COVID-19 pre-procedural testing strategy and early outcomes at a large tertiary care children's hospital

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Abstract

Purpose With the emergence of the coronavirus disease-2019 (COVID-19) pandemic, institutions were tasked with developing individualized pre-procedural testing strategies that allowed for re-initiation of elective procedures within national and state guidelines. This report describes the experience of a single US children's hospital (Children's Wisconsin, CW) in developing a universal pre-procedural COVID-19 testing protocol and reports early outcomes.

Methods The CW pre-procedural COVID-19 response began with the creation of a multi-disciplinary taskforce that sought to develop a strategy for universal pre-procedural COVID-19 testing which (1) maximized patient safety, (2) prevented in-hospital viral transmission, (3) conserved resources, and (4) allowed for resumption of procedural care within institutional capacity.

Results Of 11,209 general anesthetics performed at CW from March 16, 2020 to October 31, 2020, 11,150 patients (99.5%) underwent pre-procedural COVID-19 testing. Overall, 1.4% of pre-procedural patients tested positive for COVID-19. By June 2020, CW was operating at near-normal procedural volume and there were no documented cases of in-hospital viral transmission. Only 0.5% of procedures were performed under augmented COVID-19 precautions (negative pressure environment and highest-level personal protective equipment).

Conclusion CW successfully developed a multi-disciplinary pre-procedural COVID-19 testing protocol that enabled resumption of near-normal procedural volume within three months while limiting in-hospital viral transmission and resource use.

Keywords COVID-19 · Pre-procedure · Testing · Pediatric

Introduction

With the emergence of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2, COVID-19) pandemic in early 2020, procedural management of surgical patients

changed dramatically across the world. Initially this involved delaying all non-emergent surgeries and procedures as recommended by the United States Centers for Disease Control and Prevention (CDC) and American College of Surgeons (ACS) in mid-March 2020, and similar strategies were

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deployed world-wide [1, 2]. The initial near-total shutdown was motivated by calls to flatten the transmission curve, with hopes to contain the pandemic spread despite limited understanding of specific transmission dynamics of SARS-CoV-2. Following this initial response, healthcare institutions were tasked with developing individualized strategies for COVID-19 screening and testing in the pre-procedural setting that would limit SARS-CoV-2 transmission and allow for the systematic reintroduction of elective procedures. Surgical and procedural care were targets for increased precautions because of concerns that anesthesia administration and airway manipulation would increase nosocomial viral transmission via a respiratory route. As discussed in a joint statement released on April 17, 2020 by the ACS, American Society of Anesthesiologists, Association of periOperative Registered Nurses, and the American Hospital Association, considerations for the resumption of elective surgery needed to include local geographic trends in COVID-19 cases, hospital capacity and available medical/surgical supplies, local and state-based directives, staffing capabilities, and availability of pre-procedural COVID-19 testing as well as associated personal protective equipment (PPE) [3].

Following the initial suspension of elective procedures in the US, there has been wide variability in COVID-19 pre-procedural screening and testing strategies implemented across the country secondary to differences in geographic region, testing availability, existing procedural workflow, and the dynamic nature of events [4–6]. There is an overall paucity of literature related to pre-procedural COVID-19 testing strategies in the pediatric population despite important differences in COVID-19 disease transmission and presentation in children compared to adults. Specifically, reliance on a symptom-based screening strategy may be inadequate as children who test positive for SARS-CoV-2 are often asymptomatic or manifest less severe disease [7]. The high prevalence of asymptomatic or minimally-symptomatic infections in infants and children must be considered when developing pediatric pre-procedural COVID-19 screening and testing protocols, not only for optimal care of the individual patient, but also for resource preservation (PPE, blood products, ventilators) as well as prevention of nosocomial viral transmission. These considerations are magnified in pediatric hospitals because of the near-universal requirement for anesthesia in the care of children undergoing surgical, interventional, and certain diagnostic procedures.

