RESEARCH ARTICLE

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Ultrasonographic Markers of Perforated Appendicitis in Children: A Retrospective Diagnostic Accuracy Study

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Abstract

Objectives: Accurate preoperative differentiation between perforated and uncomplicated appendicitis in children remains challenging, but is essential for appropriate management. This study evaluated the diagnostic performance of predefined ultrasonographic signs and inflammatory markers at admission for differentiating perforated from uncomplicated appendicitis.

Methods: This retrospective diagnostic accuracy study included 174 pediatric patients who were evaluated with ultrasonography for suspected acute appendicitis. Final reference diagnoses were: no appendicitis (normal appendix) (n=55), simple appendicitis (n=82), and perforated appendicitis (n=37). The sonographic variables included loculated periappendiceal fluid, appendicolith, complex free fluid, periappendiceal fat echogenicity, distribution of free fluid in five abdominal regions, and periportal echogenicity. Leukocyte count, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) were recorded at admission. Diagnostic performance was calculated for perforated versus simple appendicitis.

Results: Children with perforated appendicitis were younger than those with simple appendicitis or no appendicitis/normal appendix. ESR and CRP levels were highest in the perforated group ($p<0.001$). Loculated periappendiceal fluid was observed in 18 of 37 perforated cases and 7 of 82 simple cases, yielding 48.6% sensitivity and 91.5% specificity ($p<0.001$). Complex free fluid had a sensitivity of 51.4% and a specificity of 87.8% ($p<0.001$). Echogenic periappendiceal fat occurred frequently in both appendicitis groups and was not specific to perforation.

Conclusion: Loculated periappendiceal fluid and complex free fluid are specific but incompletely sensitive sonographic signs of perforated appendicitis in children. CRP and ESR reflect the severity of inflammation and should be interpreted together with ultrasound findings, rather than as isolated diagnostic tests.

Keywords: Appendicitis, child, ultrasonography, C-reactive protein, perforation, erythrocyte sedimentation rate

Introduction

Acute appendicitis is a common reason for emergency abdominal surgery in children. Diagnosis is less straightforward in younger patients because abdominal pain may be poorly localized and overlap with gastroenteritis, mesenteric lymphadenitis, urinary tract infection, or gynecologic disease.[1,2] Detecting perforation at initial assessment is important because perforated appendicitis is associated with abscess formation, peritonitis, prolonged hospitalization, broader antibiotic use, and increased resource utilization.[3,4]

Ultrasonography is commonly used initially in children with suspected appendicitis because it avoids ionizing radiation and can be repeated at the bedside or in the radiology suite.[2,5-9] In uncomplicated appendicitis, the expected finding is a blind-ending, non-compressible, enlarged tubular appendix arising from the cecum, often accompanied by adjacent inflammatory change.[5,9]

Perforation changes this appearance. The appendix may decompress, collapse, or become indistinct within phlegmon, bowel gas, inflamed fat, or fluid. In that setting, failure to show a clearly enlarged appendix is not reassuring when secondary inflammatory signs are present.[10-16]

Secondary signs associated with perforated or complicated appendicitis include loculated periappendiceal fluid or abscess, complex free fluid, appendicolith, free fluid beyond the right lower quadrant, bowel dilatation, mural disruption or loss of stratification, and marked periappendiceal fat echogenicity.[10-16] Prior pediatric studies show a

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consistent pattern: these signs tend to be specific but not sufficiently sensitive; their absence does not exclude perforation.[11-16] The presence of an appendicolith is associated with prolonged symptoms and a higher risk of perforation, although its value as a single diagnostic sign varies across cohorts.[17]

Inflammatory markers such as C-reactive protein (CRP), erythrocyte sedimentation rate (ESR), and leukocyte count may help grade disease severity, but individual blood tests do not reliably separate complicated from uncomplicated appendicitis.[18-20] Recent work supports a combined interpretation of clinical, laboratory, and imaging findings rather than reliance on a single variable.[21-23] This study assessed selected ultrasound findings and admission inflammatory markers to differentiate perforated appendicitis, simple appendicitis, and no appendicitis in children.

