REVIEW ARTICLE

Mechanical circulatory support—Challenges, strategies, and preparations

Wael I. Awad MBBS, MD, FRCS (C/Th)1 © | Mohamad Bashir MD, MRCS, PhD2 ©

1Department of Cardiothoracic Surgery, Barts Heart Centre, St Bartholomew’s Hospital, London, UK
2Department of Vascular & Endovascular Surgery, Royal Blackburn Teaching Hospital, Blackburn, Lancashire, UK

Correspondence
Wael I. Awad, Department of Cardiothoracic Surgery, St Bartholomew’s Hospital, West Smithfield, London EC1A 7BE, UK.
Email: wael.awad@nhs.net

Abstract
Background: Coronavirus disease 2019 (COVID-19) is usually mild, but patients can present with pneumonia, acute respiratory distress syndrome (ARDS), and circulatory shock. Although the symptoms of the disease are predominantly respiratory, the involvement of the cardiovascular system is common. Patients with heart failure (HF) are particularly vulnerable when suffering from COVID-19.

Aim of the Review: To examine the challenges faced by healthcare organizations, and mechanical circulatory support management strategies available to patients with heart failure, during the COVID-19 pandemic.

Results: Extracorporeal membrane oxygenation (ECMO) can be lifesaving in patients with severe forms of ARDS, or refractory cardio-circulatory compromise. The Impella RP can provide right ventricular circulatory support for patients who develop right side ventricular failure or decompensation caused by COVID-19 complications, including pulmonary embolus. HT are reserved for only those patients with a high short-term mortality. LVAD as a bridge to transplant may be a viable strategy to get at-risk patients home quickly. Elective LVAD implantations have been reduced and only patients classified as INTERMACS profile 1 and 2 are being considered for LVAD implantation. Delayed recognition of LVAD-related complications, misdiagnosis of COVID-19, and impaired social and psychological well-being for patients and families may ensue. Remote patient care with virtual or telephone contacts is becoming the norm.

Conclusions: HF incidence, prevalence, and undertreatment will grow as a result of new COVID-19-related heart disease. ECMO should be reserved for highly selected cases of COVID-19 with a reasonable probability of recovery. Special considerations are needed for patients with advanced HF, including those supported by durable LVADs.

KEYWORDS
acute respiratory distress syndrome, COVID-19, extracorporeal membrane oxygenation, pandemic
1 | COVID-19

Coronavirus disease 2019 (COVID-19) is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The disease is usually mild, although occasionally severe with patients presenting with pneumonia, acute respiratory distress syndrome (ARDS), and circulatory shock (CS). In a recent report, 26.1% of 138 COVID-19 patients needed to be admitted to the intensive care unit (ICU), of which 61.1% were suffering from ARDS. The heterogeneity of responses between individual patients is marked indicating host characteristics promote progression of the disease with a range of different presentations from mild symptoms to multiorgan failure.

Although the clinical symptoms of the disease are predominantly respiratory, direct and indirect involvement of other organs is common, with the cardiovascular (CV) system being particularly affected. Moreover, pre-existing conditions, largely linked to CV disease (CVD), increase the risk of severe outcomes of the infection. A large Chinese study analyzing data of 44,672 confirmed COVID-19 cases revealed 12.8% had hypertension, 5.3% diabetes, and 4.2% CVD. A further study of 5700 patients from the United States reported a similar message that hypertension (56.6%), obesity (41.7%), diabetes (33.8%), CAD (11.1%), and congestive heart failure (6.9%) were common comorbidities in patients with COVID-19. Older patients are more likely to experience ICU admission, mechanical ventilation, or death compared with younger patients, and males seem to be more susceptible to COVID-19-related complications.

COVID-19 has resulted in substantial policy change and strain on existing healthcare infrastructure. Many healthcare providers have had to scale down outpatient services and defer elective cardiac procedures and operations with re-deployment of the workforce to help manage the pandemic. The long-term clinical impact of scaling down outpatient activity, reduced access to investigations, and cancellation of routine procedures will have consequences beyond the pandemic. In addition, the perceived risk of being exposed to COVID-19 has led to a delay in presentation of acute cardiac emergencies with a likelihood of increasing cardiac mortality and morbidity. Until now, no specific treatment has been recommended for COVID-19, although extracorporeal membrane oxygenation (ECMO), providing effective respiratory or cardiac support, can be regarded as a rescue therapy for severe ARDS.

