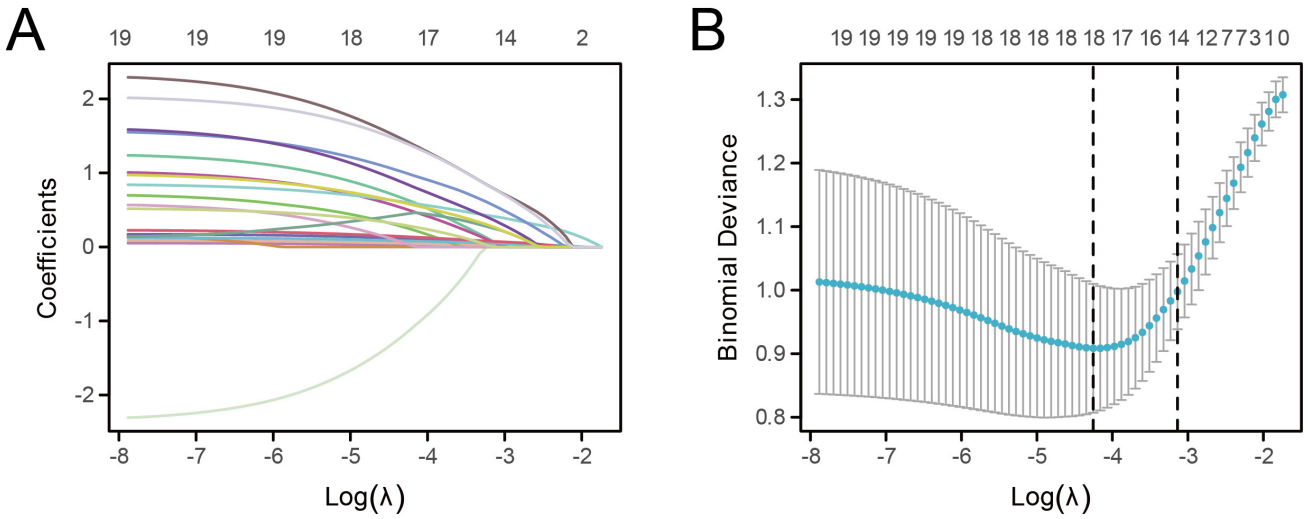

Fig. 1. Variable screening process based on LASSO regression. (A) LASSO regression coefficient convergence path diagram. (B) Ten-fold cross-validation diagram. LASSO, Least Absolute Shrinkage and Selection Operator.

Table 2. Comparison of US characteristics between NCAA and CAA patients.

Variables	NCAA group (n = 115)	CAA group (n = 63)	t/χ^2	p
AOD (mm)	11.36 ± 2.30	12.57 ± 2.14	–3.43	<0.001
PIFT (mm)	4.00 (3.00, 5.00)	5.00 (4.50, 6.00)	–4.71	<0.001
PAFC (%)			11.98	<0.001
Negative	106 (92.17)	46 (73.02)		
Positive	9 (7.83)	17 (26.98)		
ALF (%)			1.88	0.170
Negative	81 (70.43)	38 (60.32)		
Positive	34 (29.57)	25 (39.68)		
AFO (%)			6.80	0.009
Negative	99 (86.09)	44 (69.84)		
Positive	16 (13.91)	19 (30.16)		
IWV (%)			1.15	0.283
Negative	82 (71.30)	40 (63.49)		
Positive	33 (28.70)	23 (36.51)		
MI (%)			10.78	0.001
Negative	104 (90.43)	45 (71.43)		
Positive	11 (9.57)	18 (28.57)		
IWT (%)			7.70	0.006
Negative	105 (91.30)	48 (76.19)		
Positive	10 (8.70)	15 (23.81)		
PAMT (%)			5.84	0.016
Negative	95 (82.61)	42 (66.67)		
Positive	20 (17.39)	21 (33.33)		
ABP (%)			11.80	<0.001
Negative	109 (94.78)	49 (77.78)		
Positive	6 (5.22)	14 (22.22)		

Abbreviations: ABP, altered bowel peristalsis; AOD, appendiceal outer diameter; AFO, appendiceal fecolith obstruction; ALF, appendiceal luminal fecolith; IWT, ileocecal wall thickening; IWV, increased wall vascularity; MI, marginal indistinctness; PAFC, periappendiceal fluid collection; PAMT, periappendiceal mesentery thickening; PIFT, periappendiceal inflammatory fat thickness; US, ultrasound.

