

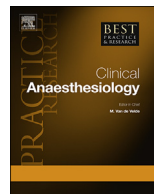


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Best practice in cardiac anesthesia during the COVID-19 pandemic: Practical recommendations



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The COVID-19 outbreak has influenced the entire health care system, including cardiac surgery. In this review, the authors reveal practical aspects that are important during the COVID-19 pandemic with regards to the safe delivery of cardiac anesthesia. Timing for operations of the cardio-vascular system may be well programmed in most cases. Hence, the level of priorities must be defined for any single patient. The postponement of surgery may

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Abbreviations list

ACE	Angiotensin Converting Enzyme
ACS	Acute Coronary Syndrome
ACT	Activated Clotting Time
AMBU	Artificial Manual Breathing Unit
ARDS	Acute Respiratory Distress Syndrome
COVID	Corona Virus Disease
CPB	Cardiopulmonary Bypass
CRP	C Reactive Protein
CT scan	Computerized Tomography scan
CV	Central Venous
ECMO	Extra Corporeal Membrane Oxygenator
EtCO ₂	End Tidal Carbon Dioxide
ETI	Endotracheal Intubation
ETT	Endotracheal Tube
FFP mask	Filtering Face Piece mask
GA	General Anesthesia
HMEF	Heat and Moisture Exchange Filter
IABP	Intra – Aortic Balloon Pump
ICU	Intensive Care Unit
IG	Immune Globulin
IL	Interleukin
INR	International Normalized Ratio
JAK 2 Inhibitor	Janus Kinase 2 Inhibitor
LM trunk	Left Main trunk
LoP	Level of Priority
LV	Left Ventricle
MI	Myocardial Infarction
OR	Operating Room
PAPR	Powered Air Purifying Respirators
PCI	Percutaneous Coronary Intervention
PiCCO	Pulse Contour Cardiac Output
PoCUS	Point of Care Ultrasound
PPE	Personal Protective Equipment
PT	Prothrombin Time
PTT	partial thromboplastin time
RA	Regional Anesthesia
RAAS System	Renin Angiotensin Aldosterone System
RV	right Ventricle
SARS	Severe Acute Respiratory Syndrome
SYNTAX	Synergy between Percutaneous Coronary Intervention (PCI) with Taxus and Cardiac Surgery
TOE	Trans–Esophageal Echocardiography
TRALI	Transfusion Lung Injury
US	Ultrasound
WHO	World Health Organization

be convenient for most cases, if it is made in the best interest of the patient.

The preanesthetic evaluation should be attentive of the respiratory history of the patient. Cardiac anesthesia always implies some respiratory monitoring; hence the existing clinical situation of the patient's respiratory system should be clear. In case of emergency surgery, the patient should be treated as if they potentially have or are at risk for the virus.

In the case of a COVID-19 confirmed or suspected patient, attention must be made to preserve operating room and team integrity. The machineries are to be draped with plastic to simplify the disinfection after the operation.

Perioperative management of suspected or confirmed COVID-19 patients must strictly follow the most relevant international guidelines. This review article has synthesized the common aspects present in the most important of these.

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Introduction

The outbreak of the novel coronavirus and coronavirus disease (COVID–19) was labelled as a Public Health Emergency of International Concern, in January 2020 [1,2]. In March 2020, the rapid and exponential increase in confirmed cases of infection and number of deaths globally obliged the WHO to raise the alarm and declare COVID–19 a pandemic, triggering upscaling of emergency response mechanisms worldwide. COVID–19 control has been extremely critical and demanding, having unfolded serious challenges to disease prevention and public health protection [3,4]. Although common clinical manifestations are mostly respiratory, some patients may develop severe cardiovascular damage and are consequently at higher mortality risk [5].

Patients with suspected or confirmed COVID–19 infection, who undergo cardiac surgery procedures, represent numerous challenges for the cardiac anesthesia team. They necessitate an extremely careful approach during perioperative anesthetic care and may reflect higher risks of perioperative morbidity and mortality. It is emphasized that management of the infected COVID–19 cardiovascular patients, as well as self–protection of involved personnel, are extremely challenging and of equal importance, mandating a meticulous handling in the perioperative setting [6,7].

Cardiac surgery and related anesthesia practice might not be in the frontline of COVID–19 patients' care, but the growth of the coronavirus pandemic resulted in an important impact on this surgical and anesthesia subspecialty. Indeed, the pandemic has already affected cardiac surgery units in multiple ways: limited number of available ICU beds and ventilation sites, the need to postpone or cancel elective and/or complex cardiac interventional procedures, patients developing COVID-19 post cardiac surgery, coronavirus patients needing urgent cardiac operations, cardiac anesthesiologists' in–hospital transfer to staff and support ICUs in front of the pandemic, infected health care providers with consequent shortage of medical and nursing practitioners, restrictions in clinical meetings, and cancellation of training and continuing medical education [6,8].

Cardiac anesthesiologists have the responsibility to ensure that evidence–based anesthetic care and only essential cardiac operations are provided to the general public. In this context, the wider burden of such procedures on health care systems and health care workers need to be minimized in the current coronavirus pandemic by delaying elective cases to sustain health care services [6,8,9]. Based on the current understanding of COVID–19, pathophysiology and clinical characteristics of cardiovascular surgical patients, in this review the authors highlight related anesthesia concerns and provide practical recommendations in reference to perioperative planning and management of patients undergoing cardiac surgery, along with a focus on disease control and prevention in the context of the COVID–19 outbreak.

