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Favorable postoperative outcomes for children with COVID-19 infection undergoing surgical intervention: Experience at a free-standing children's hospital

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ABSTRACT

Background: Current literature has shown that adult patients with perioperative Coronavirus Disease-2019 (COVID-19) have increased rates of postoperative morbidity and mortality. We hypothesized that children with COVID-19 have favorable postoperative outcomes compared to the reported adult experience.
Methods: We performed a retrospective cohort study for children with a confirmed preoperative COVID-19 diagnosis from April 1st, 2020 to August 15th, 2020 at a free-standing children's hospital. Primary outcomes evaluated were postoperative complications, readmissions, reoperations, and mortality within 30 days of operation. Secondary outcomes included hospital resource utilization, hospital length of stay, and postoperative oxygen support.
Results: A total of 66 children with preoperative confirmed COVID-19 were evaluated with median age of 9.5 years (interquartile range (IQR) 5–14) with 65% male and 70% Hispanic White. Sixty-five percent of patients had no comorbidities, with abdominal pain identified as the most common preoperative symptom (65%). Twenty-three percent of patients presented with no COVID-19 related symptoms. Eighty-two percent of patients had no preoperative chest imaging and 98% of patients did not receive preoperative oxygen support. General pediatric surgeons performed the majority of procedures (68%) with the most common diagnosis appendicitis (47%). Forty-one percent of patients were discharged the same day as surgery with 9% of patients utilizing postoperative intensive care unit resources and only 5% receiving postoperative invasive mechanical ventilation. Postoperative complications (7%), readmission (6%), and reoperation (6%) were infrequent, with no mortality.
Conclusion: COVID-19+ children requiring surgery have a favorable postoperative course and short-term outcomes compared to the reported adult experience.
Type of study: Prognosis Study.
Level of evidence: Level IV.

1. Introduction

The arrival of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) to the United States resulted in a drastic change to our healthcare system as healthcare resources were optimized to deal with the impending pandemic. As our surgical community adapts to these changes, uncertainty remains around perioperative care and potential postoperative complications related to Coronavirus Disease-2019 (COVID-19). The current COVID-19 literature has evaluated surgical outcomes; however, it is limited to adults [1–3].

By the end of August, approximately 8% of laboratory-verified or clinically confirmed COVID-19 cases occurred in children [4]. Pediatric patients develop similar symptoms as adults with the most prevalent including fever, dyspnea, and cough; however, the disease course is typically milder and death is exceedingly rare [5, 6].

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Nevertheless, COVID-19 manifests as a wide spectrum of disease states in children, ranging from asymptomatic infection to multisystem inflammatory syndrome in children in critical cases [7–9]. Adult surgical patients with COVID-19 have higher rates of surgical mortality, pulmonary and thrombotic complications compared to patients without COVID-19 [1, 3] with few studies evaluating outcomes in children [10–13]. The possibility of postoperative complications in children with COVID-19 is an important consideration in assessing the risks and benefits of both elective and urgent surgery. The paucity of data regarding the effects of COVID-19 on the pediatric postoperative course has raised questions concerning timing and appropriateness of surgical interventions.

Due to the limited evidence in an evolving COVID-19 environment, policies in surgical care of children are constantly changing. Descriptive studies by Ingram et al. [13,14] evaluated local pediatric surgical policy changes from 38 well-known North American children's hospitals. Common changes included decreased staff coverage and limitations to work for providers with underlying medical conditions, pregnancy, or > 65 years of age. Similarly, operative management of acute surgical conditions such as appendicitis has been adjusted at some children's hospitals to preserve hospital resources and prepare for a possible COVID-19 surge [15]. Pediatric surgical protocols and procedures continue to change as we improve our understanding of COVID-19 in children. Therefore, the purpose of this study was to describe our institutional experience in the surgical management of children, to briefly describe perioperative protocols and characterize the short-term clinical outcomes in children with COVID-19 who underwent surgery at a free-standing children's hospital. We hypothesized that children with COVID-19 have favorable postoperative outcomes compared to the reported adult experience.

2. Methods

2.1. Study setting, study design & data collection

On March 22nd, Texas Governor Greg Abbott released an executive order directing all licensed health care facilities to postpone all surgeries and procedures not immediately medically necessary, reflecting recommendations from the CDC, the U.S. Surgeon General and the American College of Surgeons [16]. On April 17th, Governor Abbott issued a new executive order loosening elective surgery restrictions with an essential caveat: the hospital would reserve at least 25% of its hospital capacity for treatment of COVID-19 patients. As the state of Texas began to reopen with increasing laxity towards social restrictions, the Texas Medical Center in Houston experienced a surge of COVID-19 cases with a peak of 2962 new cases on July 14th [17].

