

Systematic Review

Paediatric surgery and COVID-19: urgent lessons to be learned

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Abstract

Background: The dissemination of scientific data on coronavirus disease 2019 (COVID-19) continually builds but, in April 2020, could not keep up with the spread of the disease. Through technology, surgeons in Italy and the UK, representing both peak and pre-peak infective time zones, were able to communicate so that the urgent lessons on the huge expected demands of care learned in Italy could be brought to the UK in advance. This paper specifically discusses the issues related to paediatric surgery, currently under-reported in the literature.

Methods: The aim of this paper is to conjoin experience from the field to provide a framework for a safe assessment and treatment of paediatric patients by adopting a systemic approach aimed at reducing the risk of contamination. We reviewed the processes and good practices that were undertaken in contexts of emergency such as in Italy and the UK and then adapted them within the Systems Engineering Initiative for Patient Safety (SEIPS) framework to provide an assessment of how to reorganize the services in order to cope with an unexpected situation. The SEIPS model is the adopted theoretical framework, which allows to analyse the system in its main components with a human factors and ergonomics (HFE) perspective.

Results: The results introduce some of the good practices and recommendations developed during the emergency in the surgical scenario with a focus on the paediatric patients. They represent the lessons learned from the combination of the little existing evidence of literature and the experience from surgical teams who responded in an impromptu and unrehearsed way.

Conclusions: Lessons learned from the frontline 'on the fly' during COVID-19 emergency should be consolidated and taken into the future. In order to prepare proactively for the next phases and get ahead of the curve of these hospital accesses, there is a need for a risk assessment of the new clinical pathways with a multidisciplinary approach centred on HFE with the adoption of the SEIPS model and an involvement of all the surgical teams.

Key words: paediatric surgery, human factors, risk management, COVID-19

Introduction

The world population is divided into those geographical areas that are pre-, peri- and post-peak severe acute respiratory syndrome coro-

navirus 2 (coronavirus disease 2019 [COVID-19]) infection. At the start of the outbreak, COVID-19 was thought to seriously affect only vulnerable or older people, and the focus on children had been

minimal. By following guidelines devised for adult patients, the treatment of our younger patients may not have been optimal and requires clarity prior to a resurgence in the virus as lockdowns are relaxed. Scientific evidence is slowly increasing, but many uncertainties still exist. As Italy reeled from the first wave and the UK awaited peak levels, clinicians could not afford to wait for future data and guidelines in order to protect our young patients, and instead turned to those who were living through peak infection at that time, in order to learn from their experience. We contend that to prepare for crises such as the COVID-19 pandemic, one needs to have a human factors and ergonomics (HFE) framework that can allow systems to design a response in a logical and safe manner. We describe a framework for paediatric surgery, which can be adapted to other clinical pathways. The presented framework will be structured around the Systems Engineering Initiative for Patient Safety (SEIPS) model [1], following the HFE approach that allows for a rational organization of the presented knowledge acquired from experience on the field, for assessment and treatment in paediatric surgery. The urgent lessons learned in China, Italy and the UK can be of great value at the global level as COVID-19 became a pandemic with high level of contagions present in all the major regions of the globe.

Methods

The aim of this paper is to conjoin experience to provide a framework for assessment and treatment. We reviewed the processes and good practices that were undertaken in contexts of emergency such as Italy and the UK and then adapted them within the SEIPS framework to provide an assessment of how to reorganize the services in order to cope with an unexpected situation. The SEIPS model provides a framework to analyse the work system and the related strategic components: people, environment, processes, technology and organization. The results introduce some of the good practices and recommendations developed during the emergency in the surgical scenario with a focus on the paediatric patient. They represent the lessons learned from the combination of the little existing evidence of literature and the experience from surgical teams who responded in an impromptu and unrehearsed way.