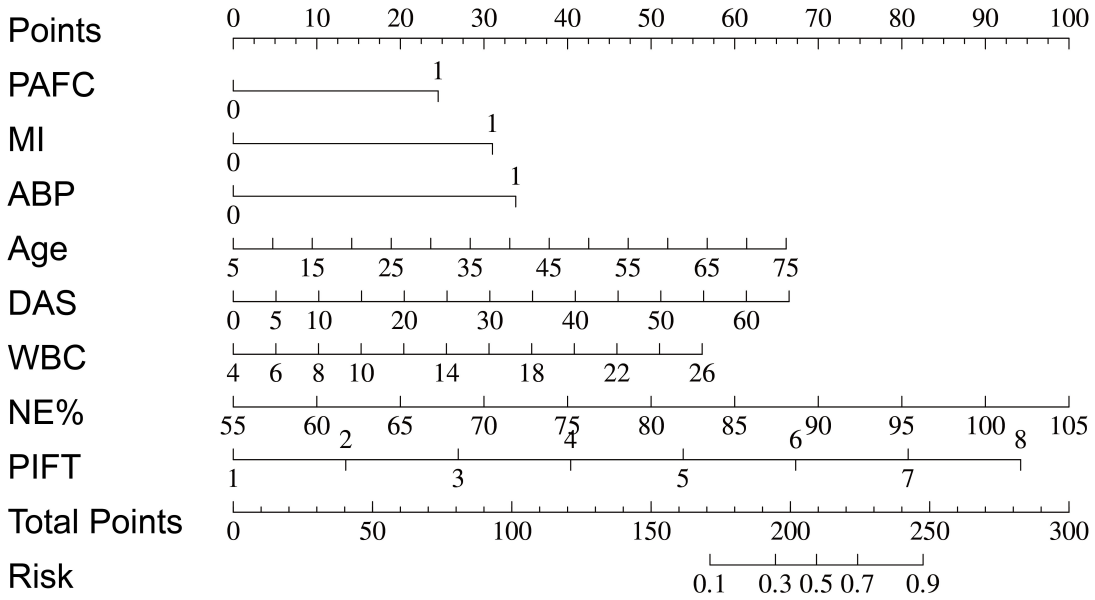

Fig. 2. Nomogram for predicting acute appendicitis. Abbreviations: ABP, altered bowel peristalsis; DAS, duration of acute symptoms; MI, marginal indistinctness; PAFC, periappendiceal fluid collection; PIFT, periappendiceal inflammatory fat thickness; WBC, white blood cell.

change with the penalty parameter λ. According to the λ value that gave the minimum cross-validated deviance, the model retained 12 predictors with non-zero coefficients. These 12 variables, extracted directly from the LASSO output, were: PIFT, MI, ABP, PAFC, AOD, WBC, NE%, age, IWT, PAMT, DAS, and AFO. They were subsequently entered into the multivariable logistic regression to identify independent predictors of complicated acute appendicitis.

Screening of Independent Influencing Factors

Using grouping as the dependent variable, the 12 variables identified in the LASSO method were included as independent variables in a multivariate logistic regression analysis. The variable assignment is detailed in Table 3. Results indicated that age (OR = 1.06, 95% CI: 1.01–1.10, $p = 0.008$), DAS (OR = 1.06, 95% CI: 1.02–1.10, $p = 0.003$), WBC (OR = 1.16, 95% CI: 1.02–1.32, $p = 0.028$), NE% (OR = 1.12, 95% CI: 1.06–1.19, $p < 0.001$), PIFT (OR = 2.17, 95% CI: 1.49–3.15, $p < 0.001$), PAFC (OR = 4.09, 95% CI: 1.24–13.54, $p = 0.021$), MI (OR = 5.94, 95% CI: 1.78–19.78, $p = 0.004$), and ABP (OR = 6.97, 95% CI: 1.84–26.43, $p = 0.004$) are independent risk factors distinguishing CAA from NCAA.

Nomogram of US-based Diagnosis of CAA and NCAA

Based on the results of the LASSO logistic regression analyses, we built a multivariate prediction model that included age, DAS score, white blood cell count, neutrophil percentage, PIFT score, PAFC score, MI score, and ABP score, which was used to differentiate between CAA and non-CAA. For clinical application, we drew a column-line graph based on the model, which was used to visually estimate the probability of CAA (Fig. 2). The ROC of the predictive model is shown in Fig. 3, with an AUC of 0.890. The accuracy, sensitivity, and specificity of this model were 78.57%, 74.32%, and 88.71%, respectively. The consistency between the actual values and the predicted values of the calibration curve shown in Fig. 4 is high (Hosmer–Lemeshow test, $p = 0.108$).