Children's Wisconsin (CW) consists of a 298-bed, free-standing, quaternary care children's hospital located in Milwaukee, Wisconsin, as well as a stand-alone outpatient Surgicenter. CW has a combined total of 30 dedicated procedural areas. In 2019, CW performed over 24,000 procedures under general anesthesia between the main hospital and Surgicenter. Currently, CW is the only ACS Level 1 verified Children's Surgery Center and one of two Level 1

Pediatric Trauma Centers in the state, and therefore provides care for the most emergent and complex pediatric surgical conditions. The initial delay of elective cases recommended by the CDC and ACS resulted rapidly in a backlog of hundreds of procedures at CW. Further, all emergent procedures were initially treated as presumed COVID-19 positive and therefore required full airborne, respiratory, and contact precautions including utilization of a negative pressure operating room (OR) and appropriate high-grade PPE [gown, gloves, and either a fit-tested N95 Respirator or Controlled Air Purifying Respirator (CAPR)] for all personnel. To provide needed procedural care while simultaneously keeping patients, staff, and providers safe from disease transmission and preserving PPE, the CW leadership was tasked with developing a pre-procedural COVID-19 screening and testing protocol. This report describes the protocol development process, current pre-procedural testing strategy, and early outcomes of SARS-CoV-2 testing at CW.

Methods

COVID-19 procedural taskforce

On March 15, 2020, CW suspended all non-life or limb threatening procedures. As a practical matter, this meant that only patients who required intervention within the next 72 h were scheduled for a procedure. At this time, the existing CW Surgical Executive Committee (SEC) rapidly re-organized to create a multi-disciplinary COVID-19 procedural taskforce consisting of leaders from hospital administration, nursing, and the departments of surgery, anesthesiology, and pathology. The taskforce was charged with developing a strategy for pre-procedural COVID-19 testing that (1) maximized patient safety in the rapidly changing environment, (2) prevented patient care-associated viral transmission, (3) conserved resources (PPE, testing supplies, blood products), and (4) allowed for resumption of procedural care within institutional capacity. This strategy was applied to all potentially aerosol-generating procedures (AGPs). All surgical, interventional, and diagnostic procedures that required anesthesia care were considered AGPs due to the potential need for airway management. Other examples of AGPs included endoscopy, bronchoscopy, and transesophageal echocardiography.

In the initial response implemented by the taskforce, urgent and emergent procedures only were individually triaged through the SEC and were performed in one of three designated anesthetizing locations. Standard specialty- or surgeon-based access to procedural scheduling was abandoned in favor of a scalable strategy to equitably modulate the flow of procedural care. This strategy was based on a hierarchical model with access to supplies, equipment, PPE,

testing, and personnel as the primary rate-limiting factors that determined the number of anesthetizing locations that could be run. This variable supply of locations and hours was then allocated to super-specialty service clusters based on overlapping patient and procedural needs, while maintaining access for urgent and emergent care. This model included hierarchical dynamic triage layers that required increased cooperation within and between specialties and the SEC.

To ensure a strong representative sample of surgical and procedural services were included on the taskforce moving forward, faculty leaders from general surgery/urology, orthopedic surgery, neurosurgery, plastic surgery, otolaryngology, cardiac surgery, ophthalmology, anesthesiology, and interventional radiology were requested to participate. Each leader was tasked with developing a triage protocol for elective AGPs (those that could safely wait at least 72 h) within their specialty depending on urgency. These triage protocols were then used to generate a ranked list of all postponed AGPs within each specialty (Table 1). Early in the pandemic as the backlog of cases increased (> 1700 cases at its peak), the COVID taskforce met daily to go through each triage list and equitably schedule pre-procedural testing and procedures based on urgency. As pre-procedural COVID-19 testing ramped up, the backlog of previously canceled cases was able to be systematically addressed and patients that tested positive for COVID-19 were re-triaged on a rolling basis again dependent on urgency of the procedure. Another consideration that was addressed during these procedural scheduling meetings was that as a certain procedure was continually delayed, it could ultimately result in a negative impact on the underlying condition for which the procedure was indicated. Therefore, the triaging protocols were used as a starting point for scheduling cases, but individual patient and disease factors had to be taken into account as well.