2 | COVID-19 AND CARDIOVASCULAR DISEASE

Patients with cardiovascular risk factors and established cardiovascular disease, including heart failure (HF), are particularly vulnerable when suffering from COVID-19 and patients with cardiac injury in the context of COVID-19 have an increased risk of morbidity and mortality. Guzik et al. report a mortality rate ~0.9% for patients with no comorbidities and much higher for patients with comorbidities (10.5% for patients with CV disease, 7.3% for those with diabetes, 6% for those with hypertension and 6.3% for those with chronic respiratory disease).

SARS-CoV-2 anchors on transmembrane ACE2 to enter the host cells including type 2 pneumocytes, macrophages, endothelial cells, pericytes, and cardiac myocytes, leading to inflammation, severe microvascular and macrovascular dysfunction and multiorgan failure.

Furthermore, COVID-19 infection leads to systemic inflammation and immune cell overactivation, and a "cytokine storm," with resultant release of in an elevated level of cytokines such as IL-6, IL-7, IL-22, and CXCL10. Subsequently, activated T cells and macrophages may infiltrate infected myocardium, resulting in the development of fulminant myocarditis and severe cardiac damage and impairment of left ventricular function.

Thus, the mechanisms by which COVID-19 affects the cardiovascular system possibly include direct myocardial injury, indirect injury through sepsis, hypoxia, cytokine release, a prothrombotic state causing microvascular thrombosis, and exacerbation of underlying cardiovascular disease, for example, plaque rupture in susceptible patients. Supply/demand mismatch (Type 2 myocardial infarction [MI]) or microvascular thrombosis can lead to left ventricular dysfunction and ventricular arrhythmias. Fulminant myocarditis can lead to rapidly progressive cardiogenic shock from decompensation in patients with known or subclinical cardiomyopathy. Among hospitalized patients, the presence of cardiac injury has been independently associated with a 4-fold increased risk of mortality in patients infected with COVID-19.

In patients with COVID-19 infection, hypoxemic respiratory failure, and ARDS can exacerbate pulmonary vasoconstriction and interstitial edema, worsening pulmonary hypertension even in patients without pre-existing lung disease. In patients with pre-existing biventricular failure, further elevation in pulmonary pressures secondary to ARDS can worsen right ventricular function.

In a large cohort study of 138 patients, 8.7% of patients presented with shock, 7.2% with acute cardiac injury, and 16.7% with arrhythmias. Various other reports show new-onset heart failure/ cardiomyopathy in up to one-third of critically ill patients admitted with COVID-19 infection.

A special population at risk for COVID-19 includes patients supported with left ventricular assist devices (LVADs). These patients are chronically affected by long-standing cardiovascular diseases and are subjected to variations of the normal cardiovascular physiology due to a non-pulsatile blood flow, exposure of the blood to artificial surfaces, and risk of hemorrhagic and thrombotic events. Patients with advanced HF, including those with durable LVAD support, have severely reduced functional capacity, as measured by peak VO2, and impaired ability to augment cardiac output in response to physiological stressors. These factors collectively decrease their cardiopulmonary reserve.

Patients with COVID-19 infection are at higher risk for thrombosis in the arterial and venous circulations due to endothelial dysfunction, inflammation, oxidative stress, and platelet activation, both may trigger decompensation of pre-existing HF or development...
of de novo acute HF. Right ventricular failure can also develop secondary to elevated pulmonary pressures in the setting of ARDS and/or pulmonary embolism.23

HF incidence, prevalence, and undertreatment will likely grow as a result of new COVID-19-related heart disease, delays in the recognition and treatment of ischemic heart disease, rising unemployment, and loss of income and health benefits for large segments of the population. Special considerations are needed for patients with advanced HF, including those supported by durable LVADs and heart transplantation (HT) recipients.

3 | ECMO

Treatment options for COVID-19 myocarditis are still evolving. However, mechanical circulatory support devices and life support therapies such as veno-venous ECMO (VV-ECMO) and VA-ECMO may be beneficial in select cases.

The mortality in COVID-19 patients who require mechanical ventilation is high. Extracorporeal membrane oxygenation can be lifesaving in patients with severe forms of ARDS, or refractory cardio-circulatory compromise. While accepting that resource scarcity may be the overwhelming concern for healthcare systems during this pandemic, VA-ECMO can be considered in highly selected cases of refractory CS and biventricular failure. The decision to initiate this therapy should take into consideration the availability of resources, perceived benefit, and risks of transmitting disease to patients and staff.

