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Coronavirus disease 2019 and mechanical circulatory support devices: a comprehensive review

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Abstract

Coronavirus disease (COVID-19) can cause circulatory shock refractory to medical therapy. Such patients can be managed with mechanical circulatory support (MCS) devices like IABP, Impella, VA ECMO, and Left ventricular assist devices (LVADs). Moreover, patients on long-term durable LVADs are a special population having increased susceptibility and mortality to COVID-19 infection. In this narrative review, we searched PubMed and Medline for studies on COVID-19 patients on short-term MCS devices. We found 36 papers with 110 patients who met our review criteria, including 89 LVAD patients and 21 COVID-19 patients who needed MCS device therapy. These studies were used to extract patient demographics, clinical presentation, MCS device details, management, and outcomes. Mean age of patients with COVID-19 infection on LVADs was 60, 73% were male, and HeartMate 3 was the most common device (53%). Most patients (77.5%) needed hospitalization, and mortality was 23.6%. Among the 21 reported cases of critically ill COVID-19 patients who required MCS, the mean age was 49.8 years, 52% were women, and the most common MCS device used was VA ECMO (62%) in conjunction with an Impella for LV venting. Comorbidities were not present in 43%, but 71% had abnormal ventricular function on echocardiography. MCS is a viable option for managing severe COVID-19 infection with shock, with many reported cases of favorable outcomes.

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Core tip

Refractory circulatory shock in COVID-19 can be successfully managed with mechanical circulatory support (MCS) devices such as intra aortic balloon pump (IABP), Impella, venoarterial extra corporeal membrane oxygenation (VA ECMO), and durable left ventricular assist devices (LVADs). The most common MCS device used in such patients was VA ECMO (62%) in conjunction with an Impella for LV venting, and there are many reported cases of favorable outcomes. Patients on long-term durable LVADs are a special population having increased susceptibility and mortality with COVID-19 infection. Among the reported cases, most were elderly males on HeartMate 3, and the hospitalization and mortality rates were 77.5% and 23.6%, respectively.

Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a highly transmissible pathogen that causes the coronavirus disease 2019 (COVID-19) in humans. This virus has caused a pandemic and, as of March 10, 2022, has infected more than 450 million people worldwide, resulting in more than six million deaths [1]. Although COVID-19 predominantly affects the respiratory system, direct and indirect involvement of other organ sys-

tems is also seen, the cardiovascular system in particular. COVID-19 can affect the myocardium directly or indirectly through sepsis-related injury, hypoxia, cytokine release, microvascular thrombosis secondary to a prothrombotic state, and plaque rupture in susceptible patients.[2] This can result in ventricular dysfunction, arrhythmia, and rapidly progressive cardiogenic shock. Unsurprisingly, cardiac injury was independently associated with higher mortality (adjusted HR, 4.26) in COVID-19 [3]. COVID-19 infection can interact with patients with heart failure in multiple ways [4]. It can cause *de novo* heart failure, as well as lead to increased mortality of patients with pre-existing heart failure [5]. Today, many options exist to manage heart failure, both pharmaceutically and mechanically. The latter group includes intra-aortic balloon pump (IABP), Impella, venoarterial extra corporeal membrane oxygenation (VA ECMO), and durable left ventricular assist devices (LVADs). The literature on this subject is fragmented and predominantly includes case reports and case series. In this review, we comprehensively review the use of mechanical circulatory support (MCS) devices to manage circulatory shock in COVID-19 and the impact of COVID-19 infection on patients on long-term MCS devices.

Methods

We searched the PubMed and Medline databases for the MeSH terms "COVID-19", "Heart-Assist Devices," "Intra-Aortic Balloon Pumping," "Extracorporeal Membrane Oxygenation," References of manuscripts were screened to identify additional papers. Studies that included adult patients with COVID-19 infection were included in this review. All studies published before February 2022 were included. Studies that provided details on patient demographics, clinical presentation, MCS device details, management, and outcome were analyzed. Treatment details were included, including medications, vasopressors, invasive mechanical ventilation, and procedures. Other details that were obtained were the type of organ dysfunction, COVID-19 specific treatment, duration of illness, the course on MCS device, and complications. Articles without patient details, opinions, comments, and letters were excluded from the analysis. Two independent reviewers screened all articles.

Results

As of February 2022, 36 papers were identified, with 110 patients. Three were observational studies, while the rest were case reports or case series. We analyzed the studies that reported outcomes of MCS among critically ill patients with COVID-19 and patients on durable LVADs separately. We identified 89 patients reported in the literature who were on long-term durable LVADs and got COVID-19 infection (Tables 1 and 2). All the observational studies and most reported cases were from the United States of America. The mean age of patients was 60 years, and 73% were male. The most common device was HeartMate 3 (53%), followed by HeartWare HVAD (25%) and HeartMate 2 (21%). The median duration on LVAD was between 1.3 and 3.2 years, with at least 38% of devices implanted with the intention of 'destination therapy'. Most patients (77.5%) required hospitalization, and a significant proportion of them required intensive care unit (ICU) care. LVAD thrombosis was seen in five (6%) patients, while nine (10%) had major bleeding. In addition, two patients had LVAD driveline site infections. The mortality in this group of patients was 23.6%. There were 21 reported cases of critically ill COVID-19 patients who required MCS device therapy (Table 3). The mean age of this cohort was 49.8 years (range 25-84), and 52% were women. At presentation, respiratory failure was present in 57.1% and shock in 47.6%. Others decompensated while in the hospital. Although only 19.1% had known chronic heart failure, most patients (71%) had an abnormal ventricular function on echocardiography. Eventually, all patients developed cardiogenic shock. The most common MCS device used was VA (or VAV) ECMO (62%) in conjunction with an Impella for LV venting. Interestingly, 43% of the patients had no comorbidities. Two patients (9.5%) from this cohort died despite advanced MCS therapy.

Discussion

In this paper, we have provided a comprehensive review on the impact of COVID-19 infection in patients on long-term MCS devices and the use of MCS devices to manage circulatory shock in COVID-19 (Figure 1). We identified 89 patients on long-term LVAD, the most common device being HeartMate 3. We also identified 21 cases of critically ill COVID-19 patients on MCS therapy. The most common MCS was VA (or VAV) ECMO (62%) in conjunction with an Impella for LV venting.

