European Journal of Cardio-Thoracic Surgery 00 (2020) 1–9
doi:10.1093/ejcts/ezaa228

Cite this article as: George I, Salna M, Kobsa S, Deroo S, Kriegel J, Blitzer D *et al*. The rapid transformation of cardiac surgery practice in the coronavirus disease 2019 (COVID-19) pandemic: insights and clinical strategies from a centre at the epicentre. Eur J Cardiothorac Surg 2020; doi:10.1093/ejcts/ezaa228.

The rapid transformation of cardiac surgery practice in the coronavirus disease 2019 (COVID-19) pandemic: insights and clinical strategies from a centre at the epicentre

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Abstract

OBJECTIVES: The onset of the coronavirus disease 2019 (COVID-19) pandemic has forced our cardiac surgery programme and hospital to enact drastic measures that has forced us to change how we care for cardiac surgery patients, assist with COVID-19 care and enable support for the hospital in terms of physical resources, providers and resident training.

METHODS: In this review, we review the cardiovascular manifestations of COVID-19 and describe our system-wide adaptations to the pandemic, including the use of telemedicine, how a severe reduction in operative volume affected our programme, the process of redeployment of staff, repurposing of residents into specific task teams, the creation of operation room intensive care units, and the challenges that we faced in this process.

RESULTS: We offer a revised set of definitions of surgical priority during this pandemic and how this was applied to our system, followed by specific considerations in coronary/valve, aortic, heart failure and transplant surgery. Finally, we outline a path forward for cardiac surgery for the near future.

CONCLUSIONS: We recognize that individual programmes around the world will eventually face COVID-19 with varying levels of infection burden and different resources, and we hope this document can assist programmes to plan for the future.

Keywords: Cardiac surgery • Coronavirus disease 2019 • Pandemic • New York • Reorganization

ABBREVIATIONS

COVID-19	Coronavirus disease 2019
ECMO	Extracorporeal membrane oxygenation
ICU	Intensive care unit
LVAD	Left ventricular assist device
OR	Operating room
ORICU	Operating room intensive care unit
PPE	Personal protective equipment
SARS-CoV	Severe acute respiratory syndrome coronavirus
STS	Society of Thoracic Surgeons
SWAT	Surgical Access Workforce Team

Coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus (SARS-CoV)-2, has fundamentally altered the lives of people around the world, and on 11 March 2020, the World Health Organization declared COVID-19 a global pandemic. As of 12 April 2020, there were almost 2 million confirmed cases globally, with >500 000 cases in the USA—more than any other country. New York City, alone with more cases than any individual country, is considered to be the global epicentre of the virus at this time, with 6900 deaths [1]. A major component of the international response to the pandemic has been social distancing, which has prompted travel restrictions, shelter-in-place recommendations and closures of all non-essential businesses throughout the USA. This has drastically

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This article was received at JTCVS on 14 April 2020, Received in revised form and accepted at JTCVS on 18 April 2020.
This article has been copublished in the European Journal of Cardio-Thoracic Surgery, The Journal of Thoracic and Cardiovascular Surgery and The Annals of Thoracic Surgery

transformed everyday life, and although hospitals have been busier than ever dealing with a massive influx of patients with COVID-19, resource-intensive specialties, including cardiac surgery, have been nearly completely sidelined.

As the number of COVID-19 cases continues to rise, particularly in states with high numbers of cardiac surgery centres, an understanding of how the current pandemic affects the practice of cardiac surgery is important. This review highlights the effects of COVID-19 from the perspective of a busy cardiac surgery programme at the epicentre of the COVID-19 pandemic, including implications for those with cardiovascular disease, disease pathophysiology in the context of common cardiac surgical procedures and the impact on adult cardiac surgical practice during and after the pandemic.

CARDIOVASCULAR MANIFESTATIONS OF COVID-19

Although primarily a disease of the respiratory system, the cardiovascular manifestations of COVID-19 are important in the evaluation and treatment of infected patients across all disease severity classes. These include transient and chronic myocardial dysfunction, cardiogenic shock, arrhythmias and vascular thrombosis. In addition, multiple studies have identified cardiovascular disease, hypertension and diabetes mellitus as among the most common comorbidities reported among patients with COVID-19 [2], and the reported case fatality rate among patients with cardiovascular disease has been reported at 10.5%, compared with only 0.9% in patients with no comorbidities [3]. Cardiovascular disease appears to have profound impact on mortality when also associated with myocardial injury; patients with an elevated troponin T level present with greater rates of malignant arrhythmia and a mortality of >69% [4]. Proposed mechanisms for the cardiac dysfunction observed in COVID-19 infections include viral myocarditis and myocardial dysfunction secondary to hypoxia or cytokine-mediated systemic inflammation. Decreased activity of angiotensin-converting enzyme-2 in the heart has also been suggested as a potential mediator of cardiac dysfunction, as has been described in the SARS-CoV-1 disease [5].

