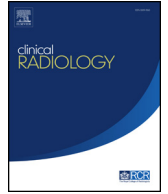




Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



# Impact of the coronavirus disease 2019 (COVID-19) pandemic on the presentation of paediatric acute appendicitis: an observational study

K.K. Horst<sup>a,\*</sup>, B.M. Carr<sup>b</sup>, A. Parvinian<sup>a</sup>, J.S. McDonald<sup>a</sup>

<sup>a</sup>Department of Radiology, Mayo Clinic, 200 1st St. SW, Rochester, MN 55905, USA

<sup>b</sup>Department of Emergency Medicine, Mayo Clinic, 200 1st St. SW, Rochester, MN 55905, USA

## ARTICLE INFORMATION

### Article history:

Received 29 June 2022

Received in revised form  
10 August 2022

Accepted 12 August 2022

**AIM:** To determine whether there were differences in the clinical presentation of patients imaged to evaluate for acute appendicitis in 2020 compared to 2019 with the hope that this information might better identify patients who should undergo imaging work-up and those who should not.

**MATERIALS AND METHODS:** This retrospective observational study included patients <18 years who were evaluated for appendicitis between 1 March and 31 May 2019 and 2020. A total of 465 patients were stratified by final diagnosis (appendicitis versus not appendicitis) and compared based on presenting symptoms, physical examination findings, vital signs, and laboratory test results.

**RESULTS:** Symptoms and physical examination findings that were significant in the positive cohort in both years included right lower quadrant pain, pain with movement, migration of pain, right lower quadrant tenderness, and peritoneal findings. Reporting upper respiratory symptoms was an independent predictor of negative results among all patients and in 2019. Both negative cohorts were more likely to have negative physical examinations. Anorexia and nausea/vomiting were more likely among positive cases in 2019 whereas diarrhoea was more likely among positive cases in 2020.

**CONCLUSIONS:** The COVID-19 pandemic did not significantly change the presenting features of acute appendicitis. The results of the present study emphasise the importance of the physical examination. The ambiguity of symptoms that mimic gastroenteritis justifies imaging in these patients.

© 2022 The Royal College of Radiologists. Published by Elsevier Ltd. All rights reserved.

## Introduction

It has been over 2 years since coronavirus disease 2019 (COVID-19) was declared a worldwide pandemic, but the effects have rippled through every aspect of healthcare,

providing unique opportunities to gain new insight into well-studied disease processes. United States emergency departments (EDs) experienced a 42% decrease in overall patient visits during the first months of the pandemic compared to the same time period during the prior year and

\* Guarantor and correspondent: K. K. Horst, Department of Radiology, Mayo Clinic, 200 1st St. SW, Rochester, MN 55905, USA.  
E-mail address: [Horst.Kelly@mayo.edu](mailto:Horst.Kelly@mayo.edu) (K.K. Horst).

remained 25% below expected as of January 2021.<sup>1,2</sup> Conscientious concern for overwhelming the healthcare system and perhaps some degree of fear of nosocomial infection presumably resulted in fewer patients seeking treatment for non-COVID-19 illnesses, particularly during the early phase of the pandemic. Admission rates (as a percentage of ED visits) remained constant in many locations; however, at least until local COVID-19 rates increased.<sup>3</sup> Multiple other studies have demonstrated a decreased incidence of specific disease processes including ST-elevation myocardial infarction,<sup>4–6</sup> stroke,<sup>7</sup> trauma,<sup>8</sup> and acute cholecystitis.<sup>9–12</sup>

Visits to paediatric emergency departments have been studied separately and also dropped significantly during this time, by around 45% according to two different studies.<sup>13–15</sup> Several studies have been published since the beginning of the pandemic that looked at the incidence of specific emergent paediatric presentations, with paediatric appendicitis being one of the most commonly studied. These studies have shown a stable or decreased incidence of paediatric acute appendicitis, delayed presentation, and increased rate of complications in the acute phase of the pandemic.<sup>16–21</sup>

Our group recently reported similar numbers of paediatric appendicitis diagnoses between 2019 and 2020 in the same 3-month span, despite a 43% drop in the volume of patients worked up for this indication (294 versus 171).<sup>22</sup> This mirrored a 44% drop in total patient volumes in the paediatric ED, which went from 15,514 in 2019 to 8,703 in 2020. Despite this decreased volume, however, the total patients diagnosed with acute appendicitis was similar between the two years (60 in 2019 and 54 in 2020). If half the children who had been worked up for appendicitis in 2019 did not present in 2020, and their condition was self-limited without imaging or treatment, are there characteristics of this population that may help identify which patients may need imaging in the future versus those who do not?

The aim of the present study was to determine whether there were differences in the clinical presentation (e.g., symptoms, vital signs, physical examination, or laboratory test results) of patients imaged to evaluate for acute appendicitis in 2020 compared to 2019 with the hope that this information might help inform imaging decisions after the pandemic. A null hypothesis that the prevalence of these clinical variables in the 2019 cohorts would not differ from the 2020 cohorts was tested. As a secondary goal, a null hypothesis that the prevalence of these clinical variables would not differ between the positive and negative cohorts within each year was tested. Logistic regression modelling was used to identify variables that were independent predictors of a positive appendicitis diagnosis.

