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MINI-REVIEW

Cardiac Surgery During the Coronavirus Disease 2019 Pandemic: Perioperative Considerations and Triage Recommendations

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ABSTRACT: The coronavirus disease 2019 pandemic, caused by severe acute respiratory syndrome coronavirus-2, represents the third human affliction attributed to the highly pathogenic coronavirus in the current century. Because of its highly contagious nature and unprecedented global spread, its aggressive clinical presentation, and the lack of effective treatment, severe acute respiratory syndrome coronavirus-2 infection is causing the loss of thousands of lives and imparting unparalleled strain on healthcare systems around the world. In the current report, we discuss perioperative considerations for patients undergoing cardiac surgery and provide clinicians with recommendations to effectively triage and plan these procedures during the coronavirus disease 2019 outbreak. This will help reduce the risk of exposure to patients and healthcare workers and allocate resources appropriately to those in greatest need. We include an algorithm for preoperative testing for coronavirus disease 2019, personal protective equipment recommendations, and a classification system to categorize and prioritize common cardiac surgery procedures.

Key Words: cardiac ■ coronary artery bypass grafting ■ COVID-19 ■ SARS-CoV-2 ■ surgery ■ virus

The epidemic caused by the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) virus, the causative agent of coronavirus disease 2019 (COVID-19), represents the third introduction of the highly pathogenic coronavirus into the population. COVID-19 and the previous iterations, SARS coronavirus-1 in 2002 and Middle East respiratory syndrome coronavirus in 2012, are RNA viruses transmitted from animals to humans that can cause a spectrum of respiratory symptoms, ranging from mild symptoms (cough, fever, malaise, anosmia, fatigue, and loss of appetite) to acute respiratory distress syndrome (ARDS).[1,2] Because of the highly contagious nature of COVID-19, the unprecedented rate of spread on a global scale, and lack of effective treatment, healthcare systems around the world are already overwhelmed and their infrastructure is strained. Accordingly, several societies have offered guidelines and recommendations on how to conserve resources and triage patients who need more urgent care.[3,4] The Department of Health and Human Services and the American College of Surgeons have, therefore, postponed all elective surgical cases and procedures throughout the United States.[5] This is undertaken to minimize exposure of surgical patients and healthcare workers (HCWs) to COVID-19, allocate needed staff to emergency departments and intensive

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Nonstandard Abbreviations and Acronyms

AGP	aerosol-generating procedure
AIIR	airborne infection isolation room
ARDS	acute respiratory distress syndrome
AS	aortic stenosis
COVID-19	coronavirus disease 2019
HCW	healthcare worker
HF	heart failure
ICU	intensive care unit
MR	mitral regurgitation
OR	operating room
PPE	personal protective equipment
SARS-CoV-2	severe acute respiratory syndrome coronavirus-2

care units (ICUs), and ration the use of critical supplies, including ventilators, personal protective equipment (PPE), and blood products.

To this end, the American College of Surgeons has provided recommendations for cases that should be postponed or prioritized for general surgery, trauma, and several subspecialties, including thoracic surgery.[5] However, limited recommendations are currently available for adult cardiac surgery patients.[6–8] Given the extensive perioperative and postoperative care and resources required for cardiac surgery, including anesthesia staff, blood products, ventilators, ICU care, and need for subsequent procedures, we have constructed a triage classification system to help prioritize patients in need of urgent care and identify those who can be safely postponed. In addition, we provide a preoperative testing algorithm for SARS-CoV-2 and perioperative recommendations for cardiac surgery patients. To our knowledge, the following report is one of the earliest and most comprehensive documents providing guidance and clinical recommendations specific to cardiac surgery in the contemporary COVID-19 era. Notably, the principles provided herein may also be useful for other surgical specialties.

PERIOPERATIVE TESTING RECOMMENDATIONS FOR COVID-19

To safely perform procedures or surgeries during the current pandemic, clinicians must be aware of the epidemiological characteristics of COVID-19 and testing limitations and benefits to protect other patients and HCWs. In communities with established transmission, there will be a growing population of patients with COVID-19 who will be minimally symptomatic, presymptomatic, or asymptomatic (estimated to be up to 60%).[9,10] There will be also a growing population of patients who present to surgery with recent symptoms of COVID-19 but who are unaware of their disease because of its variable presentation or because they never tested for it. For those with SARS-CoV-2 infection, shedding may occur through the respiratory or gastrointestinal tract for up to 2 to 4 weeks.[11] As we learn more about SARS-CoV-2, questions about perioperative testing for surgical patients (and all patients) will continually emerge.

