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Original Contribution

Utility of applying white blood cell cutoffs to non-diagnostic MRI and ultrasound studies for suspected pediatric appendicitis

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ABSTRACT

Background: Non-contrast magnetic resonance imaging (MRI) and ultrasound studies in pediatric patients with suspected appendicitis are often non-diagnostic. The primary objective of this investigation was to determine if combining these non-diagnostic imaging results with white blood cell (WBC) cutoffs improves their negative predictive values (NPVs).

Methods: A retrospective chart review was conducted including patients ≤18 years old with suspected appendicitis who had MRI performed with or without a preceding ultrasound study in a pediatric emergency department. Imaging results were sorted into 2 diagnostic and 5 non-diagnostic categories. NPVs were calculated for the non-diagnostic MRI and ultrasound categories with and without combining them with WBC cutoffs of <10.0 and <7.5 × 10^9/L.

Results: Of the 612 patients with MRI studies included, 402 had ultrasound studies performed. MRI with incomplete visualization of a normal appendix without secondary signs of appendicitis had an NPV of 97.9% that changed to 98.1% and 98.2% when combined with WBC cutoffs of <10.0 and <7.5, respectively. Ultrasound studies with incomplete visualization of a normal appendix without secondary signs had an NPV of 85.3% that improved to 94.8% and 96.5% when combined with WBC cutoffs of <10.0 and <7.5, respectively.

Conclusions: In pediatric patients with suspected appendicitis, MRI studies with incomplete visualization of a normal appendix without secondary signs have a high NPV that does not significantly change with the use of these WBC cutoffs. In contrast, combining WBC cutoffs with ultrasound studies with the same interpretation identifies low-risk groups.

1. Introduction

Despite being the most common reason for urgent pediatric abdominal surgery, there is still much debate regarding the ideal diagnostic approach for patients with suspected appendicitis. One recommended method is to use clinical scores or decision algorithms, such as the Pediatric Appendicitis Score, to risk stratify patients into those who may be safely discharged home, those who warrant diagnostic imaging, and those who should have immediate surgical consultation [1]. But, a meta-analysis published in 2017 suggests that physical examination or clinical decision algorithms alone are insufficient to rule out appendicitis and that imaging is required in pediatric patients once the condition is suspected [2]. Due to the potential long-term risk of radiation exposure, the use of ultrasound or magnetic resonance imaging (MRI) is favored over computed tomography (CT) scans when possible [3,4].

Further controversy exists regarding the initial imaging modality of choice. The American College of Radiology recommends that ultrasound be the first-line imaging study for children [5]. However, ultrasound has several limitations. For example, non-diagnostic results, including those with partial or non-visualization of the appendix with or without secondary signs of appendicitis and those with equivocal interpretations, commonly occur. Recent retrospective investigations reviewed a total of 2,228 ultrasound studies performed for suspected appendicitis at 2 pediatric tertiary hospitals and reported non-visualization of the appendix in over 50% of cases [6,7]. Consequently, several institutions have abandoned ultrasound and use MRI as their first-line imaging modality

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[8-10]. A study analyzing this approach provides evidence that it is more cost-effective for ultrasound to be the first-line imaging test despite its shortcomings [11].

Several investigations have combined laboratory test results or other clinical parameters with non-diagnostic ultrasound studies to improve their negative predictive values (NPVs) and thereby avoid the need for additional imaging or admission for observation [6,7,12,13]. No one has investigated whether combining laboratory test results with non-diagnostic MRI studies improves their NPVs. Non-contrast MRI studies frequently fail to visualize the appendix or are interpreted as equivocal. Kulaylat and colleagues reported incomplete visualization of the appendix and equivocal interpretations in 35% and 6% of 510 non-contrast MRI studies, respectively [14]. Unlike ultrasound, MRI with non-visualization of the appendix without secondary signs is generally considered to be a negative test result. Although, the only investigation specifically addressing the NPV of this imaging result included 31 MRI studies with this finding and therefore lacked confidence in its point estimate [15].

The primary objective of this investigation was to determine if combining peripheral white blood cell (WBC) cutoffs with non-diagnostic MRI and ultrasound studies significantly improves their NPVs. The secondary objective was to determine the test characteristics of the fast, non-contrast MRI protocol used at our institution. We hypothesized that combining WBC cutoffs with non-diagnostic imaging results would identify low-risk groups that may be safely discharged home from the emergency department (ED) with close follow-up.

