

Increase in Pediatric Perforated Appendicitis in the New York City Metropolitan Region at the Epicenter of the COVID-19 Outbreak

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Objective: The aim of the study was to determine whether perforated appendicitis rates in children were influenced by the Coronavirus disease 2019 (COVID-19) surge.

Background: Disruption of care pathways during a public health crisis may prevent children from obtaining prompt assessment for surgical conditions. Progression of appendicitis to perforation is influenced by timeliness of presentation. In the context of state-mandated controls and public wariness of hospitals, we investigated the impact of the COVID-19 outbreak on perforated appendicitis in children.

Study Design: We conducted an analysis of all children presenting to 3 hospital sites with acute appendicitis between March 1 and May 7, 2020, corresponding with the peak COVID-19 outbreak in the New York City region. Control variables were collected from the same institutions for the preceding 5 years. The primary outcome measure was appendiceal perforation.

Results: Fifty-five children presented with acute appendicitis over 10 weeks. Compared to a 5-year control cohort of 1291 patients, we observed a higher perforation rate (45% vs 27%, odds ratio 2.23, 95% confidence interval 1.29–3.85, $P = 0.005$) and longer mean duration of symptoms in children with perforations (71 ± 39 vs 47 ± 27 h, $P = 0.001$) during the COVID-19 period. There were no differences in perforation rates (55% vs 59%, $P = 0.99$) or median length of stay (1.0 vs 3.0 days, $P = 0.58$) among children screening positive or negative for SARS-CoV-2.

Conclusions: Children in the epicenter of the COVID-19 outbreak demonstrated higher rates of perforated appendicitis compared to historical controls. Preoperative detection of SARS-CoV-2 was not associated with inferior outcomes. Although children likely avoid much of the morbidity directly linked to COVID-19, disruption to local healthcare delivery systems may negatively impact other aspects of pediatric surgical disease.

Keywords: appendicitis, coronavirus, COVID-19, pediatric, perforation, SARS-CoV-2

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Numerous clinical, environmental, and socioeconomic determinants can influence the progression of pediatric appendicitis from inflammation to perforation.^{1–3} Although barriers to prompt evaluation can reflect baseline disparities in healthcare access,⁴ a

public health crisis may generate additional obstacles to providing timely surgical care. The greater New York City (NYC) metropolitan area was overwhelmed with the country's largest and most deadly outbreak of Coronavirus disease 2019 (COVID-19) during the spring of 2020.⁵ In response, state and local governments closed schools, issued stay-at-home orders, and prohibited hospitals from performing elective surgeries. As emergency rooms swelled with COVID-19 patients, and children were spared the worst of the illness, resources were rapidly reorganized to accommodate the surge in critically ill adults.^{6–8} Limited access to pediatrician's offices and fears of an invisible contagion inundating hospitals may have deterred families from obtaining timely assessment early in the course of appendicitis, as evidenced by decreased emergency room visits for acute illnesses not related to COVID-19.⁹ We investigated how a sudden disruption in the perceived safety of seeking surgical care at the epicenter of the COVID-19 outbreak might affect perforation rates and outcomes for appendicitis in children.

METHODS

We reviewed records of all children younger than 18 years old treated for acute appendicitis across 3 large academic medical centers in the NYC metropolitan region during 2 discrete time periods: a control period from January 1, 2014 through June 1, 2019; and a COVID-19 era between March 1, 2020 and May 7, 2020. The COVID-19 period was defined based on the first confirmed cases in New York State¹⁰ and the achievement of a stable plateau in new cases per day.¹¹ Due to limited testing supplies and evolution of protocols, universal screening for SARS-CoV-2 even in children with no respiratory symptoms was not implemented until week 5 of the study period. This prompted delineation of 2 subgroups within the COVID-19 cohort: those treated in the initial 4 weeks versus the last 6 weeks, corresponding to the change from sporadic to universal COVID-19 testing.

Pediatric surgical care was provided at 3 study sites, representing 3 distinct regional health systems—Hassenfeld Children's Hospital at NYU Langone (NYU Langone Health), Joseph M. Sanzari Children's Hospital (Hackensack Meridian Health), and Bellevue Hospital Medical Center (NYC Health and Hospitals). A single academic pediatric surgical division oversaw care across all 3 sites, and used a standardized triage, work-up, and management algorithm for all patients throughout both time periods. Additional data characterizing institutional trends for COVID-19–related admissions were compiled from hospital operational dashboards and reflect all SARS-CoV-2–positive patients—not just pediatric cases. Approval was granted through institutional review board agreements coordinated across all locations.