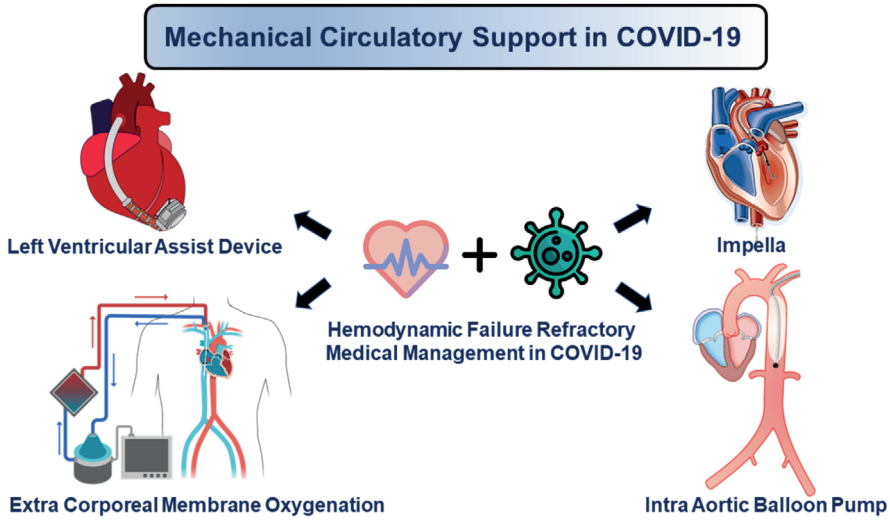

Figure 1. Mechanical circulatory support options in COVID-19.

Table 1. Case reports of COVID-19 infection in patients with left ventricular assist devices (LVADs).

Sl. no	Author	Age in years, Sex	Device	Comorbidities	Chest imaging	Echocardiography	LVAD parameters at admission	Treatment, course and complications	COVID specific medications	Outcome
1	Maharaj *et al.* [6]	64, M	HeartMate 3	Non-ischemic cardiomyopathy on LVAD as 'bridge-to-transplant'	CT Chest: Filling defect within the outflow graft (lung findings not reported). Cardiac CT angiogram confirmed non-occlusive thrombus extending throughout the entire outflow cannula	Not reported	Normal (RPM 5500, flow: 5.1 LPM, pulsatility index: 3.2, pump power: 4.4 W)	Intubation and mechanical ventilation, LVAD flows declined to 2.0-2.5 LPM, dobutamine support, bivalirudin infusion and dipyridamole, increasing supraventricular and ventricular arrhythmias, developed cardiogenic shock. Repeat CT showed progression of thrombus	None	Family elected to pursue comfort measures and patient died
2	Piperata *et al.* [7]	72, M	Jarvik 2000	Post-ischemic dilated cardiomyopathy, diabetes mellitus, CKD, atrial fibrillation, dyslipidemia, past history of endocarditis and two cerebral ischemic strokes	CT chest: normal	Not reported	Normal	Developed LVAD exit-site infection treated with levofloxacin	None	Stable, admitted in hospital at the time of publication of case report
3	Piperata *et al.* [7]	61, M	HeartMate 3	Primary dilated cardiomyopathy, obesity, diabetes mellitus, chronic obstructive pulmonary disease, CKD, atrial flutter, on CRT defibrillator	Chest radiograph: mild ground-glass opacities, left sided pleural effusion	Right ventricular dysfunction and pulmonary hypertension	Normal	Required infusion of dobutamine, levosimendan and furosemide. Gradually improved	None	Discharged

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Table 1. Continued from previous page.

Sl. no	Author	Age in years, Sex	Device	Comorbidities	Chest imaging	Echocardiography	LVAD parameters at admission	Treatment, course and complications	COVID specific medications	Outcome
4	Özgür *et al.* [8]	43, M	HeartMate 2	End-stage heart failure	CT chest: bilateral sub-pleural and peripheral hazy, mild ground-glass opacities	No signs of pump-induced left ventricular suction and TAPSE of 12 mm	Normal	Required supplemental oxygen	Favipiravir	Discharged on day 7
5	Özgür *et al.* [8]	51, M	HeartWare HVAD	End-stage heart failure	CT chest: peripheral hazy opacities	Not reported	Normal	Initially stable and hence discharged, readmitted one week later due to worsening dyspnea. Required supplemental oxygen	Favipiravir, hydroxychloroquine and corticosteroids	Discharged on day 7
6	Arshad *et al.* [9]	78, M	HeartMate 2	Chronic heart failure on LVAD	Chest X-ray: right lobe opacity	Not reported	Pump thrombosis was diagnosed	Received tPA for pump thrombosis followed by pump exchange, supplemental oxygen	Remdesivir and dexamethasone	Discharged after recovery
7	Belfort *et al.* [10]	31, M	HeartMate 3	Dilated cardiomyopathy on LVAD as 'bridge-to-transplant'	CT Chest: bilateral ground glass opacities, bilateral pneumothorax and consolidation	Severe left ventricular dysfunction (ejection fraction 24%) and moderate right ventricular dysfunction (RVD)	Not reported	Intubation and mechanical ventilation, shock requiring vasopressors, secondary bacterial pneumonia, hemothorax, catheter-related bloodstream infection and pneumothorax due to barotrauma	None	Discharged after 4 weeks
8	Jarrett *et al.* [11]	53, M	HeartMate 2	Dilated cardiomyopathy, morbid obesity	Chest X-ray: unremarkable	Dilated left ventricle and persistent opening of the aortic valve	Increasing LVAD power readings consistent with LVAD thrombosis, RPM: 10000, Flow: 6.5 LPM, pulsatility index: 4.1	Admitted and administered intravenous tPA, required multiple blood transfusions for severe anemia	None	Extubated on day 48, discharged on day 199, awaiting heart transplantation

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Table 1. Continued from previous page.

Sl. no	Author	Age in years, Sex	Device	Comorbidities	Chest imaging	Echocardiography	LVAD parameters at admission	Treatment, course and complications	COVID specific medications	Outcome
9	Korada *et al.* [12]	48, F	HeartMate 2	Chronic systolic heart failure, hypertension, type 2 diabetes mellitus, CKD (stage IIIb), and morbid obesity	Chest X-ray: bilateral peripheral hazy opacities	Not reported	Normal (RPM 9600, Flow: 4.4 LPM, pulsatility index: 7.2, pump power: 5.7 W, no alarms)	Supplemental oxygen, admitted to intensive care unit	Lopinavir-ritonavir	Discharged on day 8, readmitted on day 37 and treated for post-viral subacute thyroiditis with methimazole
10	Hodges *et al.* [13]	44, M	HeartMate 3	End-stage ischemic cardiomyopathy with LVAD as 'destination therapy'	Chest X-ray: bilateral patchy airspace opacities	Not reported	Normal (RPM 5400, Flow: 4.5 LPM, pulsatility index: 2.6, pump power: 4.1 W)	Intubation and mechanical ventilation, shock on vasopressors, left foot ischemia due to presumed intravascular thrombosis, nasopharyngeal bleeding, gross hematuria, and retroperitoneal hematoma requiring transfusion	Hydroxychloroquine (later stopped due to QT prolongation and an episode of torsade de pointes), tocilizumab, heparin infusion, and aspirin	Extubated on day 11, discharged on day 31
11	Frick *et al.* [14]	56, F	HeartMate 2	Ischemic cardiomyopathy with LVAD as 'destination therapy', morbid obesity	CT chest: patchy bilateral ground glass opacities	Dilated left ventricle with end diastolic diameter of 5.8 cm and a dilated hypokinetic right ventricle	Single elevated power of 10 W, 10 days after patient was symptomatic. Multi-tonal hum on auscultation, instead of the monotonic hum of HMII	Admitted and evaluated for possible pump thrombosis, started on milrinone	Diuretics, cangrelor, heparin	The patient was discharged home on warfarin, ticagrelor, and aspirin
12	Mahmood *et al.* [15]	54, M	HeartMate 3	End-stage cardiomyopathy with LVAD as 'destination therapy', coronary heart disease, prior CABG, diabetes mellitus, HIV/AIDS (on emtricitabine-tenofovir and dolutegravir)	Chest X-ray: no air space or interstitial infiltrates	Not reported	RPM 4900, flow: 3.4 LPM, single low-flow LVAD alarm noted 3 days prior to admission	Self-isolation and monitoring	Hydroxychloroquine	Recovered

