





# Cardiac surgery considerations and lessons learned during the COVID-19 pandemic

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## Abstract

The COVID-19 pandemic has transformed cardiac surgical practices. Limitations in intensive care resources and personal protective equipment have required many practices throughout the globe to pause elective operations and now slowly resume operations. However, much of cardiac surgery is not elective and patients continue to require surgery on an urgent or emergent basis during the pandemic. This continued need for providing surgical services has introduced several unique considerations ranging from how to prioritize surgery, how to ensure safety for cardiac surgical teams, and how best to resume elective operations to ensure the

safety of patients. Additionally, the COVID-19 pandemic has required a careful analysis of how best to carry out heart transplantation, extra-corporeal membrane oxygenation, and congenital heart surgery. In this review, we present the many areas of multidisciplinary consideration, and the lessons learned that have allowed us to carry out cardiac surgery with excellence during the COVID-19 pandemic. As various states experience plateaus, declines, and rises in COVID-19 cases, these considerations are particularly important for cardiac surgical programs throughout the globe.

#### KEYWORDS

cardiac surgery, COVID-19

## 1 | INTRODUCTION

The COVID-19 pandemic has transformed cardiac surgical practices throughout the globe.<sup>1</sup> Although many elective operations were delayed, surgeons were forced to balance the ongoing need of providing urgent and emergent surgical care with the new realities of limited resources. However, cardiac surgery is a resource-intensive specialty where excellence requires multidisciplinary coordination between cardiology, surgery, anesthesia, critical care, perfusionists, and nursing. Moreover, cardiac surgery patients transition through different phases of care (preoperative, operative, intensive care, step-down, and cardiac rehabilitation), which creates unique challenges for preventing disease transmission for patients and their care teams. In this review, we discuss the challenges that COVID-19 has created for cardiac surgery, the solutions hospitals have developed to maintain safety and excellence during the pandemic, and the strategies surgical teams have employed as we re-open cardiac surgical programs.

## 2 | PRIORITIZATION OF OPERATIONS

Although a limited amount of cardiac surgery continued during the peak of the pandemic, critical attention to case selection and triage are now standard practice. Deferral of elective cardiac surgery and now subsequent rescheduling to address backlogs and waiting lists has become a reality. The American College of Surgeons (ACS) released recommendations for surgical management of elective operations during the COVID-19 pandemic.<sup>2</sup> The ACS scale categorized elective procedures into three tiers: Tier 1 (low acuity), Tier 2 (intermediate acuity), and Tier 3 (high acuity) with subcategories A and B in each tier differentiated as a healthy or nonhealthy patient, respectively. The scale was developed for multiple subspecialties, but was less pertinent to cardiac surgery because the scale was limited to elective cases and did not account for urgent and emergent cases.

We developed an expert consensus document to further characterize case prioritization in cardiac surgery in the safest manner, while providing appropriate patient education of the continuously evolving situation unique to local state epidemiology. A Cardiac Surgery Acuity Scale is shown in Table 1 and builds upon the widely accepted ACS

Elective Surgery Acuity Scale by accounting for inpatients who require urgent or emergent treatment. In addition to Tier 1 to 3 elective interventions, the Cardiac Surgery Acuity Scale includes Tier 4a: urgent surgery required to permit safe hospital discharge, Tier 4b: urgent surgery required within 24 to 48 hours to prevent clinical deterioration, and Tier 5: emergent surgery required to prevent immediate death.

Medical therapy while waiting for cardiac surgery includes prudent monitoring of symptom progression and timely cardiac imaging by taking advantage of modern virtual technology. Telehealth via phone or videoconferencing has rapidly expanded as an alternative to in-person outpatient clinic visits. Moreover, advances in digital health technology provide opportunities for remote monitoring of physiologic parameters. Leveraging the convenience and social distancing provided by virtual clinic visits, telehealth allows the cardiac surgeon and healthcare team to actively monitor the condition of patients whose cardiac surgery has been postponed. New onset or progression of symptoms increases the surgical acuity of patients waiting for elective surgery and in some cases requires hospitalization. Sudden cardiac death and unplanned hospital admissions for clinical deterioration may be avoided by aggressive monitoring of symptoms and interval cardiac imaging to assess for disease progression.