The Extracorporeal Life Support Organization (ELSO) recommends consideration of VA-ECMO in refractory CS that persists despite adequate fluid resuscitation, inotropes, and vasopressor support.24 Contraindications to VA-ECMO include advanced age, life-threatening noncompliance, and significant medical comorbidities.24

The Society of Critical Care Medicine guidelines for the management of COVID-19 patients recommends the use of ECMO when conventional management fails.25 Due to the intensive hospital resource utilization, substantial staff training, and multidisciplinary needs associated with starting an ECMO program, ELSO recommends against starting new ECMO centers for the sole purpose of treating patients with COVID-19. During the COVID-19 surge, it is reasonable to concentrate those patients with the greatest chance of benefit from receiving ECMO in a hospital where an experienced ECMO team is available.

Patient selection for VA-ECMO in the setting of COVID-19 infection is a challenging task. However, a multidisciplinary CS team that includes representation of cardiac surgery, cardiology, intensive care, anesthesia, and advanced heart failure/transplant physicians may facilitate decision-making.

Although patients with COVID-19 infection are in a pro-inflammatory and prothrombotic state, coagulopathy occurs in up to one-fifth of cases.26 Thus, vigilant monitoring for both thrombotic complications (intracardiac thrombi, aortic root/aortic valve thrombi, cannula thrombi, thrombosis of oxygenator) is necessary. Severe cases of COVID-19 tend to present with multiorgan failure. The use of VA-ECMO in such patients may be considered a futile resource-intensive endeavor. Use of validated prognostic scores such as the Sequential Organ Failure Assessment and Survival after Veno-arterial ECMO scores together with clinical judgment may identify those who are more likely to recover.27

The provision of ECMO, also is dependent on local institution and regional policies. ECMO requires specialized equipment, training (of physicians, nursing staff, and perfusionists), and delivery of care in specialized critical care units. MacLaren et al.28 suggest, resources may well be better concentrated to ensure that enough ICU beds, ventilators, and personal protective equipment are available to deal with the influx of patients encountered during the pandemic. Providing this level of care should be considered dynamically on a case-by-case basis as the local situation and resource availability changes (ie, critical care beds, healthcare personnel, equipment).

Many factors could affect the outcomes of ECMO treatment, including the duration of mechanical ventilation, the severity of underlying disease, the experience of trained medical staff, and ECMO equipment. Use of ECMO in patients with a combination of advanced age, multiple co-morbidities, or multiple organ failure should be avoided.

Not all patients will improve with ECMO support. As is standard with usual ECMO care, clinicians should be continuously evaluating when ECMO no longer provides a positive benefit-risk ratio and should at that point return to conventional management. As prognosis is worse with time on invasive mechanical ventilation, patients on mechanical ventilation greater than 7 days can probably be excluded, and observing no lung or cardiac recovery after approximately 21 days on ECMO can be considered futile.

In the present time of global uncertainty with limited evidence to guide care, we must be mindful of balancing resource scarcity. We anticipate that Extracorporeal Membrane Oxygenation for 2019 Novel Coronavirus Acute Respiratory Disease (ECMO-CARD), an ongoing multicentre prospective observational study of ECMO use in COVID-19, will inform practice for both VV-ECMO and VA-ECMO use when published.29 For now, it seems reasonable to reserve VA-ECMO for highly selected cases of COVID-19 where there is a perceived reasonable probability of recovery.

4 | HEART TRANSPLANTATION AND VENTRICULAR ASSIST DEVICES

Heart transplantation and VAD patients face unprecedented challenges during the coronavirus disease 2019 (COVID-19) pandemic. These populations are at increased risk for acquiring COVID-19 infection. For heart transplant (HT) clinicians, the global pandemic has unique implications for patients, including those on the waiting list and transplant recipients.

Many centers have inactivated most of their HT waiting list, reserving active transplant status for only those patients with a presumed waiting list mortality of 1 to 2 weeks, thus limiting transplant to patients in tiers 1 or 2 of the new heart allocation
policy. For listed patients who are hospitalized without a strict contraindication to durable left ventricular assist device implanta-
tion, LVAD as a bridge to transplant may be a viable strategy to get
at-risk patients home and out of the hospital, minimizing their ex-
posure to COVID-19. Left ventricular assist device implants should
not be performed in elective cases because of resource constraints
and potential for nosocomial infection.

The COVID-19 pandemic has had far-reaching implications for
donor selection, organ procurement, waiting-list candidates, and
transplant programs.30 Given the limitations of current testing and
risks for asymptomatic transmission and infection, the HT commu-
nity must be careful to select uninfected donors. As the pandemic
continues to evolve, a center’s transplant volume may require staged
reduction to meet ITU bed, staffing, and medical equipment needs of
the majority nontransplant population.