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Table 1. Continued from previous page.

Sl. no	Author	Age in years, Sex	Device	Comorbidities	Chest imaging	Echocardiography	LVAD parameters at admission	Treatment, course and complications	COVID specific medications	Outcome
13	Chau *et al.* [16]	70, M	HeartMate 3	End-stage ischemic cardiomyopathy with LVAD as 'destination therapy', CKD stage III, obesity	Chest X-ray: bilateral infiltrates suggestive of atypical pneumonia	Not reported	Normal	Intubation and mechanical ventilation, multi-organ dysfunction syndrome	Tocilizumab	After initial improvement, patient developed worsening shock, refractory hypoxemia, PEA and died
14	Loforte *et al.* [17]	55, M	HeartWare HVAD	Idiopathic dilated cardiomyopathy	PET CT: pathologic FDG accumulation located at the left inferior and right inferior pulmonary lobes (multi-lobular and sub-pleural ground-glass opacities and consolidation)	Not reported	Normal	Self-isolation, patient developed driveline wound site infection	Driveline percutaneous site medication and dressing	Recovered
15	Singh *et al.* [18]	66, M	HeartMate 2	Hypertension, end-stage ischemic cardiomyopathy with LVAD as 'destination therapy', atrial flutter, ischemic stroke	Chest radiograph: bilateral pulmonary infiltrates suggestive of multifocal pneumonia	baseline moderate right ventricular dysfunction	Normal	Intubation and mechanical ventilation, hypotension requiring vasopressors, renal failure requiring CRRT, sepsis (E. coli and Lactobacillus), acalculous cholecystitis requiring percutaneous cholecystostomy, gastrointestinal bleed requiring transfusion	Hydroxychloroquine, oseltamivir which was switched to lopinavir–ritonavir	Patient critically ill at the time of publication of case report

M, male; F, female; LVAD, left ventricular assist device; CKD, chronic kidney disease; CRT, cardiac resynchronization therapy ; CABG, coronary artery bypass grafting; HIV/AIDS, human immunodeficiency virus; acquired immunodeficiency syndrome; CT, computed tomography; FDG, fluorodeoxyglucose; TAPSE, tricuspid annular plane systolic excursion; RPM, LPM, liters per minute; W, watts; RPM, rotations per minute; HMII, HeartMate 2; tPA, tissue plasminogen activator; CRRT, continuous renal replacement therapy; PEA, pulseless electrical activity.

Table 2. Observational studies of COVID-19 infection in patients with left ventricular assist devices (LVADs).

Sl. no	Author	N of patients	Median age in years	Male sex, n (%)	Device, n (%)	Duration on LVAD support, median years (IQR)	Intent of therapy, n (%)	Comorbidities, n (%)	Prior medications, n (%)	Hospitalization, n (%)	Complications, n (%)	Treatment, n (%)	Mortality, n (%)
1	Zakrzewski *et al.* [19]	28	65 (IQR,57 -70)	22 (79)	HeartMate 2: 6 (21), HeartWare HVAD: 10 (36), HeartMate 3: 12 (43)	2.4 (0.9–3.4)	BTT: 5 (18), DT: 23 (82)	Hypertension: 26 (93), diabetes mellitus: 12 (43), smoking: 12 (43), chronic lung disease: 10 (36), prior stroke or TIA: 9 (32)	RAAS inhibitors: 9 (32), warfarin: 27 (98), antiplatelets: 19 (68)	24 (86) [ICU admission: 13 (46)]	Ventricular arrhythmia: 8 (29), GI bleeding requiring blood transfusion: 5 (18), cardiac arrest: 5 (18), pump hemolysis: 2 (7)	Supplemental oxygen: 11 (39), mechanical ventilation: 5 (18), vasopressor support: 4 (14), RRT: 2 (7), therapeutic anticoagulation:14(50), remdesivir: 11 (39), steroids: 9 (32), azithromycin: 3 (11), tocilizumab: 2 (7), convalescent plasma:1 (4)	9 (32)
2	Birati *et al.* [20]	40	56 (IQR,46 -68)	26 (65)	HeartMate 2: 5 (12), HeartWare HVAD: 9 (22), HeartMate 3: 26 (65)	1.3 (0.6-3.1)	Not reported	Ischemic cardiomyopathy:9 (22), hypertension: 29 (72), diabetes: 18 (45), past stroke(pre implant):10 (25), atrial fibrillation: 15 (38), OSA: 10 (25), smoking: 20 (50)	RAAS inhibitors: 22 (55), beta blocker: 19 (48), MRA: 21 (52), aspirin: 28 (70), oral anticoagulation: 39 98), statin: 20 (50)	26 (65)	Secondary infection: 3 (7.5), AKI: 2 (5), LVAD thrombosis (suspected): 1 (2.5), multisystem organ failure: 4(10), hemorrhagic stroke: 1 (2.5)	Supplemental oxygen: 8 (20), mechanical ventilation: 6(15), vasopressor support: 7 (17.5), RRT: 2 (5), hydroxychloroquine: 6 (15), convalescent plasma: 3 (7.5), tocilizumab: 2 (5), remdesivir: 1 (2.5), lopinavir-ritonavir: 1(2.5), dexamethasone: 1(2.5)	8 (20) [Median time to death from admission: 22 days (range, 8-122)]
3	Sobol *et al.* [21]	6	74.5 (IQR,74 -76)	4 (66)	HeartMate 2: 2 (33), HeartWare HVAD: 1 (16.6), HeartMate 3: 3 (50)	3.2 (0.9-5.9)	BTD: 1 (16.6), DT: 5 (83.3)	Ischemic cardiomyopathy:1 (16.6), hypertension: 4 (66.6), diabetes: 2 (33.3), coronary artery disease: 2 (33.3), obesity: 1 (16.6), end stage renal disease: 1 (16.6)	Aspirin: 3 (50), Heparin: 2 (33.3), Argatroban: 1 (16.6)	4 (66.6) [ICU admission: 3 (50)]	Cytokine storm: 1 (16.6), suspected fontan thrombosis: 1 (16.6), cardiac arrest: 1 (16.6)	Supplemental oxygen: 5 (83.3), mechanical ventilation: 2 (33.3), RRT (de novo): 1 (16.6), hydroxychloroquine: 3 (50), steroids: 2 (33.3), IL-1 antagonist: 1 (16.6)	2 (33.3)