Timing of cardiac surgery procedures and level of priority in selecting operations to be performed or postponed

While a conclusion to proceed with or postpone a cardiovascular operation seemed easy during the low and medium escalation phase, continued escalation resulting in restricted ICU capacity made such a decision very difficult [6,8]; for example, it is difficult to answer critical dilemmas such as offering surgery only to younger or lower risk patients whose outcomes might be better. Cardiovascular surgical patients are usually characterized by a relatively progressive disease. The necessity for surgery for a given disease condition must be identified by an experienced surgeon, who will prioritize patients' underlying problems and will recognize potential risks encountered which might delay the operation, also taking into consideration the risks for health care providers. As such, making a decision to postpone or perform a cardiac operation is not at all easy. Indeed, it can be tricky and needs to be made after careful evaluation of patient status and health care system capacity, rather than being exclusively based on COVID–19 associated risks. In all cases, availability of medical staff (e.g., cardiac surgeon, cardiac anesthetist, ICU bed, perfusionist), potential need for isolated ICU bed, equipment (e.g., ventilators, pumps, extracorporeal membrane oxygenation, intra-aortic balloon pump (IABP), trans-esophageal echo), medical supplies, and blood and blood products, should be balanced and taken into account prior to a definite conclusion. Importantly, when such decisions are taken, both the decision process and the decision making should be well documented, for obvious medicolegal reasons [9–11].

A knowledgeable decision-making process is emphasized and has to be based on a classification of planned interventions or/and operations in Levels of Priority (LoP), such as (a) elective (LoP I), (b) urgent (LoP II), (c) emergency (LoP III), and (d) salvage (LoP IV), in accordance with international guidelines. In a progressively escalating situation, as has happened in most European countries, routine elective cardiac surgery (LoP I) should be postponed as much as possible. Conversely, operations at LoP II–IV should be further evaluated on an individual basis by the whole cardiac surgery team, keeping in mind that PCI or endovascular interventions are preferable and should be selected if applicable. Additionally, in-house urgent cases (LoP II) at risk of adverse cardiac events if they are discharged instead of remaining hospitalized might still undergo cardiac surgery at this time point, with the application of all precautions and protective measures, in accordance with recent recommendations. The same rule applies for LoP III & IV interventions [6,8,10–12]. However, one must seriously consider such patients' exposure risk to a possible COVID–19 infection during hospitalization and/or exposure of health care workers to patients with a potential COVID–19 infection. Most COVID–19 patients have mild or no symptoms and therefore, it might be difficult to identify them from the pool of in-hospital urgent cases. Moreover, patients with acute coronary syndrome (ACS) in case of severe coronary artery disease (e.g. severe LM trunk stenosis, severe triple vessel disease with high SYNTAX score) who are not eligible candidates for conservative or interventional treatment should be operated. This may be true also for younger patients with symptomatic severe aortic valve stenosis, left-sided endocarditis with a severe valve defect and/or large mobile vegetation, large ascending aortic aneurysm (>6 cm in diameter), and symptomatic severe mitral valve insufficiency. If the pandemic escalates into a crisis, characterized by an absolute shortage of ICU beds and ventilation sites, cardiac procedures will need to be extremely limited to absolutely essential emergency surgeries such as acute type A aortic dissection, acute heart failure due to severe coronary artery or valvular heart disease, and ventricular septal defect. Under these circumstances, such decisions obviously remain tough to resolve and should be made after examining available hospital resources and reserves and must always be supported by an ethical and legal framework [8,11,12].

In all cases, postponing elective cardiac surgery does not necessarily translate into a delay in or a neglect of patient care. It is a fully understandable and realistic assumption that cardiac surgery units are responsible for their patients' best outcome, but also equally responsible toward the health care workers and the wider health care service in a region or country. Therefore, in an escalating pandemic, patients normally scheduled for elective cardiac procedures are best managed by delaying their care until a few weeks or even months later. This is probably in the patients' best interest, to avoid their exposure to the hospital environment, and to eliminate chances of an incidental COVID–19 development in their postoperative course. It is already documented that ACS patients infected by coronavirus usually end up with a poor prognosis. Therefore, developing COVID–19 post cardiac

surgery might be associated with higher mortality rates. However, cardiac patients whose operations are postponed should be regularly reevaluated and strictly followed – up before their underlying conditions evolve further and they arrive at a point of needing a cardiac surgery of LoP II or higher. Finally, the cardiac surgery team should not only take decisions on postponing elective operations but should also discuss and plan regarding the timing of surgery in the future, based on the rapidly evolving COVID–19 circumstances and the continuously evolving regulations and restrictions [11–15].

Preanesthetic – preoperative approach and evaluation of cardiac surgery patients in the COVID–19 era

The coronavirus is highly contagious. Its incubation period fluctuates between 4 and 6 days, although its latency period can extend up to 14 days. Most infected patients usually present with mild, flu–like symptoms, including low fever, dry cough, and fatigue, or can be even asymptomatic. The mean age of a COVID–19 case is reported to be 49 years. Worse outcomes are associated with geriatric populations and those with underlying diseases, such as obesity, cardiovascular comorbidities, pulmonary disorders, and/or diabetes. Differential diagnosis can appear extremely challenging, as common influenza is characterized by similar signs and symptoms. Chest radiography or thoracic CT scan may be utilized in identifying evidence of secondary pneumonia [4,5,14].

Taking into consideration that invasive or at least minimally invasive cardiorespiratory monitoring is usually required in most cardiac surgery procedures, all patients proceeding to OR must be treated as confirmed COVID–19 cases, not only if the disease is suspected, but until a test result becomes available. Additionally, in an escalating pandemic, candidates for elective or semi–elective cardiac operations may be best managed by delaying their care for a few weeks or even months, or in the worst case by postponing care until their COVID–19 virus detection results are negative at least twice with a minimum of 24 h between tests [6–9,13]. It is known that patients with ACS who are infected with coronavirus often have a poorer prognosis compared to the general population. Therefore, developing COVID–19 after cardiac surgery might contribute to a complicated postoperative course and be associated with higher morbidity and mortality rates [15,16].