Results

People in the work system: presentation and testing of the paediatric vs adult patient

As with many paediatric presentations, children with COVID-19 do not necessarily follow adult patterns. In April 2020, clinicians in the UK understood at that time that fever with respiratory symptoms should arouse suspicion for COVID. In Italy, however, there were cohorts of children presenting with abdominal pains and diarrhoea masquerading as appendicitis as the presenting feature of COVID in younger children, typically up to around 6 years of age. Some children had no fever at all and, in addition to coughing, other symptoms included sore throat, nasal congestion or rhinorrhoea, and diarrhoea. Adult symptoms typically include lethargy, dyspnoea, myalgia, headache, nausea and vomiting, loss of taste or smell, and disorientation; these did not appear commonly to be present in children. Furthermore, children's blood tests had been found to be completely normal, including inflammatory markers. The communication of this pattern of illness enabled surgeons in the UK to respond appropriately, which had two effects; first, the need to suspect COVID, isolate and test children presenting with predominantly abdominal symptoms and second, confidence not to

Table 1 Clinical recommendation on testing for COVID19 in paediatric patients

Clinical recommendation

The ideal scenario, as employed in some parts of Italy at the peak of the outbreak, is that all children already in hospital, and those admitted with any condition, be tested for the virus. With cases classed as National Confidential Enquiry into Peri-operative Death level 1 or 2, or where testing is unavailable, clinical judgement defined whether a CT was indicated. Unless screening is negative, full personal protective equipment should be worn. This was relayed to the UK ahead of official guidelines being published and became the foundation of the rapidly emergent testing strategy pre-outbreak, and now is accepted as the current policy to protect children and staff.

Table 2 Socio-technical recommendations for managing the operating room space

Sociotechnical recommendations

The patient journey to and around the OR needs to be carefully monitored with limitation of access for the family and for healthcare providers.

A protocol to transfer suspected COVID-19 patients to and from theatre should be devised and simulated to minimize exposure and to maintain 'hot' zones away from COVID-free areas. The minimum number of staff should be used to maintain safety, but consider that this may include security staff to ensure smooth transfer of the patient. Staff numbers in theatre should be kept to a minimum, and for the entire surgical team, full personal protective equipment (PPE), including visors or other full eye protection, should be used unless the patient is categorically negative. Training in donning and doffing PPE should be given in advance. Surgical loupes can be worn under visors. Separate theatres for COVID-19-positive and -negative patients (hot and cold) should be used.

perform unnecessary surgery on COVID-positive children. Children, therefore, and their accompanying parent, undergo nasopharyngeal and mouth swabs to diagnose the presence of this virus, characterized first by bronchoalveolar lavage in adult pneumonia patients in China [2].

Current intercollegiate surgical guidelines for adults in the UK suggest that in a symptomatic patient requiring urgent surgery and where the COVID-19 test result is not known, a chest computed tomography (CT) is indicated to identify signs of pneumonia such as isolated or multiple patchy ground-glass opacities, effusion or enlarged lymph nodes. If a CT is not possible, a chest X-ray (CXR) should be performed. In children, however, CXR and CT changes are not always evident, but a small series of children with COVID-19 has shown a greater prevalence of peripheral halo (halo-sign) lung consolidations on CT, which is a more sensitive test in this group [3]. Coupled with the burden of such a high exposure to ionising radiation, the question of whether this is indicated in children is debatable. Screening paediatric patients with chest ultrasound could be an option, but data are lacking to support this strategy. Positive real-time polymerase chain reaction of rectal swabs in paediatric patients remained detectable well after nasopharyngeal swabs turned negative [4]. This raises the likelihood that the gastrointestinal (GI) tract can shed virus and that rectal swab testing may be better at determining the success of treatment and indeed the duration of isolation (See table 1 and 2 for recommendations).

Environment in the work system: the theatre/operating room space

From an HFE point of view, we can affirm that the operating room (OR) is a complex system in itself; there are multidisciplinary teams with the presence of not only clinical, nursing and theatre staff but also those in training, which make the space always very busy. The design of equipment interfaces and the interaction of clinicians and others with medical equipment also make COVID-19 transmission possible within this space.