## Materials and methods

### *Study population*

This retrospective observational cohort study was approved by the institutional review board. Only patients whose parents consented for research were included and all data management was compliant with the Health Insurance Portability and Accountability Act (HIPAA). The medical

record was searched for patients 18 years and under who were evaluated for acute appendicitis at the main institution and surrounding sites from 1 March to 31 May 2019 and 2020. Imaging dictations were searched for the term “appendicitis” and these reports were compared to the medical record to identify patients evaluated for acute appendicitis. Positive cases were identified as those coded in the electronic medical record by the International Classification of Diseases (ICD-10) as “acute appendicitis,” and included cases managed surgically and non-surgically.

### *Institutional acute appendicitis imaging guidelines*

Institutional guidelines existed during the time periods studied that provided a framework for evaluating children with suspected appendicitis during this time period. Providers were free to use their own clinical judgement, although adherence to the guideline was high at the main children’s hospital location. Per this guideline, ultrasound is recommended as the first-line diagnostic test for children with suspected appendicitis, and this test is available 24/7 at the main children’s hospital and select community locations. Laboratory testing such as obtaining a white blood cell count (WBC) or C-reactive protein level (CRP) was generally deferred per that guideline and performed only if the initial ultrasound is indeterminate or positive. In cases of an indeterminate ultrasound (e.g., the appendix cannot be definitively visualised by the radiologist), a paediatric surgery consultation is then obtained if the emergency physician has any ongoing suspicion for acute appendicitis. Clinical decision tools such as the Alvarado Score<sup>23</sup> or Paediatric Appendicitis Score<sup>24</sup> may be used, but typically by paediatric surgery only after imaging to determine management in unclear cases. Adherence to this guideline is more variable outside of the main academic centre, however, in part due to limited availability of diagnostic ultrasound in those locations. In these locations, computed tomography (CT) of the abdomen/pelvis with intravenous (IV) contrast medium is the most common first-line diagnostic test, and blood is typically drawn for testing around the time of IV placement for CT.

### *Clinical data retrieval*

Vital signs and specific laboratory test results (WBC, platelet count, and CRP) were gathered electronically for each patient. Provider documentation was then reviewed manually for each patient, and positive clinical symptoms and physical examination findings were recorded. The duration of symptoms rounded to the closest day was also recorded. Symptoms that began the same day as presentation were estimated at 0.5 day. Data extraction was performed independently by at least two of the three co-investigators for each record and results merged to ensure data completeness and reliability.

### *Statistical analysis*

Symptoms, examination findings, vital signs, and laboratory values were compared between positive and

**Table 1**  
Demographics, vital signs, laboratory values.

	2019		2020		2019 Negative versus 2020 negative p-value		2019 Negative versus 2020 positive p-value		2019 Positive versus 2020 positive p-value	
	Negative cases [n]	Positive cases [n]	Negative cases [n]	Positive cases [n]						
Cases (n)	234	60	117	54						
Age (median in years, IQR)	9 (6–14)	11 (9–14)	11 (7–15)	12 (10–14)	0.0105	0.0081	0.61	0.72	0.0205	0.94
Female (%)	139 (59%)	26 (43%)	72 (62%)	23 (43%)	0.70	0.0252	0.0205	0.94		
Presentation										
Highest temperature (°C)	37 (37–38) [221]	37 (37–38) [60]	37 (37–38) [111]	37 (37–38) [53]	0.63	0.66	0.96	0.98		
Highest heart rate/pulse* (beats/min)	103 (88–120) [222]	101 (87–116) [60]	101 (88–131) [110]	108 (96–125) [53]	0.93	0.87	0.12	0.14		
Leukocytes ( $\times 10^9/l$ )	80.4 (6.1–12) [158]	15 (12–19) [59]	9.0 (6.7–12) [88]	14 (11–17) [52]	0.28	<0.0001	<0.0001	0.10		
Neutrophils ( $\times 10^9/l$ )	5.3 (3.5–8.6) [148]	13 (11–16) [43]	5.9 (3.8–9.2) [84]	10 (8.0–14) [34]	0.60	<0.0001	<0.0001	0.06		
Platelets ( $\times 10^9/l$ )	279 (237–321) [158]	288 (258–325) [59]	265 (234–315) [88]	269 (227–312) [52]	0.53	0.27	0.84	0.10		
C-reactive protein (mg/l)	3.7 (2.9–29) [42]	37 (3.7–88) [11]	18 (2.9–34) [20]	42 (20–115) [8]	0.26	0.0289	0.07	0.51		
Length of symptoms (days)	2 (1–4) [231]	1 (0.5–1) [59]	2 (1–5) [114]	1 (1–3) [54]	0.07	<0.0001	0.0116	0.0080		

negative cohorts in 2019 and 2020. The Wilcoxon rank-sum test was used for continuous variables and Pearson’s chi-squared test for categorical variables. Number and percentage were used for categorical results and interquartile range and median were used for continuous results. JMP (version 14, SAS Institute, Cary, NC, USA) was used to calculate statistical analyses. The effect of patient and examination variables on positive versus negative imaging findings (as classified by the original radiology report) was evaluated using logistic regression models, with imaging finding (positive/negative) as the dependent variable and patient age, sex, race, leukocyte results, length of symptoms, and reported symptoms and examination findings as the independent variables. A p-value of <0.05 was considered statistically significant.