In the event of an emergency cardiac surgery operation, COVID–19 status mandates immediate evaluation, in terms of patient recent epidemiologic and respiratory infection history, clinical manifestations, and laboratory and radiographic testing, including but not limited to temperature, respiratory pathogen testing, serum IgG level, complete blood count, CRP and procalcitonin levels, SARS–CoV–2 nucleic acid testing, and chest CT scanning. In case enough time is not available for a complete preoperative evaluation prior to surgery, preoperative hospitalization and preparation must strictly follow the already published guidelines for suspected/confirmed COVID–19 cases. Such patients should be admitted to an airborne isolation room (single room with negative pressure and frequent air exchange), with the quarantine necessity being evaluated and finally decided according to SARS–CoV–2 nucleic acid testing and chest CT scanning examination results [17].

A multidisciplinary team consisting of cardiac surgeons, cardiac anesthesiologists, respiratory infectious disease experts, perfusionists, and nursing staff should be involved in coordinating such patients care. For health care personnel involved in suspected or confirmed coronavirus cases, level 3 infection control precautions (such as disposable hat, medical masks [N95 or above], powered air purifying respirators [PAPR], scrubs, disposable gloves, and disposable shoe covers) should be strictly applied throughout the whole perioperative period. Personnel clinical observation and follow–up for signs and symptoms of COVID–19 must not be forgotten and should be carried out closely after their clinical involvement in such patients' care. In case of the possibility of health care personnel's exposure, an isolation period of at least 14 days is mandatory [6–8,12].

OR preparation and readiness prior to cardiac surgery in suspected/confirmed COVID–19 patients

Keeping in mind the ease of in–hospital coronavirus contaminating capability and spread and that all health care workers are among those at high risk of infection, they must all routinely apply protective and preventive measures, with attention to details, to avoid any nosocomial spread to patients

and health care nursing and medical personnel. Indeed, precautions in the care of all patients and in the interaction between health care personnel are of paramount importance to limit infection spread as much as possible.

It is highly recommended that all health care providers focus on their personal protective equipment. In this regard, all should wear an N95 mask, surgical cap, gown, protective eye goggles, shoe covers, double gloves, and PAPRs or protective full–face shield during every contact with suspected or confirmed COVID–19 cardiac surgery candidates [6–8]. A dedicated operating room for the suspected/confirmed cardiac surgery COVID–19 patients must be readily available and in absolute isolation from the other operating theatres, with a warning sign posted outside and with predefined, dedicated preoperative and postoperative patient transportation pathways, which must be disinfected regularly. COVID–19 OR set up, workflow, and organization are extremely critical. Surgical devices and anesthetic equipment must be unique and dedicated only to the predefined COVID–19 OR, without any chance of being transferred to other operating sites. All non–essential surgical and anesthetic equipment needs to be removed outside this dedicated OR. The operating room should also be converted to a negative pressure environment with airflow changes, with doors remaining shut at all times, to maintain an optimal negative pressure at all time points of the cardiac patient perioperative care [6,7,17–19].

Coordination of and collaboration between health care practitioners, workflow of the COVID–19 OR (including but not restricted to routine universal infection prevention practices, donning and doffing personal protective equipment [PPE], and decontamination after the procedures), and designated personnel must be planned on a daily basis and evaluated and adapted to dynamic circumstances. Cardiac surgery is a complex operative procedure that cannot be completed successfully without a group of health care practitioners. Such operations must involve a dedicated team limited to the minimum number of nursing and medical personnel (cardiac surgeon, anesthesiologist, anesthesia nurse/technician, CPB (cardiopulmonary bypass) technician, perfusionist, scrub, and nurse). All team members should be assigned their roles prior to COVID–19 patient entrance in the OR. Irrelevant staff should not enter the COVID–19 OR to minimize unnecessary traffic. Staff management can take appropriate measures to separate workers/anesthesiologists/surgeons into groups, so that possible necessary quarantines can be applied to groups within each unit rather than the unit as a whole which could lead to the closure of the entire cardiac surgery service, something that is especially true for smaller cardiac surgery units [6–9,13,19].

All equipment and devices required such as those for endotracheal intubation and arterial and central venous cannulation and syringes, gauzes, surgical drapes, surgical instruments, sutures, material for cannulation prior to CPB, oxygenator and circuit for CPB, and prosthetic grafts and valves must be checked for adequacy prior to surgery and be set and positioned properly and definitely prior to patients arrival in the OR. The aim is to have as minimal as possible traffic in circulation across the COVID – 19 OR. Additionally, high–touch surfaces of devices like anesthesia machines/workstation, infusion pumps, CPB machine, cell–saver device, IABP, heat exchangers, and computerized devices for documentation should be wrapped with plastic sheets, to facilitate cleaning and decontamination after the end of surgery and following patients transportation to ICU, in accordance with international general guidelines. Strict measures and precautions for infection control should be implemented, especially for suspected/confirmed COVID–19 cardiac surgery patients [6–9].

Anesthetic preoperative preparation and management of suspected or confirmed COVID–19 patients

First, in reference to staffing management and based on the potential complexity of a cardiac operation, two experienced cardiac anesthesiologists and a cardiac anesthesia nurse are necessary inside the cardiac surgery OR, being directly responsible for patient anesthetic care. A third cardiac anesthesiologist should be readily available outside the OR, serving as backup and consultant, in case it becomes necessary [6,9].

OR traffic should be limited to the minimum. Only dedicated staff should be allocated for specimen collection and delivery (e.g. arterial blood samples analysis, activated clotting time (ACT), thromboelastography, blood tests, etc.). All health care providers involved should be covered by level III protection and should wear in the following order: N95 mask, disposable surgical cap, disposable work

uniform, disposable medical protective uniform, scrub, gown, anti-fog goggles, shoe covers, first layer disposable latex gloves, isolation gown, and full-face respiratory devices or powered air-purifying respirator (PAPR), if available. Anesthesiologists must wear gloves before contacting the patient, patient body fluids such as blood, urine, or mucus, and other potentially contaminated objects. In such case, vigilance is required to remove the outer gloves, followed by appropriate hand hygiene, with gloves repositioning being strongly advised afterwards. Extreme care should be applied to avoid touching surfaces prior to contaminated gloves removal. Further, contaminated, semi-contaminated, and clean zones should be clearly defined, and protective equipment must be removed when necessary, according to the hospital guidelines and protocols [6,8,13,17,19].