Of particular relevance to the cardiothoracic surgeon is the prothrombotic state that has been described with SARS-CoV-2. In analysis of 1099 patients from >550 hospitals across China, D-dimer was elevated in 46.4% of those tested (260/560), and this abnormality was a possible predictor of mortality [6]. It has also been suggested that microvascular thrombosis and endothelial injury of the pulmonary vasculature may mediate the profound hypoxaemia seen in severe cases. Guidelines for anticoagulation are emerging, and prophylactic low-molecular weight heparin is reasonable in all hospitalized patients without contraindications [7]. The risk of thrombosis must be considered for all cardiovascular interventions, including mechanical circulatory support and standard monitoring/infusion catheters. Anticoagulation with unfractionated heparin is likely indicated for mechanical circulatory support.

SYSTEM-WIDE ADAPTIONS TO THE PANDEMIC

Extensive organizational changes have been required to increase our capacity to care for victims of COVID-19 requiring hospitalization and admission to the intensive care unit (ICU) but also to minimize the risk of nosocomial infection in patients without COVID-19. This involved a coordinated effort across all levels of institutional leadership, including the enterprise, hospital, Department of Surgery and our own Division of Cardiac, Thoracic and Vascular Surgery (Table 1).

TELEMEDICINE

From the outset of the pandemic, a primary goal was to minimize the risk of spreading COVID-19 to patients and providers. As a result, our entire institution, across all its campuses, departments and divisions, transitioned to a distance model of health care, using existing telemedicine platforms within the Epic electronic medical record system, as well as hospital-sanctioned, Health Insurance Portability and Accountability Act-compliant versions of publicly available platforms, such as Zoom. This has required a significant effort on the part of the hospital and university's information technology department, as well as clinicians, who had to master virtual visit software, modify clinical practice and decision-making in the absence of in-person encounters and learn to properly code and bill these visits.

For patients unable to participate in telemedicine visits through these systems, publicly available and familiar platforms, such as smartphone video chat applications, or even voice calls, were a backup. Virtual visits were not appropriate for a small proportion of patients, such as those requiring physical examination or intervention, and these were seen in person.

OPERATIVE VOLUME REDUCTION

The potential for the COVID-19 pandemic to overwhelm hospital capacity has been a real concern throughout the crisis, and worldwide shortages of important resources, especially personal protective equipment (PPE) and ventilators, have been continuously reported in the media. Early on, we implemented measures to reduce the use of PPE during operations, such as limiting the number of scrubbed staff and minimizing the switching of personnel, and the medical school removed all students from clinical rotations. As the number of patients with COVID-19 admitted to our hospital rapidly increased, and facing the possibility of exhausting our supply of PPE, ventilators, continuous haemodialysis machines and ICU beds, the difficult decision was made on 15 March 2020, to halt all elective surgery. This had a dramatic effect on all surgical specialties, including cardiac surgery, and we rapidly implemented systems for identifying patients eligible for postponement, notifying them and their physicians and monitoring postponed patients for changes in clinical status. Specifically, we developed a rubric for classifying the urgency of all scheduled operations so that the most pressing cases could be done in severely limited operating room (OR) slots. This process was often challenging, and will be discussed in greater detail later.

This sudden elimination of elective surgery severely reduced the throughput of patients in our system, so that within days, our inpatient census was at record lows. This allowed reorganization of our service staffing, making most of our personnel—including residents, fellows, faculty, mid-level providers and administrative staff—available for redeployment. In the 4 weeks since cessation of elective cases, we have performed 12 adult cardiac operations and have deferred the remainder (see Supplementary Material, Table S1 for a detailed clinical breakdown of cases). This is a 92%

Table 1: COVID-19 driven changes in the Department of Surgery

Change	Goals	Challenges	Level
Telemedicine patient visits	• Minimizing risk of nosocomial COVID-19 infections to patients/providers • Minimizing need to staff and support services	• Inability to examine patients • Difficulties obtaining outpatient studies • Technical issues with telehealth applications • Lack of technical savvy among patients	• Division • Department • Hospital • Enterprise
Case volume reduction	• Minimizing risk of nosocomial COVID-19 infections • Preserving PPE, vital equipment, medications • Preserving floor and ICU beds • Opening space for additional ICU capacity (ORICU) • Making providers available to care for patients with COVID-19	• Balancing risk of delaying operations versus risk of in-hospital COVID transmission • Disruption of trainees' education and surgical skills • Significant drop in revenue	• Division • Department • Hospital • Enterprise
Attendings/staff/ resident redeployment	• Serving as ICU attendings, ICU fellows, mid-level providers, junior residents, SWAT team, perfusion and support staff in EDs, medicine floors, step-down units and newly created COVID-19 ICUs	• Adequate training and expertise in newly created roles • Maintaining adequate core staffing of divisional and departmental services • Increased risk of contracting COVID-19 • Family exposure to COVID-19 • Mental and emotional well-being given increased levels of stress	• Division • Department • Hospital • Enterprise
Service and on-call staffing	• Making residents, attendings and staff available for redeployment to COVID-19 units	• Maintaining staffing levels to safely care for remaining patients without COVID-19 (floors and ICUs) • Availability of adequate senior resident/fellow and attendings to cover emergent cardiothoracic cases, urgent procedures, heart/lung transplantation and organ procurement	• Division • Department

COVID-19: coronavirus disease 2019; ICU: intensive care unit; ORICU: operating room intensive care unit; PPE: personal protective equipment; SWAT: Surgical Access Workforce Team.

reduction compared with the same period in 2019 (153 cases), and it is obvious that the financial implications of this case reduction are profound for both the hospital and our surgical practice and not likely mitigated by continued billing of telehealth visits and ICU care by redeployed physicians. These emergency cases had an overall low risk and resource use profile [Society of Thoracic Surgeons (STS) score 0.94, estimated length of stay and ICU stay 6 and 2.2 days, respectively, for cases appropriate for STS risk scoring].