We performed a retrospective cohort study at Texas Children's Hospital, a free-standing children's hospital with two community campuses, in Houston, TX. After IRB approval (H-48,227), we reviewed all surgical cases for children ≤ 18 years of age who had surgery from April 1st to August 14th 2020. We identified 73 patients who underwent a surgical procedure and had perioperative SARS-CoV-2 RT PCR positive test results. Two patients were excluded who initially presented with COVID-19 pneumonia, receiving invasive mechanical ventilation with eventual transition to either venoarterial or venovenous extracorporeal membrane oxygenation. Five additional patients were excluded with initial negative preoperative surveillance test, and subsequent positive test results during their hospitalization within 4 days of surgery. On institutional review of their contact history, these patients were likely in the early incubation period at the time of their initial presentation and were felt to be in a different time course of their COVID-19 infection relative to those with confirmed preoperative COVID-19. The preoperative diagnoses were thigh abscess, septic arthritis, gram negative bacteremia, and obesity with respective surgical procedures including incision and drainage, incision and drainage, central line removal, and elective sleeve gastrectomy. The patient who underwent sleeve gastrectomy had a diagnostic laparoscopy on postoperative day 3 due to persistent fever to rule out staple line leak. The fever was determined to be secondary to COVID-19 following negative laparoscopy and confirmatory test. No patients experienced significant postoperative complications. Preoperative, intraoperative, and postoperative data were collected. Preoperative data included age, sex, race, ethnicity, weight, body mass index (BMI), ASA class, comorbidities, surgical diagnosis, preoperative symptoms, preoperative laboratory assessment, preoperative chest imaging, and preoperative respiratory support. Operative data included surgical specialty, surgical procedure, surgical site and method (minimally invasive or open), operating room time, surgical time, and estimated blood loss. Postoperative data included postoperative resource utilization (acute care floor or intensive care unit (ICU)), need for oxygen support, duration of oxygen support, use of prophylactic anticoagulation, hospital length of stay, postoperative complications, readmission, reoperation, and mortality. Primary outcomes evaluated were overall mortality, postoperative complications, readmission, and reoperation within 30 days of surgery. Secondary outcomes included hospital resource utilization, hospital length of stay, and postoperative oxygen support. Hospital resource utilization was defined as need for ICU resources based on inotropic support, invasive hemodynamic monitoring, and invasive mechanical ventilation. Postoperative oxygen support was defined as non-invasive nasal cannula, non-invasive mechanical ventilation, or invasive mechanical ventilation. Results are reported as median with interquartile range (IQR) or percentages. Chi-squared analysis or Fisher's Exact test was performed to compare presenting symptoms between surgical specialty and surgical diagnosis. Analyses were performed using Stata version 16 (StataCorp, College Station, TX).

2.2. Perioperative care

2.2.1. Emergent and elective surgery classification

We drafted guidelines for classification of elective and urgent surgeries while conforming to state-wide mandates and recommendations from national health organizations and surgical societies [16,18]. Our guidelines have continued to evolve over the course of the pandemic with Fig. 1 highlighting various components in effect in early April 2020.

2.2.2. Preoperative testing for all patients

Preoperative test with SARS-CoV-2 RT PCR nasopharyngeal swab was performed for all patients undergoing surgery. In life-threatening and emergent cases, the patient was treated as a "Patient Under Investigation" (PUI) and taken to the operating room within the appropriate time period prior to final test results. For urgent, semi-urgent, and non-urgent surgical cases, the preoperative test is resulted prior to proceeding to the operating room.

All elective, outpatient cases received surveillance testing within 3 days prior to the surgical procedure. This is performed through our institution at a predetermined campus via drive-through stations. Following surveillance testing the patient and family members quarantined until the day of surgery. If the preoperative surveillance results were positive, elective procedures were classified by the attending surgeon as medically necessary or elective, respectively causing cases to proceed or defer.