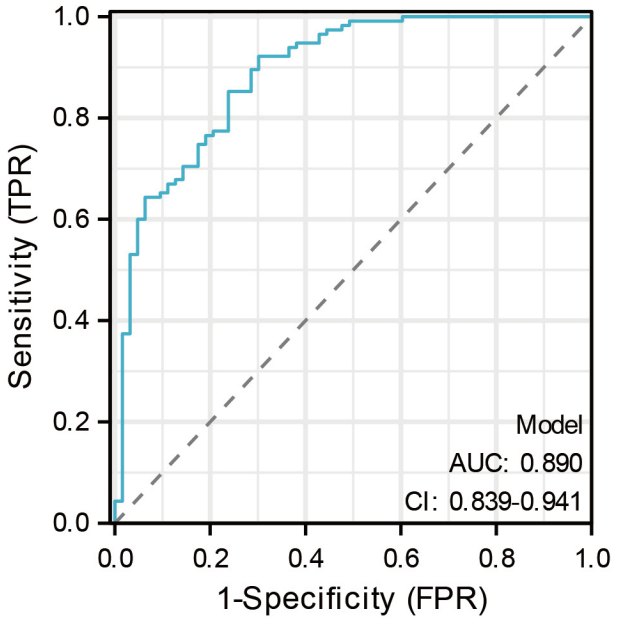

Fig. 3. ROC curve analysis of the modeling set. Abbreviations: AUC, area under the receiver operating characteristic curve; CI, confidence intervals; FPR, false positive rate; ROC, receiver operating characteristic; TPR, true positive rate.

Table 3. Results of multivariate logistic regression analysis.

Variables	β	S.E	Z	p	OR (95% CI)	Cutoff value
Age	0.05	0.02	2.65	0.008	1.06 (1.01–1.10)	43.00
DAS	0.06	0.02	2.96	0.003	1.06 (1.02 –1.10)	32.50
WBC	0.15	0.07	2.19	0.028	1.16 (1.02–1.32)	16.05
NE%	0.11	0.03	3.80	<0.001	1.12 (1.06–1.19)	76.83
PIFT	0.77	0.19	4.06	<0.001	2.17 (1.49–3.15)	4.50
PAFC						
Negative					1.00 (Reference)	
Positive	1.41	0.61	2.31	0.021	4.09 (1.24–13.54)	
MI						
Negative					1.00 (Reference)	
Positive	1.78	0.61	2.90	0.004	5.94 (1.78–19.78)	
ABP						
Negative					1.00 (Reference)	
Positive	1.94	0.68	2.85	0.004	6.97 (1.84–26.43)	

Abbreviation: ABP, altered bowel peristalsis; DAS, duration of acute symptoms; MI, marginal indistinctness; PAFC, periappendiceal fluid collection; PIFT, periappendiceal inflammatory fat thickness; WBC, white blood cell; OR, odds ratios; CI, confidence intervals; S.E, Standard Error.

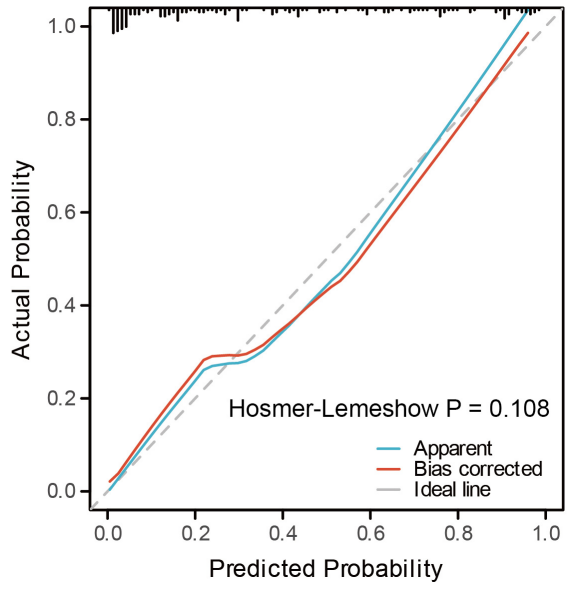

Fig. 4. Calibration curve analysis of the modeling set.

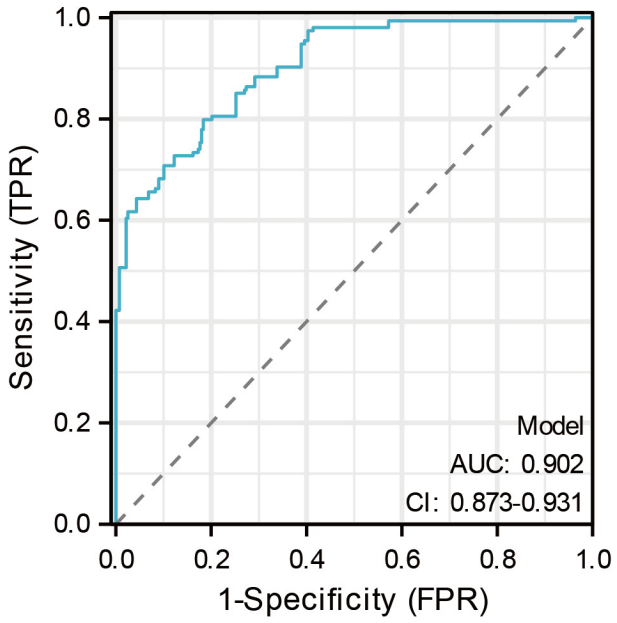

Fig. 5. ROC curve analysis of the internal validation set.