Data analyzed included demographics, presentation variables, preoperative assessments, and inpatient length of stay. Inspection of all study variables identified no missing data among those selected for analysis. The primary outcome measure was presence of appendiceal perforation, as determined by attending surgeon documentation or a description of perforation in the surgical pathology report.

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TABLE 1. Clinical Variables Among 55 Children With Acute Appendicitis During the COVID-19 Outbreak

	Nonperforated (N = 30)	Perforated (N = 25)	P
Age, y*	10.8 (8.3–13.8)	10.2 (7.7–13.7)	0.47
Male sex	24 (80%)	16 (64%)	0.23
Symptoms duration, h†	28 ± 12	71 ± 39	<0.001
Final diagnostic imaging			
Ultrasound only	16 (53%)	8 (32%)	0.17
Computed tomography	10 (33%)	14 (56%)	0.11
MRI	4 (13%)	3 (12%)	0.99
WBC at presentation, 10 ³ /μL*	14.8 (11.6–18.3)	16.1 (12.0–21.9)	0.45
Appendectomy performed	30 (100%)	20 (80%)	0.02
Length of stay, days*	0.0 (0.0–1.0)	4.0 (3.0–6.0)	<0.001
Positive SARS-CoV-2 test	5/12 (42%)	6/16 (38%)	0.99

*Data presented as medians with interquartile ranges.

†Data presented as means with standard deviations.

MRI indicates magnetic resonance imaging; WBC, white blood cell count.

Before comparative analyses, continuous variables were evaluated for distribution normality using a Shapiro-Wilk statistic and normality plots to guide nonparametric testing. Data were then analyzed using Student *t*, Mann-Whitney *U*, or Fisher exact testing. Results containing continuous variables are presented as means with standard deviations or medians with interquartile ranges (IQRs) based on normality distribution. Odds ratios (ORs) and 95% confidence intervals (CIs) are provided for pertinent categorical comparisons. Statistical significance was assumed at *P* < 0.05. Data analyses were performed using IBM Statistical Package for the Social Sciences (IBM SPSS 25.0, Armonk, NY).

RESULTS

During the 10-week COVID-19 study period, we identified 55 patients with acute appendicitis across 3 institutions. Fifty of these children (91%) underwent surgical appendectomy. All 5 patients treated nonoperatively involved cases of perforated appendicitis: 3 patients had large intra-abdominal abscesses managed with percutaneous image-guided drainage and intravenous antibiotics; 1 child was managed nonoperatively based on strong family preference for medical management; the fifth patient was a teenager who developed concomitant severe COVID-19 systemic illness, prompting a decision to avoid general anesthesia.

Perforations accounted for 25 (45%) of the 55 appendicitis cases treated during the COVID-19 period (Table 1). As expected, children with perforations had a longer mean duration of symptoms (71 ± 39 vs 28 ± 12 h, *P* < 0.001) as well as a longer median hospital length of stay (4.0, IQR 3.0–6.0 vs 0.0, IQR 0.0–1.0 days, *P* < 0.001). No differences were observed in rates of preoperative SARS-CoV-2 detection between children with perforated versus

nonperforated appendicitis (38% vs 42%, OR 0.84, 95% CI 0.18–3.9, *P* = 0.99).

A baseline cohort of 1291 children with acute appendicitis was identified over the 65-month control period, with comparisons to the COVID-19 cohort outlined in Table 2. Most notably, we observed an increase in the perforated appendicitis rate during the COVID-19 period compared to the control period (45% vs 27%, OR 2.2, 95% CI 1.3–3.9, *P* = 0.005). This corresponded with a longer mean preoperative duration of symptoms in COVID-19 era patients with perforated appendicitis (71 ± 39 vs 47 ± 27 h, *P* = 0.005). There were no statistical differences in the median age of patients or mean number of appendicitis cases treated per week between the COVID-19 and control periods.