Although there are no data about the clinical benefit of preoperative screening for SARS-CoV-2, we recommend preoperative screening in asymptomatic patients be considered in specific situations (Figure 1). Patients undergoing cardiac surgery are a unique population in this COVID-19 epidemic because of the risk of exposure to others from a highly invasive, aerosol-generating procedure (AGP), the potentially prolonged hospitalization or ICU stay, and the overall intense healthcare resource use. In addition, knowing a patient's preoperative COVID-19 status may help with postoperative management and counseling as recent evidence suggests that asymptomatic COVID-19 patients who undergo surgery may be more susceptible to pneumonia and ARDS postoperatively.[12]

In healthcare settings where testing is limited, the testing of patients at highest risk (on the basis of epidemiologic factors, clinical factors, or both) needs to be prioritized, as proposed by the Infectious Diseases Society of America Recommendations for Testing Prioritization.[13,14] In healthcare settings where COVID-19 PPE resources are limited or shortage is anticipated, but testing resources are not limited, expanded preoperative testing for COVID-19 should be strongly encouraged. Expansion of testing may enhance surgical decision making, patient counseling, and allocation of health resources.

Anticipating that many, if not most, hospitals are currently in a resource-limited setting, we recommend a pretest probability stratified approach for testing. The pretest probability is based on the presence of symptoms, travel, and exposure history, and the community prevalence of the disease. The pretest probability may be accordingly categorized into low, intermediate, and high. Low pretest probability corresponds to an asymptomatic patient with no sick contacts or recent history of travel in the past 14 days who comes from a low prevalence area (no documented local community-based transmission). We expect most patients in urban areas to fall into intermediate- or high-pretest probability categories given the prevalence of the disease in larger cities. The rationale for the pretest probability stratified approach is that, in low prevalence settings, the positive