Special attention must be given to surgeons' and scrub nurses' preparation in terms of personal protection. They should put on the surgical mask and cap above their PPE, get scrubbed in, and then move on with putting on the surgical coat with double gloves. Gloves should be long-sleeve and fixed to sterile coat with adhesive tape or drapes.

Regarding equipment and devices preparation, anesthesia machines, monitors, trans-esophageal echocardiography (TOE) probes, US machines, blood gas analyzers, ACT machines, and disposable OR supplies must be prepared well in advance. The Waste Anesthetic Gas Disposal system should be checked for proper working provisionally and must be equipped with the necessary filtering and sterilizing functionalities. The Centralized Waste Anesthetic Gas Disposal system should be avoided to prevent the spread of coronavirus across operating rooms in case standard negative pressure in the OR cannot be achieved. An independent (preferentially portable) negative pressure suction device should be readily available in each OR. The use of a video laryngoscope (disposable laryngoscope, whenever possible), if available, is strongly recommended and advised to improve the success rate of endotracheal intubation, thus reducing exposure time. Video laryngoscope must also be used even in case of unplanned emergency circumstances for securing airway [6–8,17,18].

Cardiac surgery patients must always wear an N95/surgical mask and should be transported to the OR through a predesigned pathway. Nasal oxygen supply/therapy can be offered underneath the surgical mask when needed. It is advised to avoid a Venturi mask [7,17]. In patients with severe cardiac and pulmonary dysfunction, IABP or extracorporeal membrane oxygenation (ECMO) might be considered [6–8,19,20].

Intraoperative management of suspected or confirmed COVID–19 cardiac surgical patients

General rules and principles: current guidelines

1. All non-essential or unnecessary equipment and devices must be kept outside the COVID–19 OR during anesthesia induction and endotracheal intubation (ETI). All anesthesia induction and resuscitation equipment must be prepared and ready for use, prior to patient transfer in the OR. Anesthesia and intubation protocols for COVID–19 cases must be strictly followed [6–8,18,21].

2. It is advised that arterial and CV catheterization be facilitated by ultrasound guidance to improve success rates, reduce procedural times, and avoid multiple vessel punctures that could contaminate surrounding personnel via blood [6,7,17,22].

3. In general, regional anesthesia (RA) is preferred to GA in surgical procedures. However, in most cardiac surgery circumstances, a single RA technique cannot be applicable, although it may be combined with GA, based on the type of surgery, as an adjunct to a GA technique for adequate perioperative pain management [6,23,24].

4. Aerosol generating processes, such as airway manipulation, face-mask ventilation, and open airway suctioning should be avoided or performed with great caution, and only if they are absolutely necessary. Anesthesia induction and preoxygenation should be performed quickly, with a well-fitting face mask, to reduce manual ventilation time [25,26].

5. Awake ETI or topical airway anesthesia should not be selected, if feasible and possible, due to the resulting coughing, nebulization, and resulting aerosol dispersal and coronavirus spread [6,8,25,27].

6. The most experienced anesthesiologist is recommended to be responsible for ETI to avoid multiple attempts.

7. Rapid sequence induction and endotracheal intubation are recommended, with utilization of fast-acting muscle relaxants, such as succinylcholine or rocuronium, as first-line choice. Low-pressure mask ventilation with 100% oxygen can be given to patients with poor oxygen reservoir, to avoid critical desaturation circumstances [6–8,25,27].

8. A video laryngoscope is the preferred choice of ETI, if available. After endotracheal tube (ETT) cuff inflation, the ventilator can be connected, prior to positive pressure continuous mechanical ventilation initiation. Circuit disconnection should be avoided throughout the whole procedure, despite the fact that under normal circumstances this is often (if not routinely) demanded by cardiac surgeons during internal mammary preparation. Additionally, closed tracheal suction is strongly advised.

9. With PPE use, anesthesiologists are unable to auscultate the patient to confirm correct placement of the endotracheal tube (ETT). Tube position should be verified by detection of end-tidal carbon dioxide (EtCO₂) waveform, symmetrical chest rises, pulse oximetry, and depth of the ETT [25–28].

10. Electrostatic heat and moisture exchange filters (HMEF) must always be used in the anesthesia circuit throughout the intubation process as its virus filtration efficiency reaches 99.9995%. For suspected patients, lower respiratory tract secretions should be collected through the ETT, and specimens should be sent for examination as soon as possible [25–28].

Cardiovascular manifestations and considerations in suspected or confirmed COVID–19 patients

COVID–19 patients may suffer from severe viral myocardial damage. Elevated cardiac injury biomarkers are commonly found in COVID-19 patients. Among other manifestations, hypertension, heart failure (with a high incidence in elderly), hypoxia-induced myocardial damage (especially after myocardial infarction, unstable angina, or in patients with a PCI history), and stunned myocardium have been reported. Multiple explanations have been described, all related to a high expression of ACE2 receptors in the heart, blood vessels, and lungs, possibly being responsible for the virus induced activation of the RAAS system. Patients receiving ACE inhibitors prior to surgery might be at higher risk for complications and worse outcomes [5,14–16,29].

In reference to cardiovascular monitoring, which is necessary in COVID–19 cardiac surgery patients, minimally or advanced invasive hemodynamic monitoring (PiCCO, FloTrac, pulmonary artery catheterization) and TOE are recommended to guide fluid therapy and inotropic/vasoactive drugs usage. Patients with acute MI might need IABP insertion, ventricular assist device, or ECMO mechanical circulatory support, and these devices should be applied with extreme caution to avoid transmission of infection. Intraoperative TOE is the routine technique of choice for LV function monitoring, volume status optimization, and valvular diseases evaluation, and may serve as a useful guide during cardiac anesthetic management. Concise and comprehensive TOE examination represents the primary modality for the evaluation of every cardiac disease and of a COVID–19 induced cardiac dysfunction. RV (right ventricle) dysfunction, after CPB, is a possible manifestation in COVID–19 cases related to increased pulmonary vascular resistance and pulmonary edema, LV dysfunction, and related stress cardiomyopathy [6–8].