Given the asymmetric durations of the control (65 mo) and COVID-19 periods (10 wk), we performed a more granular analysis of quarterly perforation rates throughout the control period to account for any naturally occurring 3-month variations in the perforation rate. Across 22 consecutive quarters in the control period, there were no 3-month periods that individually demonstrated a statistically different perforation rate when compared to the 27% overall 65-month control rate (Supplemental Table 1, <http://links.lww.com/SLA/C538>). The 45% perforation rate observed during the COVID-19 period was the only timeframe to show a significant difference against the 65-month control rate (Fig. 1).

An exponential increase in confirmed COVID-19 patients (adult and pediatric) presenting to NYC regional hospitals occurred within the 10-week study period. Figure 2 illustrates the relationship between the surge in COVID-19 admissions to the study institutions and the distribution of pediatric appendicitis cases. Nineteen patients presented in the first 4 weeks of the COVID-19 study period, when

TABLE 2. Comparison of Perforated Appendicitis in Children During the COVID-19 Outbreak Versus the Preceding 5-Year Control Period

	Control Period (N = 1291)	COVID-19 Period (N = 55)	P
No. of appendicitis cases per week*	4.6 ± 2.5	5.5 ± 2.5	0.25
Age, y†	10.0 (8.0–13.0)	10.7 (8.0–13.7)	0.30
Perforated appendicitis	351 (27%)	25 (45%)	0.005
Symptom duration, h*	47 ± 27	71 ± 39	0.005
Admission WBC, 10 ³ /μL†	16.7 (13.8–20.0)	16.1 (12.0–21.9)	0.60
Length of stay, days†	4.0 (3.0–6.0)	4.0 (3.0–6.0)	0.93

*Data presented as means with standard deviations.

†Data presented as medians with interquartile ranges.

WBC indicates white blood cell count.