SARS-CoV-2 testing

Prior to the March 15 moratorium on non-emergent AGPs, an in-house SARS-CoV-2 reverse transcription polymerase

chain reaction (RT-PCR) assay was developed by the Midwest Respiratory Virus Program (MRVP) laboratory (Medical College of Wisconsin Department of Pediatrics) and was used in collaboration with the CW laboratory. It utilized nasopharyngeal (NP) swab samples that were analyzed with a modified version of the CDC COVID-19 RT-PCR test [8], and allowed for reliable, in-house results within 5–6 h. It was validated using a combination of known negative pre-COVID NP swabs, SARS-CoV-2 RNA, and known positive COVID-19 samples from a neighboring adult hospital and the Wisconsin State Laboratory of Hygiene. Test validity of the MRVP SARS-CoV-2 PCR test was established by February 7, 2020, and by March 11, 2020 it was being utilized for in-house testing of new admissions, pre-procedural patients, and symptomatic or exposed staff and providers.

The initial testing capacity of the in-house PCR test was 54 samples every 5–6 h, of which pre-procedural testing represented a small proportion. Initial pre-procedural testing capacity for non-emergent AGPs was around 15 patients per day. In mid-April 2020, CW obtained the Simplexa™ COVID-19 Direct Assay (DiaSorin Molecular LLC) which had a 90-min processing time. The Simplexa™ test could be run on three separate instruments that each ran eight samples at a time. The addition of this second testing platform allowed for a significantly increased capacity of pre-procedural testing to be performed, as one testing instrument was run at specific times on a published schedule throughout the day and the others could be used for more urgent unscheduled testing. The Simplexa™ assay manufacturer-reported negative and positive percent agreement are each 100% for NP samples based on internal clinical performance evaluation, and the manufacturer provides an external control for quality control testing at individual laboratories. The Simplexa™ test was internally validated using a combination of known negative pre-COVID NP swabs, SARS-CoV-2 RNA, and known positive COVID-19 samples. There was 99% correlation between the Simplexa™ test and MRVP in-house assay.

In early June 2020, the rapid 15-min Abbott ID Now Covid-19 test (Abbott Diagnostics Scarborough, Inc.)

Table 1 Example of the general surgery procedural triage protocol

Triage level	Elective procedures	Urgency
Level 1	Newborn with inguinal hernia < 6 mo, possible neoplastic mass, symptomatic cholelithiasis, need for CVL access, bowel resection (hospitalized patients), feeding access (not a candidate for NG/NJ tube)	> 72 h and < 2 weeks
Level 2	Inguinal hernia > 6 mo–< 1 yr, bowel resection/Ladd procedure (non-hospitalized patients)	2–4 weeks
Level 3	Inguinal hernia > 1 yr, benign lung mass, benign soft tissue mass, feeding access (with NG/NJ tube), endo-rectal pull-through (not diverted), Histrelin implant, thyroidectomy, CVL removal	1–3 months
Level 4	Umbilical and epigastric hernias, endorectal pull-through (diverted), colostomy closure, gynecomastia, port removal	3–6 months
Level 5	Nuss/Ravitch procedures, Nuss bar removal	> 6 months