As social distancing is impossible in this environment, essential communications such as the handover process outside this area is critical; this allows for the physical flow of people and the correct transmission of key information between the external units and the OR.

Processes and technology in the work system: emergency and elective surgery

Some recent work [5] underlines that the response of work systems is seriously challenged by the complexity of this emergency. The complex technologies involved together with the absence of a real expertise and of an adequate mental model in professionals creates a real crisis in the sociotechnical system. Because this pandemic was a new kind of emergency, the healthcare workers had to

compensate for the lack of an adequate mental model with adaptation and improvisation. This was especially true in emergency surgery where undeferrable performance required professionals to apply new rules to new situations but in traditional contexts. The HFE approach is an important resource to understand new categories and focus on the new interactions between the person and its environment.

In the UK, Intercollegiate General Surgery guidance [6] on COVID-19 is published on its website. It is important to mention that this guidance covers both adult and paediatric patients. Critical considerations and related recommendations for action for paediatric patients in emergency surgery are discussed as follows (see table 3). Should COVID-19 be present, the consent process and post-operative planning must reflect this in terms of a greater risk of adverse outcomes.

Most elective surgery was placed on hold because of limitation of resources and preparation. In paediatric surgery and urology, certain cases should be performed in a timely fashion for improved outcomes; delay in such will arguably impact directly on the child's future, e.g. an obstructed or infected renal tract, hernia or anorectal anomalies. We must be prepared to accept that some children's outcomes will be poorer than we would expect due to this crisis. Where consultants must regularly review their current cohort of

Table 3 Clinical recommendations for emergency surgery

Clinical recommendations

It should be noted that the criteria for the definition of ARDS and septic shock, the guidelines for the management of sepsis and septic shock and the use of non-invasive ventilation in children are different from those of adults [7].

- As children desaturate more easily during intubation, it is important to pre-oxygenate with 100% oxygen with a mask with a reservoir before intubating [7]. This process may interfere with normal hospital practice over the presence of parents during anaesthesia.
- Extra precautions when discussing the anaesthetic process to parents should be made to minimize stress for parent and child alike. Naso-gastric tube placement is an aerosol-generating procedure (AGP) and so full personal protective equipment (PPE) is required.
- At peak infection, laparoscopy and robotic surgery were contraindicated, due to the risk of aerosol formation and dissemination, unless there was a profound patient mortality risk danger of not doing so (although COVID-19 itself has not been shown to be carried by electro cautery, other viruses have [8]). Chinese and Italian [9] experience reflected this, and the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) offered guidance [10]. Much has been discussed over AGP and those medical staff at greater risk. Mitigating safety mechanisms are being advocated by various groups, for example in robotics, but it was felt that most centres would not be able to safely implement these in the time available.
- Smoke evacuation from sources such as diathermy should be cleared by filtered smoke extraction equipment, NOT by using the suction device, which further disseminates any viable virus. There is increasing and pressing demand for international guidelines to allow safe use of these technologies, as it is abundantly clear that some patient outcomes will deteriorate if open surgery remains the only option, for instance in open versus robotic radical prostatectomy. Appendicitis in children was treated either medically, with intravenous antibiotics, or by open surgery, and time will tell how effective these measures have been. Since the peak has passed in Italy and the UK, specialist devices have been utilized, such as the AirSeal system (Conmed), which clears airborne virus particles, allowing the re-commencement of minimally invasive procedures. If and when another peak COVID outbreak occurs, similar technologies will give surgeons confidence to treat children in the optimal way, while protecting themselves and other theatre staff [11].
- The establishment of an effective swallowing reflex or sensation to defecate is dependent on early learning, and surgery to correct such fundamental congenital problems cannot reasonably be delayed. This should be balanced against the risk of further unplanned surgery for complications, so more rapidly performed temporary measures may be favoured in place of more definitive, but complex and lengthier, surgery; for example, neonates receiving stoma formation in place of corrective primary surgery in anorectal conditions.
- Appendicitis can be reasonably treated, in some cases, with parenteral antibiotics with or without interval appendectomy. Clinical appraisal is vital in order not to make the situation worse for the patient.
- The airway has attracted most attention as an AGP, but endoscopic procedures are also AGPs. Guidance was required urgently for endoscopic procedures at peak infection, particularly in light of the information on gastrointestinal viral shedding, and only emergency endoscopic procedures were performed with full PPE utilised. Thankfully, updated advice following surveys of clinicians have been produced to guide endoscopists in the post-lockdown period [12].
- Oncology cases should be considered to be either emergency or urgent cases and, given appropriate safeguarding from the risks of the virus including the increased immunosuppression of this population.

