Extracorporeal membrane oxygenation and microaxial left ventricular assist device in cardiogenic shock: Choosing the right mechanical circulatory support to improve outcomes

Olina Dagher, MD,[a,b,c] Pierre-Emmanuel Noly, MD, PhD,[a] Walid Ben Ali, MD, PhD,[a] Nadia Bouabdallaoui, MD, PhD,[d] Lucian Geicu, MD,[a] Roxanne Lamanna,[b] Pavan Malhi, BScN,[b] Elizabeth Romero,[b] Anique Ducharme, MD, MSc,[b,d] Philippe Demers, MD, MSc,[a] and Yoan Lamarche, MD, MSc[a]

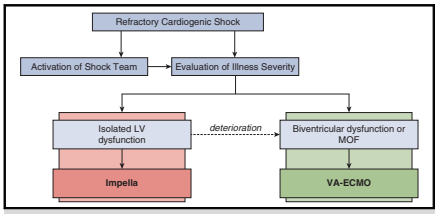
ABSTRACT

Objective: To evaluate the outcomes of patients supported with Impella (CP/5.0) or venoarterial extracorporeal membrane oxygenation (VA-ECMO) for cardiogenic shock according to shock phenotype. The primary end point was 30-day survival.

Methods: A retrospective study of patients supported with Impella (CP/5.0) or VA-ECMO between 2010 and 2020 was performed. Patients were grouped according to 1 of 2 shock phenotypes: isolated left ventricular (LV) dysfunction versus biventricular dysfunction or multiple organ failure (MOF). The local practice favors Impella for isolated LV dysfunction and VA-ECMO for biventricular dysfunction or MOF.

Results: Among the 75 patients included, 17 (23%) had isolated LV dysfunction. Patients with biventricular dysfunction or MOF had a greater median lactate level compared with those with isolated LV dysfunction (7.9 [2.9-11.8] vs 3.8 [1.1-5.8] mmol/L, respectively). Among patients with isolated LV dysfunction, 30-day survival was 46% for the Impella group (n = 13) and 75% for VA-ECMO (n = 4). Among patients with biventricular dysfunction or MOF, 30-day survival was 9% for the Impella group (n = 11) and 28% for VA-ECMO (n = 47). Patients supported with Impella 5.0 had better 30-day survival compared with those supported with Impella CP, for both shock phenotypes (83% vs 14% and 14% vs 0%, respectively).

Conclusions: In this small cohort, patients supported with Impella for isolated LV dysfunction and VA-ECMO for biventricular dysfunction or MOF had acceptable survival at 30 days. Patients with biventricular dysfunction or MOF who were supported by Impella had the lowest survival rates. Patients with isolated LV dysfunction who were supported with VA-ECMO had good 30-day survival. (JTCVS Open 2023;13:200-13)



Proposed algorithm to guide MCS device selection based on phenotype of cardiogenic shock.

CENTRAL MESSAGE

When selecting mechanical support for patients in cardiogenic shock, Impella or ECMO may be used in isolated LV dysfunction. Impella led to poor outcomes when used in biventricular dysfunction or MOF.

PERSPECTIVE

A support strategy that distinguishes 2 cardiac phenotypes—isolated LV dysfunction and biventricular dysfunction or MOF—can streamline clinical decision-making in patients with SCAI stages C-D-E. Patients with biventricular dysfunction or MOF supported with Impella had worse 30-day survival. Patients with isolated LV dysfunction who were supported by Impella or VA-ECMO had good 30-day survival.

From the [a]Department of Surgery, and [d]Department of Cardiology, Montreal Heart Institute, Montreal, Quebec, Canada; [b]Faculty of Medicine, Université de Montréal, Montreal, Quebec, Canada; and [c]Department of Cardiac Sciences, Libin Cardiovascular Institute, Calgary, Alberta, Canada.

Read at the 102nd Annual Meeting of The American Association for Thoracic Surgery, Boston, Massachusetts, May 14-17, 2022.

