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Pediatric surgery during the COVID-19 pandemic

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Abstract

The coronavirus disease 2019 (COVID-19) pandemic has had a major impact on pediatric surgery. The infection is often asymptomatic and atypical in children, while overlapping presentations with other infectious diseases generate additional diagnostic challenges. The high probability of missed pediatric cases and the invasive nature of surgery generate great concern for widespread transmission in this setting. Current guidelines suggest that triage of cases should be made on a case-by-case basis by a multidisciplinary team of experts. Decision-making can be assisted by classifying cases as elective, urgent, or an emergency according to the risks of delaying their surgical management. A workflow diagram should ideally guide the management of all cases from admission to discharge. When surgery is necessary, all staff should use appropriate personal protective equipment, and high-risk practices, such as aerosol-generating tools or procedures, should be avoided if possible. Furthermore, carefully designed organizational protocols should be established to minimize transmission while ensuring the uninterrupted operation of pediatric surgery units. For example, surgical teams can be divided into small weekly rotating groups, and healthcare workers should be continuously monitored for COVID-19 symptoms. Additionally, team protocols in the operating room can optimize communication and improve adherence to personal protective equipment use. Isolated operating

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rooms, pediatric intensive care units, and surgical wards should be specifically designed for suspected or confirmed COVID-19 cases. Finally, transportation of patients should be minimal and follow designated short routes. All these measures can help mitigate the effects of the COVID-19 pandemic on pediatric surgery units.

Key Words: Pediatric surgery; COVID-19; SARS-CoV-2; Coronavirus; Emergency surgery; Personal protective equipment

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Core Tip: The coronavirus disease 2019 (COVID-19) pandemic has had a major impact on pediatric surgery. The diagnostic challenges in the pediatric population and the invasive nature of surgery generate concern for widespread transmission. Each case should be assessed individually, categorized by urgency and managed according to a predesigned workflow diagram. All staff should use appropriate personal protective equipment and high-risk practices should be avoided. Protocols for organization of the surgical team and hospital infrastructure should be established to maximize safety and efficiency, while minimizing transmission. All these measures can help mitigate the effects of the COVID-19 pandemic on pediatric surgery units.

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CORONAVIRUS DISEASE 2019: A WORLDWIDE PANDEMIC

Several pneumonia cases of unknown etiology were reported on December 31, 2019 in the city of Wuhan, China. A novel coronavirus was soon identified to be the causative agent^[1,2]. The virus was provisionally named 2019-nCoV and was later renamed as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by the International Committee on Taxonomy of Viruses^[3]. On January 30, 2020, the World Health Organization declared the outbreak a "Public Health Emergency of International Concern" following rapid transmission in multiple countries and named the disease "coronavirus disease 2019" (COVID-19) 12 d later^[4,5]. By March 11, 2020, COVID-19 was officially declared a pandemic^[5]. This outbreak has affected multiple aspects of healthcare and patient populations, including children requiring a surgical procedure.

DIFFERENCES IN COVID-19 BETWEEN CHILDREN AND ADULTS

Although some patients are asymptomatic^[6], the presentation of COVID-19 typically includes fever, cough, myalgia and fatigue, while some patients may also experience dyspnea, productive cough, gastrointestinal symptoms, and thrombotic complications^[7-10]. The disease is mild in most cases (> 80%), but severe disease develops in a considerable number of patients (approximately 14%), while nearly one-third of patients with severe disease are in a critical condition. The overall case-fatality rate was initially estimated to be 2.3% by the Chinese Center for Disease Control and Prevention, although a precise determination of the case fatality rate still cannot be made^[6,11-13]. However, this rate is estimated to be approximately 50% in patients diagnosed with severe COVID-19^[6]. Increasing age and underlying comorbidities are thought to be associated with inferior outcomes, including severe disease, admission to the intensive care unit (ICU), and death^[7,14]. Transmission of the virus mainly occurs *via* contact of mucosal surfaces with infectious respiratory droplets, similar to other respiratory viruses^[15,16]. Wölfel *et al*^[17] reported that although throat and lung-derived samples showed signs of infectious SARS-CoV-2, fecal samples yielded only viral RNA, but not an infectious virus. Also, the virus was not detected in blood and urine^[17]. However, the possibility for fecal-oral, parenteral, or aerosol transmission

cannot be excluded^[16,18,19]. Recent data have shown that the transmission potential of the virus might be much higher than previously estimated^[20].