REDEPLOYMENT

As our hospital became overrun by patients with COVID-19, especially in 'pop-up' ICUs established in ORs and other available spaces, our hospital sought to redeploy clinicians to these units. Surgeons were logical candidates for these roles, both because they had been idled by the elimination of elective surgery, and more importantly because of their broad skillset and training, including critical care expertise. This is particularly true of cardiac surgeons, whose understanding of cardiovascular and respiratory physiology makes them well-suited for care of the sickest patients with COVID-19. Our division recognized this need, and many of our faculty, trainees, extenders and staff were among the first to volunteer for redeployment. At the hospital level, a system was developed in which clinical section heads and training programme directors identify the number of clinical staff on a daily basis, including attendings and trainees, and report these figures through a web-based portal. These clinicians are then redeployed to needed areas in the hospital or on other campuses. A similar system is in place for redeployment of nurses, mid-level providers and administrative staff. Reorganization of the cardiac surgery service allowed at least partial redeployment of 4 of 7 faculty, 9 of 15 residents and fellows and 4 of 8 extenders. Our perfusion team, in addition to overseeing extracorporeal membrane oxygenation (ECMO), was retrained to manage continuous haemodialysis machines. While our staff has been redeployed across the institution, our clinicians have played a particularly important role in 2 newly created teams to help care for patients who test positive for COVID-19: the Surgical Access Workforce Team (SWAT) and the operating room intensive care units (ORICUs).

THE SURGICAL ACCESS WORKFORCE TEAM

The Department of Surgery organized a team of its clinicians with expertise and ability to quickly and efficiently place indwelling lines or catheters, and perform other bedside procedures, freeing up emergency department and ICU teams to focus on triaging and treating patients with COVID-19. SWAT teams each consist of a surgical attending, 1–2 senior residents or experienced physician assistants and 1–2 junior residents, who work in 12-hour shifts. Prompted by requests through the electronic medical record system, the SWAT team is dispatched with necessary supplies to place arterial lines, central lines, dialysis catheters, nasogastric tubes, Foley catheters, chest tubes or perform other procedures. This has proven to be a remarkably efficient system, benefiting not only clinicians who can focus on other tasks, but also surgical trainees who get significant experience with these procedures.

OPERATING ROOM INTENSIVE CARE UNITS

Using projected numbers of COVID-19 cases in the metropolitan area, and taking into account Wuhan and Hubei historic data, our hospital system developed projections for numbers of inpatient and ICU beds as well as ventilators that would be needed for the surge of COVID-19 patients. A plan was developed to nearly triple the capacity of ICU beds. First, all existing ICUs were repurposed: our surgical ICU was converted into an overflow ICU for patients with COVID-19, as was the smaller of the 2 cardiothoracic ICUs; all non-surgical ICUs (medical, neurology and cardiology) were converted into COVID-19 units; and our main cardiothoracic ICU was designated as the 'COVID-free' ICU, housing all COVID-negative medical and surgical critical care patients. Second, to increase the complement of ICU beds, the Departments of Surgery and Anesthesiology worked with hospital leadership to convert all but 2 ORs at our adult hospital into ICUs (ORICUs) (Fig. 1). Each OR was reorganized to house 3–5 ICU beds, and each ORICU bed has an ICU ventilator, repurposed anaesthesia machine or older transport ventilator, as well as a suction setup and vital sign monitor. In addition, significant efforts are underway to optimize protocols for split ventilation, enabling 2 patients to be connected to a single anaesthesia machine ventilator. One other important technical point is that ORs, normally under positive pressure, were converted to negative pressure by an impressive effort of our construction and engineering teams.

In our hospital, ORs are organized in groups of 3–5 rooms around central sub-sterile cores. In the ORICU setup, each of these cores was designated as a 'pod'. In a pyramidal management system (Supplementary Material, Table S2), each pod is staffed with a single senior-level cardiothoracic surgical or anaesthesia resident (typically postgraduate year 4–6), who serves as a critical care fellow and oversees a team of juniors, each of whom covers a single OR with 3–5 patients and 1 nurse. Depending on experience, these junior roles are filled by surgical or anaesthesia interns or junior residents, advanced residents from other specialties, experienced surgical physician assistants and certified registered nurse anaesthetists. Each pod also has a 'lead' clinician, typically an anaesthesia critical care fellow or surgery attending. Finally, collections of 2–4 pods are each overseen by a board-certified critical care attending. Despite its makeshift nature, this model has allowed us to provide ICU care to nearly 120 additional patients with COVID-19.