Received for publication May 18, 2022; revisions received Nov 11, 2022; accepted for publication Dec 5, 2022.

Address for reprints: Yoan Lamarche, MD, MSc, 5000 rue Bélanger Est, Montréal, Quebec, H1T 1C8, Canada (E-mail: yoan.lamarche@umontreal.ca).

2666-2736

https://doi.org/10.1016/j.xjon.2022.12.011

Abbreviations and Acronyms

ALT = alanine aminotransferase
CS = cardiogenic shock
IABP = intra-aortic balloon pump
LV = left ventricular
MCS = mechanical circulatory support
MOF = multiple organ failure
RRT = renal-replacement therapy
RV = right ventricular
SCAI = Society for Cardiovascular Angiography and Interventions
VA-ECMO = veno-arterial extra-corporeal membrane oxygenation

To view the AATS Annual Meeting Webcast, see the URL next to the webcast thumbnail.

Devices that provide mechanical circulatory support (MCS) represent a vital intervention for managing patients with refractory cardiogenic shock (CS) when medical therapy proves insufficient to increase cardiac output and provide adequate end-organ tissue perfusion. Although intra-aortic balloon pump (IABP) counterpulsation has been the mainstay of temporary MCS, randomized clinical trials have demonstrated its lack of benefit.[1-3] More supportive devices such as Impella (Abiomed Inc), TandemHeart (CardiacAssist, Inc), and venoarterial extracorporeal membrane oxygenation (VA-ECMO) have been increasingly used. Each device presents specific features that result in distinct hemodynamic profiles, but all improve cardiac output and blood pressure, to varying degrees.[4]

Despite currently available treatment modalities, the ongoing, high levels of mortality associated with CS indicate that some challenges persist.[5] The initial steps of prompt recognition of therapy-refractory CS, determination of candidacy for MCS, and activation of the shock team can be considered well-established in theory but remain highly variable in practice.[6,7] Moreover, the significant variability in the use of MCS across centers seems unexplained by patient or hospital characteristics.[8]

The local support philosophy has been to favor an Impella for isolated LV dysfunction without multiple organ failure (MOF) and a VA-ECMO for LV dysfunction complicated by MOF or for biventricular dysfunction with or without MOF. Distinguishing these 2 cardiac phenotypes could help simplify decision-making and encourage consistency among members of the shock team regarding the choice of MCS device in CS. The aim of this retrospective study was to evaluate the short-term outcomes of patients according to these 2 shock phenotypes and the type of MCS device implanted. We hypothesized that Impella and VA-ECMO would have similar survival rates in isolated LV dysfunction whereas VA-ECMO would yield greater survival rates in biventricular dysfunction or MOF.

METHODS

Study Design

We conducted a retrospective, single-institution, chart review of all adult patients who received a high-output MCS device (Impella CP/5.0 or VA-ECMO) in the setting of severe, refractory CS between January 1, 2010, and December 31, 2020. Patients were excluded if the MCS device was placed for high-risk percutaneous coronary intervention or catheter ablation, postcardiotomy CS, extracorporeal cardiopulmonary resuscitation, or for isolated right ventricular (RV) dysfunction. Patients were also excluded if they only received a passive or a low-flow hemodynamic support, such as an IABP or an Impella LP 2.5, without any escalation to a greater-output support. Patients who received an Impella device that was later converted to VA-ECMO were included into the Impella group as per the intention-to-treat principle.

The primary end point was 30-day survival. Secondary end points included successful weaning and in-hospital mortality. Patient demographics, procedural characteristics, hemodynamics, laboratory values, complications, and clinical outcomes were obtained by complete review of electronic medical records.

The institutional review board approved the study as posing minimal risk to patients, and it was performed under a waiver of informed consent (institutional review board no.: 2017-2261, approved on September 28, 2017). The investigation conforms with the principles outlined in the World Medical Association Declaration of Helsinki.