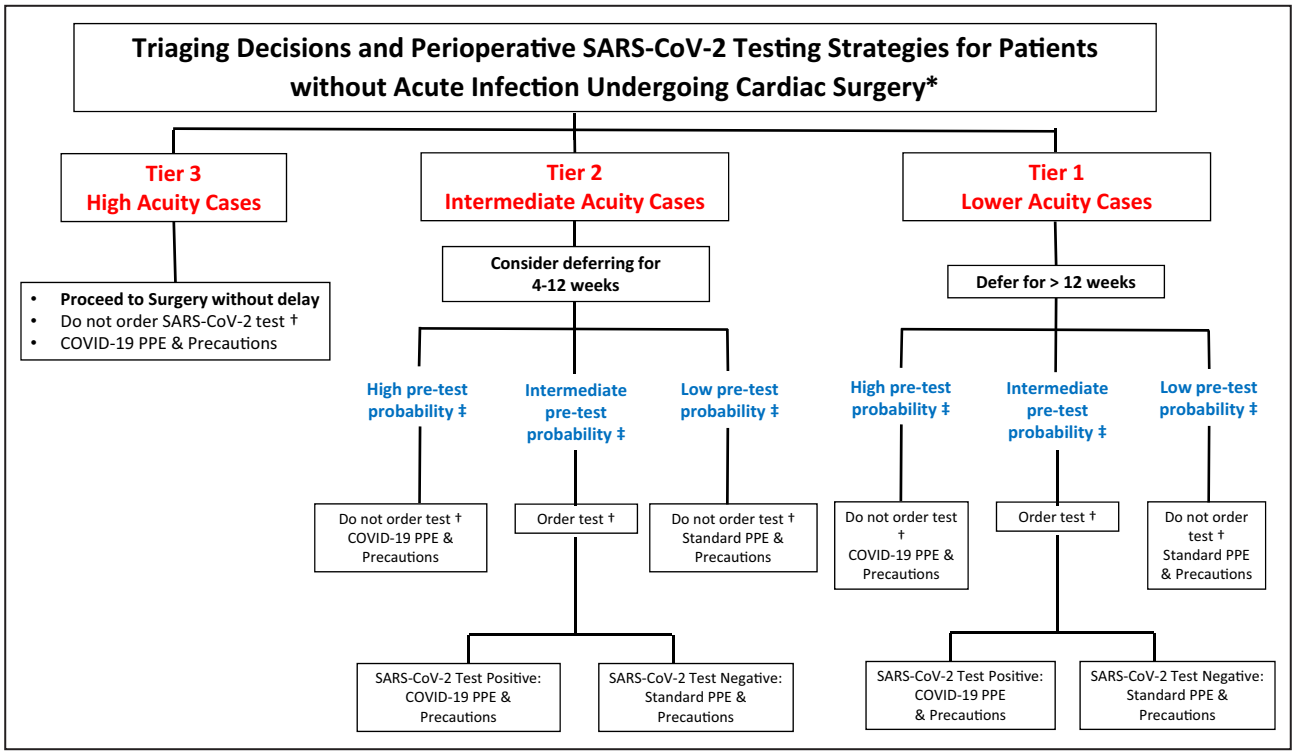

Figure 1. Perioperative severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) testing strategy for patients without acute infection undergoing cardiac surgery.
*This testing algorithm provides guidance on personal protective equipment (PPE). The decision to perform a case is primarily dependent on the surgical indication (tier 1, 2 or 3 [Table 2]) and not coronavirus disease 2019 (COVID-19) testing. However, knowing the COVID-19 test results may help with guidance for surgical timing, patient counseling on postoperative complications, and allocation of hospital resources. †If resources to test all preoperative patients are available, we recommend universal testing for the reasons mentioned above. The test should be performed as close to surgery as possible. Time permitting, tier 3 patients may also be tested. ‡Stratification by pretest probability is useful in limited-resource settings. Local/regional disease prevalence may serve as a surrogate for the pretest probability. **High pretest probability:** local community/facility prevalence of >20% to 50%; **intermediate pretest probability:** for patients who are not considered to have high pretest probability or low pretest probability; **low pretest probability:** no documented local community-based transmission, asymptomatic patient, and the patient and patient's close contacts have not traveled within 14 days.

predictive value is low; and in high prevalence settings, the negative predictive value is low (Figure 2). Therefore, the test may be most helpful for those in the intermediate-pretest probability category, where it may change clinical decision making and help identify who needs the COVID-19 PPE. Identifying the patient's pretest probability or local prevalence can be challenging, and is a dynamic process that should rely on available local epidemiological data. Until a more sophisticated pretest probability calculator (which takes into account patient risk factors, sick contacts, symptoms, and prevalence of disease) is available, the local and regional prevalence of the disease (percentage of positive SARS-CoV-2 tests) may serve as surrogate markers for the pretest probability. Prevalence data are readily available at the hospital, city or county, and state levels from several resources (Table 1).

The optimal method and site of collection for perioperative screening for SARS-CoV-2 are currently controversial. The diagnostic performance of tests for SARS-CoV-2, approved under the Federal Drug Administration Emergency Use Authorization, indicates significant variability in sensitivity.[15] The initial and most common test is the reverse transcription–polymerase chain reaction, of the 1ab region of the SARS-CoV-2 virus, from samples obtained from the patient. The sample is typically obtained from the nasopharynx in nonintubated patients or bronchoalveolar lavage in intubated patients. Lower respiratory samples are more likely to be positive compared with nasopharyngeal samples.[15] However, the false-negative rate may vary from institution to institution and may be as high as 20%. Recently, a rapid immunoassay that detects COVID-19 immunoglobulins M and G has also been developed, but antibodies to COVID-19 may not form for up to 5 to 7 days after the onset of illness.[16] At this time, we recommend reverse transcription–polymerase chain reaction as the preferred method, with the caveat that there may be significant variability

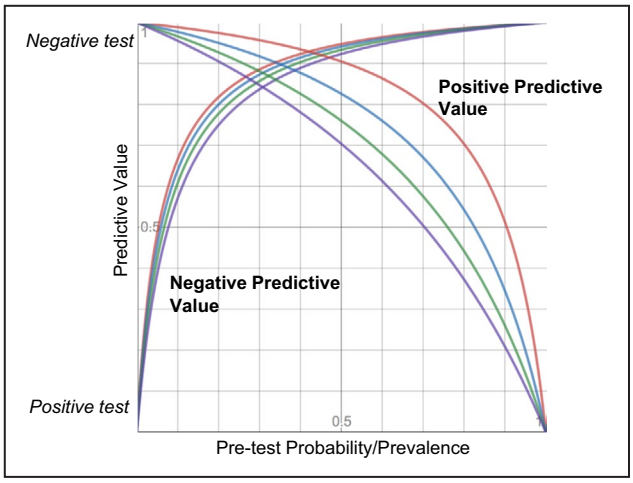

Figure 2. The relationship of positive and negative predictive value to prevalence.
This schematic illustrates the relationship between positive predictive value (PPV), upper left, and negative predictive value (NPV), lower left, to prevalence. Varying sensitivities for these assays are also illustrated (red, 90%; blue, 80%; green, 70%; purple, 60%; all groups use specificity of 95%). In a low-prevalence setting, the PPV is low. In high-prevalence settings, the NPV falls below 80% to 90%. In intermediate-prevalence settings, the PPV and NPV are both high. The diagnostic test may, therefore, be the most valuable for patients with intermediate pretest probability. Each facility should review its local thresholds for PPV and NPV, and review its facility's diagnostic assay. The schematic was created by A.C.[3]

between laboratories. Fortunately, improvements in testing are anticipated soon.