Important decisions have already appeared about actively listed
patients. At any given time, a significant portion of patients are
waiting in-hospital for HT. These patients are at higher risk for
contracting the virus compared with others waiting at home. If they
subsequently contract COVID-19, they are at risk for more severe
infection because of their underlying health conditions, and risk
delisting. For listed patients, transplant centers should highlight the
waiting list mortality risk–benefit ratio and provide institutional
updates.

Left ventricular assist device patients are affected by long-
standing cardiovascular diseases and subjected to variations of
the normal cardiovascular physiology, thus requiring an even closer
monitoring during the COVID-19 outbreak. Potential deleterious
effects of such a situation can be a delayed recognition of LVAD-
related complications, misdiagnosis of COVID-19, and impaired so-
cial and psychological well-being for patients and families.

LVAD patients are at increased risk of COVID-19 infection for
several reasons including most LVAD patients share the same risk
factors for COVID-19 infection and represent a very vulnerable
population. These patients may manifest impaired immunity with
increased risk for opportunistic infections and activation or en-
hanced release of the inflammatory cytokines in COVID-19 may
augment the pre-existing myocardial injury.31 This “functionally im-
munocompromised state” increases susceptibility to complications
from opportunistic infections.

Due to the general reorganization of healthcare resources in
many hospitals, elective LVAD implantations have been reduced to
allow for a higher availability of intensive care beds. Consequently,
only patients classified as INTERMACS profile 1 and 2 are being con-
sidered for LVAD implantation.

With suspension of elective surgeries there is a potential mor-
bidity and mortality increase in LVAD candidates waiting for im-
plantation. Furthermore, there is a risk that the close connection
between LVAD patients and their treating centers becomes looser
with increased LVAD-related complications and impaired well-being.
Patients undergoing HT/LVAD evaluation experiencing delays in
listing and/or surgery can develop worsening nutritional, functional,
or hemodynamic status. LVAD supported patients with the indication
of bridge to transplantation might decline an offer to undergo heart
transportation because of the fear of being infected from the donor
or because they fear they will not get the optimal care from the
overstressed healthcare system. Although delay of these procedures
may not immediately affect clinical outcomes, there are important
long-term and indirect implications for patients with HF.

While it is important to prevent COVID-19, the routine care
should not be discontinued to avoid severe complications both on
clinical and psychological sides. Therefore, specific LVAD manage-
ment algorithms should be implemented by every implanting and
referring LVAD centre to aim for early diagnosis and treatment of
COVID-19 or LVAD complications.

COVID-19 can create a prothrombotic environment in some
patients resulting in acute pulmonary embolism which may lead to
acute right ventricular failure. Early recognition of right ventricular
dysfunction and early intervention in patients who are hypotensive
can be lifesaving. The Impella RP is a temporary heart pump that
provides right ventricular circulatory support for patients who de-
velop right side ventricular failure or decompensation caused by
COVID-19 complications, including pulmonary embolus. For critically
ill patients the Impella RP can be rapidly deployed in a matter of
minutes using a minimally invasive technique in the cardiac cathe-
terization laboratory or operating room.

In LVAD patients with COVID-19 developing right ventricular
(RV) failure, medical management is the mainstay of therapy.
Management should be focused on volume management and opti-
mization of RV preload, reduction in RV afterload, improvement in
the contractile state of the right ventricle and optimization of cardiac
rhythm.32 Regulation of the LVAD parameters is equally as im-
portant. Device speeds are chosen to obtain satisfactory hemody-
namic goals without inappropriate left ventricular unloading,
maintaining a rightward or neutral position of the interventricular
septum, and limiting cardiac output while maintaining an adequate
mean arterial pressure. Vasodilatation or low systemic perfusion
pressures may result in inappropriate unloading of the left ventricle
and can contribute to leftward septal shift and suction events which
impair LVAD output and RV function and may additionally trigger
ventricular arrhythmias.