In circumstances where healthcare systems face significant shortages of critical care beds, a situation that has fortunately become less common, there may be *unique* situations where certain inpatients may benefit from either: (a) a temporizing catheter-based therapy as an alternative to cardiac surgery for urgent (Tier 4) and emergent (Tier 5) pathologies to minimize hospital stay and/or (b) transfer to a center where the system is less stressed to conserve resources. The American College of Cardiology (ACC) Interventional Cardiology Council has addressed the management of interventional procedures including coronary and structural heart disease<sup>3,4</sup> and addressed the concern for periprocedural COVID-19 exposure. Endovascular options for thoracoabdominal aortic disease similarly expedite patient recovery and should be given consideration during this time of limited critical care resources. Although decisions on optimal patient management must ultimately be made in accordance with best practices and clinical guidelines, there may be circumstances where less invasive strategies may be beneficial for patients requiring urgent care with limited critical care resources.

**TABLE 1** Cardiac surgery acuity scale

STS COVID-19 Hospital Burden		ACC Cardiac Surgery Acuity Scale		Acuity	Status	ACS Elective Surgery Acuity Scale
Definition		Definition	Conditions			Definition
Tier 1	<30% inpatient COVID 19 occupancy	Consider Deferral	Tier 1 Low acuity Asymptomatic MR / TR atrial septal defect / patent foramen ovale Isolated atrial fibrillation	E L E C T I V E	O u t p a t i e n t	Tier 1 Low acuity surgery 1a - healthy patient 1b - unhealthy patient
Tier 2	30 - 60% inpatient COVID 19 occupancy	Consider Deferral	Tier 2 Intermediate acuity Symptomatic MR / TR Asymptomatic aortic aneurysm with demonstrated stable size Hypertrophic obstructive cardiomyopathy Chronic thromboembolic pulmonary hypertension Pericardial constriction			Tier 2 Intermediate acuity surgery 2a - healthy patient 2b - unhealthy patient
Tier 3	60 - 80% inpatient COVID 19 occupancy	Consider Deferral	Tier 3 High acuity CAD with stable angina Symptomatic AS Aortic aneurysm with risk factors Asymptomatic cardiac tumor			Tier 3 High acuity surgery 3a - healthy patient 3b - unhealthy patient
Tier 4	> 80% inpatient COVID 19 occupancy	Consider Deferral or Transfer	Tier 4a Treatment before discharge CAD with large territory of myocardium at risk, reduced EF, progressive angina Cardiac tumor with obstruction or embolism Heart failure patients awaiting transplant or VAD Infective endocarditis with uncontrolled infection or embolism Infected or dysfunctional pacemaker / AICD / leads	U R G E N T	I n p a t i e n t	
			Tier 4b Treatment within 48 hours CAD with heart failure (IABP required) Acute coronary syndrome with mechanical complications (VSD, MR, rupture) Acute valvular regurgitation with heart failure Infective endocarditis with heart failure Aortic fistula or contained rupture			
			Tier 5 Immediate treatment Acute type A aortic dissection Acute type B aortic dissection with rupture / malperfusion Acute, massive pulmonary embolism Penetrating cardiovascular trauma Acute cardiogenic shock (ECMO)	E M E R G E N T		

AICD - automated implantable cardioverter-defibrillator  
 AS - aortic stenosis  
 CAD - coronary artery disease  
 ECMO - extracorporeal membrane oxygenator  
 MR - mitral regurgitation  
 TR - tricuspid regurgitation  
 VAD - ventricular assist device  
 VSD - ventricular septal defect

Lastly, we acknowledge that except for emergency operations, each healthcare system will need to adjust prioritization of surgery based on available institutional resources and local COVID-19 epidemiology. The Society of Thoracic Surgeons (STS) has created a tiered patient triage guide that provides recommendations based on the COVID-19 hospital burden.<sup>5</sup> The hospital burden of COVID-19 is determined by the inpatient census of COVID-19 patients and reduction in operative capacity. Four tiers of inpatient COVID-19 load are described, and a strategy of case deferral is suggested in Table 1 according to the cardiac surgery acuity scale. Cases with Tier 4 acuity (urgent and inpatient) that cannot be performed, should be transferred to a center with operative capacity. Lastly, the STS has created two online instruments to assist in prediction of postoperative resource utilization.<sup>6,7</sup> The Resource Utilization Tool and COVID-19 Resource Prediction Instrument provide estimates of postoperative resource utilization such as a ventilator hours, intensive care unit (ICU) time, blood transfusion, and reoperation based on STS historical data.

