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.

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Management of pediatric appendicitis during the COVID-19 pandemic: A nationwide multicenter cohort study

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Abbreviations: CT, Computed Tomography; ED, Emergency Department; GLM, Generalized Linear Model; IAA, Intra-abdominal abscess; IQR, Interquartile Ranges; Kg, Kilogram; LOS, Length of stay; NSQIP, National Surgical Quality Improvement Program; PAS, Pediatric Appendicitis Score; PedSRC, Pediatric Surgery Research Collaborative; Post-SAHO, Post-stay at home order; Pre-SAHO, Pre-stay at home order; REDCap, Research electronic data-capture registry; SAHO, Stay at home order; SSI, Surgical site infection.

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ABSTRACT

Background: The COVID-19 pandemic has impacted timely access to care for children, including patients with appendicitis. This study aimed to evaluate the effect of the COVID-19 pandemic on management of appendicitis and patient outcomes.

Methods: A multicenter retrospective study was performed including 19 children's hospitals from April 2019-October 2020 of children (age≤18 years) diagnosed with appendicitis. Groups were defined by each hospital's city/state stay-at-home orders (SAHO), designating patients as Pre-COVID (Pre-SAHO) or COVID (Post-SAHO). Demographic, treatment, and outcome data were obtained, and univariate and multivariable analysis was performed.

Results: Of 6,014 patients, 2,413 (40.1%) presented during the COVID-19 pandemic. More patients were managed non-operatively during the COVID-19 pandemic compared to before the pandemic (147 (6.1%) vs 144 (4.0%), $p < 0.001$). Despite this change, there was no difference in the proportion of complicated appendicitis between groups (1,247 (34.6%) vs 849 (35.2%), $p = 0.12$). COVID era non-operative patients received fewer additional procedures, including interventional radiology (IR) drain placements, compared to pre-COVID non-operative patients (29 (19.7%) vs 69 (47.9%), $p < 0.001$). On adjusted analysis, factors associated with increased odds of receiving non-operative management included: increasing duration of symptoms (OR=1.01, 95% CI: 1.01–1.012), African American race (OR=2.4, 95% CI: 1.3–4.6), and testing positive for COVID-19 (OR=10.8, 95% CI: 5.4–21.6).

Conclusion: Non-operative management of appendicitis increased during the COVID-19 pandemic. Additionally, fewer COVID era cases required IR procedures. These changes in the management of pediatric appendicitis during the COVID pandemic demonstrates the potential for future utilization of non-operative management.

1. Introduction

Appendicitis is the most frequently encountered surgical condition in the pediatric population [1,2]. It is estimated that approximately 60,000 to 80,000 appendectomies for acute appendicitis are performed every year on pediatric patients [1,3]. Management of pediatric appendicitis remains mainly surgical, however, several studies have found non-operative management for appendicitis to be an effective management strategy [4–6]. Patient outcomes are dependent on the severity of disease at time of presentation, with complicated appendicitis patients having longer length of stays and higher risk of complications. These findings emphasize the need for timely access to care to optimize patient outcomes [1,7].

The emergence of COVID-19 presented an unprecedented burden on our healthcare system, impacting hospitals and healthcare systems across the country. Subsequently, to decrease the spread of the virus, state and local governments issued Stay at Home Orders (SAHOs) that led to the closure of schools and other non-essential businesses. These SAHOs often resulted in limitations of non-urgent medical care and encouraged avoidance of emergency rooms unless absolutely necessary [8]. These measures were taken to mitigate the spread of COVID-19 and resulted in delays in healthcare for a wide range of medical problems, including pediatric appendicitis [9–11].

Prior work examining the impact of COVID-19 on the management of pediatric appendicitis and subsequent patient outcomes are limited to single institution, single city, or single state observational studies [9,12,13]. We aimed to broadly evaluate the effects of the COVID-19 pandemic on the management of pediatric appendicitis across multiple pediatric centers within the Pediatric Surgery Research Collaborative (PedSRC) [14]. We hypothesized that there would be an increase in non-operative management of appendicitis during the COVID-19 pandemic with a subsequent increase in patient complications as well as an increase in the rates of complicated appendicitis.

2. Methods

2.1. Study design

A multicenter retrospective cohort study was performed evaluating all pediatric patients (age ≤ 18 years old) who presented with a diagnosis of appendicitis from April 1, 2019 to October 31, 2020 at 19 centers within the PedSRC [14]. Patients were identified through the use of either ICD codes for diagnosis of appendicitis or from the hospital's National Surgical Quality Improvement Program (NSQIP) appendicitis patient registry. Patients were included in analysis if they were diagnosed with appendicitis within the study period. Patients with incomplete available data on patient demographics, diagnostic tools utilized, treatment details, and outcomes were excluded. Institutional Review Boards at each participating center approved this study with waiver of consent. McGovern Medical School at The University of Texas Health Science Center at Houston and Children's Memorial Hermann Hospital served as the lead institution (IRB#: HSC-MS-20–0770).