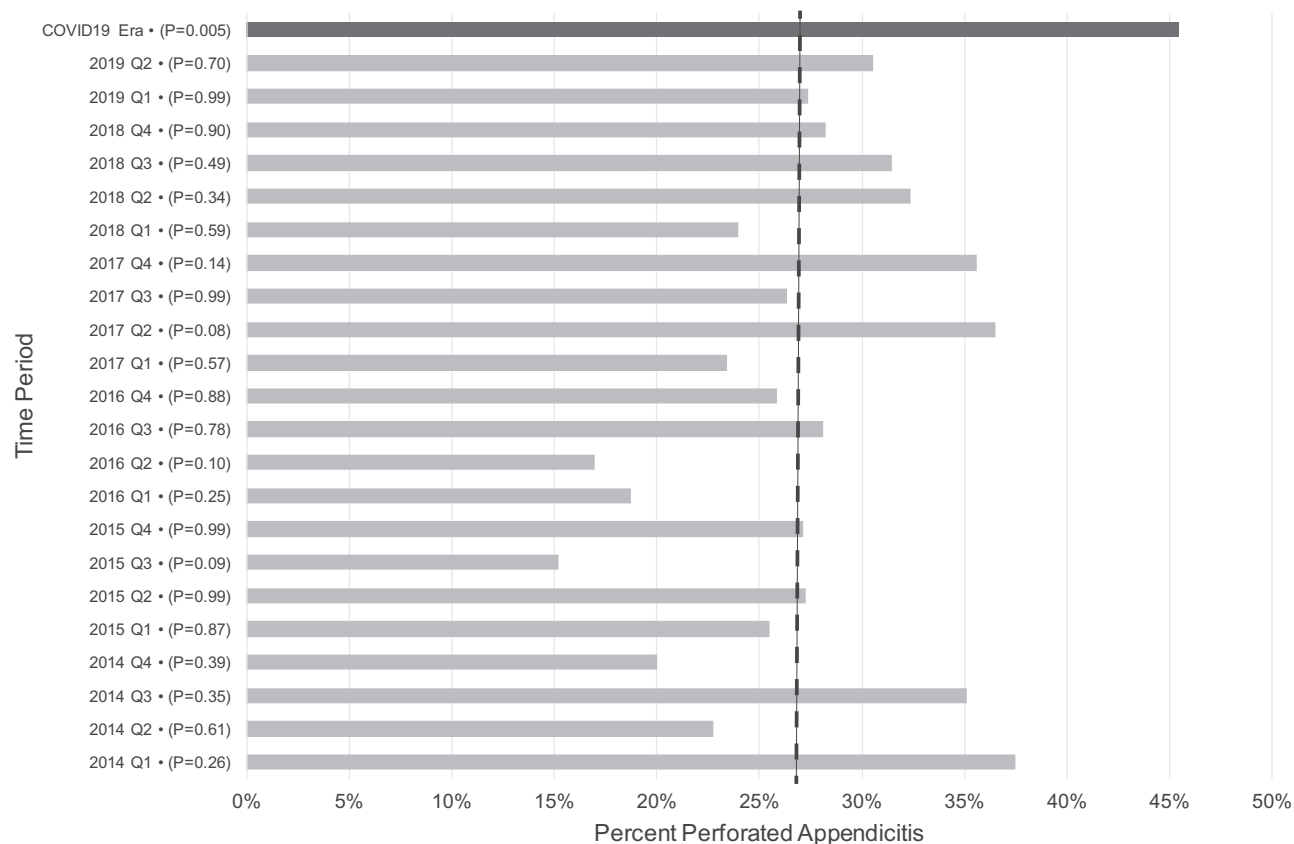


FIGURE 1. Perforation rates for appendicitis treated by quarter. Across the control period, there is natural variability against the 65-month overall perforation rate (dashed vertical line). None of the 22 quarters comprising the control period demonstrated any statistical differences in their individual perforation rates when compared back to the 27% overall control perforation rate (P values provided for each quarter). Perforation rates observed during the COVID-19 era represent a statistical outlier.

state-recommended restrictions were first initiated and SARS-CoV-2 testing was less consistent. In contrast, 36 patients were treated during the final 6 weeks when maximum public controls were in place and universal SARS-CoV-2 testing was performed. We noted more perforations in the latter half of the study period (56% vs 26%, OR 3.5, 95% CI 1.04–11.8, $P = 0.049$), but no differences in mean symptom duration (43 ± 20 vs 77 ± 39 h, $P = 0.08$), median white blood cell count at presentation (18.1, IQR 8.8–24 vs $16.0 \times 10^3/\mu\text{L}$, IQR 12–23, $P = 0.92$), nor median length of stay (5.0, IQR 3.5–10 vs 4.0 days, IQR 3.0–5.8, $P = 0.34$) between children treated in the first 4 weeks versus final 6 weeks (Supplemental Table 2, <http://links.lww.com/SLA/C538>).

Twenty-eight of the children (51%) who presented with appendicitis in the COVID-19 era were tested for the presence of SARS-CoV-2. Novel coronavirus was detected in 11 children (39% of those tested), only one of which manifested symptomatology directly attributable to COVID-19 illness. There were no differences in perforation rates (59% vs 55%, OR 0.84, 95% CI 0.18–3.9, $P = 0.99$) or any other measured clinical variable between those testing negative or positive for SARS-CoV-2 (Table 3).

DISCUSSION

The COVID-19 outbreak projected a sobering epidemiology across many urban landscapes in the United States. The exceptionally dense population of the NYC metropolitan area facilitated its rapid

progression into the national epicenter of the COVID-19 outbreak. Approximately one-third of the nation's confirmed COVID-19 cases occurred in NYC and northern New Jersey through the spring of 2020.¹¹ Despite a high prevalence of confirmed SARS-CoV-2 infection across every demographic, the morbidity of COVID-19 has thus far more severely impacted the adult population.^{12,13} Aside from a newly described pediatric multisystem inflammatory syndrome sharing features of toxic shock syndrome and Kawasaki disease,¹⁴ significant pediatric morbidity directly attributable to SARS-CoV-2 infection remains low.^{15,16} Data, however, presented in this study call attention to the secondary impact on pediatric disease patterns, namely an increased perforated appendicitis rate as an indirect morbidity of the COVID-19 outbreak.

Unlike regions where one large children's hospital may serve broad geographic areas, healthcare for children in the NYC metro area is delivered across a variety of university-affiliated, private community, and city-chartered institutions. Combined with neighboring counties in northern New Jersey, more than 90 hospitals are available to provide clinical care for territory spanning only a 25 mile radius.^{17,18} Academic surgical practices across the region therefore provide surgical care at diverse neighboring health systems across the region. This interrelated infrastructure provides a unique perspective for witnessing the impact of the COVID-19 outbreak on pediatric surgical disease in a population replete with ethnic, cultural, and socioeconomic diversity where access to a sprawling healthcare system was suddenly disrupted.