patients and stratify them into order of surgical need according to local guidelines, outcome, both surgically and psychologically, must be the driving factors in this prioritization. Should sufficient capacity be available in the hospital to support the full patient pathway (considering availability of beds, aftercare, possible complications and nurse specialist/outpatient support), then less urgent cases can be considered.

Surgeons and other health care professionals generally make decisions based on the best available evidence. At peak infection, there was a lack of reliable evidence about COVID-19, which made it difficult to determine best practices in offering care to paediatric patients. However, it was essential in that historic moment to try and offer safe, reproducible care through the scientific community and learn from each other. The American College of Surgeons' guidelines listed below helped this task in regards to paediatric surgery [13].

1. The goal is to provide timely surgical care to children with emergent and urgent paediatric surgical issues while optimizing patient care resources (e.g. hospital and intensive care

unit beds, personal protective equipment, ventilators) and preserving the health of caregivers.

2. There is no substitute for sound surgical judgement
3. Surgery should be performed only if delaying the procedure is likely to prolong hospital stay, increase the likelihood of later hospital admission or cause harm to the patient.
4. Children who have failed attempts at medical management of a surgical condition should be considered for surgery to decrease the future use of resources.
5. Multidisciplinary shared decisions regarding surgical scheduling should be made in the context of available institutional resources that will be variable and rapidly evolving.
6. Telemedicine and teleconsultation services should be used for patient and physician interaction when available.

The following list of examples of emergency, urgent and elective cases is not exhaustive and may vary slightly from country to country (see table 4).

Table 4 Examples of emergency, urgent and elective cases in pediatric patients during COVID-19

Emergency and urgent cases, where delay is life-threatening	Urgent cases, where delays of days to weeks may be detrimental	Elective cases, where delay results in minimal patient risk
<ul style="list-style-type: none"> • Acute intestinal obstruction (abnormal intestinal rotation; incarcerated inguinal hernia; pyloromyotomy for hypertrophic pyloric stenosis; intussusception reduction not amenable to radiographic reduction (in itself, an AGP)) • Extracorporeal life support • Intestinal perforation • Necrotizing enterocolitis with perforation • Trauma with uncontrolled haemorrhage or penetration • Ischemia • Testicular torsion, ovarian torsion • Limb ischemia from trauma or iatrogenic causes • Most congenital anomalies (oesophageal atresia with tracheo-oesophageal fistula; symptomatic congenital diaphragmatic hernia; intestinal atresia; intestinal diversion for anorectal anomalies; intestinal diversion for Hirschsprung disease not improved with irrigations) • Appendectomy for acute appendicitis (depending on institutional resources outpatient or short stay should be considered for uncomplicated appendicitis in order to maintain hospital beds; depending on available resources patients with complicated appendicitis should receive parenteral antibiotics and percutaneous drainage if an abscess is present) • Oesophageal or tracheal foreign body ingestion (as an AGP, special note should be made of higher risk of COVID-19 for endoscopic procedures) 	<ul style="list-style-type: none"> • Most cancer surgery (solid tumours—initial biopsy, resection following neo-adjuvant therapy; consideration should be given for continuing chemotherapy in patients who will require postoperative intensive care or ventilation) • Portoenterostomy for biliary atresia with jaundice • Abscess incision and drainage • Resection or diversion for acute exacerbation of inflammatory bowel disease not responsive to medical management • Vascular access device insertion (consideration should be given to peripherally inserted central catheters) • Repair of symptomatic inguinal hernia • Cholecystectomy for symptomatic cholelithiasis • Gastrostomy if required for discharge 	<ul style="list-style-type: none"> • Vascular access device removal (not infected) • Chest wall reconstruction • Asymptomatic inguinal hernia • Anorectal malformation reconstruction following diversion • Hirschsprung disease reconstruction following diversion • Inflammatory bowel disease reconstruction following diversion • Enterostomy closure • Breast lesion excision (i.e. fibroadenoma) • Brachial cleft cyst/sinus excision • Thyroglossal duct cyst excision • Fundoplication • Orchidopexy • Hypospadias • Bariatric surgery • Splenectomy for haematologic disease • Cholecystectomy for biliary colic • Repair of asymptomatic choledochal cyst