Internal Validation of the Model

Data from the modeling cohort were resampled using the Bootstrap self-sampling method, with a sampling frequency of 1000 times. The results showed that the AUC of the model was 0.902 (Fig. 5). The accuracy, sensitivity, and specificity of the internally validated model were 81.02%, 79.87%, and 81.66% respectively.

Evaluation of the Model's Clinical Utility

In this study, the decision curve of the risk predictive model was constructed based on the nomogram, as shown in Fig. 6. When the threshold probability is between 0.1 and 0.8, the decision curve of the model lies above the "all treatment" and "no treatment" strategies, indicating that the model is likely to provide greater net clinical benefit within the threshold probability.

Discussion

Acute appendicitis (AA) ranks among the most prevalent acute abdominal conditions globally, presenting a spectrum of disease severity ranging from simple inflammation to complex states such as perforation, gangrene, and abscess

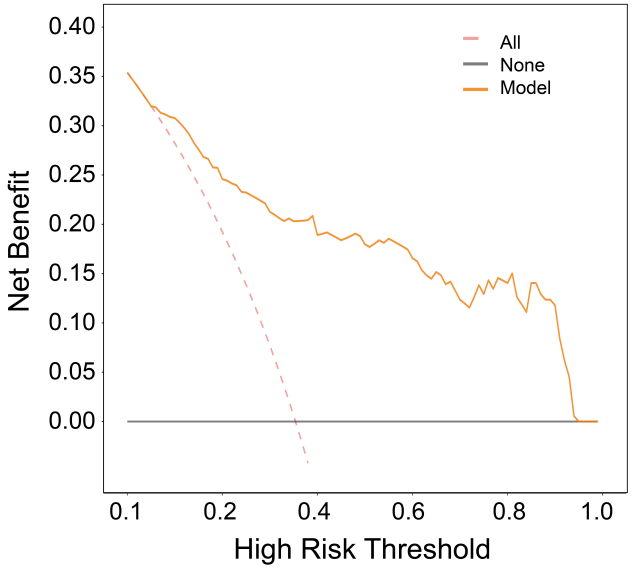

Fig. 6. Decision curve analysis of the nomogram constructed for clinical prediction of acute appendicitis.

formation [15]. Given the significant differences in treatment approaches and prognosis between CAA and NCAA, accurate preoperative differentiation between the two conditions is of considerable clinical importance [16,17]. This study constructed and validated a US-based differential diagnosis model through retrospective analysis of US characteristics and clinical data of 178 patients with AA. The results demonstrated that age, DAS, WBC, NE%, AOD, PAFC, MI, and ABP were significantly higher in the CAA group compared to the NCAA group. Through LASSO regression and multivariate logistic regression analysis, we successfully identified eight independent predictors and constructed a nomogram with high discriminatory ability (AUC = 0.890).

The findings of this study indicate that patients in the CAA group exhibited significantly higher mean age, longer DAS, and elevated WBC count and NE% compared with those in the NCAA group. This phenomenon may be closely associated with the pathological mechanisms underlying the progression of CAA. In previous studies, Vigil Escalera Bejarano *et al.* [18] reported a potential association between age and the severity of AA, that is, older patients tend to experience more severe disease progression. Fujiwara *et al.* [19] reported that age >40 and DAS >24 hours are important preoperative diagnostic factors for CAA. Moreover, numerous studies have reported significant associations between WBC, NE%, and CAA [20,21]. From a pathophysiological perspective, as individuals age, immune function gradually declines and the body's capacity to regulate inflammatory stress responses diminishes. Appendicitis in elderly patients is marked by reduced efficiency in pathogen eradication and inflammation control, making them more susceptible to appendiceal wall ischemia and necrosis, which facilitates the progression to CAA [22]. The prolonged duration of symptoms indicates an intensified cumulative effect of inflammation at the appendiceal site. If early inflammation remains unchecked, damage to the appendiceal mucosa will progressively extend to the muscularis and serosal layers, compromising the structural integrity of the appendix wall and heightening the risk of perforation and gangrene [23]. In the present study, WBC and NE%, as important indicators of inflammatory response, were significantly increased in the CAA group [24]. The release of inflammatory mediators and neutrophil infiltration plays a pivotal role in the pathological process of appendicitis. In cases of appendiceal wall rupture, destruction of the appendix wall structure and extensive inflammatory infiltration lead to markedly elevated levels of these indicators, such as WBC and NE% [25]. These results further confirm the clinical significance of the above-mentioned indicators in the differentiation of CAA.