Figure 1: Representative photograph of an operating room intensive care unit: this is an operating room that has been modified to accommodate up to 4 ventilated patients with COVID-19, each with a separate ventilator, gas lines and other equipment.

CHALLENGES OF REDEPLOYMENT

It is crucially important that redeployed clinicians have adequate training and skills for their new roles. In addition to shadowing in the ICU, an extensive library of ICU principles and protocols was also developed and distributed online. Alternative roles (e.g. telehealth visits or caring for patients without COVID-19) were considered for older providers, as well as those who have significant medical comorbidities or are immunosuppressed. Additional protections, such as providing alternate temporary housing, were provided by the hospital to redeployed staff members who normally live with family members at high risk of complications from COVID-19.

Finally, to promote mental and emotional well-being and provide support during these times of increased stress, our Department and Programme have been organizing frequent meetings over Zoom for residents, fellows and faculty.

Despite the elimination of elective surgery, we retained a core of our usual staff to cover continued practice activity. Most of our non-redeployed staff worked from home, although a rotation was established in which 1 office worker and 1 clinical extender were physically present in our office each day, to check mail, receive outside medical records and films and conduct in-person patient visits. Similarly, although many of our residents and some faculty were redeployed, a core number of each were maintained to cover our clinical services, respond to emergencies and perform urgent and emergent surgery. Specifically, we kept at least 1 surgeon available at all times who was capable of general cardiac surgery procedures, as well as more specialized areas such as aortic surgery and mechanical cardiac assistance/transplant. A rotation schedule is particularly important for programmes in high infection areas, in which a percentage of providers will inevitably get sick—in our programme, 2 of 10 surgical attendings and 2 of 12 integrated residents have tested positive for COVID-19.

REDEFINING 'URGENT' SURGERY AND ALLOCATION OF RESOURCES DURING THE PANDEMIC

Three stages of pandemic in relation to hospital resources can be identified: (i) an 'early' phase, in which resources are plentiful and there is no interruption of services; (ii) a surge or 'peak' phase, in which cases reach a maximum level in the community and cause maximal effect on health care services for that area; and (iii) a 'late' phase, with slow resolution of the surge evolving into a 'steady-state' of cases (Fig. 2). Each phase must be interpreted in comparison with a centre's expected resource level at peak surge. If peak cases exceed hospital resources, which occurred in our centre, a severe reduction in resources devoted to non-COVID care, including elective surgery, should be expected and drastic changes to clinical practice are necessary. In contrast, if hospital resources exceed expected peak numbers throughout early, peak and late phases, elective cases may continue, depending on urgency level and predicted resource needs.

The sudden hospital-mandated reduction of operating capacity to <10% of our normal required postponement of all but emergent and the most urgent procedures. Although emergency indications for surgery were least common and easiest to define (e.g. patients who will die without immediate surgery, e.g. acute type A aortic dissection, unstable coronary ischaemia), our definition of urgent surgery, which described as many as 40% of our practice, required refinement. Our usual definition of urgent surgery—procedures that must be done not immediately, but within the current hospitalization—assumed normal hospital and OR capacity, which no longer applied, so we developed our own classification system based on best estimates of how long each patient could wait before becoming emergent: 1 to 2 weeks, 3 to 4 weeks, or >4 weeks (Table 2). Such a classification is very helpful in minimizing the adverse consequences of postponement by prioritizing patients at highest risk of decompensation, and can be modified as resource limitations change.

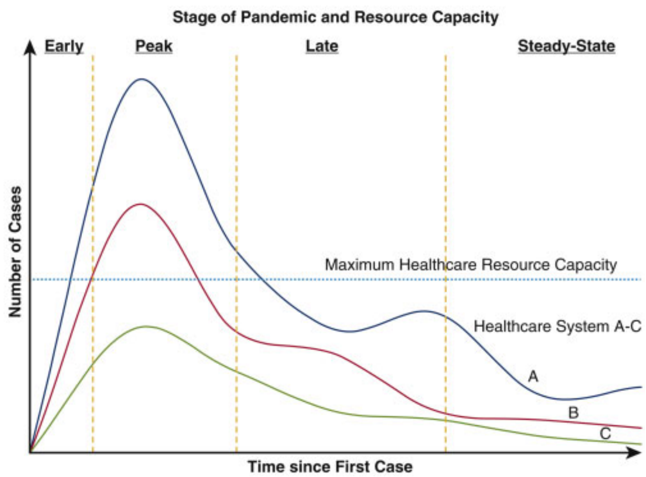

Figure 2: The anticipated resource use depends on the stage of the pandemic at a given health care system. Three potential scenarios can exist: system A: COVID-19 cases exceed resources, causing a complete cessation of surgery throughout the peak and affect the late phase, system B: COVID-19 cases cause major disruption only in the peak phase and system C: COVID-19 cases stay below maximum resource capacity, allowing elective cases to proceed. Note there is a predicted bump in cases within the late phase as distancing measures are relaxed.