To further simplify principles related to testing, we created a testing algorithm (Figure 1), which mirrors the tier-based surgical triage system (Table 2). The purpose of this algorithm flowchart is to help determine appropriate PPE. The decision to perform a case is defined by the acuity of the clinical situation (Table 2). For *tier 3* patients (higher-acuity cases), we recommend proceeding to surgery with COVID-19 precautions on the basis of the clinical indication, and not delaying the case for testing for SARS-CoV-2, as delay would likely result in patient harm. Facilities with adequate SARS-CoV-2 testing turnaround time can consider preoperative testing for SARS-CoV-2 to guide PPE decisions. Facilities with low local prevalence and patients with no epidemiological exposure can consider using standard PPE.

In *tier 2* patients (intermediate-acuity cases that may be deferred 4–12 weeks) with **high pretest probability** of COVID-19 (ie, >20%–50% community prevalence), we recommend proceeding to surgery with COVID-19 PPE precautions and without preoperative testing for SARS-CoV-2. In patients with an **intermediate pretest probability** of COVID-19, we recommend preoperative testing for SARS-CoV-2 to determine appropriate PPE. For patients with a **low pretest probability** of COVID-19, we recommend using standard PPE. We expect most patients to fall into the high- or intermediate-pretest probability categories. For *tier 3* patients (low-acuity cases that may be deferred >12 weeks), we recommend the same pretest probability stratified approach as tier 2 patients. When testing is more reliable and universally available, we recommend the testing of all tier 2 and 3 patients with the qualification that in low-pretest probability scenarios, the positive predictive value of the test will be lower. In other words, as the disease prevalence decreases with time, the value of preoperative testing will decrease.

Table 1. Resources for Determining Local and Regional Prevalence of COVID-19

Location	Resources
Hospital level	1. Facility infection control 2. Facility microbiology/laboratory
City/county level	1. City health department 2. County health department 3. Coronavirus Resource Center, Johns Hopkins University and Medicine (https://coronavirus.jhu.edu/us-map)
State level	1. State health department 2. Institute for Health Metrics and Evaluation (https://covid19.healthdata.org) 3. Coronavirus Resource Center, Johns Hopkins University and Medicine (https://coronavirus.jhu.edu/us-map)

COVID-19 indicates coronavirus disease 2019.

Overall, we encourage cardiac surgeons to risk stratify their patients according to the acuity of their condition (tiers 1–3) to guide their timing of the planned surgery. We also encourage them to use the COVID-19 pretest probability tool and testing to help guide their use of the scarcely available COVID-19 PPE and precautions. Recommendations for PPE and perioperative processes are provided in the next section. A surgical review committee may be consulted for patients with intermediate risk (tier 2), when controversy arises, or both.

For patients diagnosed with COVID-19 who require cardiac surgery, the optimal perioperative approach is controversial. It is unknown whether patients recently recovered from COVID-19 are more susceptible to postoperative complications, as their angiotensin-converting enzyme 2, which may be protective against acute lung injury, may be consumed during SARS-CoV-2 entry.[17–20] Although patients who have recovered after COVID-19 still have SARS-CoV-2 detected by reverse transcription–polymerase chain reaction, it is unclear how contagious these patients may be. Therefore, for patients recently recovered from COVID-19, we recommend delaying cardiac surgery for at least 2 to 4 weeks after the positive SARS-CoV-2 test. In our opinion, routine repeated testing is not indicated at this time.

Table 2. Triage Recommendations for Cardiac Surgery Patients During the COVID-19 Epidemic

Tier	Definition	Category	Diagnosis	Action
3	High acuity	Aortic disease	1. Acute aortic dissection of ascending aorta, or complicated descending thoracic or aortic arch dissection 2. Aortic aneurysm (ascending, arch, descending, or thoracoabdominal) with symptoms	Do not defer*
		Coronary disease	1. Acute coronary syndrome not amenable to or failed PCI 2. Significant left main stenosis with unstable ischemia symptoms 3. Acute myocardial infarction with mechanical complication 4. Life-threatening PCI complication requiring surgical bailout	
		Valvular disease	1. Acute ischemic mitral regurgitation or acute flail mitral leaflet 2. Severe mitral regurgitation with acute refractory or recurrent HF† 3. Severe mitral stenosis with acute refractory or recurrent HF† 4. Severe aortic stenosis with acute refractory or recurrent HF,† or with recent or recurrent exertional syncope 5. Severe aortic regurgitation with acute refractory or recurrent HF† 6. Endocarditis with surgical indications 7. Thrombosed left-sided prosthetic valve	
2	Intermediate acuity	Valvular disease	1. Severe mitral regurgitation with chronic HF 2. Severe mitral stenosis with chronic HF 3. Severe aortic stenosis with chronic angina or chest pain 4. Severe aortic regurgitation with chronic HF	Consider deferring for 4–12 wk*
1	Low acuity	Aortic disease	1. Aortic aneurysm (ascending, arch, descending, or thoracoabdominal) without symptoms 2. Uncomplicated descending thoracic or aortic arch dissection	Consider deferring >12 wk*
		Coronary disease	1. Multivessel CAD without ACS.	
		Valvular disease	1. Severe asymptomatic AS without HF 2. Asymptomatic valvular disease	

ACS indicates acute coronary syndrome; AS, aortic stenosis; CAD, coronary artery disease; COVID-19, coronavirus disease 2019; HF, heart failure; and PCI, percutaneous coronary intervention.