MCS Policy

The institution is a tertiary referral center that offers interventional and cardiac surgical care. All options from temporary MCS to long-term ventricular assist devices and heart transplantation were available to patients. Between 110 and 150 patients are hospitalized yearly for CS, and approximately 20% of these patients require temporary MCS. During the 10-year study period, a total of 79 Impella devices and 204 ECMO were implanted—all indications included.

The local decision to initiate MCS was made by a multidisciplinary team. A patient was first identified as suffering from refractory CS if they presented signs of low cardiac output despite optimal volume status and inotropic support. Patients who were deemed candidates for MCS were then brought up for discussion among the on-call members of the shock team, who weighed in on the decision to insert a MCS device, device selection, and timing of placement.

Definitions

For 30-day survival, the definition from the Society of Thoracic Surgeons was used, ie, alive and discharged home within 30 days of MCS device implantation. Ventricular function was assessed by transthoracic echocardiography before device placement in all patients. All echocardiographic evaluations were performed by a fellowship-trained imaging cardiologist. Isolated LV dysfunction was defined as an LV ejection fraction <35% on echocardiogram with preserved RV function. RV function was assessed with a qualitative approach (normal function or mild/moderate/severe dysfunction), which integrated guideline-recommended RV evaluation parameters. Patients who had severe LV and moderate/severe RV dysfunction were classified as having biventricular dysfunction. MOF was defined by a physiological dysfunction of at least 2 extra-pulmonary and extracardiac organ systems, supported by clinical and biochemical evidence. Clinically relevant hemolysis was defined as hemolysis requiring transfusion or device removal. For precannulation biochemistry, the worst values

within 6 hours of cannulation were collected.[9,10] Since an intention-to-treat principle was adopted when defining comparison groups, vascular and bleeding complications were applied to patients according to the first support device used. Some patients were escalated form Impella to ECMO, and some patients receiving ECMO were deescalated to Impella.

The Society for Cardiovascular Angiography and Interventions (SCAI) shock stages were determined retrospectively using a combination of descriptors (physical findings, biochemical markers, and hemodynamics) and definitions provided by the SCAI Consensus Statement Classification.[11] The (A) modifier for cardiac arrest was attributed to patients who suffered a cardiac arrest before device implantation. As mentioned previously, in-hospital cardiac arrests managed with extracorporeal cardiopulmonary resuscitation were excluded. Cases were independently assessed by 2 reviewers (O.D., L.G.). A third reviewer (Y.L.) was added in cases of discordant opinion.

MCS Systems

Implant. The Impella CP was delivered percutaneously via a 14-Fr sheath by an interventional cardiologist. The Impella LP 5.0 required surgical cutdown of the femoral or axillary artery and insertion through a 10-mm tunneled Dacron side graft. The presence of an LV thrombus was systematically ruled out in all patients. The Impella CP and LP 5.0 have been used locally since 2013 and 2010, respectively.

The ECMO system used was a Cardiohelp set (Maquet Medical Systems USA). Blood flows were set at 3.5 to 5.0 L/min to reach stable hemodynamics (venous oxygen saturation >60%, mean arterial pressure ≥60 mm Hg, low lactate level, and diminished need for vasopressors) and regular aortic valve opening. In all cases, VA-ECMO was placed by bifemoral cannulation by way of a percutaneous or surgical insertion, in which an antegrade cannula for leg perfusion was routinely implanted. Strategies for LV venting were used in all patients with LV dilatation, pulmonary edema, high LV end-diastolic pressure, and absence of aortic valve opening. Those venting strategies included the use of inotropes, IABP, LV pigtail drainage catheter, or endovascular interatrial septostomy. No upfront simultaneous ECMO and Impella (ie, ECMELLA or ECPELLA strategy) were used in this cohort.

Clinical management. All patients were treated with unfractionated heparin during MCS. The anti-Xa was used as a monitoring tool of heparin levels and was aimed at 0.30 to 0.50. Heparin was continued until device removal. Dual antiplatelet therapy was prescribed in all patients who underwent percutaneous coronary intervention.