For patients classified as elective (i.e. can wait >4 weeks), postponement for as long as possible is reasonable not only as a resource-preserving measure, but also to avoid the risk of perioperative COVID-19 infection. Given the poor prognosis of COVID-19 patients with acute coronary syndrome [8], COVID-19 infection during cardiac surgery may be associated with high mortality, regardless of the calculated STS score. Data from China support this hypothesis: in 34 patients undergoing elective noncardiac surgery in Wuhan China during the early period of infection, all patients became infected with COVID-19, 44% required ICU admission, and mortality was 20.5% [9]. In our experience of 12 cases, 2 patients tested positive for COVID-19 postoperatively (Supplementary Material, Table S1): 1 patient with unknown preoperative infection and 1 patient with a negative preoperative test followed by clinical symptoms and seroconversion postoperatively.

Even with this prioritization scheme, severely limited resources may not be able to accommodate all deserving patients. The first option in these situations is draw upon the full armamentarium of treatment options, including non-surgical percutaneous options, even if they may normally be considered less definitive or durable. For example, severe symptomatic aortic stenosis or prosthetic aortic valve insufficiency (even in low-risk patients) could be treated by transcatheter aortic valve replacement, avoiding a long hospital stay. Other examples include percutaneous coronary intervention for severe coronary disease and MitraClip (Abbott, Chicago, IL, USA) for acutely decompensated degenerative or functional mitral regurgitation.

For patients deemed urgent after adjudication by individual surgical divisions, and without percutaneous alternatives, we applied a further level of selection, in which the predicted resource intensity of a specific operation was considered in the filling of very limited available OR slots. Factors considered in the estimation of this 'resource intensity', in addition to OR space and personnel, included the anticipated need for limited

Table 2: Timing of cardiac surgery intervention depending on case type and urgency category

Category Timing	Emergent Immediate entry–72 h	1: Urgent 1–2 weeks	2: Semi-urgent 3–4 weeks	3: Elective >1 month
CAD (not amenable to PCI)	• Critical CAD/LM ± shock/ IABP/pressors	• LM, ACS or w/3VD with high-risk anatomy	• 3VD w/increasing Sx	• Stable CAD
AV (not amenable to TAVR)	• Severe AI w/shock • Severe AS w/shock	• Severe AI/AS w/NYHA IV HF, syncope • BHV SVD w/NYHA IV HF	• Critical/severe AS w/high-risk features or progressive Sx • Progressive severe AI with progressive Sx	• Stable severe AI/AS
MV disease (not amenable to MC)	• Acute MR w/shock	• Acute MR with NYHA IV HF • BHV SVD w/NYHA IV HF	• Severe MR w/drop in EF, recurrent HF • MS with NYHA III–IV HF	• Stable severe MR/MS
Tricuspid valve disease	• NA	• NA	• NYHA IV Sx	• Stable severe TR
Aortic surgery/other	• Type A dissection • PTE w/massive clot	• Giant TAA/PSA w/Sx or rapid expansion	• TAA >6–7 cm	• Stable TAA • PTE for CTEPH
Transplant	• NA	• Inpatient + status 1–2	• NA	• Stable outpatient

ACS: acute coronary syndrome; AI: aortic insufficiency; AS: aortic stenosis; AV: aortic valve; BHV: bioprosthetic heart valve; CAD: coronary artery disease; CTEPH: chronic thromboembolic pulmonary hypertension; EF: ejection fraction; HF: heart failure; IABP: intra-aortic balloon pump; LM: left main; MC: MitraClip; MR: mitral regurgitation; MS: mitral stenosis; MV: mitral valve; NA: not available; NYHA: New York Heart Association; PCI: percutaneous coronary intervention; PSA: pseudoaneurysm; PTE: pulmonary thromboendarterectomy; SVD: structural valve degeneration; Sx: symptoms; TAA: thoracic aortic aneurysm; TAVR: transcatheter aortic valve replacement; TR: tricuspid regurgitation; 3VD: triple-vessel disease.

resources such as PPE, ventilators, dialysis machines and blood products, as well as the expected consumption of postoperative resources, such as ICU beds. This system allowed flexibility in selection of appropriate cases to be performed, according to which specific resources were in greater or lesser abundance at a given time. So that all available information could be considered, ultimate decisions about scheduling of these urgent operations were made at the highest levels of hospital administration, with input from the Chairman of Surgery.

Our system has thus far allowed us to manage our urgent caseload, but this may not be the case, as our resources are increasingly strained by the unrelenting pandemic. For urgent and even emergent patients at the high end of the risk spectrum, or for whom the expected benefit of surgery is marginal, palliative care may need to play a more prominent role, since prolonged ICU and hospital stays cannot be justified. In the end, the anticipated benefit and risk, as well as resource intensity, of a proposed procedure must be balanced against available resources at a given time, and this complex relationship is represented in Fig. 3A, with sample cases in Fig. 3B and C.