Patient data were abstracted and stored in a research electronic data-capture registry (REDCap) [15]. The study protocol was developed in consensus with the involved pediatric centers and outcome data measures were agreed upon prior to study initiation. Patient's operative or non-operative management was determined, and data regarding demographics and various outcome measures within 30 days post-operatively were collected. These outcomes included rates of superficial and deep surgical site infection (SSI), return emergency department (ED) visits, intraabdominal abscess (IAA), failure of non-operative management resulting in surgery, and interventional radiology (IR) procedures. Data quality checks were performed by the lead institutions research team, and any subsequent concerns were addressed with the involved centers.

Patient care across all institutions was not standardized because of the retrospective nature of this study. All institutions continued to provide care to patients with appendicitis in accordance with their own institutional guidelines and practice preferences.

2.2. Outcomes

The primary outcome was rate of non-operative management for pediatric appendicitis. Secondary outcomes included length of stay, symptom duration prior to presentation, Pediatric Appendicitis Scores (PAS), rate of complicated appendicitis, and subsequent complications within 30 days post-operatively. Complications

included re-operation, SSIs including IAAs, return ED visits, readmissions, failure of non-operative management requiring surgery, and IR drain placements or aspirations.

2.3. Statistical analysis

Patients were divided into two groups for comparisons: the pre-COVID-19 group, which was defined as patients presenting prior to the city/state issued SAHO, and the COVID-19 group, which was defined as those who presented after the city/state issued SAHO. Continuous variables were presented as means with standard deviations if data were normally distributed and as medians with interquartile ranges (IQR) if data were not normally distributed. Comparisons of continuous data between groups were completed using Wilcoxon rank sum tests and Student's T tests. Categorical variables were presented as counts or percentages, and comparisons between groups were presented as Pearson's Chi Square tests or Fischer's Exact tests.

A sensitivity analysis was completed looking at outcome measures and stratifying by diagnostic categories of appendicitis: uncomplicated or complicated. Complicated appendicitis was defined if any of the four NSQIP defined intraoperative findings criteria were met: visible perforation, fibropurulent exudate in more than 2 quadrants, presence of an abscess, or extraluminal fecalith [16]. A non-operative case was defined as complicated appendicitis based on the objective clinical data available including imaging studies describing potential perforation and/or presence of abscess upon diagnosis. Uncomplicated patients who subsequently developed an IAA meant this occurred during their course of treatment. Complicated appendicitis patients described to have an IAA meant this was a progression of the disease during their treatment course. A subgroup analysis was performed examining the difference in both non-operative management and the incidence of complicated appendicitis as time progressed through the COVID-19 pandemic. Groups treated for appendicitis from March-May 2020, June-August 2020, and September-October 2020 at all centers were compared. Given that temporal changes in the incidence of appendicitis likely occurred, we also compared the time period of patients pre-COVID (April-June 2019) to the same time period during the COVID-19 pandemic (April-June 2020) to evaluate if the rate of non-operative management or if the incidence of complicated appendicitis differed between each time period. A multilevel generalized linear model (GLM) analysis was performed utilizing the binomial distribution and logit link function to evaluate patient level factors that were associated with increased odds of receiving non-operative management. This multi-level model was developed considering fixed effects of various patient level covariates and random/clustering effects of observations being nested within each center and determined to be the best fit by comparing Akaike Information Criterion (AIC) values. Covariates adjusted for within the multilevel GLM included: age, gender, race, symptom duration, PAS scores, uncomplicated versus complicated appendicitis, and COVID positive status during the index admission. Stata version 15 was used to complete the analysis (StataCorp, College Station, TX, USA) [17].

3. Results

3.1. Demographics

Of 6014 patients included, 3601 (59.9%) were treated during the pre-COVID era and 2413 (40.1%) were treated during COVID. A total of 49 eligible patients were excluded from analysis because of incomplete available data. Of the 2020 patients tested for COVID-19, 93 (4.6%) were found to be COVID positive during their hospital admission. The COVID group were slightly older with higher weights at presentation and had marginally different ethnic makeups than the Pre-COVID group (Table 1). There are 19 different pediatric centers included in this study and each contributed a varying percentage of the total patient cohort. These centers are in various regions of the United States and provide significant heterogeneity to our studied patient population. Further data examining both regional makeup and individual center contributions are available in the Supplementary Materials (Supplementary Materials Tables 1–3).