Methods

Study Design and Patients

This retrospective, observational diagnostic accuracy study was prepared in accordance with STARD 2015 and STROBE reporting guidelines, where applicable.[24,25] Ethical approval for the retrospective review was obtained from Erzincan Binali Yıldırım University Institutional Ethics Committee (approval number: E-16377862.09.AK-16, date: 25.06.2026). The requirement for written informed consent was waived because of the retrospective design.

Medical records, laboratory data, ultrasonography reports, archived sonographic images, when available, operative notes, histopathology reports, and final clinical outcomes were reviewed for pediatric patients who were evaluated for suspected acute appendicitis.

A total of 244 pediatric patients were screened. Patients were eligible if abdominal ultrasonography had been performed during the initial diagnostic work-up and a final pathological or clinical outcome was available. Seventy patients were excluded for the following reasons: preoperative ultrasonography was unavailable; the ultrasonography report lacked sufficient information on predefined sonographic findings; relevant laboratory, operative, or histopathological data were missing; the final diagnosis could not be verified; or an appropriate reference standard could not be established. The remaining 174 patients were included in the final analysis and classified into three reference groups: no appendicitis (normal appendix), simple appendicitis, and perforated appendicitis (Figure 1).

Laboratory Parameters

Admission leukocyte count (age-dependent reference range for children aged 2-15 years: 4.5-17.0×10^9/L), CRP (reference range: 0-5 mg/L), and ESR (reference range: 0-20 mm/h) were obtained from the hospital database. These variables were compared across the three final diagnostic groups.

Ultrasonographic Evaluation

All ultrasonographic examinations during routine clinical care of children referred for suspected appendicitis were performed using a GE LOGIQ E9 ultrasound system (GE Healthcare, USA). A 5-8 MHz convex transducer was used for the initial abdominal survey; a 5-12 MHz linear transducer was then used for graded-compression evaluation of the appendix. Examinations were performed by one of two radiologists with 10 and 5 years' experience in pediatric ultrasonography.

The predefined sonographic variables included loculated periappendiceal fluid collection, appendicolith, complex free fluid, increased periappendiceal fat echogenicity, free-fluid distribution in the abdominal recesses, and increased periportal echogenicity. Complex free fluid was defined as intraperitoneal fluid containing internal echoes, debris, or heterogeneous echogenic material. Loculated periappendiceal fluid was defined as a localized fluid collection adjacent to the appendix or the expected appendiceal region, and increased periappendiceal fat echogenicity was defined as a focal hyperechoic inflammatory change surrounding the appendix or within the right lower quadrant. For free-fluid distribution, the abdomen was divided into the right upper, left upper, right lower, and left lower quadrants and the pelvis; involvement was categorized as 1-2, 3-4, or all 5 regions.