2. Methods

2.1. Study design

This was a retrospective chart review approved by the Institutional Review Board (IRB). Informed consent was waived by the IRB.

2.2. Study setting and population

The study was performed at a pediatric tertiary hospital in a suburban setting with an annual ED census of approximately 60,000 patients. The ED has ultrasound technicians, access to MRI, and attending radiologists interpreting imaging at all times. The electronic medical record (EMR) was queried to identify consecutive patients who had non-contrast MRI studies of the abdomen and/or pelvis performed in the ED from November 2014 to July 2017. Inclusion criteria were patients ≤18 years old who had MRI performed for suspected appendicitis. A portion of these patients had ultrasound studies performed in the ED to evaluate for appendicitis prior to MRI. Exclusion criteria were patients who were missing MRI interpretations by an attending radiologist, missing pathology reports, had inconclusive final diagnoses, and whose MRI studies were terminated due to movement.

2.3. Study protocol

For each included patient, ED documentation and imaging reports were reviewed. If available, laboratory results, inpatient documentation, operative reports, pathology reports, and follow-up encounter documentation were reviewed as well. Follow-up encounters included subsequent patient visits to outpatient offices and the ED. Additionally, the ED staff calls all discharged patients within 24 h to follow-up. If contact was made and resolution of symptoms was documented, the follow-up telephone call was included as a follow-up encounter.

All data collection and imaging categorization were performed by the Principal Investigator (PI). Data was entered into an electronic abstraction form using Microsoft Excel. The MRI and ultrasound interpretation categories were prespecified as: 0 = a normal appendix fully visualized; 1 = a normal appendix partly visualized without secondary signs of appendicitis; 2 = a non-visualized appendix without secondary signs; 3 = a normal appendix partly visualized with secondary signs; 4 = a non-visualized appendix with secondary signs; 5 = equivocal (defined as a visualized appendix with borderline criteria or visualization of an inflamed tubular structure in the right lower abdominal quadrant thought to be the appendix, but without visualization of a connection to the cecum); 6 = appendicitis. Clinical information from the ED, but not operative findings or pathology reports, were available to radiologists prior to documenting their interpretations.

A fast, non-contrast MRI protocol for suspected appendicitis was performed on either a 1.5-T (SIGNA HDxt, General Electric, Waukausa, WI) or 3.0-T (Discovery MR750 or SIGNA PET/MR with QuantWorks, General Electric, Waukausa, WI) machine depending on availability. The MRI protocol includes 8 sequences: fat saturated and non-fat saturated coronal single-shot fast-spin echo (SSFSE) sequences of the abdomen and pelvis, fat saturated and non-fat saturated axial SSFSE sequences of the abdomen, fat saturated and non-fat saturated axial SSFSE sequences of the pelvis, an axial diffusion weighted imaging (DWI)/apparent diffusion coefficient (ADC) sequence of the abdomen, and an axial DWI/ADC sequence of the pelvis. All imaging was performed without sedation. A positive test result required visualization of an abnormal appendix and was based on the assessment of several primary and secondary criteria. There is no set number of criteria required for a positive result, but no one criterion alone is diagnostic. The primary criteria include an appendiceal diameter >6 mm, appendiceal wall thickening with or without diffusion restriction, and periappendiceal inflammation. The secondary criteria include inflammation of right lower abdominal quadrant mesenteric fat, inflammation of adjacent bowel (isolated to the terminal ileum, proximal ascending colon, and/or the sigmoid colon), and the presence of a right lower abdominal quadrant fluid collection (i.e., a suspected abscess).

Ultrasound studies were performed by technicians using either a Philips (Epiq 5G or IU22, Philips, Bothell, WA) or General Electric (Logiq E9, General Electric, Wauwatosa, WI) machine depending on technician preference and availability. All technicians were dedicated pediatric sonographers with a range of experience. A positive test result required visualization of an abnormal appendix and was similarly based on the assessment of several primary and secondary criteria. The primary criteria include a fluid-filled appendix measuring >6 mm in diameter, non-compressibility, hyperemia of the appendiceal wall, and the presence of an appendicolith. The secondary criteria are the same as those for MRI.