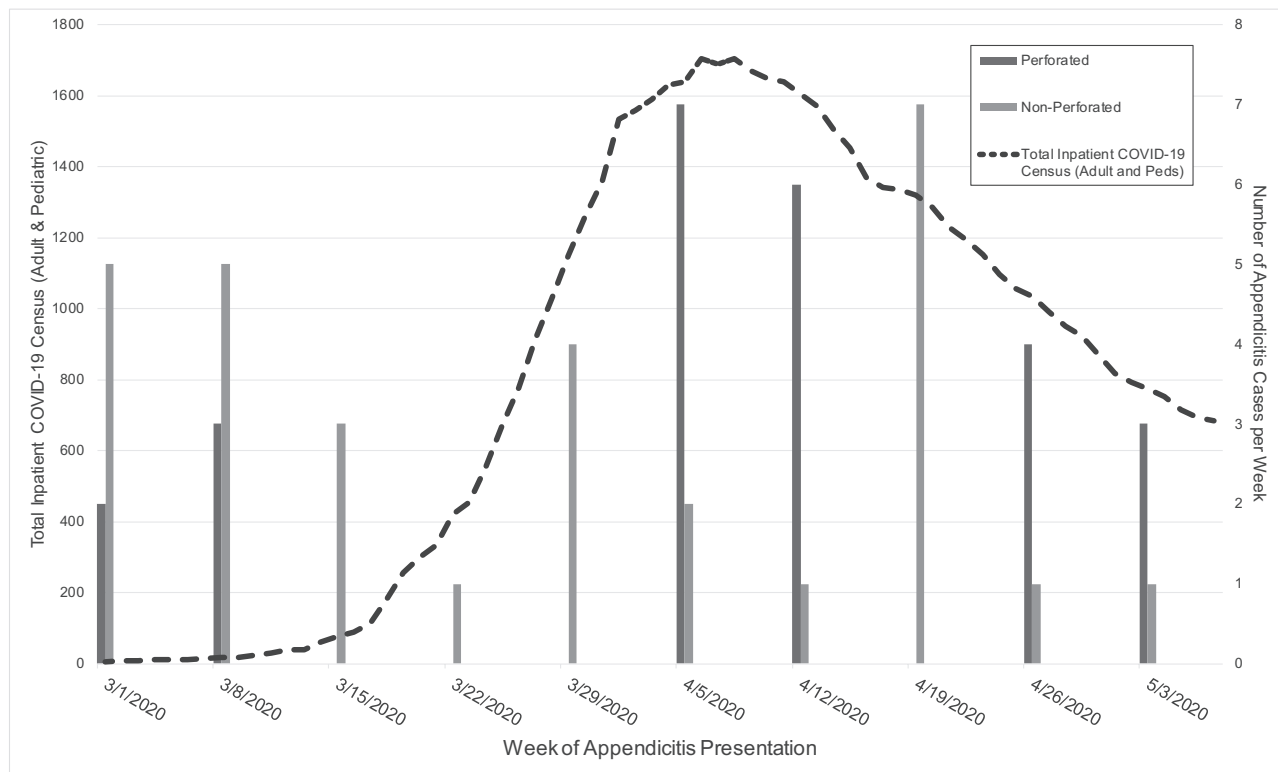


FIGURE 2. Distribution of pediatric acute appendicitis by week during the initial COVID-19 surge in the NYC area. The total number of appendicitis cases for each week during the COVID-19 study period is represented by the vertical bars, with designation of nonperforated and perforated cases. The dashed line represents the total COVID-19 hospital admissions (adult and pediatric) for the institutions included in the study.

Acute appendicitis represents the most common indication for abdominal surgery in children, and is traditionally believed to develop secondary to luminal obstruction either by fecalith or lymphoid hyperplasia.¹⁹ Progression of appendiceal distention to frank perforation occurs in 20% to 76% of cases and can impart significant morbidity.^{20,21} Delay in presentation is a major driver of perforation, with perforation rates increasing linearly with duration of symptoms.^{22,23} During the COVID-19 outbreak, many parents described a delay in seeking assessment for their child's abdominal pain due to fears of in-hospital SARS-CoV-2. Our analysis confirmed that cases of perforated appendicitis during the COVID-19 study period had a longer mean duration of symptoms by a full day (71 vs

47 h) compared to perforated appendicitis from our control period. Taken together, these data imply a relationship between barriers to prompt assessment (from combined external restrictions and reluctance to seek care) and an increase in symptom duration and resultant perforation rates during the COVID-19 period in the NYC region.