2.2.3. Perioperative measures

All providers and visitors were screened upon arrival to our institution with a brief symptom survey and temperature check. While in the hospital, surgical masks were mandatory. Only one

	% Days with Adequate PPE Supply	% Bed Capacity in Intensive Care Unit	% Bed Capacity in Acute Care Floor	% Available Ventilators
Life-threatening/emergent				
Level 1: Transplant surgery, cardiac surgery, Congenital Diaphragmatic Hernia, ExtraCorporeal Membrane Oxygenation	Urgent should be completed regardless	Urgent should be completed regardless	Urgent should be completed regardless	Urgent should be completed regardless
Level 2: All oncologic surgery, Gastroschisis, Omphalocele, Colostomy for imperforate anus, Intestinal Atresia, Hirschprung's	Urgent should be completed regardless	Urgent should be completed regardless	Urgent should be completed regardless	Urgent should be completed regardless
Urgent/Semi-urgent				
Level 3: Symptomatic Otolaryngology Procedures, Appendicitis, Cholecystitis, laryngoscopy and bronchoscopy	80%	95%	95%	90%
Level 4: Non-urgent spine and orthopaedic procedures, Tonsillectomy and Adenoidectomy, symptomatic Inguinal hernia	80%	90%	90%	85%
Non-urgent				
Level 5: EGD, colonoscopy, umbilical hernia repair, circumcision, excision of small lesion, eye muscle surgery	90%	N/A	N/A	N/A

Fig. 1. Classification of emergent and elective surgeries.

parent or guardian was allowed to stay with the child in the hospital. Perioperative protocols were developed regarding operating room preparation, patient transportation, and operating room cleaning. All operating room staff was required to complete personal protective equipment (PPE) training. Postoperative cleaning was completed after a 30 min wait time to allow for dissipation of possible aerosolized SARS-CoV-2.

2.2.4. Anesthesia precautions

We set up multiple precautions to limit exposure through the perioperative process guided by recommendations from the Anesthesia Patient Safety Foundation [19] and the American Society of Anesthesiologists [20]. These recommendations are based on previous Centers for Disease Control and Prevention experience with SARS-CoV and Middle Eastern respiratory syndrome coronavirus [21, 22]. Environmental adaptation included limiting family members and transporting patients directly to and from the operating room with a universal masking policy. Workflow adaptations included reinforcing frequent hand hygiene and proper donning and doffing of PPE. All providers used N-95 respirators, goggles, gloves, and gowns during intubation and care of COVID-19+ patients. Personnel was limited during airway manipulation. Rapid sequence induction was used to secure the airway with goals of securing the airway centered on rapid placement of an endotracheal tube (ETT) and elimination of aerosolization or secretions during intubation. Placement of an ETT was immediately followed with clamping the ETT and attachment to either an electrostatic filter or a high quality Heat and Moisture Exchanging Filter, capable of removing >99.97% of airborne particles >0.3 µm, between the Y-piece of the breathing circuit prior to instituting ventilator support. Extubation was performed deep and with limited staff to mitigate aerosolization exposure. Extubation was immediately followed by placement of a surgical mask with recovery occurring in the operating room prior to their final disposition.

2.2.5. Laparoscopy/aerosol generating procedures

Our institution has continued to perform minimally invasive procedures. During a surgical procedure for a PUI or COVID-19+ patient, all providers are required to wear PPE, including eye protection and N-95 respirators. Disposable insufflation cables and trocars are utilized. A closed smoke evacuation system is used for CO_2 evacuation and electrocautery. The operating surgeon aims to limit "leaking" of CO_2 through trocars, and utilizes low-power electrocautery at their discretion. Aspiration of residual CO_2 is performed at the conclusion of the operation via the closed filter system.

2.2.6. Postoperative care for COVID-19+ patients

Same day discharge: Same Day discharge has continued to be utilized for appropriate cases. To limit exposure in the post-anesthesia care unit at the beginning of the pandemic, patients were discharged directly from the operating room after extubation, recovery, and re-evaluation by the surgical team. However, patients are now transferred to an isolation room in post-anesthesia care unit and discharged from the post-anesthesia care unit after recovery.

Postoperative hospitalization: All patients that require postoperative hospitalization are transferred from the operating room to an isolation unit. The isolation unit limits provider exposure and all rooms have necessary isolation precautions and PPE. Following admission, the pediatric hematology team is consulted to evaluate the patient for postoperative prophylactic anticoagulation. Daily laboratory monitoring is performed with CBC with differential, DIC panel (PT, aPTT, PTT hepzyme, thrombin time, fibrinogen, D-dimer), and C-reactive protein during hospitalization to assess changes in thromboembolic risk. The patient is evaluated for ≥ 1 of the following risk factors: decreased mobility, obesity, D-Dimer > 2 times the upper limit of normal, and laboratory evidence of ongoing inflammation with C-reactive protein and Fibrinogen. Based on patient risk factors and daily labs, the hematology team makes final recommendations for postoperative prophylactic anticoagulation. Once all surgical discharge criteria are met, patients are discharged directly from the isolation unit.