## Results

The results in Table 1 summarise patient demographics, vital signs, and laboratory data. The reported length of symptoms prior to presentation is also recorded in this table. Symptoms and physical examination findings are summarised in Table 2. Patients where the appendix was not seen on the first ultrasound (n=123), where imaging was not performed (n=1), or where imaging was equivocal with no pathology confirmation (n=4) were excluded from this part of the analysis. Clinical outcomes for patients whose appendix could not be visualised on ultrasound are included in Table 3.

### Demographics, vital signs, and laboratory data

Patients in the 2019 negative cohort were younger than the positive cohort and younger than patients presenting in 2020. Significantly more patients with a positive diagnosis were male in both 2019 and 2020. There were no statistically significant differences in temperature or heart rate among groups. Patients with appendicitis had significantly higher leukocyte and neutrophil counts in both years. There were no differences in platelet counts among positive groups in either year. CRP levels were higher in the positive cohorts in both years, but only the patients evaluated in 2019 showed a statistically significant difference between positive and negative cases.

### Symptoms

There was a statistically significant difference in the presence of right lower quadrant pain among negative and positive cases in both years. This symptom was documented in around 2/3 of positive cases reported this symptom versus only 1/3 of negative cases. There was no difference in the incidence of other abdominal pain (i.e., generalised or abdominal pain located outside the right lower quadrant) between negative and positive groups. Nausea and vomiting were more common among positive cases in 2019, while diarrhoea and constipation were more common among positive cases in 2020. Pain with movement, anorexia, and migration of pain into the right lower quadrant were

**Table 2**  
Symptoms and physical examination findings.

	2019		2020		2019 negative versus 2020 negative p-value	2019 negative versus 2019 positive p-value	2020 negative versus 2020 positive p-value	2019 positive versus 2020 positive p-value
	Negative cases [n]	Positive cases [n]	Negative cases [n]	Positive cases [n]				
<b>Reported symptoms (%)</b>								
Right lower quadrant pain	77 (33%)	40 (67%)	19 (16%)	33 (61%)	0.0010	<0.0001	<0.0001	0.54
Generalised or other location abdominal pain	146 (62%)	39 (65%)	96 (82%)	43 (80%)	0.0002	0.71	0.71	0.08
Nausea and/or vomiting	145 (62%)	47 (78%)	66 (56%)	34 (63%)	0.32	0.0175	0.42	0.07
Diarrhoea	48 (21%)	12 (20%)	21 (18%)	24 (44%)	0.57	0.93	0.0003	0.0051
Constipation	23 (9.8%)	4 (6.7%)	4 (3.4%)	10 (19%)	0.0336	0.45	0.0008	0.0542
Pain with movement	22 (9.4%)	13 (22%)	3 (2.6%)	19 (35%)	0.0189	0.0089	<0.0001	0.11
Anorexia	72 (31%)	30 (50%)	15 (13%)	13 (24%)	0.0002	0.0052	0.06	0.0043
Migration of pain	10 (4.3%)	14 (23%)	0	8 (15%)	0.0233	<0.0001	<0.0001	0.25
Upper respiratory infection symptoms	18 (7.7%)	4 (6.7%)	12 (10%)	3 (5.6%)	0.42	0.79	0.31	0.81
Urinary symptoms	20 (8.6%)	7 (12%)	12 (10%)	5 (9.3%)	0.60	0.46	0.84	0.68
Chills	5 (2.1%)	4 (6.7%)	7 (6.0%)	4 (7.4%)	0.06	0.07	0.72	0.88
Other symptoms	48 (21%)	9 (15%)	18 (15%)	13 (24%)	0.25	0.34	0.17	0.22
<b>Physical examination findings (%)</b>								
Right lower quadrant tenderness	96 (41%)	50 (83%)	36 (31%)	40 (74%)	0.06	<0.0001	<0.0001	0.23
Generalised or other location abdominal tenderness	101 (43%)	29 (48%)	77 (66%)	30 (56%)	<0.0001	0.47	0.20	0.44
Peritoneal signs	46 (20%)	35 (58%)	15 (13%)	26 (48%)	0.11	<0.0001	<0.0001	0.28
Other physical examination findings	27 (12%)	0	7 (6.0%)	3 (5.6%)	0.10	0.0058	0.91	0.06
No major findings at exam	38 (16%)	1 (1.7%)	23 (20%)	1 (1.9%)	0.43	0.0030	0.0018	0.94
Examination not performed (video visit)	0	0	1	0	0.06	<0.0001	<0.0001	0.23

greater in the positive cohort in both years. There were no statistically significant differences in the negative and positive cohort in either year regarding upper respiratory infection symptoms (e.g., runny nose, cough), urinary symptoms (e.g., dysuria, urinary frequency), chills, or symptoms categorised as “other.”