2.4. Key outcome measures

A patient's final diagnosis was categorized as positive for appendicitis if the patient underwent an appendectomy and the pathologist documented a diagnosis of primary appendicitis in the pathology report. The pathologic diagnosis of primary appendicitis is defined as neutrophils in the lumen of the appendix with acute inflammation of, at a minimum, the mucosal layer. ED documentation, imaging results, and operative findings were available to pathologists prior to documenting their reports. A patient that had a pathology report with non-specific inflammatory changes of the appendix documented was categorized as positive for appendicitis if the surgeon documented a diagnosis of primary appendicitis in the operative report. Patients who did not undergo appendectomies and were treated medically for perforated appendicitis with antibiotic therapy with or without percutaneous drainage were categorized as positive for appendicitis as well. If a patient treated medically had an interval appendectomy performed, the documented pathology and operative report diagnoses were used for categorization as previously discussed. However, the pathologic definition of primary appendicitis in these instances includes transmural chronic inflammation often associated with histiocytic inflammation, foreign body giant cell reaction, and mural fibrosis. A patient's final diagnosis was categorized as negative for appendicitis if the pathologist documented that findings were not consistent with primary appendicitis, if the pathologist documented non-specific inflammatory changes and the surgeon documented that operative findings were not consistent with primary appendicitis, if the patient was admitted to an inpatient unit and appendicitis was clinically excluded, if the patient was discharged home from the ED and the follow-up encounter provided no evidence of a missed diagnosis of appendicitis, and if the patient had no follow-up encounter after discharge from the ED. Lastly, if there was clear clinical evidence that the pathology diagnosis was a false positive, the patient was classified as negative for appendicitis.

2.5. Data analysis

NPVs with 95% Clopper-Pearson confidence intervals were calculated for non-diagnostic MRI and ultrasound categories. Non-diagnostic MRI categories with similar prevalence of appendicitis were grouped together. Non-diagnostic ultrasound categories were grouped in the same fashion. Peripheral WBC cutoffs of <10.0 and <7.5 × 10^9/L were chosen based on previous literature [6,13,16,17]. These cutoffs were then separately combined with the grouped imaging categories after which NPVs with Clopper-Pearson confidence intervals were calculated again.

To calculate the sensitivity, specificity, predictive values, and likelihood ratios of the fast, non-contrast MRI protocol, two methods were used due to controversy in the literature regarding the most appropriate way to report this data for diagnostic tests with equivocal results. As recommended by Fedko and colleagues, a 2 by 2 contingency table was used with equivocal results excluded [18]. In addition, as recommended by Schuetz and colleagues, a 3 by 2 contingency table was used with equivocal results treated as false negatives when calculating sensitivity and as false positives when calculating specificity [19]. For the purposes of these calculations, MRI categories 0–2 were considered negative, 4–5 were considered equivocal, and 6 was considered positive for appendicitis. To calculate confidence intervals, the Clopper-Pearson method was used for sensitivity, specificity, and predictive values, while the Wald method was used for likelihood ratios.

Reliability of imaging categorization by the PI was assessed by having one of the coauthors (AD) categorize 50 MRI and 50 ultrasound studies. Percentages of agreement were then calculated. Statistical analysis was performed using SAS version 9.4 (SAS Institute, Cary, NC).

3. Results

The EMR query identified 646 patients who had non-contrast MRI studies of the abdomen and/or pelvis performed in the ED. Fig. 1 illustrates the flow of patients, how included MRI studies were categorized, and the prevalence of appendicitis in each category. Of the 612 patients included for analysis, 402 had ultrasound studies performed prior to MRI during the same ED encounter. Fig. 2 displays how these ultrasound studies were categorized and the prevalence of appendicitis in each category. Agreement percentages for imaging categorization between the PI and coauthor were 86% for MRI studies and 88% for ultrasound studies. After reviewing the discrepancies in categorization, it was determined that the PI incorrectly categorized 2 of the 50 (4%) MRI studies and 2 of the 50 (4%) ultrasound studies. These 4 errors in categorization were corrected prior to performing the final statistical analysis. Table 1 presents patient characteristics.