3.2. Presentation details

There were no differences in median duration of symptoms and PAS scores between groups. However, when stratified by age, children less than 5 years old had a median duration of symptoms of 48 h (IQR: 24, 72) compared to children 6–18 years of age who had a median duration of symptoms of 24 h (IQR: 24, 48) ($p<0.001$). Of those patients that underwent laboratory testing prior to admission, there were no differences in white blood cell counts between groups. The most frequent initial imaging study utilized within the entire patient cohort were ultrasounds, with a slight increase in the proportion of ultrasounds performed during the COVID-19 pandemic. If second imaging studies were performed, most commonly they were computed tomography (CT) scans (Table 1).

3.3. Treatment details

Of 6014 patients, 291 (4.8%) were treated non-operatively. Patients treated non-operatively increased from the pre-COVID (144, 4.0%) to COVID era (147, 6.1%)($p<0.001$). More non-operatively managed patients were found to be diagnosed with uncomplicated appendicitis during the COVID-19 pandemic (83, 56.5%) compared to pre-COVID patients (31, 21.5%)($p<0.001$). More African American patients were treated non-operatively (53, 8.3%) when compared to other ethnicities (238, 4.4%)($p<0.001$). No other ethnicity noted an significant increase in non-operative management when compared as an entire patient cohort. However, when evaluated based on time of presentation the incidence of non-operative management of African American patients only marginally increased during the COVID-19 pandemic (20, 8.8%) compared to pre-COVID (33, 8.0%)($p = 0.71$). Hispanic patients had an increase in non-operative management during the COVID-19 pandemic (41, 6.3%) compared to pre-COVID (25, 2.8%)($p<0.001$). Similarly, Caucasian patients had an increase in non-operative management during the COVID-19 pandemic (70, 5.7%) compared to pre-COVID (72, 4.0%)($p = 0.03$). There were no significant increases in the incidence of complicated appendicitis between pre-COVID and COVID groups (Table 1). However, when stratified by age, more children less than 5 years old were diagnosed with complicated appendicitis (146, 38.8%) compared to older children 6–18 years old (888, 15.8%) ($p<0.001$). Of the 93 patients who tested positive for COVID-19, the majority were managed operatively (75, 80.6%). Of those that underwent operative management, laparoscopic appendectomies (5130, 86.8%) were the most common surgical approach followed by single incision laparoscopic appendectomy (670, 11.3%). Median length of stays (LOS) of the entire patient cohort were 1.2 days (IQR: 0.7, 3.2) and did not differ between pre-COVID or COVID groups. However, when stratifying by operative versus non-operative management, patients who were treated non-operatively during the COVID-19 pandemic had a shorter median hospital LOS (2.7 days, IQR: 1.2, 5.4) compared pre-COVID non-operatively managed patients (4.5 days, IQR: 2.5, 6.9) ($p <0.001$) (Table 1).

Table 1
Patient demographics and clinical details.

	All (n = 6014)	Pre-COVID (n = 3601) 59.9%	COVID (n = 2413) 40.1%	P-value
Age				
Age (years)	11.3 (8.4, 14.2)	11.2 (8.3, 14.1)	11.5 (8.7, 14.5)	0.002
Weight				
Weight (kg)	44 (30, 60)	43.5 (29.5, 59.2)	45 (30.3, 61.1)	0.003
Gender				
Male	3650 (60.7%)	2196 (61.0%)	1454 (60.3%)	0.57
Female	2364 (39.3%)	1405 (39.0%)	959 (39.7%)	
Ethnicity				
Hispanic	1527 (25.4%)	881 (24.5%)	646 (26.8%)	0.022
White	3035 (50.5%)	1800 (50.0%)	1235 (51.2%)	
Black	638 (10.6%)	412 (11.4%)	226 (9.4%)	
Asian	177 (2.9%)	111 (3.1%)	66 (2.7%)	
Other	637 (10.6%)	397 (11.0%)	240 (9.9%)	
Length of Stay (LOS)				
LOS (days)	1.2 (0.7, 3.2)	1.2 (0.7, 3.2)	1.2 (0.7, 3.2)	0.29
Operative LOS	1.2 (0.7, 3.0)	1.1 (0.7, 3.0)	0.37	
Non-Operative LOS	4.5 (2.5, 6.9)	2.7 (1.2, 5.4)	<0.001	
COVID status				
COVID positive	93 (1.5%)	0 (0%)	93 (3.9%)	<0.001
Symptom Duration				
Symptom Duration (hours)	24 (24,48)	24 (24, 48)	24 (24, 48)	0.42
PAS Score				
PAS Score	6 (5,8)	6 (5,8)	6 (5,8)	0.027
Admission WBC				
WBC	15 (11.8, 18.2)	15 (11.7, 18.2)	15 (12, 18.2)	0.42
First Line Imaging (n = 6000, 99.8%)				
US	4055 (67.6%)	2401 (66.9%)	1654 (68.6%)	0.045
CT	1650 (27.5%)	1002 (27.9%)	648 (26.9%)	
MRI	81 (1.4%)	60 (1.7%)	21 (0.9%)	
Other	214 (3.6%)	127 (3.5%)	87 (3.6%)	
Second Line Imaging (n = 1744, 29.0%)				
US	454 (26.0%)	287 (27.9%)	167 (23.3%)	0.11
CT	863 (49.5%)	491 (47.7%)	372 (52.0%)	
MRI	289 (16.6%)	187 (18.2%)	102 (14.3%)	
Other	38 (2.2%)	19 (1.8%)	19 (2.7%)	
Treatment Details				
Operative	5723 (95.2%)	3457 (96.0%)	2266 (93.9%)	<0.001
Non-operative	291 (4.8%)	144 (4.0%)	147 (6.1%)	
Uncomplicated versus Complicated Appendicitis				
Uncomplicated	3900 (64.9%)	2339 (65.0%)	1561 (64.7%)	0.12
Complicated	2096 (34.9%)	1247 (34.6%)	849 (35.2%)	
Other*	18 (0.3%)	14 (0.4%)	3 (0.1%)	