### Physical examination findings

There were significantly more patients with right lower quadrant tenderness on physical examination in the positive cohort than the negative cohort in both years. There were no differences in generalised abdominal pain or abdominal pain outside the right lower quadrant between the negative and positive cohorts in either year. There were significantly more positive patients who presented with peritoneal signs (e.g., rebound tenderness, Rovsing’s sign) in both years. A significant number of patients in the negative cohorts in both years had normal physical examinations (38/234 [16%] in 2019 and 23/117 [20%] in 2020) compared to <2% of patients in the positive cohorts in each year, ( $p=0.0030$  in 2019 and  $p=0.0018$  in 2020).

### Independent predictors of positive or negative imaging findings

Multivariate modelling was performed adjusting for age, gender, vital signs, and laboratory values to provide predictors of positive and negative imaging findings (Table 4). Patients with ultrasound results where the

appendix could not be seen were excluded from this portion of the analysis. Male gender was a predictor of positive imaging findings for acute appendicitis among all patients in both years. Leucocytosis and CRP were also independent predictors of positive imaging findings among patients in the 2019 but not 2020 cohort. The duration of symptoms was an independent predictor of positive imaging findings, with patients in the positive cohort generally presenting with a shorter duration of symptoms. Right lower quadrant abdominal pain was a predictor of positive imaging findings in all patients. Abdominal pain not localised to the right lower quadrant (i.e., generalised abdominal pain or pain localised to a different part of the patient’s abdomen) was a predictor of positive imaging findings for appendicitis in all cases and within each year. Diarrhoea and pain with movement in the history were both predictors of positive imaging findings in 2020. Migration of pain into the right lower quadrant predicted positive results in all patients and in the 2019 cohort but not the 2020 cohort in isolation. Reporting upper respiratory symptoms was a predictor of negative results among all patients and the 2019 cohort but not the 2020 cohort.

## Discussion

There were nearly twice as many paediatric patients imaged as part of a work-up for appendicitis in 2019 compared to 2020 over the same 3-month time period (294

**Table 3**

Management and outcomes in patients where appendicitis was not seen on first ultrasound.

Management	No./123 total (%)	No. treated for appendicitis (%)
Repeat ultrasound	2/123 (1.6%)	0 (0%)
Computed tomography abdomen/pelvis	6/123 (4.9%)	0 (0%)
Appendectomy without additional imaging	2/123 (1.6%)	2/2 (100%)
Discharge without additional imaging	113/123 (91.9%)	0/113 (0%)

versus 171), but about the same number of patients were treated for appendicitis in each year (60 in 2019 versus 54 in 2020). The purpose of this study was to see what could be learned from those patients that did come to the emergency department in 2020 with signs or symptoms that prompted the evaluating provider to order imaging to assess for appendicitis. Was there something different about the pre-pandemic patient cohort that made clinicians more likely to order imaging studies that turned out to be negative? Given that there was an overall 44% drop in patient volumes in the paediatric ED, it is more likely that the decrease in imaging work-up mirrored a decrease in overall volumes. Unfortunately, the data presented here cannot be used in isolation to change clinical practice or provide firm recommendations that would reduce the utilisation of diagnostic testing. That being the case, however, they do show interesting trends.

Presenting signs and symptoms of patients who had appendicitis in 2020 were similar to those in 2019. Gender