IQR, interquartile range; LVAD, left ventricular assist device; BTT, bridge-to-transplant; DT, destination therapy; BTD, bridge-to-decision, TIA, transient ischemic attack; CAD, coronary artery disease; OSA, obstructive sleep apnea; RAAS, renin-angiotensin-aldosterone system; MRA, Mineralocorticoid receptor antagonist; ICU, intensive care unit; GI, gastrointestinal; AKI, acute kidney injury; RRT, renal replacement therapy; IL-1, interleukin-1.

Table 3. Mechanical circulatory support (MCS) device use for circulatory shock in COVID-19 infection.

Author	Age in years, Sex	MCS device	Comorbidities	Clinical presentation	Pneumonia/respiratory failure at presentation	Shock at presentation	Type of shock	Type of heart failure	Echocardiography	Treatment, course and complications	COVID specific treatment	Outcome
Cohen et al [22]	57, F	Impella RP	Asthma	Fever, diarrhea, left leg swelling, and dyspnea	No	Yes	Obstructive	DN	Massive thrombus in transit in the right atrium and severe RV dysfunction	Intubated and mechanically ventilated. Underwent aspiration thrombectomy following which RV became akinetic and patient developed severe hypotension required CPR. Vasopressors started and Impella placed. AKI requiring hemodialysis.	None	Extubated on day 5. Discharged after 3 weeks.
Thaker et al [23]	42, F	IABP	None	Dyspnea and hypoxia	Yes	Yes	Obstructive	DN	Mild LV dysfunction and a pericardial effusion with impending cardiac tamponade. Later showed bi-ventricular dysfunction with LVEF ~20%	Emergent pericardial window creation. Patient developed multiorgan failure and progressive hypotension requiring intubation, mechanical ventilation, and multiple pressors. IABP placed and CRRT initiated for anuric AKI.	Tocilizumab	Improved on day 6, IABP removed.
Thaker *et al.* [23]	42, F	Impella CP, VA ECMO	Obesity	Dyspnea and hypoxia	Yes	Yes	Septic	DN	LVEF < 10%	Intubated and mechanically ventilated, inotropes started (norepinephrine, vasopressin). VA ECMO initiated and Impella CP placed. On CRRT for AKI and received multiple transfusions due to profuse epistaxis on heparin	Corticosteroids, tocilizumab and intravenous immune globulin	Decannulated on day 11, extubated and Impella removed. Improving but hospitalized at the time of publication
Mahrokhian *et al.* [24]	65, M	Impella 5.5	Hypertension, hyperlipidemia, AF, and nonischemic cardiomyopathy	Dyspnea, lower extremity edema, and abdominal distension	No	Yes	Cardiogenic	ACHF	LVEF of 5%–10% with no left atrial appendage thrombus nor ventricular apical thrombus, RV dilation with systolic function moderately reduced, severe mitral regurgitation and moderate tricuspid regurgitation	Intubated and mechanically ventilated, inotropes started (norepinephrine, vasopressin), amiodarone to maintain sinus rhythm, Impella 5.5 implanted with VA ECMO backup	Remdesivir (discontinued due to AKI), dexamethasone	Impella explanted on day 5. LVEF improved to 40% on day 23

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Table 3. Continued from previous page.

Author	Age in years, Sex	MCS device	Comorbidities	Clinical presentation	Pneumonia/respiratory failure at presentation	Shock at presentation	Type of shock	Type of heart failure	Echocardiography	Treatment, course and complications	COVID specific treatment	Outcome
Flagiello *et al.* [25]	30, F	VA ECMO	None	Fever, chest pain, and worsening dyspnea	Yes	Yes	Obstructive	DN	20-mm pericardial effusion compressing the right heart chambers and LVEF of 35% with global hypokinesia	Pericardiocentesis performed but patient developed worsening shock requiring vasopressors. Intubated and mechanically ventilated, VA ECMO implanted. Developed ventilator associated pneumonia.	None	Patient improved. Extubated, decannulated and transferred to rehabilitation centre
Fu *et al.* [26]	84, F	VA ECMO	Coronary artery disease, chronic kidney disease	Paroxysmal cough and chest tightness	Yes	No	-	DN	Not reported	CRRT initiated, intubated and mechanically ventilated. Due to worsening ARDS and shock, VA ECMO started.	Lopinavir/ritonavir	Improved and weaned from ECMO after 13 days.
Sampaio *et al.* [27]	45, F	VA ECMO	None	Dyspnea, fever, myalgia and postural hypotension	Yes	No	-	DN	Normal bi-ventricular function, moderate pericardial effusion and diastolic restriction of the RV	Developed cardiac tamponade requiring urgent pericardiocentesis which was unsuccessful and asystole developed. Emergency thoracotomy, internal cardiac compression and pericardial drainage done. In view of shock, vasopressors started and VA ECMO initiated. AKI requiring hemodialysis. Multiple transfusions for cannula site bleeding.	Methylprednisolone, tocilizumab, intravenous immune globulin, convalescent serum	ECMO removed after 9 days, extubated later. Discharged after recovery.
Luna *et al.* [28]	54, M	IABP	None	Dyspnea, chest pain, desaturation, bilateral rales, and a mitral regurgitant murmur	Yes	No data	No data	No data	LVEF 45%, flail in the posterior mitral valve	Intubated and mechanically ventilated, inotropes started (norepinephrine, vasopressin and levosimendan), mitral valve replacement surgery under IABP	Azithromycin and methylprednisolone	Extubated after 15 days
Ignaszewski *et al.* [29]	63, M	IABP, Heartmate 3	None	Respiratory distress	Yes	No	-	DN	Dilated LV cavity (6.3 cm), LVEF 10% and large apical aneurysm	Intubated and mechanically ventilated. Developed anterior STEMI with severe LV dysfunction after and cardiogenic shock after admission. Was managed initially with inotropes and axillay IABP. Later was LVAD placed.	None	Improved and discharged to rehabilitation

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Table 3. Continued from previous page.