### 3 | OPERATING ROOM MANAGEMENT AND SAFETY

#### 3.1 | Preoperative COVID screening and assessment

Inpatients should undergo daily screening for the following signs or symptoms of COVID-19: fever  $\geq 38.5^{\circ}\text{C}$ , cough, shortness of

breath, sore throat, diarrhea, respiratory distress, chills, myalgias, or loss of smell or taste. If patients become symptomatic, they should undergo COVID-19 polymerase chain reaction (PCR) testing and be placed on modified droplet precautions as per local hospital protocols.

Outpatients should be prescreened by telephone interview (Figure 1). Patients should be questioned as to whether or not they, anyone in their household, or any close contacts (as defined by the Centers for Disease Control and Prevention [CDC] as contact within a distance of 6-feet for greater than 5-minutes) have had: a fever  $\geq 38.5^{\circ}\text{C}$ ; symptoms (as listed above); close contact with any person under quarantine, isolation, or a laboratory confirmed positive test for COVID-19; or have been tested for COVID-19 with a positive or pending result. If the prescreening survey is positive, patients should be deferred for a minimum of 2-weeks. As the sensitivity of available SARs-CoV-2 PCR tests is not clearly defined, patients should only proceed to testing if their prescreening survey is negative.

Patients with a negative prescreening survey should undergo SARS-CoV-2 PCR from a nasopharyngeal swab and/or serologic testing for IgG antibodies to SARS-CoV-2 as close to the patient's scheduled operating room (OR) date as possible while still ensuring the availability of test results as defined by local institutional laboratory capabilities. The pathway for determining timing for cardiac surgery after a negative test should be performed as per the local institution. One option is that if a patient has had a negative SARS-CoV-2 PCR test within the preceding week, testing is not repeated. Interpretation of testing results can be

found in Figure 1. Patients may undergo computed tomography (CT) chest the day before surgery, however, the sensitivity of this for the diagnosis of COVID-19 in asymptomatic patients is unclear. Therefore, we do not recommend CT chest be performed as part of the routine preoperative screen. In the event of surgical emergencies, patients with an unknown COVID-19 status should be treated with full COVID-19 personal protective equipment (PPE) precautions. Testing may be performed during the postoperative period to inform the need for continued modified droplet precautions.

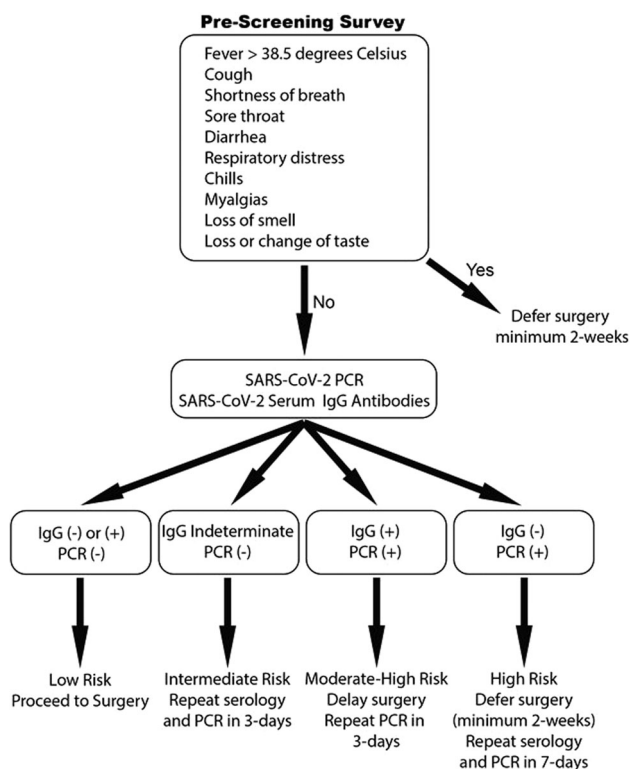
### 3.2 | Airway management for cardiac surgery