Based on the first few pediatric case series, it was speculated early on that COVID-19 affects children differently compared to adults^[21,22]. These assumptions were later confirmed by a large epidemiological study on Chinese pediatric patients; the proportion of cases in a critical condition was much lower (< 6%) compared to the general population, and only one death was documented among 2143 children^[23]. In another report from China, 15.8% of pediatric patients with COVID-19 had an asymptomatic infection (27 out of 171), compared to 1% in the general population, as reported by the Chinese Center for Disease Control^[6,24]. In addition, less than half of the children experienced fever at any time during the course of their illness, while 12 of 171 had imaging findings consistent with pneumonia but were asymptomatic^[24]. The high number of asymptomatic cases and the frequent absence of classic symptoms indicate that COVID-19 has a predilection for atypical presentation in children. In the same study, only three children – all of whom had underlying comorbidities – were admitted to the ICU, confirming the previous reports of decreased COVID-19 severity and improved outcomes in the pediatric population^[24]. The differences between pediatric and adult patients might be explained by immaturity of the immune system and differences in the expression of the viral cell receptor in children^[23,25]. Despite the lack of widespread testing for COVID-19, early reports showed a disproportionately low prevalence of the disease in children compared to adults^[6,7]; this could potentially be attributed to the lower overall exposure of children to infected individuals rather than to potential resistance to the virus^[26]. In addition, younger children show less severe symptoms than adolescents^[27]. However, this low prevalence and lack of typical clinical manifestations raise concerns about the potential role of the pediatric population in the widespread transmission of the virus^[28].

A number of upper respiratory infections are prevalent among children, with symptoms resembling COVID-19. It is essential to suspect other viral or bacterial infections as well and perform tests, in order to identify possible alternative explanations for their symptoms, or even cases of coinfection^[29,30]. Differential diagnosis might include viral disease from influenza virus, parainfluenza virus, adenovirus, respiratory syncytial virus, rhinovirus, other SARS viral infections, but also bacterial infections, which include *Mycoplasma pneumoniae*, *Chlamydia pneumoniae*, and other bacterial-related pneumonias. In addition, the co-infection of SARS-CoV-2 and other respiratory pathogens should not be excluded^[30]. Therefore, a diagnostic challenge is apparent in pediatric patients. The present guidelines suggest that all children should be screened for possible symptoms of COVID-19 infection upon arrival at the hospital^[31].

IMPACT AND RESPONSE OF THE SURGICAL COMMUNITY

Due to their invasive nature, surgeries may facilitate widespread disease transmission between patients and healthcare workers. Super-spreading events of SARS-CoV-2 have also been described in surgical departments^[32]. Apart from the high risk of transmission, it has been hypothesized that operation-associated stress may predispose COVID-19 patients to worse clinical outcomes through immune dysregulation^[33]. The surgical community has promptly responded to this imminent danger by taking decisive measures. More specifically, the American College of Surgeons (ACS) has issued guidelines suggesting that all elective procedures should be postponed or performed in an ambulatory surgery center if feasible. The only exceptions are most of the oncological and high acuity surgical procedures^[34]. Non-operative management should also be considered when appropriate. Decision-making during triage of elective surgeries should ideally be guided by a multidisciplinary team of experts^[34,35]. When operations are deemed to be non-elective, healthcare workers should use appropriate personal protective equipment (PPE), and the number of medical professionals involved in patient care should be minimized. Additional protection should be used if the operation involves a patient suspected of having COVID-19 or if it generates an aerosol (e.g., intubation)^[36]. However, the liberal use of specialized PPE, such as N95 masks, may quickly lead to a shortage of supplies^[37]. The Center for Disease Control has introduced a step-wise optimization strategy for the use of facemasks, aiming to counterbalance any potential shortage of supplies^[38]. Various individual surgical centers have implemented additional administrative measures in an effort to further decrease transmission; these include segregating healthcare workers into working groups (e.g., weekly rotating teams of attending and

resident physicians), increasing surgical turnaround times, implementing technology for communication purposes, and designing isolated operating rooms (ORs) for COVID-19 patients^[29,39-41].