Although we are currently in a situation where we can safely perform less urgent procedures, these guidelines still exist to provide a framework of action should another virus peak return. Some of these examples are controversial. Prolonged delay in orchidopexy for true undescended testes increases the risk of testicular dysfunction and the increased chance of malignancy and delay in hypospadias surgery can lead to functional and psychological injury. Common sense needs to prevail in such situations to accommodate revised but reasonable timelines for patients (see table 5).

Organization and people: team working for coping with the emergency

Knowledge about this new disease is evolving fast; thus, we must constantly review and adapt pathways. Clinical information is being disseminated as fast as possible, but research takes time. What does not take time, is communication with colleagues across the globe, facilitated by historical interactions and the use of technology. Online platforms for communication have been shown to be a strategic resource at this time. But it is not easy to identify the key knowledge to exchange when facing a new and unknown threat such as COVID-19, so it is important to approach the knowledge sharing with a systemic and human factors approach: first of all, emphasise the key aspects of the complex healthcare system with a focus on their interactions with the professionals acting in direct contact with the patients; then, adopt the same approach for all the organizational level of the system. Looking at the front end, the key is the health and well-being of all the healthcare operators, in addition to being able to maintain a service for the patients.

Following the HFE approach, one recommended solution for surgical teams during lockdown periods, in order to stay healthy and maintain continuity of care, is to divide into teams with senior and junior doctors in each group and work for a 2-week period. After the 2-week period, teams will come in to release the other. This will allow easier replacement of team members should they fall ill and an ability to maintain some service provision and clinical care. While away, the surgical team can stay at home if other family members are in good health, before starting the 2-week rota. This should not be considered 'free-time'; they should remote work as much as possible and manage those aspects of the department that can occur outside the hospital. Identification of training needs is essential in this ever changing situation and there are some challenging aspects to consider in developing just-in-time training for COVID-19: use of different platforms (web-based, smart-apps), easy production and context adaptation of training content for the front line workers [5]. A user-centred, participatory approach can support the management of these critical aspects. Delegation in this period of preparation is important, with key members of the team being able to give specific advice and leadership. Without a clear mapping in our healthcare organization of skills, competencies and related privileges, it is very difficult to act speedily.

General recommendations for paediatric patients

To date, there is still limited information regarding COVID 19 in children, and this was aptly demonstrated by the emergence of the post-COVID-19 inflammatory response which took many by surprise and is poorly understood [15]. Generally speaking, however

- Children and infants are affected and with milder forms (X-ray more often negative; CT more sensitive) [16, 17]. A

Table 5 Sociotechnical recommendations on communication and team working

Sociotechnical recommendations

Communication flow is the basic element and often critical in our healthcare systems, this becomes more evident in an emergency situation. Simple and context oriented tools should be put in place in order to facilitate this flow. These tools should be focused on strategic information defined by operators who have to use them, supported by experts and structured in handover charts. We have to train by simulation with the entire surgical team, not only surgeon, for effective communication and adaptation of operational procedures and quality systems so to support the real work which Hollnagel defines the 'work as done' vs the 'work as imagined' [14].