Fig. 1 shows that MRI categories with partial and non-visualization of the appendix without secondary signs had the same prevalence of appendicitis. Therefore, these categories were grouped together for statistical calculations. MRI categories with non-visualization of the appendix with secondary signs and equivocal results were also grouped together for statistical calculations because they had similar prevalence of appendicitis. Fig. 2 displays similar prevalence of appendicitis between the corresponding ultrasound categories. Consequently, the ultrasound categories were grouped in the same fashion for statistical analysis. There were 597 patients with a documented WBC count. Table 2 presents the effects of combining the grouped MRI and ultrasound categories with the WBC cutoffs of <10.0 and <7.5 × 10^9/L on their NPVs.

Table 3 displays the test characteristics of the fast, non-contrast MRI protocol using both calculation methods previously described. This imaging protocol identified alternative etiologies of symptoms in 10.8% of patients. The most common alternative etiologies identified included 22 cases of ovarian pathology (e.g., cysts, torsions, teratomas), 12 cases of enteritis and/or colitis (6 of these were specifically terminal ileitis), and 11 cases of mesenteric adenitis. Of the 623 MRI studies performed for suspected appendicitis, 43 were on patients 3 to 5 years old. The imaging was successful (not terminated due to movement) in 96% (24 of 25) of 5-year-old patients, 79% (11 of 14) of 4-year-old patients, and 75% (3 of 4) of 3-year-old patients.

A diagnosis of primary appendicitis was documented in 126 pathology reports. However, there was clear evidence that one of these cases was a false positive. In this instance, the patient was taken to the operating room for signs of diffuse peritonitis and septic shock, without concern for appendicitis, and was diagnosed with spontaneous bacterial peritonitis caused by Streptococcus pneumoniae proven by culture of peritoneal fluid. A non-perforated appendix was removed. Therefore, in addition to this case being considered a false positive pathology result, it is not counted in the negative appendectomy rate. There were 2 patients who had non-specific inflammation of the appendix documented in their pathology reports. One of these patients had a final diagnosis of appendicitis while the other did not. There were 4 patients with perforated appendicitis who were treated medically without an interval appendectomy. Lastly, there were 8 patients who had negative appendectomies. Of these 8 patients, 3 had MRI studies categorized as

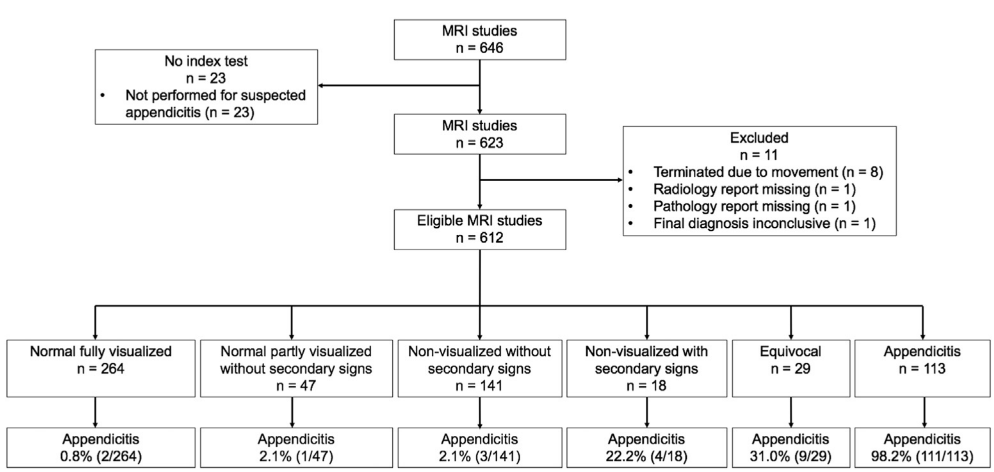

Fig. 1. Categorization of MRI studies and corresponding prevalence of appendicitis. MRI = magnetic resonance imaging.