SPECIFIC CONSIDERATIONS FOR PEDIATRIC SURGERY

Classification of cases by surgical acuity

The pediatric surgery community has been affected to a similar degree. Apart from the previous general recommendations that apply to all surgical subspecialties, the ACS has also issued guidelines pertaining specifically to pediatric surgery^[42]. Common diagnoses have been classified into three main categories according to the urgency of their surgical management. Cases are categorized as emergency, urgent, or elective according to the risk of delaying their surgical management, which is life-threatening, detrimental, or negligible, respectively. Examples from every category are presented in [Table 1](#). As for all surgeries, the ACS emphasizes that decision-making for pediatric cases should not solely depend on this classification. Rather, it should be the result of careful clinical judgment, ideally guided by a multidisciplinary panel of experts. In general, surgeries should not be postponed if their delay may cause harm to patients, prolong their hospitalization, or predispose them to re-admission. Emergency cases and many urgent cases, according to the previous classification, are examples where postponement of surgical management would have adverse outcomes for the vast majority of patients. Aside from assessing the risks and benefits for the patients, clinicians should also consider the risk of disease transmission to themselves and the impact on hospital resources^[42]. Healthcare workers, including pediatric surgeons, are considered a high-risk population for COVID-19^[43,44]. An assessment on a per case basis seems to be necessary when taking into account the complex interplay between all these parameters and the unique characteristics of COVID-19 in the pediatric population.

In many cases, surgeons are called to alter their management of acute surgical cases, according to the available resources. One such case is acute uncomplicated appendicitis. A recent meta-analysis showed that appendectomy not only has a higher success rate but also a reduced length of hospital stay compared to conservative treatment with antibiotics; in fact, about 10% of the children undergoing a non-operative treatment will eventually require appendectomy before discharge^[45]. Therefore, during the COVID-19 pandemic, earlier discharge achieved with surgery minimizes the risk of virus transmission in healthy children, and increases the availability of beds and healthcare personnel. In some cases, same-day discharge could even be considered postoperatively^[46]. However, the non-surgical approach presents some important advantages as well, as it reduces the chance of infection in physicians and patients in the OR and during aerosol-generating procedures, such as intubation^[47]. PPE and ORs are not utilized, and therefore are available for other emergent procedures^[48]. In such debatable cases, each hospital should provide its own protocol based on the availability of PPE, wards, Pediatric Intensive Care Units (PICU), ORs, and specialized personnel.

Availability of personnel, facilities, and equipment

Although guidelines have been published aiming to guide planning and operational protocols in children during the COVID-19 pandemic^[49,50], each hospital should establish and follow an internal contingency plan, based on variables such as the COVID-19 status of the local population at each given moment, the available infrastructure and the proximity of other pediatric hospitals that serve the same population.

Infrastructure and logistical preparedness play a pivotal role in order for a tertiary hospital to become a surgical referral center for children with suspected and confirmed COVID-19. Negative-pressure ORs^[51,52] and isolated recovery rooms, PICU beds, and wards are required^[49]. Furthermore, designated transportation routes are warranted from the ambulance bay or dedicated entrance to the OR, and from there to the isolated recovery room, PICU bed or ward. This planned itinerary should be isolated from high-traffic areas of the hospital and should not traverse the general, non-COVID-19 ORs^[52,53].

Another important issue that challenges all healthcare operations during the pandemic is the availability of healthcare personnel. Surgical teams present at the hospital should be smaller, with only a percentage of pediatric surgeons, anesthesiologists, and specialized nurses covering the emergency shift, with a second

Table 1 Classification of common diagnoses and procedures in pediatric surgery according to their urgency by the American College of Surgeons