In terms of US characteristics, patients in the CAA group exhibited significantly higher incidence rates of AOD, PIFT, PAFC, AFO, MI, IWT, PAMT, and ABP compared to the NCAA group. Multivariate analysis confirmed that PIFT, PAFC, MI, and ABP are independent risk factors for distinguishing CAA, reflecting a clear pathoanatomical association. AOD and PIFT reflect the lumen tension and the degree of intramural edema [26]. The AOD and PIFT in the CAA group were significantly higher than those in the NCAA group, indicating their association with the increase of intracavitary pressure, obstruction of venous return, and transmural inflammatory exudation [26,27]. Previous studies have reported that AOD is closely related to CAA; for instance, an AOD >13.5 mm was found to increase the diagnostic sensitivity for CAA [28,29]. PAFC denotes intra-luminal fecal impaction causing obstruction, where sudden intra-luminal pressure elevation leads to lymphatic fluid and exudate extravasation, forming the peripheral fluid-filled dark band characteristic of the 'target ring sign'; on the other hand, PAMT represents mesenteric vascular congestion, fat saponification, and inflammatory cell infiltration [30]. Shiihara *et al.* [31] reported that the proportion of PAFC positivity in CAA patients was significantly higher, and it has a high diagnostic value for CAA. Cai *et al.* [32] found that PAMT also has certain diagnostic value for CAA. These results are consistent with the findings of this study, suggesting heightened vigilance of disease progression and deterioration into CAA in the event of PAFC–PAMT co-occurrence. MI refers to the loss of a smooth, well-defined interface between the serosa layer and the surrounding adipose tissue, indicating that inflammation has penetrated the serosa and caused fibrin–neutrophil exudation [33]. The critical value of this sonographic sign in signifying severe appendicitis is corroborated by independent research. Chen *et al.* [34], in developing a US-based scoring system for predicting appendicitis severity, also identified "unclear boundary/marginal indistinctness" as an independent predictor for complicated ap-

pendicitis through multivariate logistic regression analysis (OR = 12.281), assigning it the highest weight in their scoring system. This independent validation strengthens the assertion that MI is a robust and reliable sonographic marker for transmural inflammation and complicated disease. Furthermore, ABP is not an isolated sign; it may be a direct consequence and an important component of a severe inflammatory response within the abdominal cavity [35]. It is noteworthy that AFO, which was significant in univariate analysis, was not retained in the final multivariate model. This is because its effect on disease progression is possibly mediated through subsequent inflammatory complications, such as PAFC, which emerged as a stronger, direct indicator of transmural inflammation and was thus selected by the model. Therefore, these US parameters, which are significantly correlated with CAA, hold potential value in clinical diagnosis. Through appropriate modeling, they can facilitate rapid and accurate clinical decision-making.

Based on the findings of this study, we recommend that clinicians prioritize the use of US examination in patients with suspected AA. Particular vigilance regarding the possibility of AA should be exercised in older patients, those presenting with prolonged symptoms, or individuals exhibiting markedly elevated levels of inflammatory markers. For patients suspected of having AA, if US reveals an abnormal increase in AOD alongside features such as PAFC, MI, or ABP, surgical intervention should be arranged promptly. Conversely, if US findings are consistent with the NCAA, conservative antibiotic therapy coupled with close monitoring may be considered. Furthermore, clinicians are advised to integrate the decision tree model developed in this study for comprehensive assessment, thereby enhancing preoperative differential diagnosis accuracy and avoiding unnecessary surgery or treatment delays. It should be noted that US findings are significantly influenced by operator experience and equipment resolution. Examinations should be performed by experienced sonographers, with CT or other imaging modalities employed for confirmatory assessment in cases of uncertainty.