small series of children with COVID-19 has shown a greater prevalence of peripheral halo (halo-sign) lung consolidations on CT

- The criteria for the definition of ARDS and septic shock, the guidelines for the management of sepsis and septic shock and the use of non-invasive ventilation in children are different from those of adults [7]
- Children desaturate more easily during intubation, therefore it is important to pre-oxygenate with 100% O₂ with a mask with a reservoir before intubating [7]
- Zhu *et al.* have used the cycle threshold values of the serial rectal and nasopharyngeal swab tests to indicate viral load. Interestingly the measurements have indicated that viral shedding from the GI system could be greater and last longer than the respiratory tract [4]. A rectal swab may be useful in children to determine the timing of the termination of quarantine.

From the HFE perspective, consider constant update of information and real-time exchange of knowledge as part of clinical care and structure briefing and debriefing according to that. Patient safety huddles and strict communication mechanisms are key elements for updating continuously the situational awareness that is so vital for the surgical team in order to act promptly and efficiently during the emergency. Handover charts and surgical checklists are cognitive supporting tools and they become more relevant during emergency when uncertainty can affect the decision-making process.

We also need to remember that the parents of our inpatient children are playing an important role and we will ask them to change the way they care for their children; one parent only should stay in the hospital with the child. The parent admitted with the child must stay in the hospital for one week at the time, no other contact is allowed from other family members including the other parent. This is very demanding for the parents and emotionally challenging for the child. In the event of theatre being required, one parent is still allowed to follow the child to the operating suite, but is not then present for any interventions or procedures.

Discussion

Statement of principal findings

The COVID-19 pandemic has reinforced the importance of meticulous planning and preparation. Planning means be prepared for the worst, thinking of, and then simulating numerous case scenarios and

implementing isolation rooms/wards. Developing preparedness and resilience in response to pandemics requires a Safety-II approach (i.e. learning from what went right [14]), aimed at identifying resilient performance and successful adaptations to deal with new conditions created by COVID-19.

Another important aspect is robust and coherent two-way communication between clinicians and management to highlight positive or negative aspects of the pathways that are being used. Regular team briefs are required, with all layers of the service/management to be able to be readily responsive to any alteration required of the care pathways.

Strengths and limitations

As strengths of the work, we can underline the focus on: the paediatric patients' management during pandemic that is scarcely treated in general; the representation of lessons learned from the experience on the frontline; the adoption of an innovative, systemic wide approach based on the SEIPS model. The paper has also limitations, which are also typical of the COVID19 studies: the source of data that is only qualitative and not systematic; the number of cases considered that is low; the lack of evidences for some statements based on the practical experience rather than on systematic studies.

Interpretation within the context of the wider literature

The paper specifically discusses lessons learned and experiences concerning paediatric surgery, currently under-reported in the literature. Urgent lessons learned can be of great value for developing preparedness to the future development of the pandemic and clarify actions to take to reduce the risk exposure.

Implications for policy, practice and research

There will be, undoubtedly, further phases of this problem—resulting in relaxation of the lockdowns, where chronically ill people attend hospital to seek help delayed by the crisis, will combine with further surges in, perhaps, mutated forms of the virus. In order to prepare proactively for the next phases, and get ahead of the curve of these hospital accesses, there is a need for practice and research to focus on risk analysis and assessment of the new clinical pathways with a multidisciplinary and HFE approach and an involvement of all the surgical team. Concerning policy, it is essential that surgical leaders are responsive as many colleagues will seek advice and guidance in this difficult crisis. Leaders should engage with the wider team and delegate specific tasks to appropriate team members to empower them.

Conclusions

As a by-product with the new way of working during the pandemic, we can learn and take forward positive aspects for the future management of paediatric surgical patient, such as optimization of the use of essential items, minimizing waste of resources and the implementation of more telemedicine and online teaching.

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Ethics and other permissions

No permissions needed for this work.

Data availability statement

No new data were generated or analysed in support of this research.

Handling Editor

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