Author	Age in years, Sex	MCS device	Comorbidities	Clinical presentation	Pneumonia/respiratory failure at presentation	Shock at presentation	Type of shock	Type of heart failure	Echocardiography	Treatment, course and complications	COVID specific treatment	Outcome
Rai *et al.* [30]	57, F	Not specified	Not reported	Chest pain followed by cardiac arrest with ROSC	No	Yes	Cardiogenic	DN	LVEF of 15%	After ROSC, developed cardiogenic shock and placed on VA ECMO. PCI done, pacemaker and ICD placed. Weaned of ECMO and IAP inserted. Due to failure to wean off IABP, LVAD implanted and initiated on amiodarone, digoxin, metoprolol, prasugrel, warfarin, spironolactone and lisinopri. Tracheostomy done	None	Improved and discharged to rehabilitation
Yeleti *et al.* [31]	25, F	Biventricular Impella, VA ECMO	None	Fever, abdominal pain, fatigue and vomiting	No	Yes	Cardiogenic	DN	Bi-ventricular failure and LVEF of 5–10%	Presented with ventricular tachycardia and defibrillated to sinus rhythm. Intubated and mechanically ventilated. Bilateral Impellas placed for circulatory shock, replaced with VA ECMO (with LV Impella) due to worsening. Developed pericardial effusion requiring pericardial window. Flail and torn anterior mitral leaflet was surgically repaired.	Methylprednisolone, remdesivir, convalescent plasma	LVEF recovered in 48 hours. Discharged on day 13 at which time normal LVEF was documented
Ruiz *et al.* [32]	35, F	Biventricular Impella	Systemic sclerosis	Malaise, fevers and cough	No	No	-	DN	LVEF less than 10% and severe right ventricular impairment with no pericardial effusion or significant valvular abnormalities seen	Had PEA cardiac arrest due to hypoxemia, and cardiagenic shock after ROSC. Right and left-sided Impella's placed.	Intravenous immunoglobulin, remdesivir	Improved after 2 weeks, weaned from Impella
Valchanov *et al.* [33]	43, M	VA ECMO, Impella 5.0	None	Chest pain	No	No	-	DN	Moderate LV systolic dysfunction	Primary PCI for STEMI done. Developed VT and PEA. Intubated, automatic chest compressions started, later initiated on VA ECMO and vasopressors. Impella 5.0 places as 'bridge-to-decision'. Developed AKI requiring veno-veno hemofiltration, and gastrointestinal bleeding	None	Due to progressive worsening, end of life care was instituted, and the patient died.

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Table 3. Continued from previous page.

Author	Age in years, Sex	MCS device	Comorbidities	Clinical presentation	Pneumonia/respiratory failure at presentation	Shock at presentation	Type of shock	Type of heart failure	Echocardiography	Treatment, course and complications	COVID specific treatment	Outcome
Rassaf *et al.* [34]	30, M	VA ECMO, Heartmate 3	Idiopathic cardiomyopathy	Fever, tachypnea	Yes	No	-	ACHF	LVEF of 23% initially, deteriorated to 6%. LVEF 6%, global longitudinal strain −1.0%, LV dilatation, impaired right ventricular function (TAPSE 9 mm), RV dilatation, severe functional mitral regurgitation.	Intubated and mechanically ventilated, VA ECMO initiated. Later heart surgery with LVAD as therapeutic bridge-to-transplant option, percutaneous temporary RVAD implantation, and tricuspid repair was performed	Convalescent serum	Patient weaned from RVAD, recovered from sepsis and cardiogenic shock
Oliveros *et al.* [35]	55, M	IABP, VA ECMO, Impella CP, CentriMag	Prior coronary bypass graft surgery, hypertension, and diabetes mellitus	Chest pain	No	Yes	Cardiogenic	DN	Not reported	Intubated and mechanically ventilated, cardiogenic shock managed initially with IABP, escalated to VA ECMO and Impella CP. Later underwent placement of extracorporeal LVAD. Developed AKI requiring RRT, liver failure, stroke, ventricular arrhythmias, and vocal cord paralysis	Hydroxychloroquine	Continued to worsen. Advanced cardiac life support was not performed due to poor prognosis, and patient died.
Salamanca *et al.* [36]	44, M	IABP, VA ECMO	None	Severe dyspnea and syncope	Yes	Yes	Cardiogenic	DN	Globally and severely dysfunctional left ventricle, LVEF of 15%	Developed third-degree atrioventricular block leading to shock, temporary pacemaker implanted and dobutamine and norepinephrine infusion started, intubated and mechanically ventilated.	Methylprednisolone, tocilizumab, hydroxychloroquine, azithromycin, and lopinavir-ritonavir.	ECMO and IABP withdrawn 6 days later, weaned from ventilator 2 days after that. Later had complete recovery to normal LV function.
Byun *et al.* [37]	72, F	VAV ECMO	Hypertension, secondary adrenal insufficiency, on implanted pacemaker.	Not reported	Yes	No	-	DN	LVEF of 55%	Intubated and mechanically ventilated, vasopressors started for shock. VAV ECMO started due to worsening.	Hydroxychloroquine, lopinavir/ritonavir	Weaned from ECMO on day 10, weaned off ventilator 6 days after that.

To be continued on next page

Table 3. Continued from previous page.

Author	Age in years, Sex	MCS device	Comorbidities	Clinical presentation	Pneumonia/respiratory failure at presentation	Shock at presentation	Type of shock	Type of heart failure	Echocardiography	Treatment, course and complications	COVID specific treatment	Outcome
Akoluk *et al.* [38]	50, M	VA ECMO	History of unprovoked pulmonary embolism	Fever, cardiac arrest	Yes	Yes	Cardiogenic	DN	McConnell Sign	Intubated and mechanically ventilated, thrombolysed and vasopressors started for shock. VA ECMO started and bail out catheter directed thrombolysis done.	None	Weaned from ECMO on day 6, extubated on day 11. Discharged on day 22
Bemtgen *et al.* [39]	52, M	VA ECMO, Impella	Dilated cardiomyopathy, on ICD	Dyspnea, fever	No	No	-	ACHF	Not reported	Developed shock requiring vasopressors (levosimendan and norepinephrine). Developed AKI. VA ECMO and Imeplla initiated and changed to VV ECMO after improvement.	Hydroxychloroquine, lopinavir and ritonavir	Patient improved, but still hospitalized at time of publication.
Fried *et al.* [40]	64, F	IABP	Hypertension, hyperlipidemia	Chest pressure	No	No	-	DN	LVEF of 30%, left ventricular end-diastolic dimension of 2.9 cm, severe concentric left ventricular hypertrophy, with a dilated, severely hypokinetic RV	IABP and dobutamine infusion started for cardiogenic shock after admission.	Hydroxychloroquine	Improved and IABP weaned off on day 7
Fried *et al.* [40]	38, M	VAV ECMO	Diabetes mellitus	Cough, pleuritic chest pain, and progressive dyspnea	Yes	No	-	DN	Normal	Intubated and mechanically ventilated, had bradycardic cardiac arrest with ROSC, initiated on VV ECMO and vasopressors, later converted to VAV ECMO.	Hydroxychloroquine	Improved and decannulated from ECMO on day 7. Remains intubated and ventilated at the time of publication