CVL central venous line, NG nasogastric, NJ nasojejunal

became available at CW. This test was utilized specifically for urgent and emergent pre-procedural patients. Initially, the Abbott 15-min test was run on all pre-procedural patients presenting from the Emergency Department along with a confirmatory 90-min Simplexa™ COVID-19 Direct Assay for validation. This strategy for validation was motivated by concern regarding reported false-negative rates near 30% for the Abbott ID Now test. The relatively high false-negative rate has since been confirmed at CW and in a recent Food and Drug Administration (FDA) review, and may be related to differences in sample source (nasal vs NP), sequence targets for RNA detection, and degree of amplification. In September 2020, the FDA restricted the relevant Emergency Use Authorization of the Abbott ID Now test such that it cannot be used for testing asymptomatic individuals; therefore, it is no longer used for routine pre-procedural testing at CW. The current COVID-19 testing capacity at CW is 300–500 tests per day, which includes pre-procedural patients as well as new admissions and symptomatic or exposed staff and providers. A designation of “asymptomatic” versus “symptomatic” is included in every COVID-19 testing order for internal auditing purposes.

Pre-procedural testing strategy

The CW COVID-19 pre-procedural screening and testing strategy is a tiered approach that incorporates COVID-19 exposure risk, symptom screening, and universal pre-procedural testing. The protocol distinguishes between patient presentation to the CW Emergency Department and Trauma Center (EDTC), currently hospitalized patients, and ambulatory/elective procedures.

EDTC to procedure

All patients who present to the CW EDTC undergo COVID-19 exposure risk and symptom screening (ERSS) as shown in Fig. 1. If a patient requires an AGP, the urgency is communicated by the managing specialty service to the EDTC provider and the designated procedural department director. All pre-procedural patients undergo Simplexa™ COVID-19 Direct testing in the EDTC with NP samples sent directly to the CW lab for processing. For emergent and urgent AGPs whose triage classification requires care within four hours, the level of COVID-19

COVID-19 Symptom Screen (version 7), Effective July 28, 2020

1. Has the parent, child/youth or anyone living in the home been in close contact with anyone who has a confirmed case of COVID-19 within the last 14 days? (Close contact means being within approximately 6 feet for a prolonged period; or having direct contact with infectious secretions – e.g. being coughed on – while not wearing a gown, gloves or eye protection.)
2. Does the parent, child/youth or anyone living in the home have either of the two following symptoms?
  - Cough
  - Shortness of breath/trouble breathing
3. Does the parent, child/youth or anyone living in the home have any of these additional symptoms?
  - Fever
  - Chills
  - Repeated shaking with chills
  - Muscle pain
  - Headache
  - Sore throat
  - New loss of smell or taste

Fig. 1 Pre-procedural exposure risk and symptom screen (ERSS) utilized at Children’s Wisconsin

precautions necessary in the peri-procedural setting is determined by the workflow outlined in Table 2. For non-emergent procedures that will be scheduled within 72 h following inpatient admission or via an ambulatory/day surgery process, the testing workflow follows the processes outlined in "Inpatient to procedure" and "Ambulatory to procedure" sections.

Inpatient to procedure

Hospitalized patients who require an AGP must have an updated COVID-19 test performed within 72 h of the scheduled procedure whenever possible. This includes retesting patients who require multiple procedures during the same hospitalization. Similarly to the EDTC to procedure workflow, the inpatient to procedure COVID-19 testing protocol utilizes the Simplexa™ NP test. For emergent and urgent AGPs that require procedural care within four hours, the workflow follows that outlined in Table 2. For AGPs in hospitalized patients that need to proceed between four and 72 h, the workflow follows the protocol demonstrated in Fig. 2.

Ambulatory to procedure

All patients presenting from the ambulatory setting who are undergoing AGPs must be tested for COVID-19 within 48 h of a scheduled procedure, and then must quarantine at home until presenting to CW for their procedure. Ambulatory patients can present for an AGP in one of three ways: (1) as an elective case (scheduled > 72 h in advance), (2) as an add-on case from outpatient clinic (scheduled < 72 h in advance), or (3) as an add-on case from the EDTC (scheduled < 72 h in advance). AGPs that are scheduled as add-ons from clinic or the EDTC undergo COVID-19 testing in those respective settings. The charge nurse from the specific procedural department involved is responsible for reviewing all test results the evening before scheduled procedures and reporting positive results to the designated proceduralist and anesthesiologist to determine how to proceed. For AGPs scheduled more than 72 h in advance, a separate workflow is in place that incorporates pre-procedural telehealth visits, drive-through testing, and procedural scheduling based on the specialty-specific triaging protocols described in "COVID-19 procedural taskforce" section. This process is further described below.