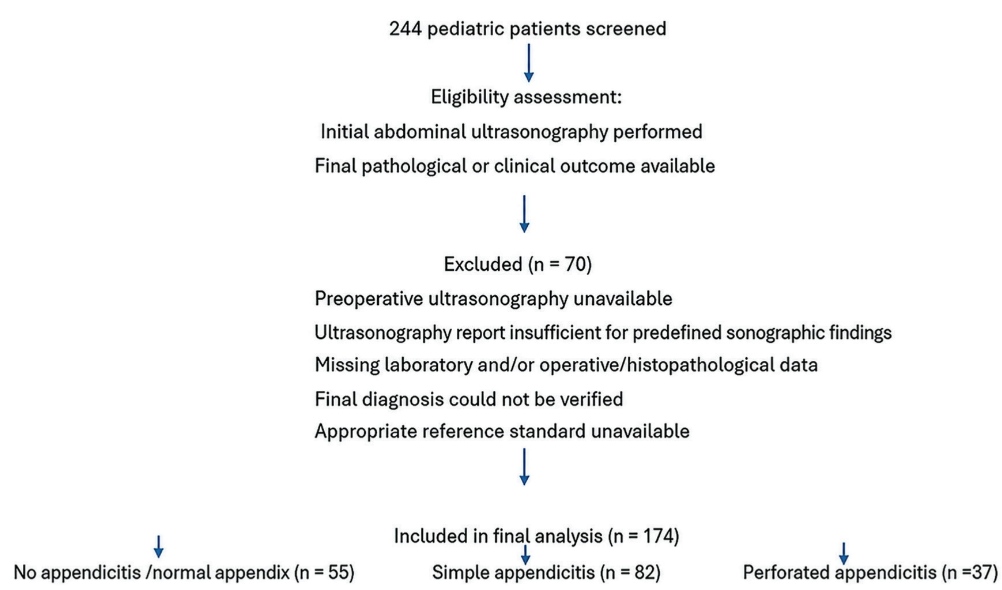

Figure 1. Workflow for the study

Study variables were extracted from the original radiology reports and, when available, archived ultrasonographic images. Archived images were reviewed jointly by the same two radiologists, who were blinded to the operative and histopathological findings. Final image interpretation was reached by consensus; therefore, interobserver agreement was not assessed.

Reference Standard

The final diagnosis was established by histopathological examination for patients who underwent appendectomy, and by final clinical diagnosis for patients managed nonoperatively. Simple appendicitis was defined as appendiceal inflammation without perforation, periappendiceal abscess, phlegmon, or transmural defect. Perforated appendicitis was defined as pathological confirmation of perforation or operative evidence of perforation, periappendiceal abscess, or phlegmon. Patients without appendicitis were assigned to the no-appendicitis/normal-appendix group based on histopathological findings or the final clinical diagnosis.

Statistical Analysis

Continuous variables are presented as mean ± standard deviation, and categorical variables as counts and percentages. Normality was assessed using the Shapiro-Wilk test. Comparisons among the three diagnostic groups were performed using ANOVA for normally distributed variables or the Kruskal-Wallis test for non-normally distributed variables. When overall group differences were significant, post-hoc pairwise comparisons were performed using the Bonferroni correction. Categorical variables were compared using the chi-square test or Fisher's exact test.

Receiver operating characteristic (ROC) curve analysis was performed to evaluate the diagnostic performance of CRP, ESR, and leukocyte count for identifying perforated appendicitis. The area under the ROC curve (AUC), optimal cut-off values, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and 95% confidence intervals (CIs) were calculated.

The diagnostic performance of predefined sonographic findings for differentiating perforated from simple appendicitis was assessed by calculating sensitivity, specificity, PPV, NPV, and 95% CIs. Cis for sensitivity and specificity were estimated using the Wilson score method. P values for sonographic findings were calculated using two-sided Fisher exact tests. A two-sided p value <0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics (version 30; IBM Corp., Armonk, NY, USA).

Results

Patient Characteristics

Between January 2024 and March 2026, a total of 174 pediatric patients aged 2-15 years who were evaluated for suspected acute appendicitis were included in the study. The final reference diagnoses were: no appendicitis (normal appendix) in 55 patients, simple appendicitis in 82 patients, and perforated appendicitis in 37 patients (Table 1).

The cohort comprised 108 boys (62.1%) and 66 girls (37.9%), with a mean age of 7.3±2.7 years. Patients with perforated appendicitis were significantly younger than those with simple appendicitis or a normal appendix (no appendicitis). Mean age was 8.3±2.9 years in the no appendicitis/normal appendix group, 7.2±2.5 years in the simple appendicitis group, and 6.0±2.7 years in the perforated appendicitis group (p=0.018).Sex distribution did not differ significantly among the three groups (p=0.214).

Laboratory Findings

Mean leukocyte count was 10.7±2.7×10^3/μL in the no appendicitis/normal appendix group, 13.0 ± 3.2 ×10^3/μL in the simple appendicitis group, and 14.1±2.8×10^3/μL in the perforated appendicitis group. Mean ESR values were 6.5±2.2 mm/h, 18.4±3.8 mm/h, and 25.8±5.0 mm/h, respectively. Mean CRP levels were 2.8±1.2 mg/L, 31.1±5.9 mg/L, and 134.5±10.8 mg/L, respectively (Table 2).