3. Results

A total of 66 patients underwent surgery with a preoperative positive SARS-CoV-2 RT PCR. The median age of patients was 9.5 years (IQR 5 – 14) with 65% male, and 70% Hispanic White (Table 1). The median weight and BMI were 41.6 kg (IQR 21.6 – 63.8) and 21.5 kg/m^2 (IQR 17.0 – 26.2), respectively. Ninety-one percent of patients initially presented to the emergency room, with only 9% of patients presenting for elective procedures. Half of the elective cases (3/6) were oncologic cases (retinoblastoma, osteosarcoma x2) with the remaining cases requiring surgery due to progressive pathology. Sixty-five percent of patients had 0 comorbidities with only 5% of patients having two or more comorbidities. The most common comorbidities were obesity (9%) and pulmonary/prematurity (8%) (Table 1). The most common preoperative symptom was abdominal pain (65%) and the least common was dyspnea (0%), with 23% of patients having no COVID-19 related symptoms (Table 1). Symptoms were further stratified by operating surgical specialty and surgical diagnosis (Fig. 2). General surgical patients presented significantly more often with abdominal pain (general surgeon 87%; other surgical specialties 19%; $p = 0.0001$) and nausea/vomiting (general surgeon 69%; other surgical specialties 14%; $p = 0.0001$ (Fig. 2**A**). Conversely, all other surgical specialty patients presented significantly more often with no COVID-19 related symptoms (general surgeon 5%; other surgical specialties 57%; $p = 0.0001$) (Fig. 2**A**). Similarly, patients with gastrointestinal pathology presented significantly more often with abdominal pain (gastrointestinal 91%; soft tissue infection/extremity fracture 0%; “Other” 33%; $p = 0.0001$) and nausea/vomiting (gastrointestinal 72%; soft tissue infection/extremity fracture 9%; “Other” 17%; $p = 0.0001$). Patients with a soft tissue abscess or extremity fracture presented significantly more often with no COVID-19 related symptoms (gastrointestinal 2%; soft tissue infection/extremity fracture 82%; “Other” 42%; $p = 0.0001$) (Fig. 2**B)**. The most common preoperative laboratory assessment performed was complete blood count in 45 patients with median values indicating mild leukocytosis (11.7 (IQR 8.9 – 16.1), lymphopenia (16.5 (IQR 6.4 – 30.8)), and normal platelet count (260 (IQR 217 – 372). A substantial majority of patients had no preoperative chest imaging (82%) with abnormal chest X-ray (2%) and abnormal thoracic computed tomography (3%) in a minority of patients. Preoperative respiratory support was utilized for a single patient by non-invasive nasal cannula (1–2 Liters/minute) which was used at baseline for pre-existing chronic lung disease.

The most common operating surgical specialty was general pediatric surgery (68%) followed by orthopedic surgery (11%) with all remaining specialties performing ≤ 4 cases (Table 2). Appendicitis was the most common diagnosis (47%) with uncomplicated appendicitis occurring almost three times as often as complicated appendicitis. After appendicitis, the most common diagnoses were extremity fracture (9%) and soft tissue abscess/foreign body (8%)

Table 1
Patient demographics and preoperative assessment.