Regardless of the specific definitions of urgent and elective surgery during a period of decreased access, it is important for surgeons to closely monitor patients who have been postponed. These patients are at risk for progression of their disease while they wait, especially since they do not have normal access to their cardiologists and primary care physicians, or even pharmacies. We have instituted a system in which all patients previously scheduled for surgery, or with new appointments for surgical consultation, are contacted regularly (at least once per week) by their surgeon or a physician extender. In at least 2 cases, this system has identified a patient who was initially deemed stable for postponement but decompensated clinically at home, requiring urgent surgery.

CONSIDERATIONS IN PATIENTS REQUIRING CARDIAC SURGERY DURING THE PANDEMIC

Preprocedural, intraprocedural and postprocedural care for patients undergoing cardiothoracic surgery amid the COVID-19 pandemic should differ from usual routines. These are detailed in Table 3, with primary principles including robust screening of patients for suspected infection, streamlining of preoperative processes, intraoperative protocols to maintain infection control and expedited postoperative recovery, including virtual follow-up. Specific recommendations for the most commonly performed procedures follow.

Coronary artery bypass grafting and valve operations

Patients with stable coronary disease are at relatively low risk of mortality and should be postponed—a proposal supported by the recent ISCHAEMIA trial [10]. However, patients presenting with acute coronary syndrome and severe left main disease or triple-vessel disease with high syntax score, especially if not amenable to percutaneous coronary intervention, should be considered for urgent surgery. Mechanical complications of coronary ischaemia, such as ventricular septal defect or acute papillary muscle rupture, can be considered for operative therapy on a case-by-case basis.

A similar strategy should be employed for valve operations. Patients with asymptomatic severe aortic stenosis should be postponed due to low annual risk of sudden cardiac death [11], and even symptomatic severe aortic stenosis patients should be stratified based on duration and severity of symptoms. Left-sided endocarditis with haemodynamic compromise or very large vegetations should be prioritized over cases that can be managed medically until resources improve. Most mitral valve patients can also be delayed but should be aggressively managed medically and monitored closely for signs of decompensated heart failure.

Aortic surgery

There is little argument about the need for emergent surgery for acute type A aortic dissection or ruptured aortic aneurysm, unless the other factors such as malperfusion, prolonged shock or older age predict a very poor prognosis. In contrast, the decision to operate on high-risk thoracic aortic aneurysms, such as symptomatic, rapidly growing or giant aneurysms (>7 cm) as well as (saccular) pseudoaneurysms, is much more complicated and may be considered for urgent surgery depending on the risk of aneurysm-related death and the availability of resources. Asymptomatic patients with smaller aneurysms can have surgery delayed for 2–3 months. Another consideration is to tailor the repair to a more conservative approach versus a more extensive aortic resection, i.e. a hemiarch and ascending replacement compared with a comprehensive aortic root and total arch replacement. Medical management should be the choice for uncomplicated acute type B aortic dissection with endovascular therapy considered for complicated cases.

Heart transplantation and mechanical circulatory support

There are numerous factors that make the normal operation of an orthotopic heart transplantation programme impractical or impossible, particularly in regions with high COVID infection rates [12]. Newly transplanted patients requiring immunosuppression are presumably at high risk for COVID infection, particularly in hospitals in highly infected areas. A recent report from China describes 2 recipients of an orthotopic heart transplantation who presented with COVID infection [12], 1 with minimal symptoms and normal recovery, the other requiring hospital admission, antiviral treatment and temporary discontinuation of immunosuppression. At our institution, newly transplanted patients have been moved to a single non-COVID ICU in an effort to minimize infection risk. Only patients who are status 1 or 2 have remained active on the waiting list, due to their increased short-term risk of mortality, and only documented COVID-negative donor offers are accepted.

The Extracorporeal Life Support Organization continues to recommend veno-arterial ECMO for standard indications; however, exclusions for patients with COVID-19 are left to the discretion of local health care organizations, based on health care work risk and resource constraints [13]. At our centre, veno-arterial ECMO is still available to patients with cardiovascular collapse, with priority given to younger patients and health care workers with fewer comorbidities, but only after discussion with our multidisciplinary heart failure team (Table 4). Currently, patients are