All OR personnel should have adequate PPE as required by the local institution. Endotracheal intubation is known to be the highest risk AGP.<sup>8</sup> A specific sequence for airway management for all patients is shown in Table 2. There are several other ventilator management strategies unique to cardiac surgery that must be considered. The first is ventilator management during sternotomy and other periods of mechanical ventilation hold. In these circumstances, circuit disconnection is strongly discouraged; during sternotomy, the ventilator is turned off for the period of time required by the surgeon and ventilation recommenced afterward. Circuit disconnection creates a high risk AGP scenario.<sup>9,10</sup> The second consideration is precautions during the use of double-lumen endobronchial tubes for robotic and

**TABLE 2** Sequence for airway intubation

1. Don appropriate PPE (N-95 or PAPR) and double-glove before induction. A second anesthesia provider is helpful to assist and control disposal of used equipment. Team members check each other for safety.
2. When possible, all other personnel should leave the room during the AGP.
3. If patient is anticipated to transfer to ICU, use 7.5 ETT or larger for adults.
4. Preoxygenate well with 100% O<sub>2</sub>, patient breathing spontaneously.
5. Maintain tight mask seal throughout; watch end-tidal O<sub>2</sub> to verify preoxygenation.
6. Don't tell patient to take "deep breaths" which may cause coughing.
7. Rapid sequence induction, without positive-pressure mask ventilation, if possible. If patient desaturates, use low tidal volume breaths.
8. Wait for complete muscle relaxation before laryngoscopy. Use of video-laryngoscopy is recommended.
9. If performing direct laryngoscopy to conserve GlideScope, wear full-face shield.
10. If using GlideScope to conserve full-face shields, wear regular eye protection.
11. Dispose of all airway equipment immediately.
12. Team members not actively performing intubation should be encouraged to watch for any potential lapse in proper use of PPE.
13. Verify appropriate tube position and turn on ventilator.
14. Note the time when air circulation will turn over at least seven times following AGP. If staff needs to enter before this time, they should also wear a N-95 or PAPR.
15. It is safe for staff to exit the room at any time as long as they are wearing N-95 masks.

Abbreviations: AGP, aerosol-generating procedure; ICU, intensive care unit; PPE, personal protective equipment.



**FIGURE 1** Outpatient prescreening survey. IgG, immunoglobulin G; PCR, polymerase chain reaction

minimally invasive procedures or lung transplantation. To avoid the creation and dispersion of viral aerosols during periods of lung isolation, the lumen of the double-lumen tube needs to be firmly clamped and connected to a viral filter. Lastly, for transport, non-intubated COVID-19 patients or patients under investigation (PUI) are at particularly high-risk for viral shedding and transmission to perioperative personnel. An oxygen hood should be incorporated when CPAP or BIPAP is used during transportation to help limit viral shedding to the surrounding environment. A viral filter is attached to the hood and suction is applied to the filter to create a negative pressure environment and facilitate air movement through the hood. For intubated patients, a bag-mask and mechanical ventilation are considered AGPs and warrant N-95 or PAPR protection for COVID-19 positive or rule-out patients. Transport ventilators require additional filtration of both inspired and expired gases.

In addition to ventilatory precautions, there are also necessary precautions endorsed by various national and international echocardiography societies when performing intraoperative transesophageal echocardiography (TEE).<sup>10-17</sup> Recent guidelines may be summarized as follows: the TEE should be limited to a goal-directed examination in COVID-19+ with the probe in a protective sleeve and the probe needs to be inserted by an experienced clinician wearing full protective PPE.