*The above recommendations for deferral and timing should be *dynamic*, based on the epidemiological characteristics of the disease and hospital resources.

†Refractory or recurrent HF refers to cases that are not responsive to medical therapy.

PERIOPERATIVE CONDUCT AND PPE RECOMMENDATIONS

The American College of Surgeons has provided some universal recommendations for perioperative conduct. These include the creation of a Surgical Review Committee to triage cases, suggestions to reduce the risk of exposure when treating COVID-19 patients, and recommendations for anesthesia management.[5] In the following sections, we propose recommendations pertinent to the preoperative, intraoperative, and postoperative settings, followed by a proposed triage system of cardiac surgery patients.

A surgical review committee should be created to discuss urgent but not necessarily emergent surgical cases as well as controversial cases with intermediate acuity to ration the available resources of the hospital. The committee should consist of surgery, anesthesiology, nursing, and administrative staff. To protect HCWs, these discussions should be done over video or telephone conference to limit the provider-to-provider contact. The objective of these discussions will be to triage cases, limit exposure of other patients and healthcare providers in the hospital, and ration resources.

Reducing the risk of exposure of HCWs and other patients to COVID-19 patients is of paramount importance. The highest risk procedures are AGPs, which are at higher risk of droplet dispersion and transmission. These AGPs include intubation, extubation, tracheostomy, bronchoscopy, endoscopy, laparoscopy, any cardiac or thoracic surgery, chest tube placement, and Bovie cautery use.[21–23] Currently, there are limited data on the amount of aerosolized SARS-CoV-2 generated from each specific AGP and

which ones pose greater or lesser risks. The use of an N95 respirator or powered air-purifying respirator, eye protection, gloves, and gowns is recommended for these procedures in COVID-19 suspected or positive patients.[21–23] Many institutions are advocating for the same universal precautions for anesthesiology, surgeons, and surgery assistants participating in AGPs regardless of the COVID-19 status. Notably, there were case reports suggesting transmission of SARS to HCWs even when N95 masks were used properly.[24]

Restriction of personnel in the operating room (OR) to only those critical to patient care cannot be emphasized enough. To that end, all surgical supplies should be in the OR before the case to limit traffic. For intubation and extubation, only anesthesiologists should be in the OR to protect the remainder of the team. The optimal duration to wait before allowing nonanesthesia staff into the OR is unknown but will be affected by factors such as the ability of the OR heating, ventilation, and air conditioning to achieve sufficient air changes and whether the OR is positive or negative pressure. Most modern ORs are positive pressure and achieve at least 15 air changes per hour, which would take 18 minutes for 99% removal and 28 minutes for 99.9% removal.[25] Eighteen minutes (ie, 99% air removed) after intubation is reasonable to consider, but teams should discuss their OR heating, ventilation, and air conditioning function with the facility environmental engineer before surgery. When operating on COVID-19 suspected or positive patients, the additional following precautions are recommended: creation of a separate "COVID-19" OR with an anteroom for PPE, separate equipment, limitation of intraoperative personnel, the use of heat and moisture exchange filters on the ventilator circuit, the use of N95 respirators or powered air-purifying respirator for all AGPs, and an isolated negative pressure room for recovery. Additional provisions for specific procedures are available through the American College of Surgeons and anesthesiology societies.[21–23]

Special consideration must also be given to patient transportation and recovery. Patients known or suspected of COVID-19 should be preemptively placed in an airborne infection isolation room (AIIR) at the time of identification, or if an AIIR is unavailable, a segregated space that mitigates risk of cross-contamination as per the institution's policy. AIIR, if available, may be preferred for patients after cardiac surgery because of greater likelihood of coughing and aerosol generation. A formal multidisciplinary workflow (from patient room to OR to postoperative room), which minimizes exposed personnel, should be discussed, disseminated, and rehearsed before the surgical procedure.

ANESTHESIA RECOMMENDATIONS

Although the triage system described takes into consideration the acuity of the patient's surgical condition, the ultimate determination of whether a suspected or known positive COVID-19 patient proceeds to the OR must also include broader considerations about the patient's medical condition, room availability, hospital staffing, and readiness of necessary supplies, such as surgical instruments and blood products. On March 24, 2020, the American College of Surgeons, the American Society of Anesthesiologists, and the Association of periOperative Registered Nurses released a joint statement advocating the formation of a "Surgical Review Committee, composed of surgery, anesthesiology, and nursing personnel" so that "decisions on surgery cases be made on a daily basis, no later than the day before surgery."[26] For urgent or emergent cases that cannot be discussed by the Surgical Review Committee, every reasonable effort should be made to come to a treatment consensus with the anesthesiology and intensivist services before proceeding.