Serum lactate dehydrogenase (LDH) is a recognized biomarker
for early recognition of lung injury and assessment of severity in
COVID-19.33 In addition, a change in biomarker levels may be useful
in grading COVID-19 severity in LVAD patients. Increase in LDH in
LVAD patients may raise specific concerns of hemolysis or LVAD
thrombosis and concomitant stroke. Infection, itself, acts as a trigger
for inflammatory response predisposing to pump thrombosis, is-
chemic or hemorrhagic stroke in LVAD patients.33

In patients with acute hypoxaemic respiratory failure due to
COVID-19, prone ventilation may be effective in COVID-19-related
severe ARDS (improving lung mechanics and gas exchange). How-
ever, it may be problematic in HF patients on LVAD support as prone
positioning could result in complications such as compression of
outflow graft and driveline, impaired venous return from increased
thoracic pressure, hardware malpositioning, and worsening right
ventricular (RV) hemodynamics. However, the probability of impaired functioning of the LVAD by rotation or mechanical compression seems to be very low.

5 VIRTUAL FOLLOW-UP

With the COVID-19 pandemic, LVAD supported patients, their close caregivers, and the healthcare professionals face some completely unprecedented and unexpected challenges that may affect their ability to maintain optimal self-care. Access to the hospital should be discouraged to reduce the risk of hospital-acquired infection. Thus, monitoring of the regular function of the device, laboratory tests, and clinical evaluation may be postponed or made less frequent.

Most LVAD centers have adapted their face to face contacts by organizing remote patient care with virtual or telephone contacts. Each LVAD recipient can be considered for a telemonitoring algorithm after an initial check of his/her status through a phone call to check the home-care situation, recent or current hospital admissions, and open clinical problems requiring regular access to the referring clinic such as in case of severe driveline infections undergoing specific treatments. Patients entering this monitoring program should have been judged as adequately educated through extensive talks and training sessions with the VAD coordinator focused on driveline dressing techniques, battery and controller exchange, blood pressure, fluids, and anticoagulation self-management.

Through virtual visits, HF clinicians can maintain face-to-face interactions with their patients, gain familiarity with patients’ domestic circumstances, obtain vital sign measurement through home blood pressure cuffs and pulse oximeters, perform limited physical examinations for jugular venous distention, peripheral edema and driveline site integrity, functional capacity, resolve medication issues and interact with caregivers. Patients can send a picture of the driveline site through email or smartphone.

Assessment provided with a virtual visit can also include evaluation of LVAD controller parameters and screening for adverse events, in addition to counseling. Since prevention is currently the best strategy for COVID-19, home management requires that healthcare professionals innovate ways to follow LVAD patients virtually and advise them with instructions to self-quarantine, take hygiene actions and social distancing measures for prevention of disease and transmission. Healthcare professionals should limit all elective medical visits and testing, arrange for in-home blood-testing and home international normalized ratio monitoring as well as emphasize the importance of nutrition, sleep, and exercise. Patients’ families and caregivers must also be protected and practice self-care measures for safety. Delivering optimal support to LVAD implanted patients during the COVID-19 pandemic include creating local support networks to deliver educational materials, extra pro-active phone calls from the VAD coordinator.

Those with limited access to the internet and/or “smart” devices may not derive benefit from the expansion of these innovations. Older adults may have educational, visual, auditory, and cognitive impairments that hinder their participation in remote care. The option for in-person clinic visits should remain available for patients without access to telemedicine services, high-risk patients, or those for whom physical examination is critical for clinical decision making.

Additionally, time should be spent for psychological support and reassurance. Optimal self-care includes behavior to maintain and increase psychological wellbeing to optimally cope with an LVAD. During the COVID-19 pandemic, patients have an increased level of anguish than the general population. Patients worry about being infected and they worry about the wellbeing of their caregiver. They also worry about changes in their relationship with their close homebound caregiver on whom they become even more dependent. Psychological distress can be accelerated by the lack of physical activity, social deprivation, isolation, and loneliness. The use of established behavioral and social science approaches need to identify the active components of “psychological support” that are most applicable to each individual patient with a VAD.

DISCLAIMER

ECMO has, and will certainly continue, to play a role in the management of COVID-19 patients. It should be emphasized that this initial guidance is based on the current best evidence for ECMO use during this pandemic. Guidance documents addressing additional portions of ECMO care are currently being assembled for rapid publication and distribution to ECMO centers worldwide.

AUTHOR CONTRIBUTIONS

Wael I. Awad: Drafting article, critical revision of article, approval of article. Mohamad Bashir: Critical revision of article, approval of article.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ORCID

Wael I. Awad https://orcid.org/0000-0003-3380-9554
Mohamad Bashir http://orcid.org/0000-0002-2605-538X

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How to cite this article: Awad WI, Bashir M. Mechanical circulatory support—Challenges, strategies, and preparations. *J Card Surg*. 2021;36:1723-1728. https://doi.org/10.1111/jocs.15301