### 3.3 | Universal precautions in the asymptomatic, COVID negative patient

For higher-risk or complex cases, preoperative COVID testing should always be considered and ultimately may include all cardiac surgical operations. Despite negative preoperative testing in patients scheduled to undergo cardiac surgical procedures, the risk of undetected infection in asymptomatic patients may still exist.<sup>18</sup> Although a variety of testing can be utilized to screen patients before operation with high sensitivity, false negative rates may occur in up to 5%.<sup>19,20</sup> Most testing is performed 24 to 48 hours before surgery as part of the preoperative planning process as there remains lack of universal testing availability and lower sensitivity of rapid point-of-care testing.<sup>19</sup> Thus, the interim risk of exposure in these patients still exists, especially if self-quarantine practices before surgery are not strictly adhered to or if patients have inadvertently come in contact with individuals who are COVID-19+.<sup>21,22</sup>

Therefore, many centers have adopted a universal precaution strategy even for patients who are asymptomatic and have had a negative preoperative COVID-19 test. These precautions have included minimizing transmission during the most vulnerable times of surgery where the risk for viral aerosolization may occur—induction and intubation.<sup>23</sup> Common precautions include full airborne and droplet precautions (Airborne isolation–Contact isolation–Eye protection [ACE]) during intubation with personal protective equipment such as isolation gowns, face shields, and N-95 masks with as few personnel in the operating room during airway management as possible.

### 3.4 | Resource utilization

Resources once taken for granted now must be carefully monitored to ensure availability before proceeding with cardiac surgery. The resources most limited and relevant include operating room staff, ventilators, and intensive care unit beds. Other crucial resources include cardiac medications, whose supply may be disrupted, as well as PPE and surgical gowns and drapes. The pandemic has also depleted routine blood donations which has led to a national shortage of blood products. We recommend a checklist that can be used preoperatively to ensure all necessary resources are available before operation (Table 3).

**TABLE 3** Brief checklist before cardiac surgery in the COVID-19 era

Resource	Yes	No
OR anesthesia and staff available		
Cardiac ICU bed available		
ICU ventilator available after surgery		
Blood products		
Personal protective equipment		
Surgical equipment, disposables, gowns		
Critical medications in OR and ICU		

Abbreviations: ICU, intensive care unit; OR, operating room.

## 4 | RESUMING ELECTIVE CARDIAC SURGERY SAFELY

Most cardiac surgical programs in the United States are now ramping up elective cardiac surgical volumes and managing the backlog of patients who were initially delayed due to the pandemic. The final decision of how quickly to resume full elective operations must be made based on federal, state, and hospital administrative recommendations. Hospitals in cities and regions that have been greatly impacted by COVID-19 have experienced a severe shortage of ICU beds and will be delayed in the performance of full scale elective cardiac surgery. Furthermore, cardiac surgeons, the cardiac surgical advance practice providers (APPs), and cardiac ICU nurses are sometimes redeployed to care for COVID-19 patients. In those locations where there has been less of an impact of COVID-19 or where the surge did not occur to the degree as expected, the “reopening” of elective cardiac surgery has already begun. This reopening will be in some manner a step-wise process as many primary care and cardiology practices have been operating on an alternate schedule for an extended period of time and some patients may be hesitant to seek attention for symptoms such as angina or dyspnea with exertion.<sup>24</sup> To maintain relationships with patients during the pandemic, many cardiac surgical practices have utilized telemedicine via video or phone conversations with high patient satisfaction rates.<sup>25,26</sup> These virtual interactions remain important to decide which patient will require conversion from an elective procedure to more urgent. Beyond traditional signs and symptoms such as peripheral edema, shortness of breath and significant weight gain, advances in digital health have provided opportunities for remote physiological monitoring. The Centers for Medicare and Medicaid services has responded to the current environment by allowing for providers to document and bill for telemedicine encounters.

As hospital systems transition to full scale elective operations, the initial set of operations should be chosen thoughtfully, balancing clinical need with implementation of screening practices, critical care resources, and hospital-level disease mitigation strategies.<sup>26,27</sup> Practices for universal precautions developed during the pandemic peak, such as aggressive hand hygiene, must continue to be adhered to aggressively.