Comparisons among the three diagnostic groups revealed significant differences in age, CRP, and ESR (all p<0.05). Post-hoc pairwise comparisons with Bonferroni correction showed that CRP and ESR levels were significantly higher in the perforated appendicitis group than in both the simple appendicitis group and the no appendicitis/normal appendix group (both p<0.001). In contrast, the leukocyte count was higher in both appendicitis groups than in the no appendicitis/normal appendix group, but it did not differ significantly between simple and perforated appendicitis after Bonferroni correction.

ROC curve analysis demonstrated that CRP had the highest diagnostic performance for discriminating perforated appendicitis, followed by ESR, while leukocyte count had limited discriminatory ability. The AUCs, 95% CIs, optimal cut-off values, sensitivities, and specificities are summarized in Table 3.

Ultrasonographic Findings

The distribution of sonographic findings is summarized in Table 4. A normal appendix was directly visualized in 41 of the 55 patients (74.5%) in the no appendicitis/normal appendix group. Among the remaining patients, no secondary signs of appendicitis, such as increased mesenteric echogenicity or free fluid, were identified, and appendicitis was excluded based on symptom resolution and an uneventful clinical follow-up lasting at least 30 days.

An appendicolith was identified in 15 patients with perforated appendicitis and in 22 patients with simple appendicitis, and was not significantly associated with perforation (p=0.142).

Increased periappendiceal fat echogenicity was observed in 34 patients with perforated appendicitis and in 73 patients with simple appendicitis (p=0.752).

Loculated periappendiceal fluid was detected in 18 of 37 patients with perforated appendicitis, compared with 7 of 82 patients with simple appendicitis (p<0.001) and was not observed in the no-appendicitis/normal-appendix group (Figure 2).

Fluid involving one or two abdominal regions occurred with similar frequency in the simple appendicitis and perforated appendicitis groups (p=0.843). Fluid involving all five abdominal regions was observed in 7 patients with perforated appendicitis, 7 with simple appendicitis, and 1 patient in the no-appendicitis/normal-appendix group (p=0.128).

Complex free fluid was present in 19 patients with perforated appendicitis, 10 with simple appendicitis (p<0.001), and 5 with no appendicitis/normal appendix (Figure 3).

Periportal echogenicity was recorded in 8 patients with no appendicitis/normal appendix, 46 with simple appendicitis, and 11 with perforated appendicitis (Figure 4).

To differentiate perforated from simple appendicitis, loculated periappendiceal fluid and complex free fluid were the most specific sonographic findings. Loculated periappendiceal fluid had a sensitivity of 48.6% and specificity of 91.5%, whereas complex free fluid had a sensitivity of 51.4% and specificity of 87.8%.

Fluid involving all five abdominal regions also demonstrated high specificity (91.5%) but low sensitivity (18.9%). In contrast, increased periappendiceal fat echogenicity demonstrated high sensitivity (91.9%) but poor specificity (11.0%) for differentiating perforated from simple appendicitis. Periportal echogenicity was significantly more frequent in simple appendicitis than in perforated appendicitis (p=0.010) and showed limited discriminatory performance when considered as an isolated finding (Table 5).

Discussion

In this pediatric cohort, loculated periappendiceal fluid and complex free fluid were the strongest ultrasound indicators of perforated appendicitis. Both signs were specific, but only moderately sensitive. This pattern is clinically useful: when present, these findings should raise suspicion of perforation; when absent, perforation cannot be excluded.