Median Age (years)	9.5 (5 – 14)
Age (%),	
< 1 year	5 (8%)
1 – 6 years	16 (24%)
7 – 12 years	23 (35%)
13 – 18 years	22 (33%)
Sex (%), male	43 (65%)
Race/Ethnicity (%),	
Hispanic White	46 (70%)
Non-Hispanic White	11 (17%)
African American	7 (11%)
Other	1 (2%)
Weight (kg)	41.6 (21.6 – 63.8)
BMI (kg/m^2)	21.5 (17.0 – 26.2)
ASA Class (%),	
1	8 (12%)
2	37 (56%)
3	18 (27%)
4	3 (5%)
5	0 (0%)
Number of Comorbidities (%),	
None	43 (65%)
One	20 (30%)
Two or more	3 (5%)
Comorbidities (%),	
None	43 (65%)
Obesity	6 (9%)
Pulmonary / Prematuriy	5 (8%)
Oncologic	4 (6%)
Hematologic	2 (3%)
Neurologic/Behavioral	2 (3%)
Congenital Cardiac	0 (0%)
Preoperative Symptoms (%),	
Cough	4 (6%)
Fever > 100.3	17 (26%)
Subjective Fever	21 (32%)
Dyspnea	0 (0%)
Abdominal Pain	43 (65%)
Nausea / Vomiting	34 (52%)
Diarrhea	9 (14%)
Fatigue	7 (11%)
No symptoms	15 (23%)
Preoperative Laboratory values	
White Blood Cell Count	11.7 (8.9 – 16.1)
Lymphocyte Count	16.5 (6.4 – 30.8)
Platelet Count	260 (217 – 372)
Preoperative Chest Imaging (%),	
None	54 (82%)
X-ray, normal	5 (8%)
Computed Tomography, normal	1 (2%)
X-ray, abnormal	1 (2%)
Computed Tomography, abnormal	2 (3%)
Preoperative Respiratory Support (%),	
None	65 (98%)
Noninvasive nasal cannula	1 (2%)
Invasive mechanical ventilation	0 (0%)

(A)

Symptoms	General Surgery (n=45)	All other Specialties (n=21)	p-value
Cough (%)	9	0	0.16
Dyspnea (%)	0	0	-
Fever (100.3) (%)	33	10	0.04
Subjective Fever (%)	40	14	0.04
Abdominal Pain (%)	87	19	0.0001
Nausea/Vomiting (%)	69	14	0.0001
Diarrhea (%)	18	5	0.15
Fatigue (%)	11	10	0.85
No symptoms (%)	5	57	0.0001

(B)

Symptoms	*Gastrointestinal Pathology (n=43)	**Soft Tissue Abscess & Extremity Fx (n=11)	***Other (n=12)	p-value
Cough (%)	9	0	0	0.32
Dyspnea (%)	0	0	0	-
Fever (100.3) (%)	35	0	17	0.05
Subjective Fever (%)	42	9	17	0.05
Abdominal Pain (%)	91	0	33	0.0001
Nausea/Vomiting (%)	72	9	17	0.0001
Diarrhea (%)	19	0	8	0.23
Fatigue (%)	12	0	17	0.40
No symptoms (%)	2	82	42	0.0001

Percent of Patients
0-25%
26-50%
51-75%
76-100%

Fig. 2. (A) Symptom stratification based on surgical specialty. (B) Symptom stratification based on surgical diagnosis.
*Gastrointestinal Pathology: Appendicitis, Intussusception, Pyloric Stenosis, Blunt Abdominal Trauma, Cecal perforation / volvulus, Sigmoid volvulus, Esophageal / gastric FB.
**Soft tissue abscess / extremity fracture: Soft tissue foreign body, Supracondylar fracture, Facial Abscess, Hand fracture, Humerus fracture, L forearm fracture, Mouth abscess, Peritonsilar abscess, Pilonidal cyst, Tibial Fracture, Patellar Fracture.
***Other: testicular torsion, anal laceration, congenital cataract, nasal bleeding, obstructed VP shunt, osteosarcoma, ovarian torsion, peri–orbital swelling, re-bleed tonsillectomy, retinoblastoma, synovial sarcoma.

with all other diagnoses representing ≤ 3 cases (Table 2). Reflective of the surgical diagnoses, laparoscopic appendectomy (47%), laparotomy (11%), extremity fracture fixation (9%), and soft tissue incision and drainage or foreign body removal (8%) were the most common procedures performed (Table 2). Abdominal minimally invasive surgery was the most common type of surgical intervention at 52% (Table 2). Median operating room time, surgery time, and estimated blood loss were respectively 129 min (IQR 102 – 207), 38 min (IQR 27 – 66), and 3 mL (IQR 0 – 5 mL).