Between 48 and 72 h prior to an elective AGP the CW Pre-anesthesia Evaluation Clinic (PEC) will contact the

Table 2 Level of COVID-19 precautions required for emergent procedures based on testing tiers

COVID-19 testing tier	Level of COVID-19 precautions required
(i) Known COVID-19 positive	Full COVID-19 PPE and negative pressure OR
(ii) Unable to obtain/wait for Simplexa™ test result	Full COVID-19 PPE and negative pressure OR
(iii) Negative Simplexa™ test prior to OR	No high-level precautions required

PPE personal protective equipment, OR operating room

Fig. 2 Schematic representing COVID-19 testing workflow for hospitalized patients at CW. *N95 Respirator use is standard for all CW Operating Room and procedural personnel

patient's family and perform a COVID-19 ERSS. If the ERSS is positive, the PEC will contact the designated surgeon and anesthesiologist to determine if the procedure can be safely postponed. If the ERSS is negative or the procedure cannot be safely postponed, the PEC orders an ambulatory COVID-19 test to be performed at a CW drive-through testing location within 48 h of the scheduled procedure. The drive-through COVID-19 testing process was implemented at CW on March 15, 2020 and is staffed by a designated team of nurses. Once an ambulatory COVID-19 test order is placed, the CW testing center nurse will contact the patient's family to schedule a pre-procedural testing appointment. On arrival to the drive-through testing center, the patient undergoes an NP swab which is then sent to the CW laboratory. The MRVP in-house PCR assay is used to test ambulatory pre-procedural samples which are batched and run at specified times throughout each day. For families that are not easily able to present to CW for pre-procedural testing, there are a number of non-CW regional laboratories across Wisconsin that perform NAAT-based COVID-19 testing which have been determined to be acceptable alternatives. If the test is negative, the patient may proceed with the procedure as scheduled. If the test is positive, the laboratory communicates directly with the specific procedural department charge RN who then contacts the designated proceduralist and anesthesiologist to determine if the procedure can be safely postponed. If not, the procedure must be performed in the negative pressure OR with full COVID-19 PPE.

Early in the process, ambulatory AGPs in COVID-19 positive patients were retested initially at two and then at four weeks. However, internal data revealed high rates of SARS-CoV-2 PCR positivity at 4 weeks without signs or symptoms of disease. Thereafter, retesting for ambulatory AGPs in COVID-19 positive patients was deferred until at least 6 weeks from an initial positive test. In late July 2020, the CDC updated their retesting guidelines to indicate that it is safe to proceed with routine medical care without retesting between 10 and 90 days following a positive test. Due to the evidence of increased risk of respiratory and airway complication following surgery in COVID-19 positive patients, the taskforce chose to defer AGPs at least 6 weeks following a positive test if it is medically safe to do so [9]. This also addressed concerns about viral dissemination as well as individual patient convalescence. Retesting is not done if the procedure is rescheduled between 42 and 90 days of the initial positive result based on the CDC's recommendations.