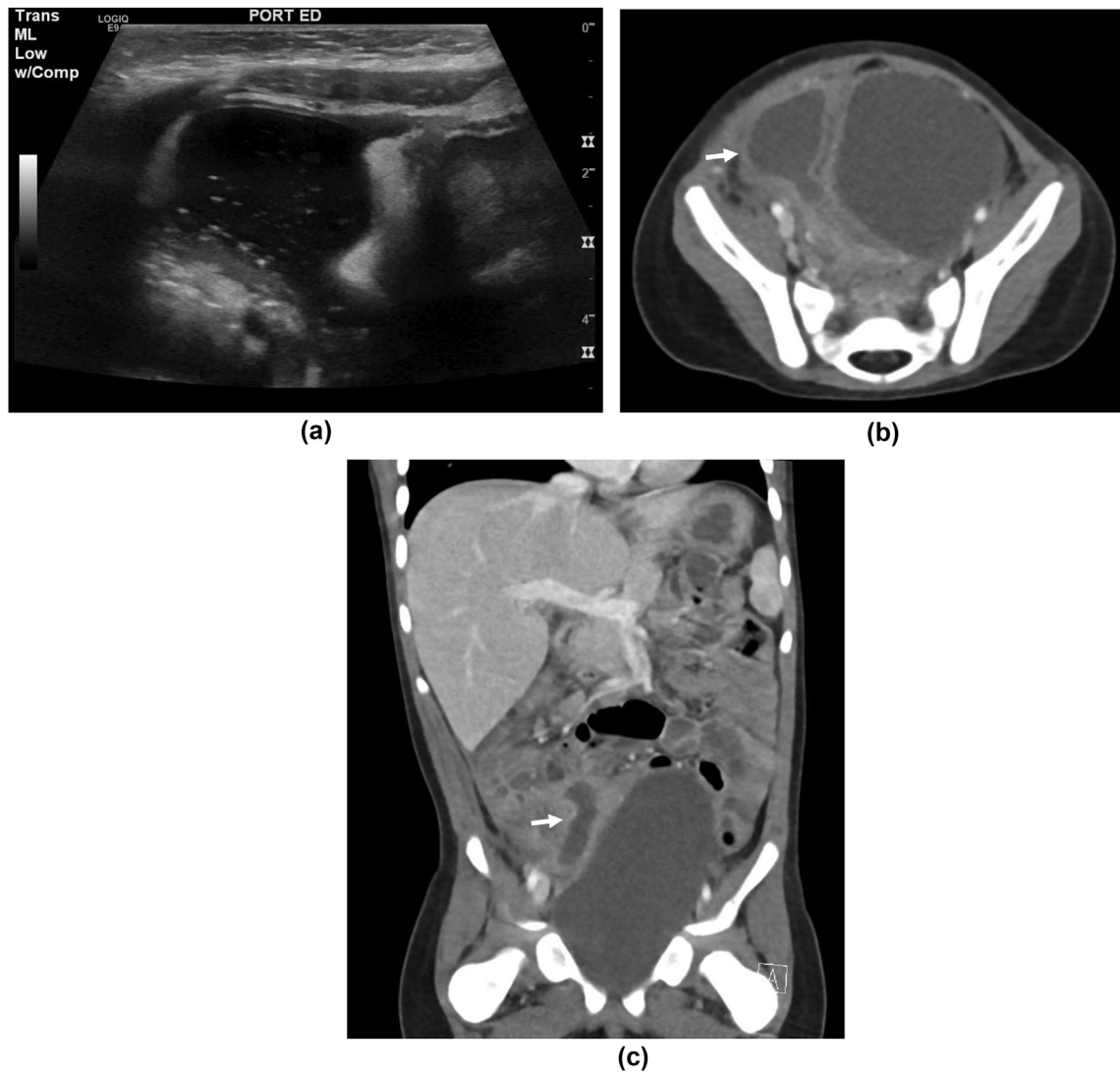
distribution, age, vital signs, and laboratory results were not significantly different between positive groups across the two years. These findings indicate that the clinical presentation of appendicitis was similar during the early months of the pandemic compared to the year before. This is not unexpected, because the pathophysiology of appendicitis did not change.

The differences were more prominent among those patients that presented for evaluation but did not have acute appendicitis. Patients with a negative work-up for appendicitis in 2020 tended to be older and were less likely to have right lower quadrant pain. They were more likely to have generalised abdominal pain or abdominal pain located outside the right lower quadrant when compared to the 2019 negative cohort. The 2020 negative cohort was also less likely to have other symptoms, such as constipation, pain with movement, anorexia, or migration of pain; and their examinations were more likely to identify generalised or

**Table 4**Predictive factors for positive versus negative imaging findings.<sup>a</sup>

	All patients	2019 cases	2020 cases
Positive cases (n)	110	58	52
Negative cases	229	147	82
Total cases	339	205	134
Variables			
Demographics			
Age	0.96	0.60	0.07
Female	0.0249	0.13	0.58
<i>Male sex was an independent predictor of positive appendicitis</i>			
Presentation			
Leukocytes	<0.0001	<0.0001	0.11
Length of symptoms	0.0189	0.0018	0.0364
Reported symptoms			
Right lower quadrant pain	<0.0001	0.0021	0.0009
Generalised or other location abdominal pain	<0.0001	0.0015	0.0176
Nausea and/or vomiting	0.12	0.86	0.06
Diarrhoea	0.0050	0.20	0.0022
Constipation	0.56	0.25	0.08
Pain with movement	0.13	0.99	0.0123
Anorexia	0.19	0.06	0.60
Migration of pain	0.0230	0.0162	0.99
Upper respiratory infection symptoms	0.0019	<0.0001	0.99
Urinary symptoms	0.06	0.06	0.06
Chills	0.71	0.55	0.31
Other symptoms	0.11	0.99	0.14
Examination findings			
Right lower quadrant pain	0.0008	0.0002	0.90
Generalised or other location abdominal pain	0.17	0.0108	0.73
Peritoneal signs	0.06	0.31	0.53
Other symptoms	0.0103	<0.0001	0.68

<sup>a</sup> Patients where appendix was not seen (n=123), where imaging was not performed (n=1), or where imaging was equivocal with no pathology confirmation (n=4) were excluded.



**Figure 1** Ultrasound and CT images from a 20-month-old male patient in 2020 with late presentation of ruptured appendicitis. (a) Ultrasound and (b,c) CT show a well-circumscribed abscess in the right lower quadrant at the tip of a fluid-filled tubular structure, a ruptured appendix.

other abdominal tenderness not limited to the right lower quadrant. These data would appear to suggest that there was less overlap in the clinical presentations of patients with versus without appendicitis in 2020 than in 2019.

Reporting upper respiratory symptoms was an independent predictor of negative results among all patients and in the 2019 cohort. These results suggest that patients that present with abdominal symptoms as well as upper respiratory tract symptoms are unlikely to have acute appendicitis. Multiple other papers have shown an association between upper respiratory tract infections and abdominal pain.<sup>25,26</sup>

A similar trend is also seen in the physical examination findings. Patients who present with abdominal symptoms, with a wide range of physical examination findings are less likely to have acute appendicitis. Results from both 2019 and 2020 emphasise the importance of the physical examination in evaluating patients with abdominal

symptoms, with patients in both years consistently demonstrating a lack of abdominal findings on physical examination among negative cohorts.