We observed an 18% increase above our baseline perforation rate during the COVID-19 period. Perforated appendicitis rates can, however, demonstrate seasonal variability,²⁴ prompting us to analyze whether this COVID-19 related spike in perforations simply coincided with natural fluctuations in our baseline rate. We demonstrate in Figure 1 that while random variation in the perforation rate across our control period oscillated from 15% to 38%, there were no 3-

TABLE 3. Comparison of Children With Acute Appendicitis Based on Underlying Preoperative SARS-CoV-2 Test Status

	SARS-CoV-2 Negative (N = 17)	SARS-CoV-2 Positive (N = 11)	P
Symptom duration, h*	52 ± 37	47 ± 24	0.68
Admission WBC, 10 ³ /μL†	15.3 (14.2–16.3)	8.8 (7.4–17.1)	0.26
Length of stay, days†	3.0 (0.0–4.0)	1.0 (0.0–5.0)	0.58
Perforated appendicitis	10 (59%)	6 (55%)	0.99
Symptom duration, h*	72 ± 38	64 ± 20	0.64
Admission WBC, 10 ³ /μL†	16.0 (14.3–20.7)	8.3 (6.9–19.4)	0.15
Length of stay, days†	3.5 (3.0–4.5)	4.5 (3.3–11.3)	0.22

*Data presented as means with standard deviations.

†Data presented as medians with interquartile ranges.

WBC indicates white blood cell count.

month periods which statistically differed from the 65 month running average of 27%—with the notable exception of the 45% perforation rate seen during the COVID-19 period. Cases of perforated appendicitis in this series more heavily clustered in the final 6 weeks of the COVID-19 period compared to the first 4 weeks. Even though public awareness of the growing COVID-19 threat aligned with the start of our study period, the exponential rise in COVID-19 admissions (Fig. 2) and cumulative public restrictions over those 10 weeks may have added progressively more emotional and logistical hurdles for families seeking care, as evidenced by an approximate 30% decline in pediatric emergency room visits (internal data) in the final 6 weeks of the study period.

Recent reports describe a similar inhibitory halo effect deterring the presentation of other acute diseases during the COVID-19 surge, including a reduction in patients with myocardial infarctions, cardiac catheterization laboratory activations, and strokes.²⁵ NYC paramedics have described an increase in patients refusing hospitalization following assessment after a 911 emergency call.²⁶ These alarming trends of deferred emergency care presumably represent the cumulative impact of school closings, shuttered businesses, wariness of public transportation, and statewide stay-at-home orders, combined with public fears of exposure to COVID-19 in emergency rooms. Our data demonstrate a discrete morbidity arising from these COVID-19 disruptions of established acute care pathways. In line with our findings, other disciplines are reporting disease-specific morbidities secondary to diminished care access, including disruptions to organ transplant,²⁷ postponing of urgent surgical procedures,²⁸ halting oncology clinical trial recruitment,²⁹ and decreased outpatient hemodialysis resources.³⁰

Although this represents the first report of an increased perforated appendicitis rate as collateral morbidity of the COVID-19 pandemic, previous studies have described that children with diminished healthcare access have higher perforated appendicitis rates.⁴ As was seen after Hurricane Katrina, minority children in certain counties of Louisiana and Mississippi where healthcare disparities already existed showed higher rates of perforation pre- and postdisaster than whites; the hurricane itself made this disparity worse in areas particularly devastated by damage.³¹ With COVID-19 disproportionately affecting minority neighborhoods in the NYC area,³² future analyses may demonstrate a similar pattern of race-based disparate morbidity for perforated appendicitis, as race and ethnicity analysis was outside the scope of this investigation.

Our findings suggest that the relationship between COVID-19 and pediatric appendicitis is largely indirect. These data revealed no differences in appendicitis severity or perforation rates based on SARS-CoV-2 status. Gastrointestinal manifestations can develop with SARS-CoV-2 infection,³³ but there are no reports suggesting a direct effect of COVID-19 on the pathogenesis of appendicitis. This highlights the important distinction between testing positive for SARS-CoV-2 versus manifesting COVID-19 illness. One child with perforated appendicitis in this series did display COVID-19 systemic illness characterized by respiratory distress, lung infiltrates, and elevated inflammatory markers. We treated the patient with intravenous antibiotics and deferred surgical appendectomy to avoid perioperative risks in the context of evolving pneumonia.