Table 1. Distribution of patients according to final diagnosis

	No appendicitis/normal appendix (n=55)	Simple appendicitis (n=82)	Perforated appendicitis (n=37)	p value
Number of patients	55	82	37	-
Age, years, mean ± SD	8.3±2.9	7.2±2.5	6.0±2.7	0.018
Sex, n (%)				0.214
Male	39 (70.9)	49 (59.8)	20 (54.1)	
Female	16 (29.1)	33 (40.2)	17 (45.9)	

Data are presented as mean ± SD or number of patients (%). P values were calculated using ANOVA for age and the chi-square test for sex distribution
SD: Standard deviation

Table 2. Laboratory findings and diagnostic performance of inflammatory markers

Parameter	No appendicitis/normal appendix (n=55)	Simple appendicitis (n=82)	Perforated appendicitis (n=37)	Overall p value
Leukocyte count ($\times 10^3/\mu L$)	10.7±2.7	13.0±3.2	14.1±2.8	NS†
ESR (mm/h)	6.5±2.2	18.4±3.8	25.8±5.0	<0.001*
CRP (mg/L)	2.8±1.2	31.1±5.9	134.5±10.8	<0.001*

Data are presented as mean ± standard deviation. *: Overall comparison among the three groups.
†: Leukocyte count differed between the appendicitis and no appendicitis groups but not between simple and perforated appendicitis on Bonferroni post-hoc analysis
CRP: C-reactive protein, ESR: Erythrocyte sedimentation rate

Table 3. Laboratory findings and diagnostic performance of inflammatory markers

Variable	AUC (95% CI)	Cut-off	Sensitivity
CRP	0.88 (0.82-0.94)	52 mg/L	86.5%
ESR	0.79 (0.71-0.87)	21 mm/h	74.3%
Leukocyte count	0.67 (0.58-0.76)	13.8 $\times 10^3/\mu L$	65.2%

Cut-off values were determined from ROC curve analysis
AUC: Area under the curve, CI: Confidence interval, CRP: C-reactive protein, ESR: Erythrocyte sedimentation rate, ROC: Receiver operating characteristic

Table 4. Distribution of ultrasonographic findings according to final diagnosis

US finding	No appendicitis/normal appendix (n=55)	Simple appendicitis (n=82)	Perforated appendicitis (n=37)
Loculated periappendiceal fluid	0 (0.0%)	7 (8.5%)	18 (48.6%)
Appendicolith	0 (0.0%)	22 (26.8%)	15 (40.5%)
Complex free fluid	5 (9.1%)	10 (12.2%)	19 (51.4%)
Echogenic periappendiceal fat	6 (10.9%)	73 (89.0%)	34 (91.9%)
Fluid involving 1-2 abdominal regions	29 (52.7%)	43 (52.4%)	18 (48.6%)
Fluid involving 3-4 abdominal regions	5 (9.1%)	22 (26.8%)	12 (32.4%)
Fluid involving all 5 abdominal regions	1 (1.8%)	7 (8.5%)	7 (18.9%)
Periportal echogenicity	8 (14.5%)	46 (56.1%)	11 (29.7%)

Data are presented as n and percentage (%)
US: Ultrasonography

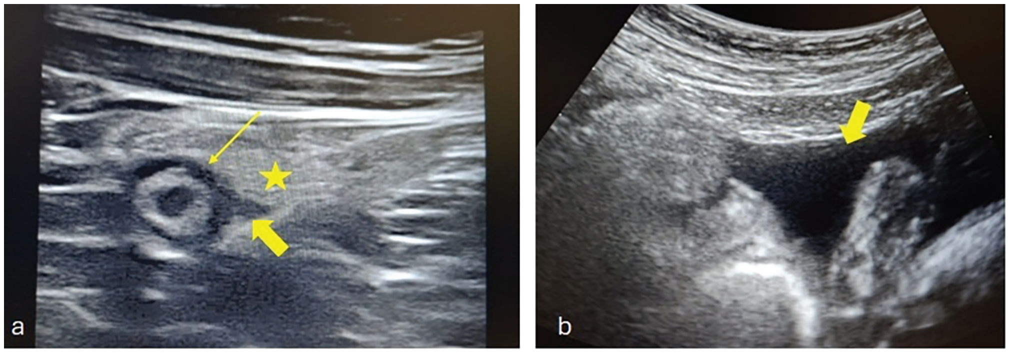

Figure 2. **a)** Linear transducer (5-12 MHz). Dilated inflamed appendix (thin arrow), small loculated periappendiceal fluid (thick arrow), and increased echogenicity of the adjacent mesenteric fat (asterisk) in a patient with simple appendicitis. **b)** Curvilinear transducer (5-8 MHz). Free pelvic fluid (thick arrow) in another patient with simple appendicitis; the appendix was not visualized