**TABLE 4** Patient selection for ECMO in COVID-19

Acute respiratory failure
a. PaO <sub>2</sub> /FiO <sub>2</sub> < 80 mm Hg for >6 h
b. PaO <sub>2</sub> /FiO <sub>2</sub> < 80 mm Hg for >3 h
c. pH < 7.25 with PaCO <sub>2</sub> > 60 mm Hg for >6 h
Failure of “salvage” therapies
a. Prone ventilation (1-2 trials)
b. Inhaled nitric oxide or epoprostenol
c. High-peep (>15mm Hg)
d. Trial of neuromuscular blockade
Consideration for criteria that has been associated with a worse prognosis <sup>a</sup>
a. Unfavorable RESP score (†)
b. Prolonged mechanical ventilation (ie, >7 d)
c. Baseline comorbidities that might also preclude “meaningful” survival from COVID infection independent from ECMO
1. Active cancer, liver disease, poor functional status. Severe COPD (ie, home oxygen)
a. Advancing “relative” age (ie, >65 y/old)
b. Refractory shock (septic, cardiac) with lactate >10 mmol/L
c. Pre-ECMO cardiopulmonary arrest

Abbreviation: COPD, chronic obstructive pulmonary disease; ECMO, Extra-corporeal membrane oxygenation; RESP, respiratory extracorporeal membrane oxygenation survival prediction.

<sup>a</sup>Relative contraindications are typically based upon Team and Center experience—combined with availability of resources at the time of evaluation.

Cardiac surgery patients are susceptible to postoperative infections and complications in the postcardiotomy setting, and multidisciplinary infection prevention vigilance is critical. Lastly, while clinical urgency will ultimately drive prioritization of surgery, consideration should also be given to planned patient disposition. Elderly patients who will require subacute nursing facility transfer rather than home discharge will often need to be tested for COVID-19 before discharge but may also be at risk due to multiple phases of care. Moreover, many outpatient cardiac rehabilitation programs have been postponed. Therefore, patients that require aggressive postoperative physical therapy may benefit from a delay in the scheduling of surgery.

## 5 | EXTRA-CORPOREAL MEMBRANE OXYGENATION FOR COVID-19

Extra-corporeal membrane oxygenation (ECMO) is a well-established therapy for acute cardiopulmonary failure.<sup>28</sup> Although existing guidelines and risk-assessment scoring systems have been previously useful for patient selection, their role in selecting patients with COVID-19 who would benefit from ECMO are poorly defined.<sup>29</sup> There is also concern that outcomes associated with ECMO use in COVID-19 patients are inherently poor, if not potentially futile.<sup>30,31</sup>

Furthermore, as ECMO is considered very resource intensive, and with concerns regarding the appropriate utilization of limited resources, this advanced therapy requires careful consideration. Nevertheless, as experience with ECMO for advanced COVID-19 evolves, several principles have been advocated<sup>32,33</sup>:

1. Unless clinically unavoidable, consideration should be given to early referral to existing or experienced ECMO centers. New programs should not be established for the sole purpose of supporting COVID-19 patients.
2. Existing criteria for patient selection, including the use of risk-scoring systems (ie, RESP score), should be utilized to guide patient selection (Table 4).
3. Given the potential for limited resources, such as ICU beds, ventilators, and respiratory therapists, a dynamic patient-selection criterion that emphasizes consideration to those with the best opportunity for a meaningful survival should be employed. Some programs will limit therapy to those patients who only manifest with single organ system dysfunction (ie, pulmonary), who are younger (an age cut-off might vary with the abilities and resources of the program), and who have few of the comorbidities that have been correlated with poor COVID-19 outcomes.
4. Patient selection and care should be coordinated as part of a multidisciplinary team with experience in managing very complex and critically ill patients. Team members should, at the very least, include cardiothoracic surgery, anesthesia/critical care, pulmonary medicine, and infectious disease.
5. Cannulation should follow conventional ECMO techniques and be performed by those experienced with large-bore vascular access. Current recommendations include preference given towards a dual-cannula femoral venous approach to avoid unnecessary exposure and potential respiratory contamination from the airways.<sup>34</sup> It is critical to remember to maintain strict droplet isolation precautions during the entire procedure.
6. Patients requiring concomitant cardiac support may be candidates for either veno-arterial (VA) ECMO or veno-veno (VV) ECMO and a percutaneous ventricular assist device (ie, Impella CP, Abiomed, Danvers, MA). However, it must be recognized that these patients have been shown to have advanced COVID-19 disease and the combination of cardiac and pulmonary failure is currently associated with an extremely poor prognosis and may only benefit from advanced mechanical support therapies in highly selected patients.<sup>35</sup>
7. Recognizing some of the concerning outcomes in this patient population, early referral to a Palliative Care Specialist should be encouraged.