Results

Between March 15 and October 31, 2020, a total of 11,209 AGPs were performed at CW including both the Milwaukee main campus and Surgicenter. As demonstrated in

Fig. 3, procedural volume increased steadily back toward a pre-COVID weekday average of 77 surgical cases per day over this time period. Pre-procedural COVID-19 testing was performed on 11,150 patients (99.5% of all pre-procedural patients). Overall, 159 (1.4%) pre-procedural patients tested positive for COVID-19, although a recent surge in community COVID-19 prevalence in Wisconsin resulted in an increase in CW pre-procedural positive cases to 3.1% during the month of October 2020. All positive patients were asymptomatic at the time of testing, and there were no known inpatient seroconversions. A total of 53 AGPs (0.5%) were performed in the designated negative pressure OR requiring augmented PPE during this time period, which included patients who tested positive and could not have their procedure safely postponed as well as the few patients who were unable to undergo testing preoperatively (either emergent cases or those limited by testing capabilities early in the pandemic). The age distribution of positive cases compared to that of all patients tested during the review period is shown in Fig. 4.

As of October 31, 2020 there has been more than adequate daily testing capacity for all pre-procedural patients. A total of 165 CW providers and staff tested positive for COVID-19 between March 15 and October 31, 2020 and none were thought to be due to patient or workplace exposure following appropriate contact tracing.

Discussion

This review highlights the current pre-procedural COVID-19 testing strategy at a single large-volume tertiary care US children's hospital and reports initial results of case volume and incidence of COVID-19 in our pediatric population. We found that the incidence of COVID-19 in pre-procedural patients was low, with only 1.4% of patients testing positive overall across all peri-procedural contexts. Further, CW was able to efficiently work through the initial backlog of AGPs and reach a near-normal daily procedural volume by early June 2020, less than three months following the March 15 institutional moratorium on elective operations. These outcomes were attained with limited excess resource use, as only 0.5% of AGPs performed since March 15, 2020 required full COVID-19 PPE precautions and negative pressure OR use. With high community prevalence of and low native immunity to COVID-19, these processes were critical to maintaining a safe work environment. Importantly, there has been no evidence of known patient to staff (or staff to patient) transmission of disease. With adherence to these processes, non-hospital exposures of personnel remain the major workforce threat.

The overall 1.4% incidence of pre-procedural COVID-19 identified at our institution is similar to other reports from

Fig. 3 Graph displaying daily surgical case volume at the main Children’s Wisconsin (CW) Milwaukee (Milw) campus and outpatient Surgicenter from 3/15/2020 to 10/31/2020. The dashed horizontal lines represent the average pre-COVID-19 weekday case volumes at the Milwaukee campus (56 cases per weekday) and Surgicenter (21

cases per weekday). The black vertical lines represent significant time points during the CW COVID-19 response including the date of first in-house PCR test implementation (3/11/2020), date when only time-sensitive (life or limb threatening) cases were performed (3/15/2020), and date of Simplexa™ PCR test implementation (mid-April 2020)

US children’s hospitals [10, 11]. Up to 86% of children who test positive for COVID-19 are asymptomatic, highlighting the importance of universal pre-procedural testing in this population [11]. Our data further demonstrate that implementation of a universal pre-procedural testing strategy limits excess resource utilization (such as PPE and negative pressure OR use), minimizes the risk of in-house viral spread, and allows for near-normal procedural volume. This type of strategy requires high-volume use of reliable and internally validated SARS-CoV-2 test kits, including swabs, media, reagents, and testing instruments. CW was fortunate to be one of the first children’s hospitals in the country to develop an in-house SARS-CoV-2 PCR test which was rapidly integrated into the pre-procedural workflow following internal validation. Development of the in-house assay was important in two ways. First, it permitted a relatively timely, reliable turn-around for results before the scheduled procedure. Second, it allowed the testing to be performed temporally close to the scheduled procedure to minimize risk of conversion between the time of the test result and the time of the procedure. As external rapid tests became available, these were incorporated into the workflow as well and allowed for a significant expansion of pre-procedural COVID-19 testing capacity. As of the end of October 2020, a total of 11,150 pre-procedural tests have been performed since the protocol was implemented and only patients with

urgent needs have undergone AGPs without a COVID-19 screening test within 48 h of their procedure.