: novo heart failure; ACHF, acute on chronic heart failure; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; VA ECMO, venoarterial extracorporeal membrane oxygenation; VAV ECMO, veno-arterio-venous extracorporeal membrane oxygenation; AF, atrial ıtion; ROSC, return of spontaneous circulation; CT, computed tomography; PE, pulmonary embolism; RV, right ventricle; LVEF, left ventricular ejection fraction; CRRT, continuous renal replacement therapy; AKI, Acute kidney injury; RVAD, right ventricular assist device; STEMI, ST-ion myocardial infarction; VT, ventricular tachycardia; PEA, pulseless electrical activity; PCI, percutaneous coronary interventio

The impact of COVID-19 on patients on long term durable LVADs

With improved technology, more patients are on LVADs with the intent of 'destination therapy' than ever before. They form a niche population, and only a few studies have investigated the impact of COVID-19 on these patients. Patients on LVADs have lower T-cell prolific responses, higher levels of suppressive T-regulatory cells, lower interleukin-2 and tumor necrosis factor-alpha levels, and more interleukin-10, resulting in a higher chance of infection [41]. This makes them a unique population at risk for COVID-19. They also have altered cardiac physiology due to non-pulsatile blood flow and have reduced functional reserve. Moreover, they are at increased risk for thrombotic and embolic events such as pump thrombosis and stroke due to blood exposure to artificial surfaces and hemorrhagic complications due to therapeutic anticoagulation. Indeed, due to the opposing effects of pro-thrombotic factors and systemic anticoagulation, these patients may exhibit both thrombotic and hemorrhagic complications during various stages of the illness, as observed in the case report described by Hodges *et al.* [13].

Several factors make the diagnosis, risk-stratification, and management of COVID-19 patients on LVADs particularly challenging. While fever is the most common symptom of COVID-19, in patients with LVAD, it can also indicate driveline site infection. Therefore, a detailed history and wound examination are crucial to differentiate the two pathologies. According to one systematic review and meta-analysis, elevated lactate dehydrogenase (LDH) in patients with COVID-19 can indicate a six-fold increase in the odds of developing severe disease and a 16-fold increase in odds of mortality [42]. However, in patients on LVADs, elevated LDH can be a harbinger of pump hemolysis, pump thrombosis, thromboembolic stroke, peripheral thromboembolism, reduced pump flow, pump failure, cardiogenic shock, and death [43-45]. Lastly, while prone ventilation is an effective strategy for managing COVID-19 patients with severe hypoxemia respiratory failure, it becomes challenging in the presence of an LVAD. Such positioning may lead to compression of the outflow graft and driveline, impaired venous return, hardware malpositioning, and worsening right ventricular hemodynamics [46]. In the case reports described by Singh *et al.* and Chau *et al.*, although the patients developed refractory hypoxemia while on maximal ventilatory supports, prone ventilation was not attempted due to concerns about the complications mentioned above [16,18].

While it is easy to understand how COVID-19 pneumonia and invasive ventilation can increase RV stress, it is also important to note that the LVAD itself can have critical hemodynamic effects that may adversely impact RV function [47]. One must choose LVAD speeds that achieve hemodynamic goals without excessive left ventricle unloading, thereby maintaining a rightward or neutral position of the interventricular septum. This is because excessive left ventricular unloading may lead to leftward septal shift and suction events, which may prevent adequate LVAD output, further impair RV function, and trigger ventricular arrhythmias [48]. These effects are more likely to be seen in states of elevated RV pressures, as seen in ventilated patients, particularly with high positive end-expiratory pressure.

One must also acknowledge the psychological impact of this pandemic on vulnerable patient groups such as those on LVADs. A qualitative analysis of eight patients using the interpretative phenomenological analysis (IPA) methodology revealed two main themes: 'worsening of psychological distress' (reflecting the negative feelings experienced by the participants during the pandemic due to their health and social circumstances) and 'moving forward' (depicting self-empowerment and coping strategies despite that helped them deal with the situation). There was one reported case of attempted suicide by a patient on destination therapy LVAD [49]. The patient felt trapped in his own house and felt the trouble of going through the LVAD surgery had not been worth it. It is essential to consider these aspects while caring for patients on LVAD during the pandemic.

Outcomes and predictors of mortality of COVID-19 infection in patients with LVAD

Three observational studies have looked at the outcomes of COVID-19 infection in patients with LVAD. The mortality rates ranged from 20 to 33% and were significantly higher than the general population. While only two patients died among the 15 case reports, publication bias must be considered before drawing robust conclusions. The Trans-CoV-VAD registry, which included data from nine sites in the United States and included a total of 40 patients with LVAD who developed COVID-19 infection, did not find a significant difference between the patients who were infected with COVID-19 and the total population that received LVADs at the participating sites in the 21 months prior [20].

While the high hospitalization rate of LVAD patients with COVID-19 could be due to a lower threshold to admit such patients, there is no denying that they have significantly higher mortality. This may be due to their comorbidities, complexity, and therapeutic limitations (such as difficulty in achieving prone ventilation) due to the presence of the LVAD. In the cohort described by Birati *et al.*, one patient had an episode of suspected pump thrombosis. Another had reduced LVAD flow and partial outflow graft obstruction that required stenting.[20] At least three more case reports have also documented pump thrombosis in LVAD patients with COVID-19 infection [9,11,14]. It is well established that COVID-19 is associated with a prothrombotic state due to upregulation of procoagulants such as factor VIII, P-selectin, and von Willebrand factor as well as downregulation of anticoagulants such as endothelial protein C receptor and thrombomodulin [50]. Patients on LVAD have additional risk factors for thrombosis, above this already elevated baseline, due to contact of blood with device surfaces.