Respiratory manifestations in suspected or confirmed COVID–19 cardiac surgery patients

Patients with SARS under mechanical ventilatory support suffer a higher risk for developing pneumothorax, which contributes to increased mortality rates in this subgroup of patients. As such, it is recommended that pneumothorax is excluded by CT scanning during preoperative patient evaluation. A protective mechanical ventilation strategy must be applied in all suspected and confirmed cardiac surgery cases. Pneumothorax should be suspected according to the patient's clinical picture (mostly decreased SpO₂ or sudden blood pressure decreases). Lung ultrasound, as a basic part of POCUS, can be useful for fast evaluation and diagnosis, and a chest tube should be placed if a pneumothorax is the final diagnosis. Lung re-expansion should be verified prior to chest closure. Lung ultrasound can also be useful in assessing the severity of pulmonary manifestations due to COVID–19 by easily identifying the presence of B-lines, air bronchogram, and pleural effusion, thus helping in selecting proper lung protective ventilating strategies [5,14,30].

Renal dysfunction in suspected or confirmed COVID–19 patients

Critically ill COVID–19 patients have a high incidence of acute kidney injury and severe acid–base imbalances, with electrolyte abnormalities commonly being encountered. Continuous renal replacement therapy should be performed perioperatively when indicated. Goal – directed fluid therapy is recommended to optimize fluid administration [5–8,31].

Blood and blood products transfusion strategy in suspected or confirmed cardiac surgery patients

Blood conservation strategies should be applied as such patients' coagulation profile is usually not normal. Coagulation status should be checked routinely via measurements of platelet counts/function, prothrombin time (PT), partial thromboplastin time (PTT), international normalized ratio (INR), and thromboelastography. Antifibrinolytics, preoperative hemodilution, autologous platelet-rich plasma technology, mild hypothermia or normothermia during CPB, and intraoperative blood salvage must be used, as in non–COVID cases, to minimize blood transfusion requirements and transfusion-related acute lung injury (TRALI). Coagulation factor concentrates are preferred over blood products when possible to reduce potential TRALI, which can worsen the already existing lung manifestations related to COVID–19 [6–8].

Inflammatory process in suspected and/or confirmed COVID–19 cardiac surgery patients

Major surgery and anesthesia produce well-documented inflammatory and immune responses in humans. In cardiac surgery procedures, extracorporeal circulation and CPB are further considered as an additional risk factor and the most important trigger for a massive perioperative inflammatory reaction, a problem that has been largely addressed in the past, because of its detrimental consequences and impact on perioperative morbidity and mortality. Continuous blood exposure to non-endothelial surfaces (perfusion circuit) is responsible for a cascade of systemic inflammatory response, via activation of coagulation pathways and complement system and production of tissue factor and cytokines, that can eventually result in Acute Respiratory Distress Syndrome (ARDS), potentially being further complicated by blood transfusion, finally causing TRALI. The inflammatory response during cardiac surgery occurs due to not only CPB, but also surgical trauma, anesthesia, cardioplegia and myocardial ischemia, cardiac manipulation, heparin, and protamine. Inflammatory response to CPB can be controlled and minimized by off–pump cardiac surgery, temperature maintenance and arrangement (32°–34 °C for operations requiring up to 2 h of CPB), heparin coated-perfusion circuits, modified ultrafiltration, complement inhibitors, and glucocorticoids [32,33].

Current COVID–19 therapies are mainly supportive. Development of novel therapies and effective prevention are an urgent need, particularly for life-threatening severe ARDS and hyper-inflammatory syndrome (characterized by a fulminant and fatal hypercytokinemia with multi-organ failure). Several cytokines are involved in the disease pathogenesis. Likewise, some of these cytokines induce increased vascular permeability and leakage, pulmonary edema, air exchange dysfunction, ARDS, acute cardiac injury, and multi-organ failure. Novel therapies such as interleukin (IL) antagonists (dupilumab), JAK2 inhibitor (fedratinib), interferon blockers and stem cell and mesenchymal cell therapies have been applied to neutralize cytokine storm and offered some improvement. In the cardiac surgery setting, extracorporeal circulation and cell-saver application might reduce the systemic cytokine load, could in part eliminate immune and inflammatory response, and thus might be reasonable alternatives and might be considered for COVID-19 patients during cardiac surgery [6–8,13,20,34].

Processes after end of cardiac surgery on suspected or confirmed COVID–19 patients

At the end of each cardiac operation, specific attention must be given to patient transportation, medical waste management, OR and equipment disinfection, and patient and health care personnel follow up.

A single dose of an antiemetic (e.g. 5–hydroxytryptamine receptor antagonist) should be administered to prevent postoperative nausea and vomiting (a common adverse effect due to high opioid

doses that are provided intraoperatively), which may be responsible for an extensive coronavirus spread. Prior to departure from OR, all health care providers should take off the outer layer of their personal protective equipment, in the sequence guided by local hospital policy and international guidelines. The transportation of COVID–19 patients should be performed by personnel with PPE. This team should wear new personal protective equipment in the clean zone.

In cases undergoing cardiovascular surgery, extubation should be planned in the OR, if possible, and for the appropriate patients. Patients to be admitted to the ICU should be transferred in accordance with the infection prevention measures for COVID-19. If the patient transported to the ICU is intubated, ventilation can be performed by a disposable Artificial Manual Breathing Unit (AMBU) bag, or an HMEF–equipped portable ventilator should be used. The positive pressure ventilation should be stopped prior to disconnection from the ventilator while using an AMBU bag or placing the patient in the portable ventilator. If the transported patient is extubated, an N95 mask should be put on patient. Regarding transportation, a pre–specified pathway must be followed to transfer the patient to an airborne isolation ICU room specifically dedicated to COVID–19 cases. Personal protective equipment can be taken off only after leaving the isolation area.