Another pertinent outcome from the CW pandemic response was the ability of the SEC to rapidly reorganize into a COVID-19 taskforce that met daily in the early period of the pandemic to develop a pre-procedural testing strategy and appropriately triage the backlog of cases. With the recent surge of COVID-19 in Wisconsin, CW has a system in place by which to determine the capacity of the hospital to handle normal operating volume, as well as revise the procedural triaging strategy as the pandemic evolves. This rapid reorganization was achieved in large part because of the multi-disciplinary approach taken by the SEC, and the development of a successful pre-procedural testing strategy was further aided by frequent collaboration with other institutions and organizations. As examples, a group of pathologists across the US initiated an email chain by which to discuss testing strategies and implementation, and CW worked closely with a neighboring adult hospital to validate the in-house PCR test. In times of medical uncertainty and necessity such as the current global pandemic, collaboration is essential to innovation.

A number of unexpected challenges became apparent in the early period of the COVID-19 pandemic at CW. First, there was a noted shift in surgical emergencies, such as open extremity fractures, presenting to outpatient clinics as

Fig. 4 Graph displaying the age distribution of patients that tested positive for COVID-19 at Children’s Wisconsin during the review period; 3/15/2020–10/31/2020 (a), and age distribution of all patients tested for COVID-19 during the same period (b)

opposed to the EDTC. Other institutions have seen similar shifts away from ED visits, likely related in part to family and referring providers’ concerns over viral transmission in the ED setting [12–14]. Another unforeseen challenge was the extended period of detectable RNA and potential viral shedding that occurs in many children who test positive for COVID-19. Determining when and how to re-screen

COVID-19 positive pre-procedural patients was an evolving process. Finally, the addition of external assays to the testing protocol required extended periods of internal validation and thoughtful inclusion (or exclusion) into the pre-procedural workflow. All of these challenges highlight the necessity of a dedicated, multi-disciplinary executive taskforce that can quickly and effectively address new issues as they arise and

Table 3 Major obstacles experienced and solutions identified at CW during the COVID-19 pandemic

Obstacles	Solutions
Need for a system-wide peri-procedural testing strategy	Rapid reorganization of the existing CW Surgical Executive Committee into a multi-disciplinary COVID-19 peri-procedural taskforce
Means of ensuring the safe and equitable allocation of peri-procedural resources	Inclusion of representative members from every procedural service on the COVID-19 taskforce Development of a hierarchical, scalable, and specialty-specific triage protocol for all pending procedures
Limited availability of PPE and other peri-procedural resources	Implementation of a universal pre-procedural testing protocol to limit COVID-enhanced PPE use to those few procedures that were done either emergently (without a resulted COVID-19 test) or in known COVID-19 positive patients that could not be safely postponed
Limited availability of COVID-19 tests and testing equipment	Development of an in-house PCR assay early in the pandemic Active identification and acquisition of other COVID-19 tests as they became available on the market to expand rapid testing capacity Utilization of out-of-network suppliers to obtain adequate testing media and equipment
Need to ensure safety of patients and providers/staff in the peri-procedural setting	Use of telehealth visits for preoperative evaluation and symptom screening in the ambulatory setting Mobilization of a robust drive-through testing process staffed by dedicated nurses and limiting patient-staff and patient-patient interactions Designation of specific peri-procedural spaces (isolation rooms in the procedural arrival and recovery areas, negative pressure ORs) for COVID-19 positive patients undergoing procedures

CW Children's Wisconsin, *PPE* personal protective equipment, *PCR* polymerase chain reaction

allow for continued innovation as the COVID-19 pandemic continues, and these challenges are highlighted in Table 3 along with the solutions put in place to overcome them. Further, the creation and implementation of a dynamic hierarchical resource allocation strategy as well as the increased interdisciplinary collaboration, knowledge, and cooperation initiated by the COVID-19 pandemic at CW might be enduring outcomes generalizable to future challenges.

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