Regardless of the patient's acuity tier, coordinated effort must be made with the anesthesiology team to render effective cardiac surgical care while minimizing risk of exposure to medical personnel and surrounding patients. Guidelines and recommendations specific to COVID-19 are still evolving, but 2 professional organizations, the American Society of Anesthesiologists and the Anesthesia Patient Safety Foundation, are offering ongoing updates and resources.[27,28] As blood product supply has been reduced around the country, the surgical plan should be formulated to reduce intraoperative time and subsequent need for transfusion. Adequate blood product availability should be ensured before posting the procedure.[29]

In cases requiring endotracheal intubation, preference is made to securing the airway at the patient's originating location (inside the AIIR or negative pressure isolation room), before transport to the OR (usually positive pressure room). The use of a negative pressure room as opposed to a positive pressure room reduces the risk of aerosolization.[21,27] Additional invasive procedures, such as central or arterial lines, can be placed at the patient's room or the OR at the discretion of the team. Noninvasive positive-pressure ventilation (continuous positive airway pressure or bilevel positive airway pressure) should be avoided because of the known risk of aerosolization. During the outbreak of SARS in Toronto, Canada, half of all cases were HCWs and those at greatest risk participated in airway procedures or were exposed to aerosolization via nebulizers, continuous positive airway pressure, bilevel

positive airway pressure, or high-flow nasal oxygen therapy.[24] Preoxygenation can be performed with a standard face mask placed over the surgical mask on the patient. Rapid sequence induction should be performed by the most experienced intubator available using video laryngoscopy to increase the distance from the airway.[21] Awake fiberoptic intubation should be avoided because of the risk of aerosolized respiratory droplets. High-efficiency particulate air filters should be used on the ventilator circuit, and disruptions should be minimized. If possible, the patient may be transported from the originating room with the ventilator. Should a circuit disconnect be necessary, the anesthesiologist must communicate with the entire team so that personnel can be distanced from the airway, the ventilator can be placed in standby, and the endotracheal tube can be clamped before proceeding. A second provider, fully donned in PPE, should be on standby for assistance while the intubator secures the airway in case of hemodynamic instability.

Turnover of anesthesia staff during the case should be minimized. Limited equipment and supplies should be inside the room so that they are not unnecessarily exposed to the patient. Alternative warming devices should be considered rather than forced-air devices (eg, Bair Huggers), and an anesthesia technician should be available outside the room in minimal PPE to facilitate delivery of needed supplies.

At the completion of the procedure, extubation of the suspected or COVID-19 positive patient should be undertaken in a negative-pressure room, preferably the originating room or AIIR. Extubation should only proceed if there is a high certainty of success, to avoid temporary measures, such as continuous positive airway pressure or bilevel positive airway pressure, which increase aerosolization. There should be a low threshold for reintubation during a more controlled situation.

Transport of the patient into and out of the OR should proceed according to the workflow developed by each institution. The important principles are minimizing exposed personnel and cross-contamination and communication. All corridors used for transport should be cordoned until cleaned in an approved manner. Patients with suspected or known COVID-19 should never be brought to the common holding or recovery areas and should proceed straight to a predesignated COVID-19 OR. If it is desired to transfer the patient to an OR ventilator, anesthesia personnel should ensure a high-efficiency particulate air filter is placed between the Y piece of the breathing circuit and the endotracheal tube, the gas sampling line is placed on the ventilator side of this filter, and any secondary viral filter (if used) is placed on the ventilator side of the expiratory limb.[28]

CONSIDERATIONS FOR THE POSTOPERATIVE CARE OF COVID-19 PATIENTS

The postoperative care of suspected or positive COVID-19 patients should involve placement of these patients in a separate ward in AIIR (ie, negative-pressure room), limitation of HCWs to those directly involved in patient care, and methods to limit traffic into the room (eg, intravenous poles outside of the room for medication administration). Postoperative care should also include avoidance of noninvasive positive-pressure ventilation (continuous positive airway pressure and bilevel positive airway pressure) and appropriate PPE (N95 respirator or powered air-purifying respirator) for AGPs (bronchoscopy and chest tube placement). The ICU team should remind all personnel entering the patient's room about these precautions, especially before any additional procedures. Precautions for in-hospital cardiopulmonary resuscitation are delineated on the American Heart Association website.[4]