All disposable equipment and medical waste (breathing tubes, infusion tubing, disposable laryngoscopes, sutures, drapes, etc.) should be discarded. These must be sealed in double–layered medical waste bags and must be treated as highly contagious medical waste.

Anesthesia machines and their surfaces, other surfaces, equipment used in OR, floor, and operating table need to be disinfected and decontaminated in accordance with dictated procedures. It is advised that they are wiped with 75% alcohol or chlorine-containing disinfectants. The inner circuit of the anesthesia machine should be removed and disinfected with 75% alcohol or hydrogen peroxide. Mixed O₃ and H₂O₂ atomized gases or pasteurization can also be applied. OR negative pressure must be maintained for at least 30 min after patient departure and transfer to ICU. OR ceiling filters of exhaust vent and OR wall return vent must be replaced. No operation should start in this OR before the OR space has been thoroughly disinfected in accordance with the description provided above. Plasma air purifiers can be used for air sterilization. Alternatively, ultraviolet light can be used for 1 h. The casing and monitor of ultrasound machines should be wiped with 75% alcohol. Quaternary ammonium disinfectants should be avoided as they can damage the casing. However, ultrasound probes can be disinfected with quaternary ammonium or hydrogen peroxide. For disinfection of the TOE probe, blood gas analyzer, and ACT machines, one should follow the manufacturer's instructions. Reusable surgical instruments must be transferred to the nearest washstand (with a COVID–19 warning sign above it) and decontaminated by personnel wearing PPE. Reusable instruments' disinfection via soaking must be carried out with a chlorine-containing disinfectant for at least 30 min [6,8,11,13,17,19].

Postoperative recommendations for cardiac surgery patients suspected or confirmed to have COVID-19

Postoperative care and intensive follow-up of COVID-19 patients necessitate the establishment of a dedicated multidimensional cardiac COVID-19 team with a particular expertise in cardiac ICU, mainly including anesthesiologist, cardiovascular surgeons, respiratory medicine physicians, infectious diseases specialists, experienced nurses, physiotherapists, and social workers. Team decisions should be taken jointly, as multidisciplinary decision-making among the COVID-19 team can minimize specialty bias and prevent self-referral from interfering with the optimal patient care.

Furthermore, there are many documented COVID-19 cases among health care workers. Close observation should be carried out for all health care providers involved in the care of COVID-19 patients, and an Infectious Disease Report Form should be completed. If there is a potential exposure risk during the operation or postoperative course of the patient, a 14-day quarantine is required.

In this context and to minimize/prevent infection, health care workers should follow the infection control policies and procedures already in place at their health care institutions. For the health care workers performing aerosol-generating procedures in patients with COVID-19 in the ICU, it is advisable to use fitted respirator masks (i.e., N95 respirators, FFP2, or equivalent) in addition to other PPE (i.e.,

Table 1

- Perioperative approach of cardiac surgery patients: Practical recommendations.

Preanesthetic – Preoperative Approach & Evaluation

- All cardiac surgery candidates → must be considered to be COVID – 19 positive
 - ✓ not only if disease is suspected
 - ✓ until a test result becomes available
- Elective or Semi – Elective Cardiac Surgery Candidates
 - ✓ best managed by delaying operation (at least for weeks)
 - ✓ in worst case scenario: postponed until COVID–19 detection results are negative (at least twice, with minimum of 24 h between tests)
- Emergency Cardiac Surgery Candidates
 - ✓ immediate Evaluation for COVID – 19
 - ✓ epidemiologic/respiratory infection history
 - ✓ clinical manifestations
 - ✓ laboratory and radiographic testing
- If insufficient time is available
 - ✓ preoperative hospitalization and preparation should follow already published Guidelines for suspected/confirmed COVID – 19 cases
 - ✓ patients' admission to airborne isolation room
 - ✓ personnel quarantine evaluated and finally decided based on COVID–19 testing
- Multidisciplinary Team for Cardiac Surgery Patients Care (cardiac surgeon, cardiac anesthesiologist, perfusionist, nursing staff, auxiliary personnel)
- Health care personnel involved in suspected or confirmed COVID – 19 cases
 - ✓ Level 3 infection control precautions
 - ✓ personnel clinical observation and follow – up
 - ✓ potential personnel isolation period of 14 days

OR Preparation prior to Cardiac Surgery in suspected/confirmed COVID – 19 patients

- Dedicated Team – roles allocation
- Health care Personnel → Personal Donning and Doffing of Protective Equipment
- Dedicated Operating Room for cardiac Surgery
 - ✓ isolated from all other OR – minimal traffic
 - ✓ warning signs
 - ✓ predefined transportation pathways with regular disinfection
 - ✓ dedicated surgical and anesthetic equipment – precheck for adequacy
 - ✓ negative pressure environment

Anesthetic Preparation/Management of suspected/confirmed Cardiac Surgery COVID – 19 patients

- Practice Points Two experienced anesthesiologists available – third one outside OR for back up
- Minimum OR traffic – Dedicated staff
- Level III Protection – Vigilance – Appropriate Hygiene Measures in accordance with Guidelines
- Equipment Preparation well in advance – Attention to airway Management

Intraoperative Management of suspected/confirmed Cardiac Surgery COVID – 19 patients