It is also important to recognize that the goals of ECMO, in general, are to allow the lungs (and potentially, the heart) to rest while avoiding barotrauma, oxygen-toxicity, and complications associated with tissue and end-organ ischemia associated with impaired oxygen-delivery from poor pulmonary function. ECMO is not a substitute for timely therapies directed toward disease management.

Although there are concerns that VA-ECMO, as used to support acute cardiac and lung injury, has been associated with prohibitively poor outcomes, it is reasonable to consider ECMO for good candidates or a potential referral to an experienced center.<sup>36</sup>

Although the exact number of ECMO cases for COVID worldwide is unclear, there have been almost 700 cases reported to the Extracorporeal Life Support Organization (ELSO) with 45% discharge alive rate. Most of the cases (>90%) are VV-ECMO with an average duration from intubation to ECMO of less than 4 days. Renal failure is common (up to 25% of cases) and the duration on ECMO has been approximately 8 days.<sup>37</sup> As this pandemic continues to evolve and ECMO utilization grows, it is imperative that such cases are tracked closely and reported to appropriate registries (ie, [www.else.org](http://www.else.org)) to better understand the role of this supportive modality in this complex patient population.

## 6 | HEART TRANSPLANTATION CONSIDERATIONS

During the continued COVID-19 pandemic it is crucial to define which patients should be considered for cardiac transplantation. Clinicians must consider the risk of recipient demise, available clinical resources, accuracy of testing, and the postoperative risk of COVID-19 infection. Both the STS and the American Society of Transplantation (AST) have recommended a triage system that considers both recipient and institutional resources to determine transplant candidacy.<sup>38,39</sup>

Most centers are considering patients in whom the risk of mortality is imminent. In the United States this will most likely be patients listed as United Network of Organ Sharing (UNOS) status 1, 2, and 3. It may also be reasonable to consider higher status patients who are failing left ventricular assist device (LVAD) therapy or who are highly sensitized. Special consideration should be used when evaluating patients with comorbidities that are known to increase the risk of COVID-19 infection.<sup>40,41</sup>

Patients who are actively infected with COVID-19 should not undergo transplantation until they are symptom free for at least 14 days with two negative PCR-based tests.<sup>42,43</sup> At the time of transplant, patients should pass a COVID-19 symptom screen and verify that they have not had a COVID-19 exposure during the previous 14 days. A negative PCR-based test, while not required, may be reassuring.

UNOS has strongly recommended that when possible local procurement teams should be used to reduce travel-related risk. The minimum number of personnel should be involved in the procurement process. Donors should be verified as COVID-19 negative with a PCR-based assay, and when appropriate, a chest CT. Appropriate PPE must be worn by all team members. When traveling, a procurement team should bring adequate personal respiratory equipment in case PPE is unavailable at the donor center. A standard surgical mask is adequate for heart-only recovery, an N-95 mask should be worn if lungs are being procured.

The question of whether immunosuppression for cardiac transplantation should be altered during the COVID-19 pandemic is relevant. At this time, there are no data supporting the lessening of

immunosuppression. In fact, the largest single report of 87 heart transplant patients who were transplanted during December 2019–February 2020 in Wuhan, China revealed only four patients with respiratory infections.<sup>44</sup> Three patients tested negative for COVID-19 and all four recovered with no sequelae. Li and colleagues reported on two COVID-19 positive cases of heart transplantation in Hubei Province in China.<sup>45</sup> One patient had mild symptoms, the other patient had more severe symptoms and required hospitalization. Treatment of the patient with severe infection did require withholding baseline immunosuppression, treatment with high-dose corticosteroids, and pooled immunoglobulin infusions. Both patients survived. It also remains unknown in the COVID-19 pandemic if baseline immunosuppression, which accompanies heart transplantation, alters the host response to COVID-19 either favorably or unfavorably.