Forty-one percent of all patients underwent same day discharge and only 9% utilized ICU resources (Table 3). Fifty-nine percent (16/27) of the same day discharges were patients with uncomplicated appendicitis. Fifty percent of patients were admitted to an isolation unit utilizing resources common to a postoperative acute care floor. Nighty-two percent of patients did not receive any postoperative oxygen support, and only 5% received postoperative mechanical ventilation (Table 3). All patients who received postoperative invasive mechanical ventilation were extubated within 48 h. Postoperative prophylactic anticoagulation was initiated in 17% of all patients and 28% (11/39) of hospitalized patients (Table 3). The median hospital length of stay was 2 days (IQR 1 – 4 days). Postoperative complications occurred in 5 patients (7%). These complications included two intra-abdominal abscesses after complicated appendicitis, wound dehiscence after excision of a thigh sarcoma, small bowel obstruction after an enterectomy for blunt abdominal trauma, and upper extremity seroma after osteosarcoma resection. Readmission occurred in 4 patients (6%), which included two intra-abdominal abscesses, wound dehiscence, and small bowel obstruction, as mentioned above. Reoperation occurred in 4 patients (6%), which included 2 percutaneous drain placements for intra-abdominal abscesses, complex wound closure after wound dehiscence, and diagnostic laparoscopy converted to laparotomy following small bowel obstruction. There were no postoperative deaths.

Table 2
Operative details.

Surgical Specialty	
General Surgery	45 (68%)
Orthopedics	7 (11%)
Otolaryngology	4 (6%)
Ophthalmology	3 (5%)
Urology	2 (3%)
Plastic Surgery	2 (3%)
Obstetrics and Gynecology	1 (2%)
Neurosurgery	1 (2%)
Gastroenterology	1 (2%)
Top Surgical Diagnoses	
Uncomplicated Appendicitis	23 (35%)
Complicated Appendicitis	8 (12%)
Extremity fracture	6 (9%)
Soft tissue abscess / Foreign Body	5 (8%)
Intussusception	3 (5%)
Pyloric Stenosis	3 (5%)
Testicular Torsion	2 (3%)
Volvulus	2 (3%)
Top Surgical Procedures	
Laparoscopic Appendectomy	31 (47%)
Laparotomy	7 (11%)
Extremity fracture fixation	6 (9%)
Incisions & Drainage / Foreign Body Removal	5 (8%)
Pyloromyotomy	3 (5%)
Surgical Site	
Abdomen – Open	8 (12%)
Abdomen – Minimally invasive	34 (52%)
HEENT	9 (14%)
Other	15 (23%)
Operating room time (minutes)	129 (102 – 207)
Surgical time (minutes)	38 (27 – 66)
Estimated blood loss (mL)	3 (0 – 5)

Table 3
Postoperative outcomes.

Postoperative admission / resources	
Floor resources	33 (50%)
Same Day Discharge	27 (41%)
ICU resources	6 (9%)
Postoperative oxygen support (%),	
None	61 (92%)
Non-invasive nasal cannula	2 (3%)
Invasive mechanical ventilation	3 (5%)
Postoperative prophylactic anticoagulation (%),	
None	58 (83%)
Enoxaparin	11 (17%)
Mean Hospital length of stay	2 (1 – 4)
Postoperative complication	5 (7%)
Mortality	0 (0%)
Readmission	4 (6%)
Reoperation	4 (6%)

4. Discussion

COVID-19+ children undergoing surgery at a free-standing children's hospital in the 4th largest metropolitan area in the nation presented primarily with general surgery pathology with postoperative complications and mortality occurring less frequently than the adult population [1, 3]. A majority of our patients were Hispanic White males > 6 years of age without comorbidities. Compared to similar pediatric cohort studies in the United States, our results show COVID-19 occurred more frequently in the Hispanic population [5, 8, 9]. Less than 10% of patients were <1 year old with pyloric stenosis diagnosed for 3/5 patients. Additionally, a majority of our patients were previously healthy without any significant pulmonary symptoms at presentation with <10% of patients with pre-existing cardiopulmonary disease. Therefore, these findings may not be generalizable to the neonatal or infant population or patients with significant underlying cardiopulmonary disease. The lack of preoperative pulmonary complaints likely led to the overwhelming majority of patients having no preoperative chest imaging. When evaluating preoperative symptomatology, patients with abdominal pain, nausea and/or vomiting were significantly more likely to present with gastrointestinal pathology or were operated on by a general pediatric surgeon. Similarly, patients with non-gastrointestinal related pathology were significantly more likely to present without COVID-19 related symptoms. While gastrointestinal-related symptoms have been described in the literature as an indicator of COVID-19 infection [23–25], it is difficult to discern whether presenting symptoms were secondary to the underlying surgical pathology or to COVID-19 diagnosis in our cohort. An important consideration with our results is the infrequent pulmonary symptomatology in our population. The largest study to date evaluating adult surgical patients reported 38% of patients with 30-day mortality and 76% of patients with pulmonary complications had preoperative dyspnea. Similarly, 27% of patients with 30-day mortality and 63% with pulmonary complications had preoperative cough [3]. These results highlight that the presence of preoperative pulmonary symptoms may correlate with the severity of the disease and possibly predict postoperative morbidity and mortality. Therefore, providers should consider whether gastrointestinal or pulmonary symptoms are dominant at the time of presentation to help guide recommendations for surgical treatment. Additionally, approximately one quarter of patients presented without any traditional COVID-19 symptoms, which further supports the growing body of literature suggesting children typically experience a milder form of COVID-19 [5, 6, 26–28]. It also supports a preoperative protocol to perform universal screening. Universal screening included all elective, outpatient cases, which represented <10% of patients in our cohort. Over our study period >100 elective cases were cancelled due to positive preoperative results. Surgeons proceeded with cases based on both surgeon preference with approval from operative leadership and our operative classification system (Fig. 1). Preoperative laboratory testing was primarily limited to complete blood count with the most notable finding of lymphopenia, a known lab abnormality related to COVID-19 [29, 30].