Several limitations of this study should be acknowledged. Firstly, this study is a single-center retrospective analysis with a relatively small sample size, which may introduce some selection bias. Due to the limitations of research design and resource constraints, we were unable to conduct prospective validation on the current set of findings in multicenter settings, and without such validations, the current model may not be applicable to different populations and regions. In the future, multicenter and prospective studies can be conducted to further verify the accuracy and generalization ability of this model. Secondly, the results of US examinations are significantly influenced by the resolution of the equipment. This study did not conduct a stratified analysis of the model and resolution of the US equipment, which may lead to differences in the detection rates of some US features. Subsequent studies may consider incorporating the equipment factor to analyze the impact of US equipment with different resolutions on diagnostic efficiency, providing a reference for the selection of clinical equipment. Furthermore, although we adopted a standardized US examination process and had scans reviewed by senior physicians, we did not quantitatively assess the inter-operator consistency, which may introduce operator-dependent bias. Subsequent studies may consider incorporating equipment factors and operator consistency into analysis to further optimize the reliability and applicability of the model. In addition, the assessment of dynamic parameters such as ABP is qualitative rather than quantitative. Future research is expected to integrate more objective quantitative parameters for analysis. The model in the present study was developed using conventional clinical and US-based morphological parameters. While these parameters offer practical clinical utility, we acknowledge that the model's discriminative performance can be further enhanced by integrating radiomics features or deep learning techniques, which would require a specifically curated imaging database. Finally, the diagnostic model constructed in this study was not externally validated, except that the stability of the model had been verified through internal bootstrap sampling. This underscores the need to conduct an independent external validation study to validate the discriminative efficacy of the model and confirm its reliability when being utilized across different populations.

Conclusions

This study retrospectively analyzed 178 patients with surgically confirmed AA to explore the clinical utility of US characteristics in differentiating CAA from NCAA. Our results demonstrated that age, DAS, WBC, NE%, PIFT, PAFC, MI, and ABP were independent risk factors for CAA. A US-based nomogram diagnosing AA was constructed using the identified factors, and it had an AUC of 0.890 in the modeling set and 0.902 in the internal validation set. The model exhibited high accuracy (78.57% in the modeling set, 81.02% in the validation set), sensitivity, and specificity, along with good calibration consistency (Hosmer–Lemeshow test, $p = 0.108$) and demonstrated clinical net benefit. In conclusion, the established US-based differential diagnosis model enables effective differentiation between CAA and NCAA before initiation of treatment interventions, providing objective and reliable predictions to inform selection of personalized treatment strategies, thereby optimizing AA management and improving patient outcomes.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

ZYX: Conceptualized and designed the study, carried out the research, analyzed the data, and drafted the initial manuscript. JFY: Contributed to the design of experiments and development of methodology. YN: Supervised the study design, conducted statistical analysis, interpreted clinical data, and provided expert clinical guidance throughout the entire research process. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This research protocol strictly adheres to all the principles of the Declaration of Helsinki. This research was approved by the Ethics Committee of The People's Hospital of Yingshang (No. 202521). Given the retrospective nature of this study, which involved the analysis of anonymized existing data, the requirement for obtaining individual patient informed consent was waived by the aforementioned ethics committee.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Talan DA. Diagnosis and Management of Acute Appendicitis. JAMA. 2022; 327: 1183. https://doi.org/10.1001/jama.2022.1262.

[2] Yang Y, Guo C, Gu Z, Hua J, Zhang J, Qian S, *et al*. The Global Burden of Appendicitis in 204 Countries and Territories from 1990 to 2019. Clinical Epidemiology. 2022; 14: 1487–1499. https://doi.org/10.2147/CLEP.S376665.

[3] GBD 2021 Appendicitis Collaborator Group. Trends and levels of the global, regional, and national burden of appendicitis between 1990 and 2021: findings from the Global Burden of Disease Study 2021. The Lancet. Gastroenterology & Hepatology. 2024; 9: 825–858. https://doi.org/10.1016/S2468-1253(24)00157-2.

[4] Polat Düzgün A, Pehlevan Özel H, Şahingöz E, Dinç T. Identification of complicated and non-complicated appendicitis: a new alvarado-based scoring system. Ulusal Travma Ve Acil Cerrahi Dergisi = Turkish Journal of Trauma & Emergency Surgery: TJTES. 2024; 30: 101–106. https://doi.org/10.14744/tjtes.2024.70979.

[5] Bolmers MDM, de Jonge J, Bom WJ, van Rossem CC, van Geloven AAW, Bemelman WA, *et al*. In-hospital Delay of Appendectomy in Acute, Complicated Appendicitis. Journal of Gastrointestinal Surgery: Official Journal of the Society for Surgery of the Alimentary Tract. 2022; 26: 1063–1069. https://doi.org/10.1007/s11605-021-05220-w.

[6] Wu J, Jiang H, Li S, Wu X, Wang P, Sawyer R, *et al*. Optimising the treatment for uncomplicated acute appendicitis (OPTIMA trial): a protocol for a multicentre, randomised, double-blinded placebo-controlled study. BMJ Open. 2022; 12: e057793. https://doi.org/10.1136/bmjopen-2021-057793.