Pump thrombosis should be considered if the patient has any of the following - LVAD power elevations, dark or tea-colored urine, elevated serum LDH, low plasma haptoglobin, elevated indirect bilirubin, or elevated plasma free hemoglobin [51]. In such patients, echocardiography (usually with a ramp study) would be the next step. Although the management of pump thrombosis would depend on multiple factors, high dose unfractionated heparin with the possible addition of a direct thrombin inhibitor or a glycoprotein IIb/IIIa inhibitor, thrombolysis with recombinant TPA, or pump exchange are options that can be considered [52]. In the case described by Maharaj *et al.*, pump exchange was not attempted due to the hypercoagulable state and the risk of thrombosing a new device. Although two COVID-19 patients developed LVAD pump or outflow thrombosis despite having an INR at or above the therapeutic range, it is not known whether higher intensity anticoagulation with elevated INR targets is needed in critically ill COVID-19 patients who have an LVAD [6,14]. One should also remember that drugs given for the treatment of COVID-19,

such as lopinavir-ritonavir, can interact with warfarin leading to an elevated INR.

Zakrzewski *et al.* determined that there was an association between ICU admission and mortality (unadjusted odds ratio 7.6, CI: 1.2-48, p=0.03) which was predominantly due to the need for mechanical ventilation (unadjusted odds ratio 14, CI: 1.3-159, p=0.03) [19]. Although they also observed that glucocorticoid use was associated with mortality (unadjusted odds ratio 10, CI: 1.7–68, p=0.01), this association must be analyzed for the presence of confounding factors [19].

Monitoring of LVADs

Monitoring of LVADs is crucial in the pandemic era. As mentioned before, increased serum LDH in patients with LVAD is associated with hemolysis, LVAD thrombosis, and stroke [43-45]. However, serum LDH is often elevated in patients with COVID-19 making the use of this marker less useful. Also, daily interrogation of LVAD parameters in patients with COVID-19 infection is crucial as abnormal parameters may indicate impending hemodynamic compromise, pump thrombosis, right ventricular failure, vasoplegia associated with secondary infection, or innate device malfunction [12].

Remote monitoring of patients with LVADs has several advantages. It ensures that the patient is not potentially exposed to COVID-19 infection while visiting the hospital and allows for more frequent monitoring of LVAD parameters. Remote monitoring should be done with attention to the following aspects- LVAD controller alarms, blood pressure, pacemaker analysis, coagulation values, and smartphone-–transmitted findings such as driveline photos [53]. Implantable devices such as the CardioMEMS HF System have a proven track record of reducing heart failure admissions by up to 58% [54]. This device was used by many centers to monitor their patients during the pandemic. Specialized smartphone applications with automated data transmission, chatbot technology, and machine-learning algorithm have also been studied for telemonitoring and may become commonplace in the future.[55] Thermal imaging of driveline exit sites using compatible smartphones is also an exciting step forward [55]. Indeed, newer LVADs such as the HeartAssist 5 and aVAD come with built-in remote monitoring capabilities via the VADLink platform [56].

The utility and outcomes of MCS in severe COVID-19 infection complicated by refractory circulatory shock

Several cases of COVID-19 are complicated by circulatory shock, and MCS is the last treatment modality available to achieve hemodynamic stability and prevent multiorgan failure. Some currently available options include IABP, TandemHeart, Impella, VA ECMO, and LVAD implantation. Most COVID-19 patients in circulatory shock also have respiratory failure making VA ECMO the MCS device of choice [57]. Moreover, it can provide high flow rates (>5 l/min), and comparison studies have shown up to 33% higher 30-day survival in patients in shock treated by VA-ECMO compared to IABP [58]. Although the evidence of better outcomes supports the use of VA ECMO, Impella (which can generate intermediate flow rates of 2-4 l/min), and TandemHeart, rather than IABP, the latter still has its place in the management of shock due to its relative ease of placement [59]. One of the drawbacks of VA ECMO is the requirement of LV venting to prevent pulmonary edema and LV thrombosis. Strategies for LV venting include inotropes, concomitant use of Impella (sometimes called ECPELLA or ECMELLA), direct surgical decompression, IABP, or percutaneous balloon atrial septostomy to open a left-to-right atrial shunt [60-62]. Because of these inherent complexities, decisions of MCS device selection in COVID-19 are best taken on a case-by-case basis by a multidisciplinary team.

Use of VA ECMO in critically-ill patients with COVID-19 with shock

While the development of drug therapies has been promising, cardiac and respiratory support with ECMO is one of the few available rescue therapies for severe ARDS. The Extracorporeal Life Support Organization (ESLO) guidelines published in 2021 state that venovenous (VV) ECMO may be used in patients with severe respiratory failure with favorable expected outcomes [63]. These guidelines also state that although the evidence is limited, venoarterial (VA) ECMO may be used in patients with COVID-19 and severe cardiac failure [63]. VA ECMO can support patients for days to weeks as a 'bridge-to-decision.' Further course of action may include weaning after the cardiac function has recovered, long-term MCS, heart transplantation, or withdrawal of support in the case of futility of care. The ELSO recommends that the indications for ECMO remain unchanged during the pandemic [63]. Therefore, the indications for VA ECMO would include COVID-19 patients with refractory circulatory shock evidenced by systolic blood pressure less than 90, urine output <30 ml/hour, lactate levels higher than 2, SVO_2 less than 60%, or altered conscious state for 6 hours unresponsive to fluids, inotropes, and, potentially, intra-aortic balloon pump (IABP) [64]. VA ECMO flow and hemoglobin concentration should be titrated to ensure systemic oxygen delivery at least three times oxygen consumption [64].

VA ECMO is contraindicated in patients who are unlikely to recover and have no indication for a heart transplant or durable left ventricular (LV) assists device, poor life expectancy (due to end-stage peripheral-organ diseases, malignant tumor, massive pulmonary embolisms in cancer patients, chemotherapy-induced chronic cardiomyopathy), severe aortic valve regurgitation, severe vascular disease with extensive aortic and peripheral vessel involvement, acute aortic dissection with extensive aortic branches involvement, severe and irreversible neurologic impairment, severe immunologic disease with marked blood and coagulation disorders and Child-Pugh class B and C liver cirrhosis [64]. Appropriate patient selection is essential before the initiation of VA ECMO, and risk predictions scores such as the survival after VA ECMO (SAVE) score, ENCOURAGE score, REMEMBER score, and CARDShock score may be helpful for risk stratification and prognostication [65-68]. A multidisciplinary team consisting of representatives from cardiovascular surgery, cardiology, critical care, anesthesia, as well as advanced heart failure, and transplant physicians can further aid in the decision making process. Some of the complications of VA ECMO include malpositioning of the cannula, ischemia of cannulated limb, deep vein thrombosis of femoral or caval vein, overloading of the left ventricle, differential oxygenation, lower body hyperoxemia or hypocapnea, device clotting, and hemorrhage [64]. The proinflammatory and prothrombot-

ic state associated with COVID-19 may favor some of these complications [63].