## 7 | CONSIDERATIONS FOR CONGENITAL CARDIAC SURGERY

Determination for congenital heart surgical intervention must be a multidisciplinary team decision including cardiologists, ICU team, anesthesia, nursing, and family. Treatment of congenital heart disease (CHD) is centered around a heart team concept. In 2007, the STS created a task force to develop quality measures for pediatric and congenital cardiac surgery, and in 2011, the Congenital Heart Surgeons Society endorsed the STS measures.<sup>46</sup> Jacobs et al defined 21 quality measures, including<sup>1</sup> multidisciplinary rounds,<sup>2</sup> multidisciplinary preoperative planning conference<sup>3</sup> and quality assurance and improvement conference.<sup>46</sup> It is critical these steps are taken during this COVID-19 pandemic. Team decisions need to be fluid with regard to present demands within the medical system and projections for any surges that may occur in the medical system. Communication is critical; all patients should be evaluated for ideal timing of surgery, with the impact to the patient for waiting weighed against the risk of attaining COVID-19.

Pediatric patients seemingly have less severe symptoms.<sup>47</sup> Certain lesions may warrant special consideration given that some pediatric patients may be at increased risk for worse prognosis.<sup>48</sup> The effects of cyanosis and shunt dependent lesions will need to be followed more closely. These shunt dependent lesions may require earlier intervention for more stable pulmonary blood flow. Patients that will be adversely affected by a pulmonary infection will have to be closely monitored and may require more expedited surgical intervention. Congenital heart specialists are familiar with the effects of respiratory syncytial virus (RSV), influenza, and other respiratory viral infections on the timing of surgery. Children with CHD have more severe acute lower respiratory infection with RSV than children without CHD.<sup>49</sup>

Elective cases that can be deferred for 6 months to a year should be rescheduled and closely followed using virtual platforms. When waiting, consideration must be given to the requirement for appropriate follow-up and unnecessary exposure to others vs moving forward with surgery.

## 8 | KNOWLEDGE GAPS

In this review, we have presented recommendations for case triaging, patient assessment before surgery, perioperative disease mitigation, and selection of patients for ECMO, congenital heart surgery, and transplantation. Although these recommendations are based on the best available evidence, the ultimate knowledge gap is understanding if these recommendations will permit cardiac surgery to continue to be carried out safely at full capacity. States are in varying stages of their respective pandemic curves, and COVID-19 has forced each cardiac surgical practice to carefully reorganize and tailor their workflows.

COVID-19 testing remains an area of active discussion. States and hospital systems are at varying levels of testing capabilities and turnaround times. In addition, many assays have low sensitivity in asymptomatic patients, drawing into question the true utility of preoperative testing in low disease prevalence regions. Antibody testing faces similar challenges in access and accuracy. Ultimately, what is needed is a low cost, widely available, rapid assay with high sensitivity and specificity that can be completed in the preoperative area—such a test does not exist.

A second major knowledge gap is the influence of the pandemic on cardiac surgery outcomes and case mix. For example, have delays in care resulted in a national increase in mechanical complications of myocardial infarction? Has the observed decrease in patients presenting with myocardial infarction translated into more deaths at home? Will a higher number of patients with valvular disease present with impaired ventricular function from waiting? National assessment of cardiac surgical data will be necessary to answer such questions.

The last major knowledge gap is how the pandemic may potentially transform cardiac surgery in a positive manner. Will the pandemic move us toward greater use of digital health technologies for remote patient assessment? Many practices have already incorporated telemedicine for patient assessment and monitoring of disease progression before surgery. The pandemic may provide us with greater knowledge of the optimal timing of surgery and how best to monitor patients before and after surgery. Cardiac surgery is often described as a highly adaptable and innovative specialty. The COVID-19 pandemic has forced us to continue to provide care in unprecedented circumstances. Continued surgical excellence during the COVID-19 pandemic will require continued multispecialty collaboration, adaptability, and innovation.

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### CONFLICT OF INTERESTS

VHT: advisor/research: Abbott Vascular, Boston Scientific, Edwards Lifesciences, Gore Vascular. CM: advisor/research: Terumo Aortic, Medtronic, and Cryolife. Dr. Thourani: Advisor/research, Abbott

Vascular, Boston Scientific, Edwards Lifesciences, Gore Vascular. Dr. Malaisrie: Advisor/research, Terumo Aortic, Medtronic, and Cryolife.

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