Emergency		Urgent	Elective
Ischemia	Testicular/ovarian torsion	Any abscess requiring incision and drainage	Reconstruction Anorectal anomaly after diversion
	Limb-threatening ischemia	Biliary atresia	Hirschsprung disease after diversion
Trauma	Trauma with uncontrolled bleeding	Symptomatic cholelithiasis	IBD after diversion
	Penetrating trauma	Most oncologic surgeries	Chest wall
Acute intestinal obstruction	Hypertrophic pyloric stenosis	Acute IBD exacerbation requiring resection	Enterostomy closure
	Intussusception non-responsive to radiographic reduction	Any diagnosis requiring gastrostomy for hospital discharge	Removal of an uninfected vascular access device
	Intestinal malrotation	Insertion of a vascular access device	Orchiopexy
	Incarcerated inguinal hernia	Symptomatic inguinal hernia	Asymptomatic inguinal hernia
Congenital malformations	Anorectal anomalies or Hirschsprung disease requiring intestinal diversion		Splenectomy for hematologic disease
	Intestinal atresia		Excision of a breast lesion
	Esophageal atresia with tracheoesophageal fistula		Fundoplication
	Congenital diaphragmatic hernia (symptomatic)		Bariatric surgery
Upper airway/GI foreign body ingestion			Cholecystectomy for biliary colic
Acute appendicitis			Asymptomatic choledochal cyst repair
Intestinal perforation			Branchial cleft cyst/sinus excision
Any diagnosis requiring ECMO			Thyroglossal duct cyst excision

IBD: Inflammatory bowel disease; GI: Gastrointestinal; ECMO: Extracorporeal membrane oxygenation.

backup team on stand-by at home^[54]. In areas with high COVID-19 prevalence, two separate surgical teams can be formed, one for children with COVID-19 and a second one for healthy children requiring surgery. In that instance, each team should be isolated as much as possible from the other to minimize cross-transmission and maximize operational continuity^[53]. Reasonable shift implementation is also required to ensure the safety of healthcare workers and prevent burnout^[55]. All healthcare workers should be monitored daily prior to their shift, and are encouraged to monitor themselves throughout the day for the presence of fever or other COVID-19-related symptoms, such as cough or fatigue^[49,53]. An organized “sick leave” policy should also be established in case a health care worker presents with symptoms suggestive of COVID-19^[31].

Because children commonly present with mild or no symptoms – as mentioned above^[53] – SARS-CoV-2 transmission from children to healthcare workers has been reported^[21]. Therefore, PPE is suggested in all cases of healthcare workers interacting with children. In cases of a potential or confirmed COVID-19 patient needing surgery, the responsible surgical team should use disposable N95/FFP2 respirators, double gloves, goggles or visors, surgical caps, shoes, and full-body gowns^[48]. Additional Powered Air-Purifying Respirators are required for the anesthesia team to minimize aerosol exposure during intubation and extubation^[48,53]. Healthcare workers are explicitly required to use N95 respirators according to the United States^[38], Chinese^[56], and Spanish guidelines^[57].

To ensure effectiveness in prevention, training of healthcare workers is of the utmost importance and mask fittings and PPE training should be arranged on a regular basis for all personnel. In addition, simulations of surgical scenarios while wearing all PPE equipment (“dress rehearsals”) should be applied to familiarize the teams with appropriate PPE protocols and troubleshooting in advance^[47,52]. An issue that presented in a simulation scenario was the noise reduction by Powered Air-Purifying Respirators worn by the anesthesia team, which impaired effective oral

communication. This was circumvented by the use of a whiteboard for communicating essential information during the operation^[53]. It was shown that physicians were more likely to become infected during the donning and doffing procedures than when actually taking care of infected patients^[58]. Thus, the designation of a colleague as a “provider” who can help and oversee the donning and doffing procedures not only reduces the likelihood of contamination of healthcare workers^[50,51] but also reduces the anxiety around a possible infection^[48].

Workflow organization for suspected and confirmed cases

Standardized protocols^[53] have been published for adult operations and should be adapted to pediatric surgery as well. If possible, all pediatric patients with respiratory symptoms or those undergoing high-risk procedures should be assessed for their COVID-19 status prior to the operation^[50]. Each patient can be tested for the SARS-CoV-2 RNA *via* rapid reverse transcription-polymerase chain reaction (RT-PCR) of an oropharyngeal swab or sputum sample, with a turnover time of 2 to 4 h^[47]. However, early intervention is crucial in urgent or emergency cases for the survival of the child. If the RT-PCR results are not accessible soon enough, the surgery team should proceed as if the child has COVID-19^[52]. In such cases, an early assessment for COVID-19 can be made based on contact history, clinical symptoms, or findings on chest imaging^[47].