Continuous variables presented as median (inter-quartile range); Categorical variables presented as frequency (percentage).
Abbreviations: LOS: Length of Stay, PAS: Pediatric Appendicitis Score, WBC: White Blood Cell Count, US: Ultrasound, CT: Computed Tomography, MRI: Magnetic Resonance Imaging. *Other: Designated if unable to stratify based on clinical data present on chart review.

3.4. Operative complications

Patients who were treated operatively for appendicitis had relatively few complications. Less than 1% of cases underwent an open appendectomy or converted from a laparoscopic to open procedure. There were no increases in open appendectomies (Pre-COVID: 31, 0.9% vs COVID: 12, 0.5%) or laparoscopic converted to open procedures (Pre-COVID: 22, 0.6% vs COVID: 12, 0.5%) during the COVID-19 pandemic (Table 1). Superficial SSIs occurred in 1.4% of total patients with fewer being diagnosed during the COVID-19 pandemic (22, 0.9%) compared to pre-COVID patients (62, 1.7%) (p = 0.009). There were no significant differences between pre-COVID and COVID-19 patients regarding the incidence of deep SSIs, IAAs, return ED visits, readmissions, or reoperations (Table 2). Management of IAAs (306, 5.2%) consisted most frequently of consulting IR (267, 87.3%) with 5.6% treated with a reoperation. IAAs were the most common reason for readmission (97, 47.6%) and reoperation (17, 37.8%) in patients who experienced these rare complications. Persistent abdominal pain (262, 65.7%) was the most common reason for a return ED visit (399, 6.8%) within the total patient cohort. Patients treated operatively who tested positive for COVID-19 had no significant difference in incidence of complications (Supplementary Material Table 4).

3.5. Non-operative complications

IAAs were the most common complication experienced by non-operatively managed patients; however, patients treated during the COVID-19 pandemic had a decreased incidence of IAAs compared to pre-COVID patients (Table 2). IAAs were more commonly diagnosed in patients with complicated appendicitis, and this trend remained consistent in both pre-COVID and COVID patients (Table 3, Supplementary Material Table 6). Failure of non-operative management requiring surgery occurred in 40 (13.8%) patients, and no differences were seen in the incidence of failure in pre-COVID versus COVID patients (Table 2) and patients with uncomplicated appendicitis (Table 3). However, patients treated non-operatively with complicated appendicitis had a decreased incidence of failure during the COVID-19 pandemic compared to pre-COVID (Table 3). More non-operatively managed patients during the pre-COVID era (69, 47.9%) required IR drain placements compared to COVID era patients (29, 19.7%)(p < 0.001). Most non-operatively managed patients who received an IR drain did so within the first 24 h of presentation (Median 1 day, IQR: 0,1). IR drains were more frequently performed in patients with complicated appendicitis (Supplemental Material Table 6), but during the COVID-19 pandemic fewer complicated appendicitis patients underwent IR drain place-

Table 2
Patient complications.