Pediatric general and orthopedic surgeons performed a majority of all surgical cases. The most common surgical pathologies were appendicitis, extremity fractures, and soft tissue abscess or foreign bodies, while the most common procedures were laparoscopic appendectomy, laparotomy, incision and drainage of soft tissue abscesses, and extremity fracture fixation. Uncomplicated appendicitis was diagnosed almost three times as often as complicated appendicitis. We had expected worsened disease severity for all appendicitis patients during the pandemic secondary to delayed presentation due to reluctance to seek medical care, as evidenced in recent reports [31]. However, the proportion of simple versus complicated appendicitis did not differ from our historical institutional trends at the population level. Prior to the pandemic, the nonoperative success rate of appendicitis in the pediatric population has ranged from 62 – 76% [32–35]. Several authors have described performing nonoperative management of appendicitis during the current pandemic [36,37]. Kvasnovsky et al. reported over half of all appendicitis cases failed initial nonoperative management, which was defined as persistence of pain, fever, or emesis after 12 – 24 h [36]. Of the 30 patients undergoing surgical intervention, over half were diagnosed with uncomplicated appendicitis. The authors explain the reason for their lower success rate was due to the majority of patients not meeting published guidelines for nonoperative management and the need for prompt decision-making to proceed with surgery if nonoperative management appeared to be failing within 12 – 24 h of admission to preserve available hospital resources. Ultimately, if hospital resources are not significantly strained at a given institution, our results suggest initial surgical intervention can be considered. An additional negative consequence of possibly delaying surgical intervention is increasing length of stay; however, Kvasnovsky et al. showed that initial failed nonoperative management only increased median length of stay by approximately 6 h [36]. At our institution, we continued surgical care for appendicitis with emphasis on same day discharge from the recovery room to decrease hospital length of stay.

Another concern in the surgical community during the COVID-19 pandemic is possible provider contraction of SARS-CoV-2 during aerosol generating procedures (AGP), specifically laparoscopic procedures. Anecdotally, some institutions have resorted to performing common minimally invasive procedures, such as appendectomy and pyloromyotomy, via open approach to eliminate the risk associated with AGP. The European Society of Pediatric Endoscopic Surgeons published guideline recommendations related to minimal invasive surgery, which we incorporated in our perioperative care protocol, such as utilizing closed-system CO_2 insufflation and limiting use of laparoscopic electrocautery [38]. An advantage of continuing to perform minimally invasive surgery when feasible is to minimize hospital length of stay for COVID-19+ patients. In our cohort, patients undergoing abdominal minimally invasive surgery had an expected shorter hospital length of stay compared to open abdominal surgery. Similarly, performing minimally invasive can allow for same day discharge, as was possible for > 40% of our COVID-19+ patients. An additional recommendation for AGP is limiting the time period of aerosolization. Only three surgical pathologies were treated laparoscopically: appendicitis, pyloric stenosis, and ovarian torsion, which collectively had median surgical time <40 min. However, a counterargument can be made to defer interventions if patients require a prolonged hospital length of stay to reserve hospital resources and potentially protect providers from possible contraction. Ensuring provider safety is of paramount importance when creating and implementing triage/classification algorithms to guide surgical decision-making and its timing. Our classification system (Fig. 1) was implemented in the spirit of delivering necessary care and to do so while protecting providers. Many factors play a role including the type of surgery and expected postoperative resource utilization. Nevertheless, a key element is the robustness of PPE supply as one category to minimize provider exposure risk for those urgent/medically necessary surgeries that must proceed. We believe that with appropriate AGP protocols and robust surgical PPE supply the benefits of minimally invasive surgery with respect to resource utilization, provider safety, and patient care outweigh the risks.