Pre-pandemic data from the ELSO registry indicated that VV ECMO and VA ECMO had a mortality rate of 40% and 55%, respectively [69] .However, data on ECMO use, particularly VA ECMO for COVID-19, is limited. In most cases, VV ECMO was used rather than VA ECMO making it challenging to draw conclusions regarding the latter's utility. Data from 177 centers from Europe and Israel with 1531 patients on ECMO, 5% of who were on VA ECMO, reported an overall mortality of 44% [70]. The analysis of the ELSO registry, which included 1093 patients with ECMO, showed an overall mortality of 37% [71]. However, this study did not report the outcomes of patients on VA ECMO separately. A French retrospective cohort study of 83 patients with COVID-19 who required ECMO reported a similar overall mortality of 36% [72]. However, only two patients from this study were on VA ECMO. More recently, Mariani *et al.* published a systematic review of 2774 COVID-19 patients who required extracorporeal life support, 4.7% of whom were on VA ECMO or Impella [73]. The overall survival was 54.6% in the VV ECMO and 28.1% in the VA/VVA ECMO group, respectively. This study also reported that 3.1% of patients initially on VV ECMO required a change to MCS for heart failure, myocarditis, or myocardial infarction.

Preliminary data from the ELSO registries shows that less than 5% of ECMO therapy in COVID-19 patients was in the VA configuration [69]. ECMO-assisted cardiopulmonary resuscitation (ECPR) was also sparingly used. While the rate of conversion from V-V mode to V-AV or other ECMO configurations was less than 3% based on the ELSO data, it may have been much higher if a more thorough hemodynamic evaluation had been performed [74]. A precise assessment of cardiovascular hemodynamics using a Swan-Ganz catheter would have been helpful in this regard. Given the 20-30% incidence of cardiovascular complications in COVID-19 infection, and acceptable outcomes as mentioned above, it is possible that VA ECMO was underused in managing critically ill COVID-19 patients with shock [74].

MCS devices other than VA ECMO for critically-ill patients with COVID-19 in shock

We found two case reports of durable LVAD implantation for patients with severe COVID-19 and shock (Table 3) [29,34]. Rassaf and colleagues successfully managed a patient with severe COVID-19 ARDS and idiopathic cardiomyopathy by implanting a Heartmate 3 LVAD as a 'bridge-to-transplant' [34]. After the implantation of a durable LVAD and a temporary percutaneous RVAD, VA ECMO was successfully weaned. While the prospect of a total artificial heart (TAH) was initially considered, it was later discarded as the surgical trauma would have been unequally larger than LVAD surgery.

While advanced ventilatory maneuvers such as prone ventilation may be difficult in patients on ECMO, it is possible with other devices such as Impella. In fact, there is one reported case where a COVID-19 patient with refractory circulatory shock on Impella 5.0 was ventilated in the prone position [33]. The authors reported good function and no malpositioning of the device with prone ventilation. This may be an important consideration while choosing circulatory support devices in patients with COVID-19. Moreover, guidance and positioning of axial LVADs can be achieved with newer approaches such as intracardiac 3D ultrasound in place of traditional aerosol-generating procedures such as TEE [75].

COVID-19 patients can develop right ventricular failure for multiple reasons such as pulmonary embolism, depressed RV contractility, elevated pulmonary vascular tone, hypercapnia, sepsis, or excessive positive end-expiratory pressure (PEEP). When medical management in the form of volume resuscitations, right ventricular preload optimization, right ventricular afterload reduction, and cardiac rhythm optimization fails, right ventricular circulatory support for such patients can be achieved using the Impella RP [46]. This device can be deployed rapidly in the cardiac catheterization laboratory or operating room using a minimally invasive technique.

A less common approach is to support the patient with VV ECMO and RVAD. A group of investigators tested this hypothesis by comparing COVID-19 patients with ARDS on VV ECMO and RV support using a percutaneous RVAD cannula with similar patients on invasive mechanical ventilation alone [76]. They designed a randomized control trial to test this hypothesis and used a TandemLife Protek Duo percutaneous right ventricular assist device (RVAD). The results of this trial were promising, with RVAD/ECMO patients demonstrating significantly lower in-hospital mortality (52.4% *versus* 11.1%, p=0.008) [76]. This benefit persisted on a Cox proportional hazard model (HR 0.17, 0.03-0.91) even after adjustment for age, tocilizumab, and convalescent plasma. However, this study could not ascertain the true benefit of concomitant RV support in COVID-19 ARDS as there was no objective measurement of RV function in this study. Lee and colleagues demonstrated a 180-day survival of 85% in lung transplant candidates bridged with Oxy-RVAD (RVAD with oxygenator) and VV ECMO. Extrapolating these findings to COVID-19 patients, we can presume that the strategy may be superior to VV ECMO alone. Although there is no strong evidence yet, this may be a promising model to focus further research on.

Limitations

Our review, although comprehensive, had several limitations. Most of our data were from case reports and case series, making it difficult to draw robust conclusions. We acknowledge that our data may not represent the true incidence of hospitalizations or complications because of this limitation.

The sample size of the observational studies was small. Moreover, they did not include granular details such as duration of therapy, the dose of medications used, INR targets, ventilatory parameters, various invasive hemodynamic parameters including cardiac index, cardiac power output, pulmonary artery pulsatility index etc. Data on VA ECMO, in particular, was scarce as most of the COVID-19 patients on ECMO used VV ECMO. Also, the ELSO COVID-19 registry does not stratify patients based on the type of ECMO used. However, the strength of this review is that it included studies with patients having COVID-19 in the background of MCS use from all over the world. We also tried to identify the predictors of mortality and the most common complications during treatment. More research focusing on this subset of patients is necessary to clarify the pathogenesis, improve screening methods and identify optimal therapeutic strategies. Considering the high-risk nature of the clinical substrate in this patient population, it would be challenging to envision an experimental randomized control design for future studies. Until then, the best data that we have is being collated from the observational studies and anecdotal evidence.

Conclusions

The use of MCS continues to impact outcomes among patients with cardiogenic shock even amidst the COVID-19 pandemic. Most robust data is available for patients on long-term durable LVADs. Patients on LVADs are a unique set of patients with a mortality rate of 23.6% due to COVID-19 infection. Analysis of the pooled data showed that the patients were primarily men, and more than three-fourths required hospitalization. Complications such as LVAD thrombosis, major bleeding requiring transfusions, and LVAD driveline site infections were observed, in addition to the complications seen in other critically ill COVID-19 patients. VA ECMO was the most common MCS device for managing refractory shock in COVID-19. Almost half of the patients had no comorbidities, and three-fourths had abnormal echocardiography findings at presentation before decompensation. MCS is a viable option for managing severe COVID-19 infection with shock, with many reported cases of favorable outcomes.

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