Operative Complications	All (n = 6014)	Pre-COVID (n = 3563)	COVID (n = 2345)	P-value
Superficial SSI	84 (1.4%)	62 (1.7%)	22 (0.9%)	0.01
Deep SSI	4 (0.1%)	3 (0.1%)	1 (<1%)	0.65
IAA	306 (5.2%)	192 (5.4%)	114 (4.9%)	0.37
Return ED Visit	399 (6.8%)	259 (7.3%)	140 (6.0%)	0.05
Readmission	210 (3.6%)	127 (3.6%)	83 (3.5%)	0.96
Reoperation	45 (0.8%)	30 (0.8%)	15 (0.6%)	0.38
Non-operative Complications				
	All (n = 291)	Pre-COVID (n = 144)	COVID (n = 147)	P-value
None	159 (54.6%)	73 (50.7%)	86 (58.5%)	0.18
IAA	80 (27.5%)	49 (34.0%)	31 (21.1%)	0.01
Other	22 (7.6%)	9 (6.3%)	13 (8.8%)	0.51
Non-operative Procedures				
None	91 (31.3%)	31 (21.5%)	60 (40.8%)	<0.001
Interval Appendectomy	152 (52.2%)	87 (60.4%)	65 (44.2%)	0.01
IR Drain	98 (33.7%)	69 (47.9%)	29 (19.7%)	<0.001
IR Aspiration	6 (2.1%)	2 (1.4%)	4 (2.7%)	0.68
Failure Requiring Surgery	40 (13.8%)	24 (16.7%)	16 (10.9%)	0.15
Other	9 (3.1%)	5 (3.5%)	4 (2.7%)	0.75

Categorical variables presented as frequency (percentage).
Abbreviations: SSI: Surgical Site Infection, IAA: Intra-abdominal Abscess, ED: Emergency Department, IR: Interventional Radiology.

Table 3
Non-operative patient complications and additional procedures stratified by uncomplicated vs complicated appendicitis and COVID status.

Nonoperative Complications Stratified by Uncomplicated vs Complicated Appendicitis and COVID status	Total (n = 291)	Pre-COVID (n = 144)	COVID (n = 147)	P-Value
IAA	(n = 74)			
Uncomplicated	1(0.3%)	0 (0%)	1 (0.7%)	1
Complicated	73 (25.1%)	44 (30.6%)	29 (19.7%)	0.04
Other	(n = 22)			
Uncomplicated	8 (2.8%)	1 (0.7%)	7 (4.8%)	0.07
Complicated	13 (4.5%)	7 (4.9%)	6 (4.1%)	0.78
None	(n = 152)			
Uncomplicated	87 (29.9%)	24 (16.7%)	63 (42.9%)	<0.001
Complicated	65 (22.3%)	44 (30.6%)	21 (14.3%)	0.001
Non-operative Procedures Stratified by Uncomplicated vs Complicated Appendicitis and COVID status				
	Total	Pre-COVID (n = 144)	COVID (n = 147)	P-Value
None	(n-87)			
Uncomplicated	74 (25.4%)	24 (16.7%)	50 (34.0%)	<0.001
Complicated	13 (4.5%)	5 (3.5%)	8 (5.4%)	0.57
Interval Appendectomy	(n = 142)			
Uncomplicated	23 (7.9%)	3 (2.1%)	20 (13.6%)	<0.001
Complicated	119 (40.9%)	75 (52.1%)	44 (29.9%)	<0.001
IR drain	(n = 96)			
Uncomplicated	3 (1.0%)	1 (0.7%)	2 (1.4%)	1
Complicated	93 (32%)	66 (45.8%)	27 (18.4%)	<0.001
IR aspiration	(n = 6)			
Uncomplicated	0 (0%)	0 (0%)	0 (0%)	–
Complicated	6 (2.1%)	2 (1.4%)	4 (2.7%)	0.68
Failure requiring surgery	(n = 40)			
Uncomplicated	16 (5.5%)	5 (3.5%)	11 (7.5%)	0.2
Complicated	24 (8.3%)	19 (13.2%)	5 (3.4%)	0.003
Other	(n = 9)			
Uncomplicated	3 (1.0%)	0 (0%)	3 (2.0%)	0.25
Complicated	6 (2.1%)	5 (3.5%)	1 (0.7%)	0.12

Categorical variables presented as frequency (percentage).
Abbreviations: IAA: Intra-abdominal Abscess, IR: Interventional Radiology.

ment (Table 3). There was no difference in the percentage of patients who received an IR drain and subsequently underwent an interval appendectomy between pre-COVID (57, 83%) and COVID era (22, 76%) groups (p = 0.66). Likewise, there was no difference in the percentage of patients who received an IR drain and then subsequently failed non-operative management requiring surgery between pre-COVID (8,12%) and COVID era (2, 7%) groups (p = 0.72). Similarly, more non-operatively managed patients during the pre-COVID era (87, 60.4%) underwent interval appendectomies compared to COVID era patients (65, 44.2%)(p = 0.006). When stratifying by uncomplicated versus complicated appendicitis and era of presentation, fewer complicated appendicitis patients underwent interval appendectomies in the COVID era compared to pre-COVID (Table 3). Uncomplicated appendicitis patients had increased incidence of experiencing no complications and requiring no additional procedures during the COVID-19 pandemic compared to pre-COVID (Table 3). Patients who tested positive for COVID-19 and were managed non-operatively had no increase in complications or need for further procedures during their non-operative management (Supplementary Material Table 5).