Several adult single center studies and case series have identified increased postoperative morbidity and mortality secondary to COVID-19 [1–3]. Postoperative morbidity is primarily related to cardiac and pulmonary complications with some studies reporting 50% of patients experience postoperative pulmonary complications with a wide range of postoperative mortality from 24% to 75% [1–3]. There is currently limited evidence suggesting whether similar postoperative morbidity and mortality occurs in children undergoing surgery [10–13]. Our results highlight a substantially smaller proportion of children required postoperative ICU resources compared to adults. Of the six patients requiring ICU resources, three patients required postoperative mechanical ventilation with extubation to room air or nasal cannula within 48 h. Of these three patients, only one required preoperative oxygen support with nasal cannula; however, this was the patient's baseline respiratory support due to pre-existing lung disease. Interestingly, none of these patients had significant pulmonary symptoms at presentation, and the decision for postoperative mechanical ventilation was made based on intraoperative findings and concern for potential worsening respiratory status after surgery. The remaining three patients were admitted to the ICU for hemodynamic monitoring and resuscitation with either blood products (oncologic patient with pancytopenia who presented with hematochezia secondary to ileocolic intussusception) or crystalloid (septic shock secondary to complicated appendicitis) without the need for vasopressors. Therefore, the ICU admission for only half of the patients was primarily driven by COVID-19. And, the three patients requiring postoperative invasive ventilation had no significant postoperative pulmonary complications.

A possible explanation for the favorable outcomes is pediatric patients experience a milder form of COVID-19 than adults. A recent Lancet article compared postoperative pulmonary complications and 30-day mortality between adult surgical patients with confirmed perioperative COVID-19 [3]. Patients with postoperative pulmonary complications had a significantly higher rate of preoperative cough (63%), dyspnea (76%), fatigue (70%), fever > 38°C (59%), and myalgia (73%) than patients without pulmonary complications. In contrast, our pediatric cohort presented with limited respiratory symptoms and only one patient received preoperative respiratory support. Beyond postoperative pulmonary complications, the growing body of COVID-19 literature has identified two additional concerning pathologies: a hypercoagulable state [39–42] and multi inflammatory syndrome in children [8,9]. Postoperative prophylactic anticoagulation was initiated in approximately one third of all hospitalized children without any patients experiencing a postoperative thrombotic complication. Postoperatively at our institution, the hematology team is consulted to evaluate COVID-19 patients for risk of postoperative thrombotic complications given the increased hypercoagulable state. If the patient has more than one of the following risk factors: decreased mobility, obesity, D-Dimer >2 times the upper limit of normal, and laboratory evidence of ongoing inflammation with elevated C-reactive protein and fibrinogen, the patient is started on prophylactic anticoagulation to decrease the risk of thrombotic complications. Finally, the only postoperative complications requiring readmission or reoperation were more indicative of the primary surgical pathology than COVID-19, again likely related to the overall healthy pediatric population in the cohort with limited severity of COVID-19.

Our study is limited as a single center review; however, it is the first study evaluating postoperative outcomes of children with SARS-CoV-2 requiring surgical care. Also, a majority of our patients were healthy children with minimal pulmonary symptoms, limiting generalizability to pediatric patients with significant comorbidities or pulmonary symptoms. Future multi-institutional studies will need to be performed to further confirm the limited morbidity related to COVID-19 and children's surgery. Future studies should also investigate the role of COVID-19 in specific surgical pathologies, such as appendicitis. Our findings may help inform the development of pediatric-specific perioperative algorithms in other settings and contribute to our understanding of COVID-19 in the pediatric population.

5. Conclusion

COVID-19+ children requiring surgery treated at a free-standing children's hospital have a favorable postoperative course and short-term outcomes. These findings suggest that COVID-19+ children have a less severe postoperative complication and mortality profile compared to COVID-19+ adult surgical patients. Our results may help guide decision making and inform guidelines around access to pediatric surgical care during the pandemic and other resource-constrained scenarios.

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