- General Rules & Principles
 - ✓ all necessary equipment/devices inside OR provisionally and prepared prior to patient transfer
 - ✓ arterial – venous cannulation to be US facilitated
 - ✓ RA preferable when applicable, combined with GA
 - ✓ avoidance of aerosol-generating processes (airway manipulation, face mask ventilation, suction)
 - ✓ awake ETI – rapid sequence induction – video laryngoscope utilization – avoidance of circuit disconnection
- Cardiovascular Considerations: hemodynamic monitoring, TOE use, attention to possible RV dysfunction
- Respiratory Considerations: protective mechanical ventilation strategy/lung ultrasound/POCUS
- Renal Dysfunction – Role of renal replacement therapy
- Blood and blood products transfusion
- Attention to Inflammatory reactions due to CPB – protective measures application

Postoperative Care of suspected/confirmed Cardiac Surgery COVID – 19 patients

- Attention to patient transportation by personnel with PPE
- Antiemetics administration at the end of the surgery and prior to weaning
- If possible, extubation in OR – N95 mask applied to patient afterwards
- Proper disposable equipment and medical waste should be discarded in accordance with guidelines and protocols
- Decontamination of OR and equipment
- Isolated ICU bed
- Attention to personnel protection in ICU and post ICU ward

gloves, gown, and eye protection, such as safety goggles), as described in the infection prevention measures for COVID-19. If possible, the shift of health care workers should be reduced to 4 h. Additionally, it is preferentially recommended that performing aerosol-generating or nonaerosol-generating procedures in ICU patients with COVID-19 should be carried out in a negative-pressure room and a portable high-efficiency particulate air filter should be used in the room, if available. In patients who require endotracheal re-intubation, intubation should be performed by the health care worker who is the most experienced with airway management to minimize the number of attempts and risk for transmission and should be performed using video-guided laryngoscopy over direct laryngoscopy, if available. During ICU follow-up of COVID-19 patients, patients should be closely monitored for ARDS, systemic inflammatory response syndrome, and cytokine release syndrome. The preventive and treatment measures (including antiviral treatment strategy which is subject to change) related to the diseases itself and subsequent serious clinical conditions (i.e., ARDS or shock) should be taken in accordance with the guideline recommendations [6,8,13,19,35,36].

Finally, one other major problem is the feeling of fear in health care providers of being diseased or contagious to their families. Therefore, they may need enormous support against burn-out during the COVID-19 pandemic.

Conclusion

Cardiac anesthesia provision presents with many challenges in the coronavirus era, as presented in [Table 1](#). For the performance of cardiac operations in the COVID-19 pandemic, it is important that a dedicated team decides on which cases to postpone for a later stage based on an assessment of level of priority. The basic goal is to support health care facilities and to protect patients from severe post-operative complications that contribute to high mortality rates and protect health care workers from potential contamination.

The operations that cannot be deferred should be performed with great caution, strictly following guidelines and health authorities' recommendations, which are readily available. Personal protective equipment is the most crucial measure during the pandemic, even if its use in this kind of working environment is challenging. Support for the health care cardiac anesthesia and surgery team is mandatory, taking into account that patients can only be treated if health care workers are healthy.

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Practice Points

- Patients with suspected or confirmed COVID-19 infection, who undergo cardiac surgery procedures, represent a real challenge for the cardiac anesthesia team
- Cardiac anesthesiologists have the responsibility to ensure that evidence-based anesthetic care and only essential cardiac operations are provided to the general public
- For the performance of cardiac operations during the COVID-19 pandemic, it is important that a dedicated team decides on which cases to postpone for a later stage, based on an assessment of level of priority
- Personal protective equipment is the most crucial measure during the pandemic, even if its use in this kind of working environment is challenging

Research Agenda

- The triaging of what constitutes an appropriate, non-emergent cardiac case to proceed with during the COVID-19 pandemic must be further investigated
- Further research is needed to improve the efficiency and safety of cardiac patients as the progress through the perioperative period during the COVID-19 pandemic

Declaration of Competing Interest

The authors have no conflicts of interest to disclose.