Postoperatively, the surgeon and ICU team should be aware of multiple potential complications. Case series of nonsurgical infected patients suggest that COVID-19 may also result in myocardial injury, arrhythmias, thromboembolic disease, liver and/or kidney injury, and even gastrointestinal distress in addition to the well-known respiratory complications.[2,12,30] A recent retrospective study from postsurgical patients in Wuhan, China (n=34), for patients who inadvertently underwent a wide range of surgical procedures during the incubation period for COVID-19 revealed that 100% of patients developed pneumonia (defined as presence of lung opacities on computed tomography), 44% of patients required ICU care, 32% of patients developed ARDS, and 21% of patients died.[12] Of 5 thoracic surgery patients, 3 died. In contrast, nonsurgical patients positive for COVID-19 had an ICU admission rate of 26.1% and a mortality rate of 2.3% for this region.[12] The time from surgery to the onset of symptoms was 2 days; and to the onset of ARDS, 11 days. The ARDS characteristics of COVID-19 should steer the anesthesiologist to minimize fluids and use a lung-protective ventilation (permissive hypercapnia) strategy of low tidal volume (6–8 mL/kg predicted body weight), respiratory rate ≤35 breaths/min, plateau airway pressure ≤30 cm H_2O, and positive end-expiratory pressure ≥5 cm H_2O.[31–34] Recent reports have also indicated that COVID-19 patients are more prone to hypercoagulability and disseminated intravascular coagulation as a result of the cytokine storm experienced by many patients with the illness. Our institution is in the process of reporting our experience with thromboembolic events in COVID-19 patients, which will invariably raise considerations for emergent cases

requiring cardiopulmonary bypass and postoperative anticoagulation. Knowledge of these postoperative complications helps in the management and preoperative counseling of COVID-19 positive patients in need of surgical intervention. Additional provisions that would help in the care of the COVID-10 positive postsurgical patient are available in the Surviving Sepsis Campaign: Guidelines on the Management of Critically Ill Adults With Coronavirus Disease 2019.[34]

TRIAGE RECOMMENDATIONS FOR CARDIAC SURGERY PATIENTS

The proposed classification system for triaging cardiac surgery patients is described below and summarized in Table 2. **High-acuity cases (ie, tier 3)** are considered urgent or emergent procedures that should not be deferred. **Intermediate-acuity cases (tier 2)** may be deferred for a 4- to 12-week time period. This range dynamic should be constantly revisited, as it may change depending on the available hospital resources and the extent of the outbreak in the local community. **Lower-acuity cases (tier 1)** are elective and may be deferred for >12 weeks. All deferred cardiac surgery patients should have a plan for follow-up through telephone or telemedicine and a surgical plan in the near future when resources become available. To our knowledge, the current classification and recommendations are one of the first proposed for cardiac surgery patients in the COVID-19 era in the United States, and complement those proposed by the American College of Surgeons, the Canadian Society of Cardiac Surgeons, and the Society of Thoracic Surgeons. The society recommendations cited above recommend a dynamic triage plan on the basis of the local and regional disease prevalence. Our proposed recommendations are consistent with these but provide the clinician with a more comprehensive triage plan. Controversial cases and especially patients at intermediate risk should be discussed by a Surgical Review Committee to determine the appropriateness of surgical timing with consideration of the available hospital resources and community outbreak status.

Cardiac surgery candidates who are hemodynamically stable and suspected to have COVID-19 should undergo appropriate testing to protect other patients and HCWs. For actively ill COVID-19 patients in tier 1 or 2 (ie, low- and intermediate-acuity cardiac status), surgical intervention should be delayed until the patient has clinically recovered and the risk of viral shedding is low (ie, 2–4 weeks after the onset of illness). For COVID-19 patients in tier 3 who have active infection, emergent high-risk surgery can be undertaken for lifesaving purposes as long as adequate COVID-19 PPE and precautions are available and the patient's critical illness is not attributable to COVID-19. In the latter case, surgery should be avoided for futility and the ethics committee may be invoked selectively. At this time, there are no surgical data informing clinical practice about the appropriate timing following a COVID-19 illness.

As the COVID epidemic evolves, there will be fluctuations in disease prevalence. Accordingly, hospitals can transition between different phases of operating capacity on the basis of disease prevalence, as previously described by the Society of Thoracic Surgery and the Canadian Society of Cardiac Surgeons. For example, as resources become available, preoperative workup (catheterization and echocardiograms) and execution of tier 2 cases can be gradually incorporated into the workflow. If there is another resurgence of COVID-19 cases, hospital operations can be scaled back again until a more appropriate time. The development of a transition plan should be undertaken by the Surgical Review Committee and hospital administration. More important, caution should be advised in slowly reopening normal operations while staying abreast of the local disease prevalence to ensure patient and HCW safety. Preoperative SARS coronavirus-19 testing (if available) should be performed during the transition period, noting that the positive predictive value of the test will decrease as the prevalence decreases. After successful transition, testing can be limited to those with a significant travel history, sick contacts, or relevant symptoms.