The results of the present study emphasise the difficulty in differentiating other causes of abdominal pain from acute appendicitis. Nausea and vomiting were independent predictors in diagnosing appendicitis in 2019. Diarrhoea was an independent predictor in diagnosing appendicitis in 2020. In the early 1990s, prior to the widespread use of imaging, appendicitis was frequently misdiagnosed as enterocolitis.<sup>27–29</sup> Likewise, even with the widespread availability and use of imaging in the current healthcare environment, cases of missed appendicitis are frequently first misdiagnosed as enterocolitis.<sup>30</sup> Multiple authors have attempted to identify clinical and laboratory findings that may accurately distinguish these diagnoses due to ambiguous symptoms. Multiple clinical decision tools exist to assist in making this distinction. Two

of the most well known, the Alvarado Score and Paediatric Appendicitis Score, have generally fared favourably in validation.<sup>31–34</sup> Another retrospective case–control study comparing paediatric patients admitted with abdominal pain and diarrhoea by Lu *et al.* identified right lower quadrant pain, stool occult blood, leucocytosis, and CRP as independent predictors to diagnose acute appendicitis over gastroenteritis, and they used this to develop a predictive model incorporating these factors that outperformed the paediatric appendicitis score (PAS) model among patients presenting with symptoms suspicious for appendicitis, including diarrhoea.<sup>27</sup> The downside of these tools, however, is that they all require that a blood sample be obtained before a score can be calculated. Thus, imaging is often utilised in lieu of these clinical decision tools to minimise the need for phlebotomy, a procedure that is often avoided in paediatric patients due to perceived pain and anxiety among patients and their parents. Given the high accuracy of imaging studies to diagnose appendicitis, the present results support the conclusion that ordering imaging studies in patients with symptoms of abdominal pain, nausea and vomiting, and diarrhoea is justified to distinguish between acute appendicitis and less emergent causes of patients' symptoms such as enterocolitis.

WBC and CRP were both independent predictors of positive imaging results for acute appendicitis in 2019, but not 2020; however, given the practice patterns both laboratory values are typically drawn when imaging findings are equivocal or negative, where a high clinical suspicion remains for appendicitis and are not used to help make the decision to order an imaging examination. The differences in these values were not statistically significant between the positive and negative cohorts in 2020 and trended towards higher values in 2020. These trends further support the conclusion that patients who presented in 2020 were generally sicker than those that presented in 2019.

The results of the present study corroborate evidence published by Binkovitz *et al.* that appendiceal ultrasound has good negative predictive value, even when the appendix is not visualised in the context of an otherwise negative scan.<sup>35</sup> Of the 123 patients in the present study who underwent ultrasound examination where the appendix was not visualised, only two patients underwent appendectomy based on clinical symptoms, two were discharged after repeat ultrasound, six were discharged after negative CT, and 113 were discharged with no further imaging (Table 5). None of the discharged patients represented with "missed appendicitis."

It is interesting to note that patients with acute appendicitis in both years had a shorter average duration of symptoms (1 day versus 2 days) with a narrower interquartile range than patients in the negative cohort (0.5–1 day in 2019 and 1–3 days in 2020 versus 1–4 days in 2019 and 1–5 days in 2020). It has been noted in previous publications that an increased duration of symptoms in 2020 among paediatric patients with appendicitis correlated with an increased perforation rate.<sup>16–20,22</sup> (Fig 1) Likewise, patients with appendicitis were more likely to present with pain with movement in 2020

compared to 2019, suggesting more peritoneal inflammation and advanced stages of disease. This is consistent with other recent studies<sup>16–20</sup> and is presumably related to a degree of hesitation in presenting for treatment for fear of nosocomial infection and/or overwhelming the healthcare system during the pandemic.<sup>3</sup>

What about the patients who would have otherwise presented to the ED for work-up for possible appendicitis but instead remained home in 2020? This also may have been due to fear of nosocomial COVID-19 infection directly, although it also may have prompted some patients and parents to view differently what symptoms might be severe enough to necessitate a visit to the ED or other acute care setting. Although severity of symptoms was not assessed here, the trends seen here raise the possibility that patients without appendicitis who eventually sought care waited longer to do so because their symptoms were generally less severe than those who had appendicitis and that the majority of these patients' symptoms resolved on their own. Of course, if this were true, it occurred at the expense of delayed presentation and increased rate of perforation among those who did have appendicitis.

It is also likely that the incidence of non-emergent conditions that can mimic the clinical presentation of appendicitis was lower. Respiratory symptoms were less common in the 2020 cohort than in the 2019 cohort. The incidence of viral gastroenteritis and influenza, both common causes of abdominal pain in children, were drastically lower in 2020 than in recent years.<sup>36,37</sup> Similarly, it is likely that the incidence mesenteric adenitis, a common cause of paediatric abdominal pain often caused by a viral infection, dropped during this time period. Although there are case reports of COVID-19 presenting as mesenteric adenitis in adults and children,<sup>38–40</sup> the overall incidence of mesenteric adenitis secondary to COVID-19 appears to be low.