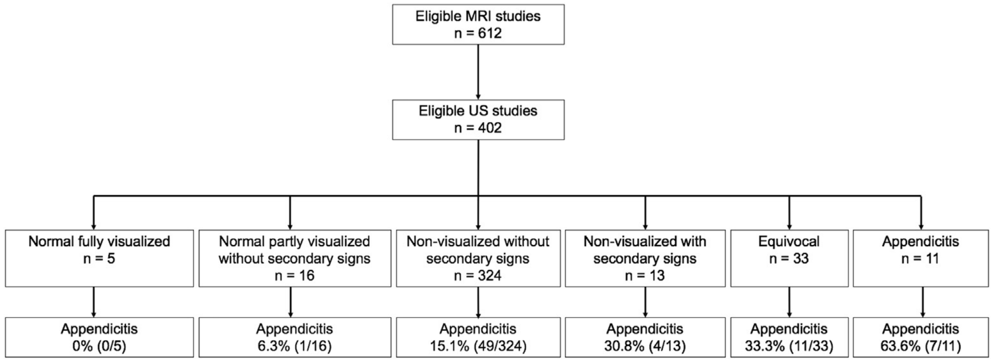

Fig. 2. Categorization of ultrasound studies and corresponding prevalence of appendicitis. MRI = magnetic resonance imaging; US = ultrasound.

non-visualization of the appendix without secondary signs and were taken to the operating room for worsening pain after a period of observation on the inpatient unit, 3 had MRI studies categorized as non-visualization of the appendix with secondary signs and were taken directly to the operating room, and 2 had equivocal MRI interpretations and were taken directly to the operating room.

4. Discussion

This is the first investigation to combine laboratory test results with non-diagnostic MRI studies to determine if doing so significantly increases their NPVs and thereby identifies low-risk groups. The data demonstrates that a fast, non-contrast MRI study with incomplete visualization of a normal appendix without secondary signs (NPV 97.9%) is nearly equivalent to a negative test result in which a normal appendix is fully visualized (NPV 99.2%). So, there is little opportunity for improvement by combining this result with WBC cutoffs. No significant effect was demonstrated by doing so.

Kearl and colleagues similarly found a high NPV for fast, non-contrast MRI studies with non-visualization of the appendix without secondary signs [15]. They reported that the NPV is 100% based on their evaluation of 31 studies with this result. So, it is reasonable to consider MRI results with incomplete visualization of a normal appendix without secondary signs as negative rather than non-diagnostic. These findings are similar to those of an investigation on the NPV of CT scans with non-visualization of the appendix in pediatric patients. Garcia and colleagues published data demonstrating that the NPV of CT scans with non-visualization of the appendix without secondary signs is 98.7% (95% CI 95.5–99.8%) compared to 99.8% (95% CI 98.7–99.9%) for a visualized normal appendix [20].

Non-visualization of the appendix with secondary signs and equivocal interpretations composed 7.7% of the MRI results. These test results create a clinical dilemma considering that 22.2% and 31.0% of patients in these categories had appendicitis, respectively. Often, these patients undergo additional imaging, admission for observation, and/or unnecessary surgery, increasing ED length of stay and healthcare costs. Having

Table 1
Patient characteristics.

Gender	57.7% female
Mean age (±SD)	11.7 years (±3.6 years)
Mean weight-for-age percentile (±SD)	
All patients	64.8% (±30.5%)
Only patients with ultrasound studies performed	62.0% (±30.6%)
Prevalence of appendicitis	21.2% (130/612)
Prevalence of perforated appendicitis	33.9% (44/130)
Negative appendectomy rate	5.9% (8/135)
Percentage of patients discharged from the ED	49.0% (300/612)
Percentage discharged without a follow-up encounter	32.7% (98/300)

ED = emergency department; SD = standard deviation.

a method to identify a low-risk group within this population that may be safely discharged home with outpatient follow-up would be ideal. While the use of WBC cutoffs may provide a means for doing so, the data from this investigation does not confidently determine the NPV point estimates.

There are advocates for the use of intravenous contrast to increase the diagnostic accuracy of MRI studies for suspected appendicitis [21]. But, contrast has potential adverse effects, such as anaphylaxis and acute kidney injury, and increases the duration of the imaging study. Furthermore, MRI has high inherent soft-tissue contrast resolution. A recent meta-analysis identified no significant difference between the test characteristics of contrast versus non-contrast MRI studies for suspected appendicitis [22]. However, Lyons and colleagues published a study demonstrating a reduction in the number of equivocal interpretations by using contrast and recommended administering it as needed for non-diagnostic studies [23]. This method requires availability of a radiologist to interpret the imaging while the patient is still in the MRI machine to determine if contrast is necessary and may be logistically difficult to do in a larger or less well staffed hospital.