[7] de Almeida Leite RM, Seo DJ, Gomez-Eslava B, Hossain S, Lesegretain A, de Souza AV, *et al*. Nonoperative vs Operative Management of Uncomplicated Acute Appendicitis: A Systematic Review and Meta-analysis. JAMA Surgery. 2022; 157: 828–834. https://doi.org/10.1001/jamasurg.2022.2937.

[8] Takami T, Yamaguchi T, Yoshitake H, Hatano K, Kataoka N, Tomita M, *et al*. A clinical comparison of laparoscopic versus open appendectomy for the treatment of complicated appendicitis: historical cohort study. European Journal of Trauma and Emergency Surgery: Official Publication of the European Trauma Society. 2020; 46: 847–851. https://doi.org/10.1007/s00068-019-01086-5.

[9] Brillantino A, Iacobellis F, Brusciano L, Abu-Omar A, Muto G, Amadu AM, *et al*. Accuracy of computed tomography in staging acute appendicitis and its impact on surgical outcome and strategy: a multi-center retrospective case-control study. La Radiologia Medica. 2023; 128: 415–425. https://doi.org/10.1007/s11547-023-01619-4.

[10] Smith-Bindman R, Chu PW, Azman Firdaus H, Stewart C, Malekhedayat M, Alber S, *et al*. Projected Lifetime Cancer Risks From Current Computed Tomography Imaging. JAMA Internal Medicine. 2025; 185: 710–719. https://doi.org/10.1001/jamainternmed.2025.0505.

[11] Roberts K, Moore H, Raju M, Gent R, Piotto L, Taranath A, *et al*. Diagnostic Ultrasound for Acute Appendicitis: The Gold Standard. Journal of Pediatric Surgery. 2024; 59: 235–239. https://doi.org/10.1016/j.jpedsurg.2023.10.028.

[12] Saukhat O, Mushailov A, Kleinbaum Y, Barash Y, Klang E, Nachmany I, *et al*. Ultrasound-Tomographic Image Fusion - A Novel Tool for Follow up After Acute Complicated Appendicitis. Surgical Innovation. 2023; 30: 432–438. https://doi.org/10.1177/15533506231161122.

[13] Guo X, Yang H, Zhao P, Li J, Zeng L, Wang C, *et al*. The application value of high-frequency ultrasound in the feasibility assessment of endoscopic retrograde appendicitis therapy in children with appendicitis. Scientific Reports. 2023; 13: 19291. https://doi.org/10.1038/s41598-023-46387-3.

[14] Li S. Diagnostic and Therapeutic Strategies for Acute Appendicitis. Chinese Journal of Practical Surgery. 2020; 40: 1331–1335. (In Chinese)

[15] Diaz JJ, Ceresoli M, Herron T, Coccolini F. Current management of acute appendicitis in adults: What you need to know. The Journal of Trauma and Acute Care Surgery. 2025; 98: 181–189. https://doi.org/10.1097/TA.0000000000004471.

[16] Liang D, Fan Y, Zeng Y, Zhou H, Zhou H, Li G, *et al*. Development and Validation of a Deep Learning and Radiomics Combined Model for Differentiating Complicated From Uncomplicated Acute Appendicitis. Academic Radiology. 2024; 31: 1344–1354. https://doi.org/10.1016/j.acra.2023.08.018.

[17] Sikander B, Andresen K, Al Fartoussi H, Baastrup NN, Kjelkvist-Born C, Rosenberg J, *et al*. A survey of preoperative diagnosis and management of complicated appendicitis. Danish Medical Journal. 2023; 70: A05230314.

[18] Vigil Escalera Bejarano M, Gallardo-Navarro E, Gomez López JM, Tirado Cortes AA. Association Between Patient Age and Severity in Acute Appendicitis. Cureus. 2025; 17: e83431. https://doi.org/10.7759/cureus.83431.

[19] Fujiwara K, Abe A, Masatsugu T, Hirano T, Hiraka K, Sada M. Usefulness of several factors and clinical scoring models in preoperative diagnosis of complicated appendicitis. PloS One. 2021; 16: e0255253. https://doi.org/10.1371/journal.pone.0255253.

[20] Bancke Laverde BL, Maak M, Langheinrich M, Kersting S, Denz A, Krautz C, *et al*. Risk factors for postoperative morbidity, prolonged length of stay and hospital readmission after appendectomy for acute appendicitis. European Journal of Trauma and Emergency

Surgery: Official Publication of the European Trauma Society. 2023; 49: 1355–1366. https://doi.org/10.1007/s00068-023-02225-9.

[21] Lin HA, Tsai HW, Chao CC, Lin SF. Periappendiceal fat-stranding models for discriminating between complicated and uncomplicated acute appendicitis: a diagnostic and validation study. World Journal of Emergency Surgery: WJES. 2021; 16: 52. https://doi.org/10.1186/s13017-021-00398-5.