3.6. Subgroup analysis of non-operative management and complicated appendicitis

As time progressed through the COVID-19 pandemic, we examined the incidence of non-operative management in all patients treated from March-May 2020, June-August 2020, and September-October 2020 to evaluate any temporal trends in non-operative management. The highest incidence of non-operative management occurred at the start of the pandemic in March-May 2020 (94, 9%), and declined as time through the pandemic progressed (June-July 2020 = 40, 4.1%, September-October 2020 = 20, 3.3%)($p<0.001$). Given the potential for temporal trends in the incidence of appendicitis, we also compared patients treated non-operatively from April-June 2019 (pre- COVID) to those treated during April-June 2020 (COVID-19 era). A higher percentage of patients were treated non-operatively during April-June 2020 (COVID-19 era) (92, 8.6%) compared to April-June 2019 pre-pandemic (38, 3.9%)($p<0.001$).

We also evaluated the incidence of complicated appendicitis as time progressed through the COVID-19 pandemic. The highest incidence of complicated appendicitis occurred at the start of the pandemic from March-May 2020 (401, 38.4%), and continued to decline as time progressed (June-August = 332, 34.4%, September-October = 187, 30.5%)($p = 0.02$). To again account for potential temporal trends in appendicitis, we compared the incidence of complicated appendicitis from April-June 2019 (pre- COVID) to the incidence in April-June 2020 (COVID-19 era). There were increases in complicated appendicitis during April-June 2020 (COVID-19 era) (415, 38.6%) compared to the April-June 2019 pre-pandemic (341, 34.7%)($p = 0.03$).

3.7. Multi-level multivariable generalized linear model analysis

Multi-level multivariable analysis found increasing age associated with a decreased odds of receiving non-operative management. This finding was likely because younger children who are unable to communicate their symptoms and complaints as well as older children were found to have longer duration of symptoms and an increased incidence of complicated appendicitis, which may in turn increase their likelihood of receiving non-operative management when compared to older children. Diagnosis of uncomplicated (OR = 0.01, 95% CI: 0.002–0.03) or complicated (OR = 0.01, 95% CI: 0.003–0.5) appendicitis were both associated with significant decreased odds of receiving non-operative management, as despite the COVID-19 pandemic the overwhelming majority of patients remained managed operatively. Increasing duration of symptoms (OR = 1.01, 95% CI: 1.01–1.012), African American race (OR = 2.45, 95% CI: 1.29–4.64), and testing positive for COVID-19 (OR = 10.77, 95% CI: 5.36–21.64) were associated with significant increased odds of receiving non-operative management (Table 4).

Table 4
Multi-level multivariable analysis of factors influencing non-operative management.

Covariates	Odds Ratio	P-value	95% Confidence Interval
Age			
Age	**0.96**	**0.04**	**0.93–0.99**
Symptom duration			
Symptom duration	**1.01**	**<0.001**	**1.01–1.012**
Gender			
Male	Ref	–	–
Female	1.10	0.50	0.84–1.43
Race			
Other	Ref	–	–
Hispanic	1.42	0.25	0.78–2.60
Caucasian	1.70	0.07	0.96–3.02
African-American	**2.45**	**0.01**	**1.29–4.64**
Asian	1.56	0.31	0.67–3.63
PAS score			
PAS 0–3	Ref	–	–
PAS 4–6	1.02	0.89	0.76–1.38
PAS 7–10	0.82	0.52	0.46–1.48
Uncomplicated vs Complicated Appendicitis			
Other*	Ref	–	–
Simple	**0.01**	**<0.001**	**0.002–0.03**
Complicated	**0.01**	**<0.001**	**0.003–0.05**
COVID status			
COVID negative	Ref	–	–
COVID positive	**10.77**	**<0.001**	**5.36–21.64**

* Other: Designated if unable to stratify based on clinical data present on chart review. Abbreviations: PAS (Pediatric Appendicitis Score).

4. Discussion

This study describes the management of pediatric appendicitis during the COVID-19 pandemic among 19 pediatric centers across the United States. Non-operative management of pediatric appendicitis within our patient cohort increased during the COVID-19 pandemic, including a significant increase in uncomplicated appendicitis treated non-operatively. This could be related to attempts to conserve hospital resources, limit exposure of healthcare personnel to the virus, and potential anesthetic/operative concerns. Despite this shift in management, there were no increases in failure of non-operative management requiring surgery when patients were compared between pre-COVID and COVID groups, and fewer complicated appendicitis patients failed non-operative management during the COVID era. Fewer IAAs were diagnosed during the COVID-19 pandemic, perhaps related to the emphasis on decreasing hospital resource use for non-emergent indications leading to fewer diagnosed IAAs in this patient cohort. Fewer IR drain placements were performed specifically in non-operatively managed complicated appendicitis patients during the COVID-19 pandemic. Given the retrospective nature of this study, certain details regarding those that received IR drains were not collected including presence of retained fecalith. Uncomplicated appendicitis patients had an increased incidence of experiencing no complications and having no need for additional procedures during the COVID-19 pandemic when compared to pre-COVID patients. These findings suggest that non-operative management of uncomplicated and complicated appendicitis may be a reasonable management strategy for pediatric appendicitis without evidence for increased patient morbidity, especially at times when available hospital resources are limited. Despite these findings, the overwhelming majority of pediatric appendicitis patients within this study were managed operatively despite the difficulties the COVID-19 pandemic placed upon our healthcare system.