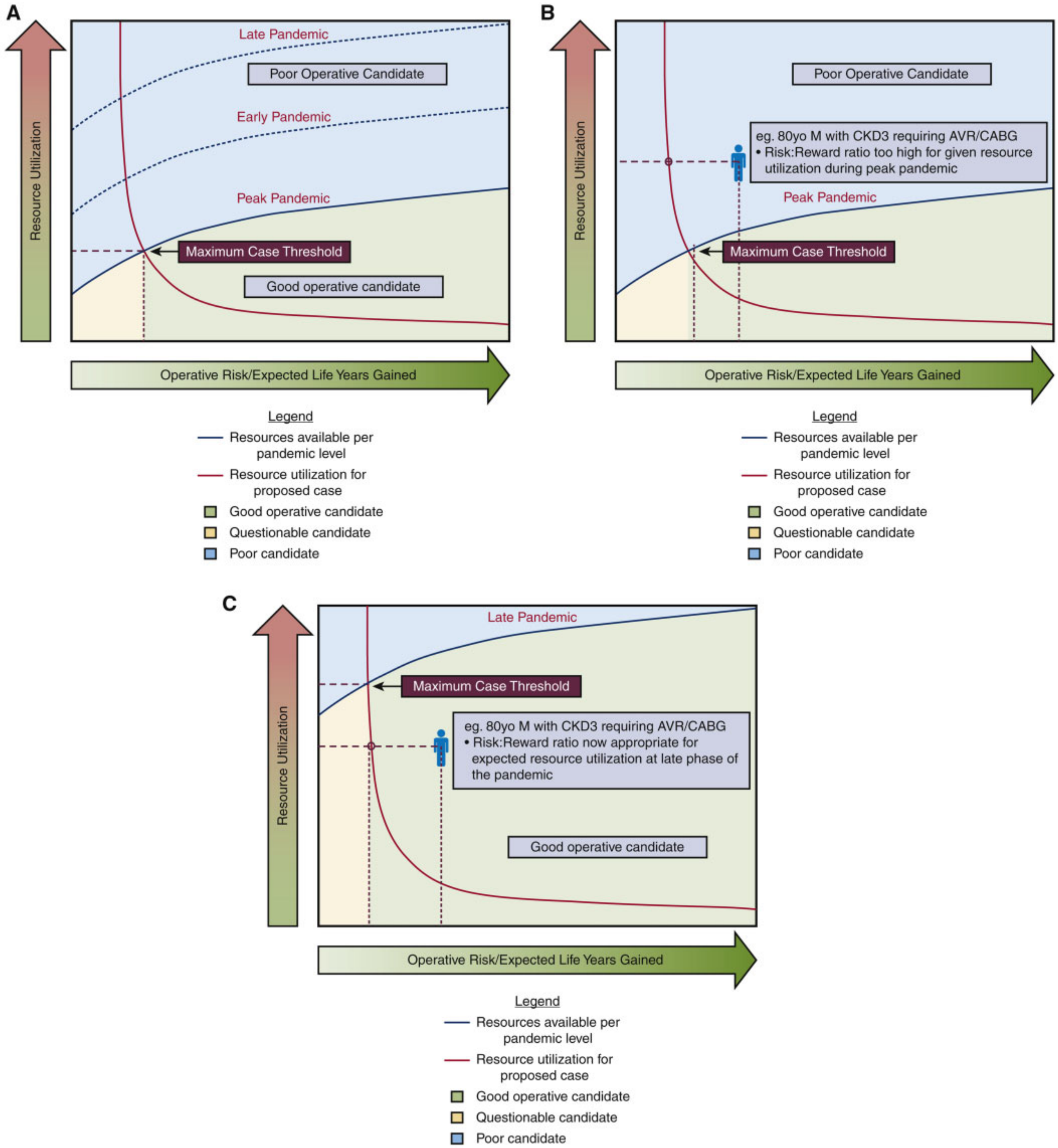

Figure 3: (**A**) Decision-making strategy for surgical planning based on pandemic phase, given operative risks and expected life years gained, resource use and resource limitations. In this figure, 3 phases of pandemic can be plotted with resource expenditure on the vertical axis (blue line: resources available; orange line: resource use), and operative risk and expected survival benefit on the horizontal axis. The intersection of the orange and blue resource lines represents the maximum case threshold for a health care system at a given time. This graph thus incorporates the changing level of resources at different stages of the pandemic, as illustrated by a sample case of an 80-year-old patient with CKD requiring AVR/CABG. In (**B**), during the peak of the pandemic, this operation is not justified; in (**C**), during later stages of the pandemic, this operation is justified. AVR: aortic valve replacement; CABG: coronary bypass grafting; CKD: chronic kidney disease.

considered for veno-arterial ECMO if meeting Society for Cardiovascular Angiography and Interventions criteria for stage C or D cardiogenic shock, and with Survival After Veno-arterial ECMO score ≥1. Patients in extremis (Society for Cardiovascular Angiography and Interventions stage E), age older than 60 years, or with septic shock, severe peripheral vascular disease, chronic lung or liver disease and end-stage renal disease are not considered. Anecdotally, the cases of COVID-induced myocardial dysfunction at our institution have often resolved concurrently with the inflammatory state, thus supporting a restrictive approach.

Table 3: Preoperative, intraoperative and postoperative considerations for caring for cardiac surgery patients in the COVID-19 era

Preoperative	Intraoperative	Postoperative
• Routine COVID-19 infection testing 24–48 h before • Travel and potential exposure history • Close CXR review • Forego non-essential testing when possible • Consider use of older testing data when possible • Preoperative care via telehealth • Patients don surgical mask upon hospital arrival • Early intubation preoperatively for suspected COVID-19 + patients in respiratory distress • Deferring case if COVID+	• Non-COVID ORs • Conversion of ORs to negative pressure • Airborne precautions and PPE worn by all providers • Non-essential staff not in room • Attending level surgical staff only • Video laryngoscopy for intubation • Minimize staff turnover within room • Forego TOE if appropriate • Avoid pleural entry and lung injury • Avoid procedures with CO_2 insufflation	• Clean recovery area • Suspect COVID-19 infection if prolonged respiratory failure • Minimize risks of renal failure and prolonged respiratory failure • Enhanced recovery protocol if appropriate: early extubation, mobilization and removal of chest tubes and pacing wires • Patients don surgical mask immediately after extubation • Early coordination with family for at-home postoperative recovery • Early discharge when medically stable • Close and frequent virtual follow-up after discharge • Repeat COVID-19 if clinical symptoms develop

COVID-19: coronavirus disease 2019; CXR: chest X-ray; OR: operating room; PPE: personal protective equipment; TOE: transoesophageal echocardiography.