There are a few limitations of the present study. This study only included patients  $\leq 18$  years old, so these results may not be generalisable to adult populations. The decision was made to include children evaluated in any setting to both maximise sample size and also increase generalisability, as the majority of children in the United States are not brought to a children's hospital initially for their healthcare. The downside of this is that access to testing and practice patterns likely varied across sites and settings, which may make the results less applicable to any single setting.

In summary, the COVID-19 pandemic provided a unique opportunity to study acute appendicitis, with a self-selected group of patients with longer symptom duration and a higher percentage of perforated appendicitis. By comparing the negative and positive cohorts presenting in 2019 and 2020, it was found that patients were more likely to report diarrhoea or anorexia, while patients worked up but negative for appendicitis in 2020 tended to be older and were less likely to have right lower quadrant pain, constipation, pain with movement, anorexia, or migration of pain. Patients in the 2020 negative cohort were also more likely to have generalised or other abdominal tenderness not limited to the right lower quadrant on history and



examination when compared to the 2019 negative cohort. Additionally, patients who had symptoms of upper respiratory tract infection or who had a normal abdominal examination were less likely to have appendicitis. Imaging may still be considered in these groups, but clinicians should consider these findings as they assess the pre-test probability of appendicitis and decide whether a particular patient should undergo imaging. The clinical distinction of appendicitis from less urgent gastrointestinal processes such as enterocolitis remains ambiguous based on symptoms and physical examination alone, however, and patients in this cohort still benefit from imaging studies to distinguish these diagnoses.

## Declaration of competing interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Some of the results contained in this work were published in Pediatric Radiology and are referenced in this paper: Horst KK, Kolbe AB, McDonald JS et al. Imaging paediatric acute appendicitis during the coronavirus disease 2019 (COVID-19) pandemic: collateral damage is variable. *Pediatr Radiol*. 2021.