[22] Hançerlioğulları O, Buldanlı MZ, Uçaner B, Çiftçi MS, Kesikli SA. Acute appendicitis over the age of 50: The evaluation of the impact of clinical variables on operative and post-operative outcomes. Ulusal Travma Ve Acil Cerrahi Dergisi = Turkish Journal of Trauma & Emergency Surgery: TJTES. 2022; 28: 1419–1427. https://doi.org/10.14744/tjtes.2022.86229.

[23] Saar S, Talving P, Laos J, Põdramägi T, Sokirjanski M, Lustenberger T, *et al*. Delay Between Onset of Symptoms and Surgery in Acute Appendicitis Increases Perioperative Morbidity: A Prospective Study. World Journal of Surgery. 2016; 40: 1308–1314. https://doi.org/10.1007/s00268-016-3416-2.

[24] Ribeiro AM, Romero I, Pereira CC, Soares F, Gonçalves Á, Costa S, *et al*. Inflammatory parameters as predictive factors for complicated appendicitis: A retrospective cohort study. Annals of Medicine and Surgery (2012). 2022; 74: 103266. https://doi.org/10.1016/j.amsu.2022.103266.

[25] Yarkaç A, Öncü Güldür Ç, Bozkurt S, Köse A, Buyurgan ÇS, Erdoğan S, *et al*. The value of inflammatory indices in the diagnosis of acute appendicitis and prediction of complicated appendicitis: a retrospective study. PeerJ. 2025; 13: e19754. https://doi.org/10.7717/peerj.19754.

[26] Kobayashi T, Hidaka E, Koganezawa I, Nakagawa M, Yokozuka K, Ochiai S, *et al*. Development of a scoring model based on objective factors to predict gangrenous/perforated appendicitis. BMC Gastroenterology. 2023; 23: 198. https://doi.org/10.1186/s12876-023-02767-7.

[27] Chicaiza HP, Malia L, Mulvey CH, Smith SR. Revisiting the Appendiceal Diameter via Ultrasound for the Diagnosis of Acute Appendicitis. Pediatric Emergency Care. 2018; 34: 757–760. https://doi.org/10.1097/PEC.0000000000001278.

[28] Wu S, Gu F, Yu M, Zhu Z. Using a sum of the cross diameters of the appendix measured on ultrasonography as a criterion can more effectively predict acute appendicitis. European Radiology. 2025; 35: 1732–1742. https://doi.org/10.1007/s00330-024-11108-5.

[29] Liang Y, Sailai M, Ding R, Yimamu B, Kazi T, He M, *et al*. Predictive model for identification of gangrenous or perforated appendicitis in adults: a multicenter retrospective study. BMC Gastroenterology. 2024; 24: 355. https://doi.org/10.1186/s12876-024-03445-y.

[30] Kanaka S, Mizutani S, Yokoyama Y, Matsutani T, Chihara N, Katsuno A, *et al*. Periappendiceal fluid collection on preoperative computed tomography can be an indication for interval appendectomy: a retrospective study. World Journal of Emergency Surgery: WJES. 2022; 17: 30. https://doi.org/10.1186/s13017-022-00437-9.

[31] Shiihara M, Sudo Y, Matsushita N, Kubota T, Hibi Y, Osugi H, *et al*. Usefulness of Preoperative Predictors of Pathological Complicated Appendicitis. Digestive Surgery. 2023; 40: 121–129. https://doi.org/10.1159/000531284.

[32] Cai JH, Zhou H, Liang D, Chen Q, Xiao Y, Li GM. Parsimonious clinical prediction model for the diagnosis of complicated appendicitis. Heliyon. 2023; 9: e19067. https://doi.org/10.1016/j.heliyon.2023.e19067.

[33] Şimşek O, Şirolu S, Özkan Irmak Y, Hamid R, Ergun S, Kepil N, *et al*. Comparative study of imaging features in uncomplicated and complicated acute appendicitis. Ulusal Travma Ve Acil Cerrahi Dergisi = Turkish Journal of Trauma & Emergency Surgery: TJTES. 2024; 30: 722–728. https://doi.org/10.14744/tjtes.2024.50363.

[34] Chen Q, Yu X, Gan L. The value of the scoring system established by color Doppler ultrasound imaging signs in predicting the severity of acute appendicitis. Journal of Clinical Emergency Medicine. 2024; 25: 539–543. https://doi.org/10.13201/j.issn.1009-5918.2024.10.006. (In Chinese)

[35] Jauregui-Amezaga A, Rimola J. Role of Intestinal Ultrasound in the Management of Patients with Inflammatory Bowel Disease. Life (Basel, Switzerland). 2021; 11: 603. https://doi.org/10.3390/life11070603.