Multi-level multivariable analysis found increasing age associated with a decreased odds of receiving non-operative management. This finding is likely because younger children are unable to communicate their symptoms and complaints as well as older children. Therefore, they frequently present with longer duration of symptoms and an increased likelihood of complicated appendicitis, which may in turn increase the possibility of receiving non-operative management. Increased duration of symptoms, African American race, and testing positive for COVID-19 were all associated with increased odds of receiving non-operative management. According to our multivariable model, African Americans are 2.4 times more likely to undergo non-operative management than other ethnicities. When African American patients were compared to patients of other ethnicities within our study cohort, there were increases in the incidence of non-operative management within this patient subgroup of about 4%. However, when stratified based on time of presentation, African American patients had a marginal increased incidence of non-operative management during the COVID-19 pandemic of 0.8% compared to pre-COVID. It is unclear as to why this trend exists within our patient population as 19 different children's centers had contributed to our

diverse data set. Further examination into potential healthcare delivery disparities between different ethnicities is important to ensure an equitable healthcare experience for all patients.

COVID-19 positive patients had 10.8 times increased odds of receiving non-operative management compared to COVID negative patients. Most of these patients continued to be treated with operative management; however, 19.4% were treated non-operatively. This is likely related to the anesthetic concerns of putting a child to sleep for surgery who is positive for COVID-19, as well as concerns for exposure of healthcare staff during laparoscopic surgery given the unknowns early during the COVID-19 pandemic. No evidence of increased complications in both operatively and non-operatively managed COVID-19 positive patients were seen.

A subgroup analysis looking at the incidence of complicated appendicitis as the COVID-19 pandemic progressed found that the highest incidence of complicated appendicitis occurred at the start of the pandemic and progressively declined. These findings may be related to the many unknowns of COVID-19 at the start of the pandemic as well as the emphasis placed on limiting the usage of hospital resources for non-emergent care leading to potential delays at the start of the pandemic. Additionally, a subgroup analysis looking at the percentage of non-operative management as the COVID-19 pandemic progressed found that the highest percentage of non-operative management occurred at the start of the pandemic and progressively declined. These findings support our hypothesis that non-operative management increased during the pandemic compared to pre-pandemic patients. When considering temporal changes in appendicitis, we compared patients treated during April-June 2019 pre-pandemic to April-June 2020 during the pandemic. We found similar results with a higher percentage of patients treated non-operatively and diagnosed with complicated appendicitis during this time period of the COVID-19 pandemic when compared to patients treated within the same time period pre-pandemic.

Several prior studies have examined pediatric appendicitis during the COVID-19 pandemic across the United States, but none to our knowledge have included this many institutions located across multiple states. Similar to our findings, previous studies have found an increase in non-operative management of pediatric appendicitis during the COVID-19 pandemic [9,12,13]. Gerall et al. conducted a study in New York City evaluating pediatric appendicitis and found that non-operative management during the COVID-19 pandemic increased from 2.5% to 7.3%. However, they noted a 50% failure rate and need for additional intervention in their patients managed non-operatively, which was notably higher than our failure rate of approximately 14% [12]. Likewise, a multicenter study conducted within the state of California by Theodorou et al. noted an increase in non-operative management during the COVID-19 pandemic from 8.8% to 16.2% [9]. An additional study by Kvasnovsky et al. focused on transitioning care during the peak of the pandemic in New York City to non-operative management of pediatric appendicitis. They found that around 45.5% of patients were able to be successfully discharged and managed non-operatively with only 3 patients returning for additional care. This study highlighted that non-operative management of pediatric appendicitis was an effective management strategy if hospital resources were limited [13].