The following information summarizes our triage recommendations based on the patient's disease. Among the highest-acuity (tier 3) cases, aortic dissections involving the ascending aorta represent true emergencies as they can lead to myocardial infarction, tamponade, malperfusion, and death.[35,36] Complicated descending thoracic aortic dissections (tier 3) require urgent repair (endovascular or open), whereas uncomplicated dissections may be deferred (tier 1). Complicated dissection includes those with imminent or actual aortic rupture, aortic expansion, hemodynamic instability, persistent pain despite medical management, drug-resistant hypertension, and malperfusion. Similarly, uncomplicated dissections of the aortic arch that do not involve the ascending aorta may be deferred.

Symptomatic ascending, transverse arch, or thoracoabdominal aortic aneurysms require expeditious repair regardless of the size. Diameter-based thresholds for repair, the point at which the risk of rupture outweighs the operative risks, are 5.5 cm for ascending and 6.5 cm for descending aortic aneurysms (although some experts advocate using cutoffs indexed to patients' height or body surface area). However, these thresholds vary on the basis of the cause- and patient-specific risk

factors.[37,38] Asymptomatic aneurysms may generally be deferred (tier 1) unless they approach a size that confers a high risk for rupture. Decisions about complex aortic pathological characteristics should be discussed with an experienced aortic surgeon and with a Surgical Review Committee to decide on appropriate surgical timing. As these cases may consume a significant amount of hospital resources, deferring repair may be the most reasonable option, if possible.

Acute coronary syndrome or significant left main stenosis not amenable to percutaneous coronary intervention will likely need emergent or urgent coronary artery bypass grafting and should not be deferred (tier 3).[39] Mechanical complications after acute myocardial infarction also represent an emergent indication for coronary artery bypass grafting and surgical repair, as well as life-threatening percutaneous coronary intervention complications needing surgical bailouts. On the other hand, multivessel coronary artery disease in patients with stable ischemic heart disease can be deferred and discussed during the multidisciplinary heart team virtual meetings (tier 1).

Valvular heart disease may vary in presentation, especially for mitral regurgitation (MR), from asymptomatic to heart failure (HF), which may be long-term or refractory to medical management. Accordingly, valvular lesions are classified and triaged from tier 3 to 1 on the basis of symptoms. Asymptomatic valvular disease without congestive HF may be medically managed with a plan for deferred repair when resources are available (tier 1).[40]

Symptomatic aortic stenosis (AS) warrants careful evaluation of the patient's symptoms before a decision on surgical timing.[41,42] Patients with acute refractory or recurrent HF and those with recent or recurrent exertional syncope or presyncope from AS are the most urgent and should undergo prompt surgery (tier 3). Without surgical treatment, AS patients with reduced left ventricular ejection fraction have an expected mortality of 60% at 1 year.[42] AS patients with chronic angina or chest pain are considered to be intermediate acuity (tier 2). Surgery for patients with severe asymptomatic AS with preserved ejection fraction should be reconsidered and may be deferred until resources become available (tier 1).

Patients with ischemic MR, resulting from ruptured papillary muscle, or acute MR, from a flail leaflet, should undergo surgery without delay (tier 3).[40,43] Patients with severe degenerative MR and acute refractory or recurrent HF should receive surgical treatment without delay (tier 3).[40] However, patients with severe degenerative MR and chronic HF may be deferred for 4 to 12 weeks (a time range that can be revisited, depending on local resources and outbreak conditions) (tier 2). Severe asymptomatic MR with indications for surgery may be deferred (tier 1). Given the complex nature of severe degenerative MR and range of symptoms, these cases should be discussed by a Surgical Review Committee.

Similarly, severe aortic regurgitation and severe mitral stenosis are classified as tier 3 if acute refractory or recurrent HF is present or tier 2 if chronic HF is present.[40] In addition, other valvular diseases considered as tier 3 cases include left-sided prosthetic valve thrombosis and endocarditis with surgical indications, such as valvular insufficiency, perforation, dehiscence, abscess, HF, vegetation >1 cm, persistent bacteremia, recurrent emboli, or high-risk organisms, such as fungi, methicillin-resistant *Staphylococcus aureus*, and *Pseudomonas*.[40,44]

ADDITIONAL RESOURCES

The American College of Surgeons has a comprehensive statement on the perioperative use of PPE for patients with or without COVID-19.[23] Several additional resources are available, including the Society of Thoracic Surgery Resource Utilization Tool, which provides hospitals with estimates of resources (blood products, days on ventilator, ICU length of stay, and hospital stay) needed for the most common cardiac surgery procedures. The Extracorporeal Life Support Organization has also provided recommendations for patients who should be considered for extracorporeal membrane oxygenation.[45] The American College of Cardiology offered recommendations for cardiac catheterization and periprocedural suggestions to limit exposure of healthcare providers.[46]

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