The test characteristics for this fast, non-contrast MRI protocol are presented in two ways for transparency. Use of the 2 by 2 contingency table method prevents underestimation of test characteristics for evaluable results, while the 3 by 2 contingency table method avoids biased overestimation of the test's diagnostic accuracy. Acknowledging that 7.7% of the studies are excluded when using the 2 by 2 contingency table, this method demonstrates that the MRI protocol has excellent test characteristics for evaluable results that are similar to those published in a systematic review and a meta-analysis evaluating the use of MRI for suspected pediatric appendicitis [22,24]. This provides more evidence for the American College of Radiology to increase its current rating of non-contrast MRI for this purpose. As of 2015, on a rating scale of 1–9, it states that ultrasound (rating of 8) and CT scan with contrast (rating of 7) are usually appropriate for suspected pediatric appendicitis, while MRI with contrast (rating of 5) and MRI without contrast (rating of 4) may be appropriate [5].

Other areas of interest in the literature include the ability of MRI to identify alternative etiologies of patients' symptoms and whether young children can tolerate the scanning protocol. This MRI protocol identified fewer alternative etiologies than previously reported by Moore and colleagues who used a similar protocol [25]. The most common alternative etiologies identified in both studies were ovarian pathology, enteritis and/or colitis, and mesenteric adenitis. Investigators have mentioned concern that patients ≤6 years old may often be unable to sufficiently cooperate for MRI to be performed [26]. This protocol demonstrated a high rate of success with 88.4% of patients 3 to 5-years-old tolerating it. Although, there were likely several patients in this age group during the study period for whom physicians did not attempt MRI due to concern for inability to cooperate.

While the previous findings contribute to the understanding of MRI for suspected pediatric appendicitis, its use for this purpose is still

Table 2
Effects of WBC cutoffs on NPVs of non-diagnostic imaging studies.

	Imaging category	Independent	WBC <10.0	WBC <7.5
MRI NPV	Partially and non-visualized appendix without secondary signs	97.9% (95% CI 94.6–99.4%) n = 188	98.1% (95% CI 93.2–99.8%) n = 104	98.2% (95% CI 90.3–100%) n = 55
	Non-visualized appendix with secondary signs and equivocal	72.3% (95% CI 57.4–84.4%) n = 47	91.7% (95% CI 61.5–99.8%) n = 12	100% (95% CI 59.0–100%) n = 7
US NPV	Partially and non-visualized appendix without secondary signs	85.3% (95% CI 81.1–88.9%) n = 340	94.8% (95% CI 90.3–97.6%) n = 172	96.5% (95% CI 90.1–99.3%) n = 86
	Non-visualized appendix with secondary signs and equivocal	67.4% (95% CI 52.0–80.5%) n = 46	78.6% (95% CI 49.2–95.3%) n = 14	87.5% (95% CI 47.4–99.7%) n = 8

CI = confidence interval; MRI = magnetic resonance imaging; NPV = negative predictive value; US = ultrasound; WBC = white blood cell.

growing and limited to a relatively small number of hospitals. The ultrasound results of this investigation are more widely applicable. Notably, the 402 ultrasound studies analyzed do not include all of the ultrasound studies performed during the time-frame of this investigation. Rather, they are a high-risk subgroup for whom advanced imaging was indicated. Therefore, if these WBC cutoffs had been combined with all ultrasound studies performed, higher NPVs may have been found. Nonetheless, depending on a physician's or surgeon's testing threshold, an increase in the NPV from 85.3% for an incompletely visualized appendix without secondary signs to 94.8% when combined with a WBC cutoff of $<10 \times 10^9$/L or 96.5% when combined with a WBC cutoff of $<7.5 \times 10^9$/L may be sufficient to discharge a patient home with follow-up the next day rather than perform additional imaging or admit for observation. In contrast, if the appendix is incompletely visualized and secondary signs are present, or the test is interpreted as equivocal, these WBC cutoffs do not appear to sufficiently increase the NPVs.