The equipment and surgical personnel inside the OR should be kept to a minimum to reduce potential exposure to and transmission of SARS-CoV-2^[53]. The use of electrocautery and high-speed tools, such as ultrasonic scalpels, should be limited as much as possible because there are reports of aerosol viral spread^[31,59] from viral particles present in the smoke produced by electrical cauterization^[21,60,61]. On the other hand, the extensive use of a suction machine is advised to limit smoke and aerosol production^[49,61]. These practices have already been reported in case series, where laparotomy was preferred over laparoscopy for the management of acute abdomen to minimize operating time and decrease the risk of contamination through airborne aerosol transmission, by relieving the pneumoperitoneum^[52]. Despite concerns, minimally invasive procedures are considered safe, as the risk of transmission from intraoperative aerosolization is minimal, and the pneumoperitoneum could be evacuated through a protective filtration system^[62,63]. Nevertheless, the safest approach in terms of aerosol spread is the one that the surgeon is most comfortable with, and can operate for a shorter period and in the safest possible way^[48,49]. At the end of the operation, any unused drugs and consumables should be considered as “potentially contaminated” and thus should be discarded^[49]. If a negative-pressure OR is not available, COVID-19 suspected or positive cases should be planned as the last cases of the day if possible, whereas in emergent situations, an adequate period of time (approximately 30 min) should be set for air exchange after the procedure^[48].

After the operation, children with confirmed COVID-19 should be transferred to an isolated ICU or ward designated for COVID-19 cases, where a dedicated COVID-19 team takes care of infected patients^[31,52]. The designated team should not travel to other in-hospital places to minimize the possible spread of the disease and should perform close follow-up of the pediatric patients, considering that children positive for SARS-CoV-2 have a higher postoperative mortality rate^[52]. If transportation of a patient is required, it is advisable that the patient is accompanied by security personnel to ensure that the route is clear of other patients, visitors, or personnel^[53].

In patients suspected of having COVID-19, the patient should not be transported to the designated COVID-19 ward or ICU immediately during the postoperative period but should remain in an isolated recovery room, while awaiting the final RT-PCR results for COVID-19. After a positive or negative result, the pediatric patient will then be transported to COVID-19 or non-COVID-19 units accordingly.

The hospital should limit visitors to only one person at a time, essential for the pediatric patient’s physical or emotional well-being and care, such as one parent, guardian, or primary caregiver^[31,64]. In some tertiary hospitals, a “parent pass” is provided to one parent at a time, to accompany their inpatient child^[64]. All visitors should actively be assessed prior to their entrance to the hospital for fever and other COVID-19 signs and symptoms^[31,53], and should be advised to wear a protective face mask while in the hospital^[31]. It should be noted that in order for the visitor to be allowed into the hospital, they must not show any COVID-19 symptoms^[64].

After departure from the hospital, postoperative follow-up should preferably be in the form of a video-call – provided that the postoperative course is normal – to minimize unnecessary exposure, or the follow-up can be rescheduled to a future date. Such options have been previously suggested in the follow-up of surgical and pediatric patients^[29,65,66]. A specialized team could visit patients at home for suture removal and wound treatment. Postoperative wound management can also be

performed by parents in some cases, following an adequate “home skills program”^[67]. In surgical cases, the use of absorbable sutures could even be considered to avoid the pediatric patient returning to the hospital for their removal. Nevertheless, the final decision on the follow-up lies with the pediatric surgeon and is decided on a case-by-case basis. In case any atypical symptoms or complications occur, the child’s family should contact the surgeon without hesitation.

CONCLUSION

In conclusion, COVID-19 has had a major impact on pediatric surgery. The diagnostic challenges of COVID-19 in children have generated great concern for widespread transmission. The surgical community has responded by establishing guidelines to ensure the continued operation of pediatric surgery units and minimize transmission in this setting. All cases should be assessed individually and managed according to pre-established protocols. Management can be assisted by classifying cases as elective, urgent, or an emergency based on the risks associated with delaying surgical treatment. Surgical teams should be organized in a way that maximizes safety, and hospital infrastructure should be appropriately modified to accommodate the needs of COVID-19 patients. These measures can mitigate the effects of this pandemic by minimizing transmission and adverse outcomes, while also safeguarding the appropriate management of pediatric surgical cases.

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