The concomitant presence of a systemic COVID-19 illness perhaps illustrates the most direct impact that SARS-CoV-2 positivity had on the treatment of these pediatric appendicitis cases. Some authors have suggested that when hospital resources are strained, surgeons should consider managing appendicitis with antibiotics alone whenever possible.^{34,35} Despite the crushing burden experienced at all 3 study facilities, all institutions committed to supporting surgical care of pediatric patients during the COVID-19 surge. We therefore offered surgical appendectomy to otherwise healthy

children (unless a large abscess/phlegmon was present) with focus on ambulatory/short-stay hospitalizations to minimize in-hospital time for patients, as advocated by the American College of Surgeons.³⁶ We, however, do recommend surgeons consider nonoperative management when confronted with true COVID-19 illness in the setting of acute appendicitis. Furthermore, providers should be mindful of the overlapping symptoms of appendicitis and a COVID-19 illness with predominantly gastrointestinal symptoms,³⁷ so they do not incorrectly attribute abdominal pain in a SARS-CoV-2 positive patient to COVID-19 when in fact, acute appendicitis is present. Consultation with surgical providers in such cases may reduce diagnostic uncertainty and assist in selection of appropriate abdominal imaging as necessary.

The other direct impact of COVID-19 on pediatric appendicitis that bears mentioning relates to the logistical challenges in navigating surgical care for a child within hospitals overwhelmed with COVID-19 illnesses. Institutional guidelines remain variable, but most require universal preoperative SARS-CoV-2 testing, protection of staff with personal protective equipment, and availability of isolation rooms during recovery. Recent data suggest that SARS-CoV-2 is unlikely to be transmitted during the course of an appendectomy.³⁸ Procedures in SARS-CoV-2 positive patients are, however, best performed in negative pressure rooms, with specific techniques employed to minimize aerosolization of infectious body fluids.³⁹

This study focused on perforated appendicitis rates in children during the COVID-19 outbreak in the NYC region, and bears several limitations inherent to its retrospective nature. In comparing pre-COVID appendicitis to those treated during the COVID-19 era, our methodology necessitated use of historical control data, which is inherently inferior to a contemporaneous control group. Although contemporaneous controls would not have been suitable for our specific study aims, this point bears mentioning because of the evolution in the management of pediatric appendicitis over the past decade. Increasing use of nonoperative management for early appendicitis,^{40,41} changes in imaging modalities,^{42,43} and evolving antibiotic regimens⁴⁴ represent some of the uncontrolled variables that could impact the veracity of our analysis when using historical versus contemporaneous controls. Given the primary focus of this investigation, however, centered on the initial presentation of appendicitis, these uncontrolled variables related to management likely have a limited impact on an analysis that focuses on the initial presentation and classification of uncomplicated versus perforated appendicitis.

We attempted to compensate for asymmetry between control and study cohorts by providing more granular analysis of random variability within the control period (Supplemental Table 1, <http://links.lww.com/SLA/C538>). Our COVID-19 sample size is small as a consequence of the 10-week study period, but offers cross-sectional assessment of 3 major institutions across the NYC metro area, inclusive of city-center, suburban, and public safety-net demographics. Future analysis may allow us to pool data from additional regional centers to better understand whether this perforated appendicitis trend is durable. We recognize we may have missed cases in patients that traveled out of the city or that were treated with antibiotics directly by pediatricians, but the mean number of appendicitis cases/week did appear similar between control and COVID-19 periods. Mandatory SARS-CoV-2 testing was only performed in the final 6 weeks, limiting our ability to definitively detect correlations between SARS-CoV-2 positivity and perforations rates, given only 51% of children during the study period received a test.

CONCLUSIONS

Given current projections that COVID-19 outbreaks may recur seasonally, trends similar to what we have observed with perforated

appendicitis may continue to impact conditions where outcomes reflect the timeliness of care. Findings from this investigation suggest surgeons should proactively anticipate delayed presentations of acute disease. To minimize the collateral impact of COVID-19 on other disease patterns, surgical providers might consider adaptations to their practice environment that balance workplace safety alongside the easing of logistical barriers to facilitate prompt assessment of patients who may be hesitant to seek care.

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