In 2015, Cohen and colleagues similarly combined WBC cutoffs with non-diagnostic ultrasound studies to determine if doing so increases their NPVs [6]. They found that combining these studies with WBC cutoffs of <11.0 and $<7.5 \times 10^9$/L resulted in NPVs of 95.6% and 97.1%, respectively. In the same year, Anandalwar and colleagues combined ultrasound studies that incompletely visualized the appendix without secondary signs of appendicitis with a WBC cutoff of $\leq 9.0 \times 10^9$/L and a neutrophil percentage of ≤65 [7]. Doing so increased the NPV from 41.9% to 95.8%. They suggested the consideration of guidelines in which imaging with CT scan or admission for observation are recommended against in patients with NPVs of >95%. Unlike our study, both of these investigations analyzed consecutive patients who had ultrasound studies performed for suspected appendicitis rather than a high-risk subgroup who had advanced imaging performed as well.

5. Limitations

There are several limitations of this study. First, as with all retrospective chart reviews, it is dependent on the availability and accuracy of the medical records. Secondly, after the PI was trained for data collection and imaging result categorization, no performance monitoring of these tasks to ensure accuracy occurred. Training for the PI to collect data and categorize imaging results was performed using a randomized selection of 100 patient charts from the 646 patients identified by the EMR query. The possibility of contamination by knowledge of previous data coding cannot be excluded for the PI's subsequent evaluation of these records when collecting data and categorizing imaging for analysis. Additionally, the PI was not blinded to the research questions and purposes of the investigation while performing these tasks, which introduces review bias.

The reference standard can have equivocal and false positive results. Radiologists were not blinded to clinical findings in the ED and pathologists were not blinded to clinical, imaging, or operative findings. There were 98 of 300 (32.7%) patients discharged from the ED who had no follow-up encounter documented. While some of these patients may have gone elsewhere for medical care after discharge and been found to have appendicitis, the likelihood is low considering this institution is the only pediatric hospital in the state. Lastly, the sample sizes for MRI and ultrasound studies with incomplete visualization of the appendix with secondary signs and equivocal interpretations were small. Future studies with larger sample sizes are needed to more accurately determine the effects of combining these imaging results with WBC cutoffs on NPVs.

6. Conclusions

Combining MRI studies that incompletely visualize the appendix without secondary signs of appendicitis with WBC cutoffs does not significantly increase their already high NPVs. These imaging results are nearly equivalent to a negative test result. In contrast, combining ultrasound studies that incompletely visualize the appendix without secondary signs with WBC cutoffs does significantly increase their NPVs and thereby identifies low-risk groups of patients that may be considered for discharge home with outpatient follow-up the next day rather than advanced imaging or admission for observation. The findings of this investigation do not provide sufficient confidence to determine

Table 3
MRI test characteristics.

Calculation method	Sensitivity	Specificity	PPV	NPV	(+) LR	(−) LR
2 × 2 contingency table	94.9% (95% CI 89.2–98.1%)	99.6% (95% CI 98.4–100%)	98.2% (95% CI 91.3–99.0%)	98.7% (95% CI 97.1–99.5%)	212.5 (95% CI 53.3–847.6)	0.05 (95% CI 0.02–0.11)
3 × 2 contingency table	85.4% (95% CI 78.1–91.0%)	92.5% (95% CI 89.8–94.7%)	98.2% (95% CI 91.3–99.0%)	98.7% (95% CI 97.1–99.5%)	11.4 (95% CI 8.3–15.8)	0.16 (95% CI 0.1–0.24)

CI = confidence interval; LR = likelihood ratio; MRI = magnetic resonance imaging; NPV = negative predictive value; PPV = positive predictive value.

the NPV point estimates for MRI and ultrasound studies with incomplete visualization of the appendix with secondary signs and equivocal interpretations combined with WBC cutoffs. While this fast, non-contrast MRI protocol was limited by a high number of equivocal results, it demonstrated excellent test characteristics for the 92.3% of studies that were evaluable.

Presentations

This study was formally presented at the Eastern Society for Pediatric Research meeting on March 17th, 2018 in Philadelphia, PA and at the Pediatric Academic Societies meeting on May 7th, 2018 in Toronto, Canada.

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Author contributions

Study concept and design (TK, AT, AC, AD), acquisition of the data (TK), analysis and interpretation of the data (TK, RC), drafting of the manuscript (TK), critical revision of the manuscript for important intellectual content (AT, AC, KS, AD), and statistical expertise (RC).

Declaration of interest

TK, AT, AC, KS, and AD have no declarations of interest.

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