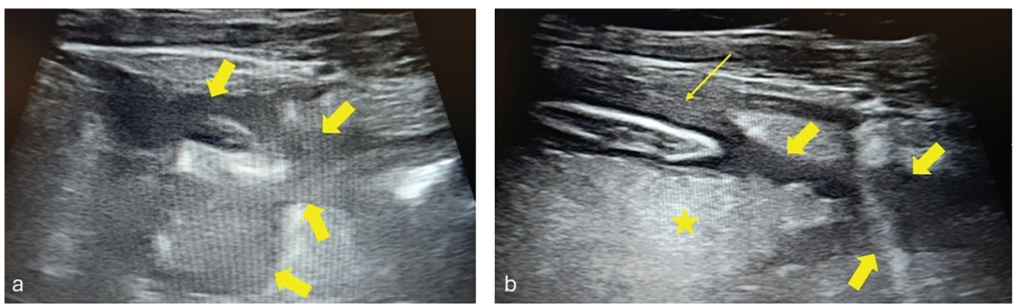

Figure 3. **a)** Linear transducer with wide view (5-12 MHz). Complex free fluid in the right lower quadrant (thick arrows). **b)** Same patient. Dilated inflamed appendix (thin arrow), adjacent hyperechoic mesenteric fat (asterisk), and complex free fluid (thick arrows). The patient had perforated appendicitis with purulent intra-abdominal fluid at surgery

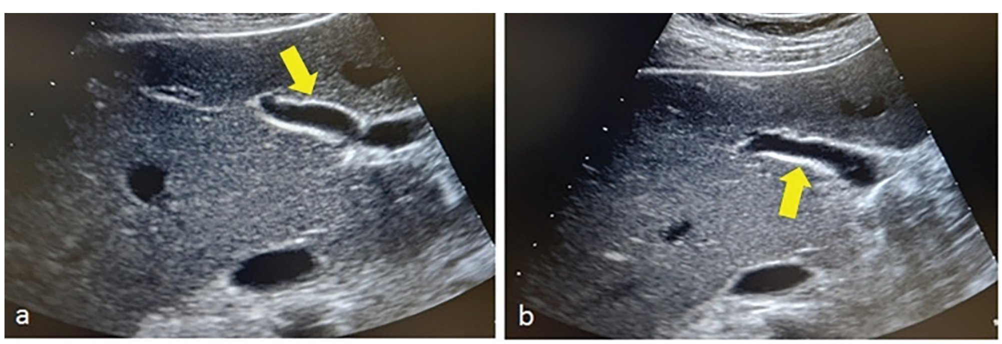

Figure 4. **a** and **b)** Curvilinear transducer (5-8 MHz). Images from the same patient demonstrate increased periportal echogenicity

Table 5. Diagnostic performance of ultrasonographic findings for differentiating perforated from simple appendicitis

Ultrasonographic finding	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	p value
Appendicolith	40.5	73.2	40.5	73.2	0.142
Echogenic periappendiceal fat	91.9	11.0	31.8	75.0	0.752
Loculated periappendiceal fluid	48.6	91.5	72.0	79.8	<0.001
Fluid involving 1-2 abdominal regions	48.6	47.6	29.5	67.2	0.843
Fluid involving 3-4 abdominal regions	32.4	73.2	35.3	70.6	0.661
Fluid involving all 5 abdominal regions	18.9	91.5	50.0	71.4	0.128
Complex free fluid	51.4	87.8	65.5	80.0	<0.001
Periportal echogenicity	29.7	43.9	19.3	58.1	0.010

P values were calculated using two-sided Fisher exact tests for perforated versus simple appendicitis
PPV: Positive predictive value, NPV: Negative predictive value