References

- [1] Wu Y, Huang Y, Jin DY, et al. SARS CoV–2 is an appropriate name for the new coronavirus. *Lancet* 2020;395:949–50.
- [2] Zhou P, Yang XL, Wang XG, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature* 2020;579:270–3.
- [3] World Health Organization. WHO announces COVID19 outbreak a pandemic. <http://www.euro.who.int/en/health-topics/health-emergencies/coronavirus-covid-19/news/news/2020/3/who-announces-covid-19-outbreak-apandemic>. [Accessed 20 May 2020].
- [4] World Health Organization. Coronavirus disease (COVID19) pandemic. <https://www.who.int/emergencies/diseases/novel-coronavirus-2019>. [Accessed 20 May 2020].
- [5] Pergolizzi Jr JV, Magnusson P, LeQuang JO, et al. The current clinically relevant findings on COVID-19 pandemic. *Anesthesiol Pain Med* 2020;10(2):e103819. <https://doi.org/10.5812/aapm.103819> [epub ahead of print].
- [6] He Y, Wei J, Bian J, et al. Special article: Chinese society of anaesthesiology expert consensus on anaesthetic management of cardiac surgical patients with suspected of confirmed coronavirus disease 2019. *J Cardiothorac Vasc Anesth* 2020;34:1397–401.
- [7] Chen X, Shang Y, Yao S, et al. Perioperative care provider's considerations in managing patients with COVID – 19 infection. *Transpl Periop & Pain Med* 2020;7:216–24.
- [8] Mavioglu HL, Unal EU, Askin G, et al. Perioperative planning for cardiovascular operations in the COVID – 19 pandemic. *Turkish J Thorac Cardiovasc Surg* 2020;28:236–43.
- [9] Hassan A, Arora RC, Adams C, et al. Cardiac Surgery in Canada During the COVID-19 Pandemic: A Guidance Statement From the Canadian Society of Cardiac Surgeons. *Can J Cardiol* 2020;36(6):952–5. <https://doi.org/10.1016/j.cjca.2020.04.001>.
- [10] American College of Surgeons. COVID-19 guidelines for triage of cardiac surgery patients. Online March 24, 2020, <https://www.facs.org/covid-19/clinical-guidance/elective-case/cardiac-surgery>.
- [11] Hassan A, Arora RC, Lother SA, et al. Ramping up the delivery of cardiac surgery during the COVID-19 pandemic: a guidance statement from the Canadian society of cardiac surgeons. *Can J Cardiol* 2020;Apr. 29. <https://doi.org/10.1016/j.cjca.2020.04.030> [epub ahead of print].
- [12] Haft JW, Atluri P, Ailawadi G, et al. Adult cardiac surgery during the COVID-19 pandemic: A tiered patient triage guidance statement. *J Cardiovasc Thorac Surg* 2020;Apr 22. <https://doi.org/10.1016/j.jtcvs.2020.04.011> [epub ahead of print].
- [13] Fudulu DP, Angelini GD. Cardiac surgery in the time of the coronavirus. *J Card Surg* 2020;1–3. <https://doi.org/10.1111/jocs.14580>.
- [14] Li LQ, Huang T, Wang YQ, et al. 2019 novel coronavirus patients' clinical characteristics, discharge rate and fatality rate of meta-analysis. *J Med Virol* 2020;12. <https://doi.org/10.1002/jmv.25757>.
- [15] Clerkin KJ, Fried JA, Raikhelkar J, et al. COVID-19 and cardiovascular disease. *Circulation* 2020;141:1648–55.
- [16] Zheng YY, Ma TT, Zhang JY, et al. COVID – 19 and the cardiovascular system. *Nat Rev Cardiol* 2020;17:259–60.
- [17] Wax RS, Christian MD. Practical Recommendations for critical care and anaesthesiology teams caring for novel coronavirus (2019-nCoV) patients. *Can J Anaesth* 2020. <https://doi.org/10.1007/s12630-020-01591-x>.
- [18] Orser BA. Recommendations for endotracheal intubation of COVID-19 patients. *Anesth Analg* 2020;130(5):1109–10. <https://doi.org/10.1213/ANE.0000000000004803>.
- [19] Mavioglu HL, Unal EU. Cardiovascular surgery in the COVID-19 pandemic. *J Card Surg* 2020;35(6):1391. <https://doi.org/10.1111/jocs.14559> [epub ahead of print].
- [20] Kowalewski M, Fina D, Sionka A, et al. COVID-19 and ECMO: the interplay between coagulation and inflammation-A narrative review. *Crit Care* 2020;24:205. <https://doi.org/10.1186/s13054-020-02925-3>.
- [21] Odor PM, Neun M, Bampoe S, et al. Anaesthesia and COVID-19: infection control. *Br J Anaesth* 2020;125(1):16–24. <https://doi.org/10.1016/j.bja.2020.03.025>.
- [22] Wunderlich R, Nikomanis PS, Häberle H, et al. COVID-19/coronavirus outbreak: how to establish A central venous access by placing A central venous catheter. *JoVE* 2020;159:e6432.
- [23] MacFarlane AJR, Harrop – Griffiths W, Pawa A. Regional anaesthesia and COVID-19: first choice at last? *Br J Anaesth* 2020; May 28. <https://doi.org/10.1016/j.bja.2020.05.016> [epub ahead of print].
- [24] Caruso TJ, Lawrence K, Tsui BCH. Regional anaesthesia for cardiac surgery. *Curr Opin Anaesthesiol* 2019;32:674–82.
- [25] Cook TM, El-Boghdady K, McGuire B, et al. Consensus guidelines for managing the airway in patients with COVID-19. *Anaesthesia* 2020;6:785–99.

- [26] World Health Organisation. Rational use of personal protective equipment for coronavirus disease 2019 (COVID-19). Interim guidance. 27 February 2020. Available from: https://apps.who.int/iris/bitstream/handle/10665/331215/WHO-2019-nCov-IPCPPE_use-2020.1-eng.pdf.
- [27] Orser BA. Recommendations for endotracheal intubation of COVID-19 patients. *Anesth Analg* 2020;130:1109–10.
- [28] Luo M, Cao S, Wei L, et al. Precautions for intubating patients with COVID-19. *Anesthesiology* 2020;132:1616–8.
- [29] Fried JA, Ramasubbu K, Bhatt R, et al. The variety of cardiovascular presentations of COVID-19. *Circulation* 2020;141:1930–6.
- [30] Lake MA. What we know so far: COVID-19 current clinical knowledge and research. *Clin Med* 2020;20:124–7.
- [31] Durvasula R, Wellington T, McNamara E, et al. COVID-19 and kidney failure in the acute care setting: our experience from seattle. *Am J Kidney Dis* 2020;76(1):4–6. <https://doi.org/10.1053/j.ajkd.2020.04.001>.
- [32] Warltier DC, Laffey JG, Boylan JF, et al. The systemic inflammatory response to cardiac surgery: implications for the anesthesiologist. *Anesthesiology* 2002;97:215–52.
- [33] Suleiman MS, Zacharowski K, Angelini GD. Inflammatory response and cardioprotection during open-heart surgery: the importance of anaesthetics. *Br J Pharmacol* 2008;153:21–33.
- [34] Squicciarro E, Rociola R, Haumann RG, et al. Extracorporeal oxygenation and coronavirus disease 2019 epidemic: is the membrane fail-safe to cross contamination? *ASAIO J* 2020. <https://doi.org/10.1097/MAT.0000000000001199>.
- [35] Rescigno G, Firstenberg M. A case of postoperative covid-19 infection after cardiac surgery: lessons learned. *Heart Surg Forum* 2020;23(2). <https://doi.org/10.1532/hhf.3011>.
- [36] Driggin E, Madhavan MV, Bikdeli B, et al. Cardiovascular considerations for patients, health care workers, and health systems during the coronavirus disease 2019 (COVID-19) pandemic. *J Am Coll Cardiol* 2020. <https://doi.org/10.1016/j.jacc.2020.03.031>.