Table 4: Columbia University Irving Medical Center's criteria for VA-ECMO use in the COVID-19 era

Criteria for consideration of VA-ECMO	Contraindication
SCAI criteria C or D	SCAI criteria E (extremis)
SAVE score $\geq$1	Ages >60 years
Minimal comorbidities	Severe peripheral vascular disease
	Septic shock as primary aetiology
	Acute stroke
	Contraindication to anticoagulation
	End-stage renal failure

COVID-19: coronavirus disease 2019; SAVE: Survival After Veno-Arterial ECMO; SCAI: Society for Cardiovascular Angiography and Interventions; VA-ECMO: veno-arterial extracorporeal membrane oxygenation.

Finally, we are not offering ECMO during cardiopulmonary resuscitation to confirmed or suspected patients with COVID-19 and have significantly limited this in patients without COVID-19 as well.

Left ventricular assist device (LVAD) implantation presents several challenges in the setting of COVID-19. These patients often suffer a profound inflammatory response, which would be exacerbated by COVID-19 infection. Specifically, patients with LVADs develop increased interleukin-6 cytokine levels within the first 6 weeks of implantation [14, 15], which are thought to correlate with COVID-19 severity [16]. Furthermore, because of the now described COVID-19-associated coagulopathy [7], infected patients with LVADs would be difficult to anticoagulate, with an increased risk of thrombotic complications. Finally, should a patient with an LVAD develop acute respiratory distress syndrome, it would be challenging to perform prone ventilation, given the risk of outflow graft and driveline compression and as well as decreased cardiac output from impaired venous return [17, 18]. In summary, the profound physiological burden of this operation, coupled with its resource intensity, make it prudent to delay as long as possible during the COVID-19 pandemic.

TRANSITION OF CARDIAC SURGICAL PRACTICE DURING THE RECOVERY PHASE

Although the incidence of COVID-19 may decline, the strain on hospital systems is likely to continue for a prolonged period of time. With this in mind, it is likely that the hardest-hit hospitals will be unable to resume elective procedures in the near future and not immediately at previous levels. As the total number of hospitalized coronavirus patients declines, it is likely that a gradual return of cardiothoracic surgical volume will occur, with the sickest patients prioritized for earlier operation. As operative volume slowly ramps up, there is likely to be a significant backlog of patients whose care was delayed due to the COVID-19 epidemic. For this reason, the continued management of the 'postponement list', including communication with patients and their physicians, is imperative so that patients ready for surgery can be scheduled when capacity returns. Another strategy we are employing to prepare for this phase is to encourage our referring physicians to talk to us about patients they are not referring due to the crisis so that we can schedule virtual visits and establish a 'bullpen' of patients who will need only a brief visit or preoperative testing to be ready for surgery. To accommodate all such patients, it may be necessary to schedule cases on weekends during this recovery phase.

Advanced presentations of common cardiac conditions will also arise because of care that was delayed due to limited resources or the reluctance of patients to seek care during the height of the pandemic. Late complications of myocardial infarction, such as heart failure or postinfarct ventricular septal defect, may be seen more frequently. Patients with valve disease may present with symptoms of advanced or decompensated heart failure, and perhaps decreased ventricular function. The reported incidence of aortic dissection presenting for acute care has anecdotally dropped, and perhaps more chronic dissections will emerge as a consequence. There is evidence that patients may be seeking medical care less frequently: in a poll by @angioplasty.org, >50% of respondents reported a 40–60% reduction in admissions for myocardial infarction. Ultimately, this delay in care may increase the chronic cardiac disease burden and may result in a need for more intensive follow-up care and repeat hospitalization, adding stress to the recovering hospital system.

CONCLUSIONS

As we continue to confront the COVID-19 pandemic, it is clear that multidisciplinary collaboration, willingness and flexibility to alter institutional practices, and the ability to maintain core surgical skills, while using them in the care of critically ill patients, will be required from cardiac surgical programmes. The impact on each individual programme will depend on the balance between the intensity of COVID-19 infection and resource capacity, and after the surge and peak of cases has been met, a return to normalcy is inevitable. Despite the unprecedented disruption of our practices and lives that this pandemic has produced, we will undoubtedly emerge from the experience stronger and more efficient as a specialty.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

ACKNOWLEDGEMENTS

The authors acknowledge their staff who has helped them through this crisis, including their residents, division administrators, nurses, physician assistants, nurse practitioners and other support staff.

Conflict of interest: none declared.

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