The results agree with previous pediatric imaging studies showing that ultrasound has limited sensitivity but good specificity for complicated or perforated appendicitis.[10-16,21,22] Once perforation occurs, the appendix may decompress or become obscured by inflammatory change; the diagnosis then depends on secondary signs rather than direct visualization of a wall defect. Previous studies have also found that combinations of secondary signs improve specificity and that complex periappendiceal fluid is an important sign.[11,12]

Periappendiceal fat echogenicity was frequent in both simple and perforated appendicitis. It is a useful sign of local inflammation, but in this dataset, it did not classify disease severity. This distinction matters because echogenic fat is often conspicuous on ultrasound and can be overinterpreted if evaluated without consideration of fluid characteristics, abscess, appendicolith, and clinical context.

An appendicolith was more frequent in perforated appendicitis, but its diagnostic performance in isolation was modest. The finding remains clinically relevant because appendicoliths have been associated with prolonged symptoms and a higher risk of perforation, but it should not be treated as a standalone marker of perforation.[17]

CRP and ESR were higher in perforated appendicitis, whereas leukocyte count did not clearly differentiate simple from perforated appendicitis. Individual blood biomarkers alone are not sufficiently accurate to diagnose complicated appendicitis.[18-20] Interpretation should therefore combine ultrasound findings, clinical assessment, and inflammatory markers.[21-23]

In the report, loculated periappendiceal fluid or complex free fluid should be explicitly communicated as findings that increase concern for perforation. These findings may affect the urgency of surgical consultation, antibiotic planning, and the search for an abscess or diffuse peritoneal fluid. In contrast, echogenic periappendiceal fat alone should be reported as inflammatory change, but not as proof of perforation.

Study Limitations

This study has several limitations. Its retrospective single-center design may limit the generalizability of the findings and introduce selection bias. In addition, ultrasonography is inherently operator-dependent, and image acquisition may have varied despite examinations being performed by experienced pediatric radiologists. Furthermore, archived ultrasound images were not available for all patients, and image interpretation was therefore based on the stored images and reports. The relatively small number of patients with perforated appendicitis may also have limited the statistical power for evaluating some secondary sonographic findings. Although several secondary sonographic findings, particularly loculated periappendiceal fluid and fluid involving all five abdominal regions, demonstrated high specificity for perforation, their sensitivities were relatively low. Therefore, the absence of these findings should not be considered sufficient to exclude perforation. Rather, secondary sonographic findings should be interpreted collectively and in conjunction with primary ultrasonographic findings, laboratory markers, and the overall clinical presentation. Prospective multicenter studies with larger patient cohorts are warranted to validate these findings.

Conclusion

Loculated periappendiceal fluid and complex free fluid are specific sonographic signs of perforated appendicitis in children; however, their sensitivity is limited. Periappendiceal fat echogenicity supports the presence of appendiceal inflammation, but does not reliably distinguish perforated from simple appendicitis. CRP and ESR provide information on disease severity when interpreted alongside ultrasound findings. A combined clinical, laboratory, and imaging assessment remains necessary for the preoperative evaluation of suspected appendiceal perforation in pediatric patients.

Ethics

Ethics Committee Approval: Ethical approval for the retrospective review was obtained from Erzincan Binali Yıldırım University Institutional Ethics Committee (approval number: E-16377862.09.AK-16, date: 25.06.2026).

Informed Consent: Since the study was a retrospective study, informed consent was not required by the ethics committee.

Footnotes

Authorship Contributions

Surgical and Medical Practices: E.Z., E.Ç.K., Concept: E.Z., M.E.Ç., Design: E.Z., E.Ç.K., Data Collection or Processing: E.Z., E.Ç.K., M.E.Ç., Analysis or Interpretation: E.Z., M.E.Ç., Literature Search: E.Z., M.E.Ç., H.K.Ö., T.Ç., Writing: E.Z., E.Ç.K., H.K.Ö., T.Ç.

Conflict of Interest: No conflict of interest was declared by the authors.

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