Additionally, multiple studies have evaluated whether presentation of pediatric appendicitis during the COVID-19 pandemic has changed. Many studies noted an increase in symptom duration prior to presentation for care during the COVID-19 pandemic; however, this was not supported in our patient cohort [12,18–21]. Several studies have also noted an increase in the incidence of complicated appendicitis presentations during the COVID-19 pandemic; however, this was also not supported in our patient cohort [8,12,22,23]. Reasons for this difference are unclear, but according to our data it appears our patient cohort was not deterred from seeking medical care because of fear of COVID-19 or city/state SAHO. Our study findings are similar to a previously conducted multicenter study by Theodorou et al. that found no increase in incidence of complicated appendicitis or delayed presentation for care [9]. Additional studies have found evidence for increased hospital LOS during the COVID-19 pandemic when compared to pre-COVID patients [9,13,19]. However, our study found no increased LOS when comparing patients treated pre-COVID to those treated during the COVID-19 pandemic. When stratifying by operative vs non-operative treatment, patients in our cohort treated non-operatively during the COVID-19 pandemic had a shorter hospital LOS compared to non-operatively managed pre-COVID-19 patients. These findings are supported by previous studies performed by Rosenthal et al. and Maita et al. that found non-operatively managed patients treated during the COVID-19 pandemic did not have increased hospital LOS [5,24]. This finding could be related to a broader utilization of non-operative management in patients with less severe, uncomplicated cases of pediatric appendicitis which may have allowed for a shorter hospital stay during the COVID-19 pandemic, as well as attempts to decrease inpatient hospital resources.

Alterations to the management strategy of pediatric appendicitis because of the COVID-19 pandemic have occurred with a noted increase in non-operatively managed patients compared to the previous standard of care—operative management. Despite this change in management, our study findings support that during times of limited available hospital resources, non-operative management of pediatric appendicitis is a viable tool to assist with appropriate allocation of those limited resources. Further coordination amongst pediatric caregivers is needed to improve not only prevention strategies and health outcomes for COVID-19, but also to facilitate adequate care delivery for other non-pandemic disease during the COVID-19 pandemic. Additional research and analysis of long-term outcome data are needed to develop consensus guidelines for the non-operative management of pediatric appendicitis that both optimizes patient outcomes and effectively utilizes hospital resources.

Our study was not without limitations. First, this study was retrospective and involved multiple institutions abstracting data from various electronic medical records. Therefore, we were unable to ensure that patient documentation was standardized across and within all centers. This lack of standardization could have led to errors during data abstraction. We sought to minimize these errors by utilizing a study protocol that had been agreed upon by all included centers prior to study initiation that defined all variables, utilization of the REDCAP database that was identical for all centers data submission, as well as multiple rounds of data quality checks. Second, this study is the largest multicenter study to date evaluating the care of pediatric appendicitis patients during the COVID-19 pandemic. However, the retrospective nature of this study did not allow for us to standardize patient care across centers. Each center continued to provide care to appendicitis patients in accordance with their own practice guidelines and preferences. Potential shifts in practice because of the COVID-19 pandemic were not uniform across all centers. Multi-level multivariable regression models were used to account for the potential confounding of center-based variation. Despite this limitation, this study was able to evaluate a diverse group of institutions' responses to pediatric appendicitis care during the COVID-19 pandemic and provide data that should be generalizable given such a diverse patient population. Third, the COVID-19 pandemic has not affected all regions of the country in the same way at the same time, which could have led to difficulties in accurately assessing practice changes across a wide range of institutions nationwide. We utilized city/state-wide SAHOs to define each institutions cohorts as pre-COVID or COVID to take this variation into account. Also, time

factors were considered with a sub-group analysis looking at practice changes as the pandemic progressed across all institutions. Finally, our study follow up period was limited to patient outcomes within 30 days post-operatively or upon discharge. This follow up period may have limited our data on failure of non-operative management and other complications within our patient cohort. Further assessment of long-term data and patient outcomes after non-operative management of pediatric appendicitis are needed in order to draw truly meaningful conclusions on its safety and efficacy.

5. Conclusion

This study evaluated the effects of the COVID-19 pandemic on the management of pediatric appendicitis within 19 pediatric centers across the United States. Non-operative management of pediatric appendicitis during the COVID-19 pandemic increased compared to patients treated pre-COVID. Despite the increased utilization of non-operative management, there was no change in the rate of failure, and no increase in the incidence of complicated appendicitis between pre-COVID and COVID era patients. Fewer patients treated during the COVID-19 era underwent IR drain placements or interval appendectomies. Increasing age was associated with decreased odds to receive non-operative management. Whereas, increasing duration of symptoms, African-American race, and testing positive for COVID-19 were all associated with increased odds of receiving non-operative management. Further research is needed to fully understand the long-lasting effects of the COVID-19 pandemic on pediatric appendicitis care to optimize patient outcomes and the effective utilization of hospital resources during times of future international events. However, this data shows that non-operative management of pediatric appendicitis is an available management strategy when healthcare resources are limited and future pandemic disease or other factors place strain on our healthcare system.

Level of Evidence

Level III

Declaration of Competing Interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jpedsurg.2022.08.005.

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