## References

- Adjemian J, Hartnett KP, Kite-Powell A, et al. Update: COVID-19 pandemic-associated changes in emergency department visits—United States, December 2020–January 2021. *MMWR Morb Mortal Wkly Rep* 2021;**70**(15):552–6.
- Hartnett KP, Kite-Powell A, DeVies J, et al. Impact of the COVID-19 pandemic on emergency department visits—United States, January 1, 2019–May 30, 2020. *MMWR Morb Mortal Wkly Rep* 2020;**69**(23):699–704.
- Jeffery MM, D'Onofrio G, Paek H, et al. Trends in emergency department visits and hospital admissions in health care systems in 5 states in the first months of the COVID-19 pandemic in the US. *JAMA Intern Med* 2020;**180**(10):1328–33.
- Fabris E, Bessi R, De Bellis A, et al. COVID-19 impact on ST-elevation myocardial infarction incidence rate in a Italian STEMI network: a U-shaped curve phenomenon. *J Cardiovasc Med (Hagerstown)* 2021;**22**(5):344–9.
- Range G, Hakim R, Beygui F, et al. Incidence, delays, and outcomes of STEMI during COVID-19 outbreak: analysis from the France PCI registry. *J Am Coll Emerg Physicians Open* 2020 Nov 23;**1**(6):1168–76.
- Zitelny E, Newman N, Zhao D. STEMI during the COVID-19 pandemic – an evaluation of incidence. *Cardiovasc Pathol* 2020;**48**:107232.
- Noel A, Alban C, Trinkl J, et al. Fewer visits, sicker patients: the changing character of emergency department visits during the COVID-19 pandemic. Epic Research; 2021 <https://epicresearch.org/articles/fewer-visits-sicker-patients-the-changing-character-of-emergency-department-visits-during-the-covid-19-pandemic>. [Accessed 5 August 2021].
- Kamine TH, Rembisz A, Barron RJ, et al. Decrease in trauma admissions with COVID-19 pandemic. *West J Emerg Med* 2020;**21**(4):819–22.
- Boyle LI, Boyle A, Jay S, et al. COVID-19 lockdown impact on common general surgical acute presentations to a regional centre in New Zealand. *N Z Med J* 2020;**133**(1525):96–105.
- Cano-Valderrama O, Morales X, Ferrigni CJ, et al. Acute care surgery during the COVID-19 pandemic in Spain: changes in volume, causes and complications. A multicentre retrospective cohort study. *Int J Surg* 2020;**80**:157–61.
- Surek A, Ferahman S, Gemici E, et al. Effects of COVID-19 pandemic on general surgical emergencies: are some emergencies really urgent? Level 1 trauma center experience. *Eur J Trauma Emerg Surg* 2021;**47**(3):647–52.
- Valles KF, Neufeld MY, Caron E, et al. COVID-19 pandemic and the cholecystitis experience at a major urban safety-net hospital. *J Surg Res* 2021;**264**:117–23.
- DeLaroche AM, Rodean J, Aronson PL, et al. Paediatric emergency department visits at US children's hospitals during the COVID-19 pandemic. *Paediatrics* 2021;**147**:e2020039628.
- Erlichman M, Zalut T, Schwartz S, et al. The ongoing indirect effect of the COVID-19 pandemic on a paediatric emergency department. *Plos One* 2021;**16**(5):e0251003.
- Isba R, Edge R, Jenner R, et al. Where have all the children gone? Decreases in paediatric emergency department attendances at the start of the COVID-19 pandemic of 2020. *Arch Dis Child* 2020;**105**(7):704.
- Fisher JC, Tomita SS, Ginsburg HB, et al. Increase in paediatric perforated appendicitis in the New York City Metropolitan region at the epicenter of the COVID-19 outbreak. *Ann Surg* 2021;**273**(3):410–5.
- Lee-Archer P, Blackall S, Campbell H, et al. Increased incidence of complicated appendicitis during the COVID-19 pandemic. *J Paediatr Child Health* 2020;**56**(8):1313–4.
- Orthopoulos G, Santone E, Izzo F, et al. Increasing incidence of complicated appendicitis during COVID-19 pandemic. *Am J Surg* 2021;**221**(5):1056–60.
- Snapiro O, Rosenberg Danziger C, Krause I, et al. Delayed diagnosis of paediatric appendicitis during the COVID-19 pandemic. *Acta Paediatr* 2020;**109**(8):1672–6.
- Gerall CD, DeFazio JR, Kahan AM, et al. Delayed presentation and sub-optimal outcomes of paediatric patients with acute appendicitis during the COVID-19 pandemic. *J Paediatr Surg* 2021;**56**(5):905–10.
- Tankel J, Keinan A, Blich O, et al. The decreasing incidence of acute appendicitis during COVID-19: a retrospective multi-centre study. *World J Surg* 2020;**44**(8):2458–63.
- Horst KK, Kolbe AB, McDonald JS, et al. Imaging paediatric acute appendicitis during the coronavirus disease 2019 (COVID-19) pandemic: collateral damage is variable. *Paediatr Radiol* 2021 Oct;**51**(11):1991–9.
- Alvarado A. A practical score for the early diagnosis of acute appendicitis. *Ann Emerg Med* 1986;**15**(5):557–64.
- Samuel M. Paediatric appendicitis score. *J Paediatr Surg* 2002;**37**(6):877–81.
- Leung AK, Sigalet DL. Acute abdominal pain in children. *Am Fam Physician* 2003;**67**(11):2321–6.
- Montgomery DF, Hormann MD. Acute abdominal pain: a challenge for the practitioner. *J Paediatr Health Care* 1998;**12**(3):157–9.
- Lu YT, Chen PC, Huang YH, et al. Making a decision between acute appendicitis and acute gastroenteritis. *Children (Basel)*. 2020;**7**:176.
- Rothrock SG, Skeoch G, Rush JJ, et al. Clinical features of misdiagnosed appendicitis in children. *Ann Emerg Med* 1991;**20**(1):45–50.
- Horwitz JR, Gursoy M, Jaksic T, et al. Importance of diarrhoea as a presenting symptom of appendicitis in very young children. *Am J Surg* 1997;**173**(2):80–2.
- Cappendijk VC, Hazebroek FW. The impact of diagnostic delay on the course of acute appendicitis. *Arch Dis Child* 2000;**83**(1):64–6.
- Bhatt M, Joseph L, Ducharme FM, et al. Prospective validation of the paediatric appendicitis score in a Canadian paediatric emergency department. *Acad Emerg Med* 2009;**16**(7):591–6.
- Goldman RD, Carter S, Stephens D, et al. Prospective validation of the paediatric appendicitis score. *J Paediatr* 2008;**153**(2):278–82.
- Ohle R, O'Reilly F, O'Brien KK, et al. The Alvarado score for predicting acute appendicitis: a systematic review. *BMC Med* 2011;**9**:139.
- Pogorelic Z, Rak S, Mrklic I, et al. Prospective validation of Alvarado score and Paediatric Appendicitis Score for the diagnosis of acute appendicitis in children. *Paediatr Emerg Care* 2015;**31**(3):164–8.
- Binkovitz LA, Unsoderfer KM, Thapa P, et al. Paediatric appendiceal ultrasound: accuracy, determinacy and clinical outcomes. *Paediatr Radiol* 2015;**45**(13):1934–44.
- Rubin R. Influenza's unprecedented low profile during COVID-19 pandemic leaves experts wondering what this flu season has in store. *JAMA* 2021;**326**(10):899–900.

37. Tanislav C, Kostev K. Fewer non-COVID-19 respiratory tract infections and gastrointestinal infections during the COVID-19 pandemic. *J Med Virol* 2022;**94**(1):298–302.
38. Ekbatani MS, Hassani SA, Tahernia L, et al. Atypical and novel presentations of coronavirus disease 2019: a case series of three children. *Br J Biomed Sci* 2021;**78**(1):47–52.
39. Iftikhar H, Najam M, Rehman MU. Mesenteric lymphadenitis due to COVID-19 in an adult. *Cureus* 2021;**13**(6):e15897.
40. Noda S, Ma J, Romberg EK, et al. Severe COVID-19 initially presenting as mesenteric adenopathy. *Paediatr Radiol* 2021;**51**(1):140–3.