Explant. Weaning of MCS was standardized for all patients. Impella pumps were weaned according to the manufacturer's algorithm, whereas VA-ECMO was weaned according to a local protocol. For both devices, a gradual decrease in support was done with clinical, echocardiographic, and biochemical monitoring. For VA-ECMO cases, most patients had a pump-controlled retrograde trial off.[12] The Impella CP was removed percutaneously approximately 1 hour after heparin cessation, followed by 30 minutes of femoral compression. The Impella LP 5.0 device and ECMO cannulae were removed surgically.

Statistical Analysis

We reported categorical variables as count with percentages and continuous variables as median with interquartile range. Given the small sample size, a non-normal distribution was assumed and nonparametric tests were used. Differences in categorical variables were analyzed using the χ^2 test of independence. Differences in continuous variables were described using the Mann–Whitney *U* or Kruskal–Wallis tests. All statistical analyses were performed using SPSS Statistics for Windows, version 27.0 (IBM Corp).

RESULTS

In total, 75 patients with CS were eligible for inclusion in our study (isolated LV dysfunction: Impella n = 13, ECMO n = 4; biventricular dysfunction or MOF: ECMO n = 47, Impella n = 11) (Figure 1). Patients had a SCAI score of C, D, or E.

Baseline Characteristics and Preimplantation Status

Patients with isolated LV dysfunction. Patients who were supported by Impella (n = 13) were most often male (92% vs 50%) and had a greater median body mass index (27.7 vs 24.6 kg/m^2) compared with patients supported by VA-ECMO (n = 4) (Table 1). The proportion of active smokers was greater in the ECMO group compared with the Impella group (50 vs 38%), but other cardiovascular risk factors were greater in patients supported by Impella. Acute coronary syndrome was the most common shock etiology in both groups. At precannulation, patients who received ECMO had a lower hemoglobin than the Impella group (median of 127 vs 141 g/L, respectively). However, the latter had greater lactate (median of 3.8 vs 2.7 mmol/L), creatinine, bilirubin, and alanine aminotransferase (ALT) compared with the ECMO group.

Patients with biventricular dysfunction or MOF. These patients had a lower median age compared with patients with isolated LV dysfunction without MOF (48.1 vs 57.1 years, respectively) (Table 1). Among the 58 patients, 47 received an ECMO, and 11 received an Impella. Patients in the ECMO group were significantly younger than those in the Impella group (median age of 55.7 vs 60.4 years, respectively; $P = .012$). They also had a lower body mass index and less frequent positive cardiovascular history. The proportion of patients with a SCAI stage C was similar between the ECMO and Impella groups (8 vs 9%, respectively). In the ECMO group, 64% of patients were classified under the SCAI stage E, whereas in the Impella group, 64% were in the SCAI stage D. Regarding precannulation biochemistry, patients in the Impella group had a lower median hemoglobin level (140 vs 131 g/L), greater median ALT level (758 vs 365 units/L), and a significantly greater median creatinine (2.59 vs 1.88 mg/dL, $P \leq .01$) compared with the ECMO group. The median lactate in the ECMO group was 8.9 mmol/L, compared with 3.0 mmol/L in the Impella group.

Clinical Course and Outcomes

Patients with isolated LV dysfunction. Among patients with isolated LV dysfunction who were supported by Impella (n = 13), 7 patients (54%) received an Impella CP and 6 (46%), an Impella 5.0 (Table 2). One patient with Impella CP required escalation to VA-ECMO. Median peak CK-MB was greater in the ECMO group compared with the Impella group (183 vs 34 IU/L). Six (46%) patients in the Impella group required renal-replacement therapy (RRT), 2 (15%) developed thrombocytopenia, and 3 (23%) had hemolysis, compared with none in the ECMO group. Median duration of device support was 4.0 days in both groups.

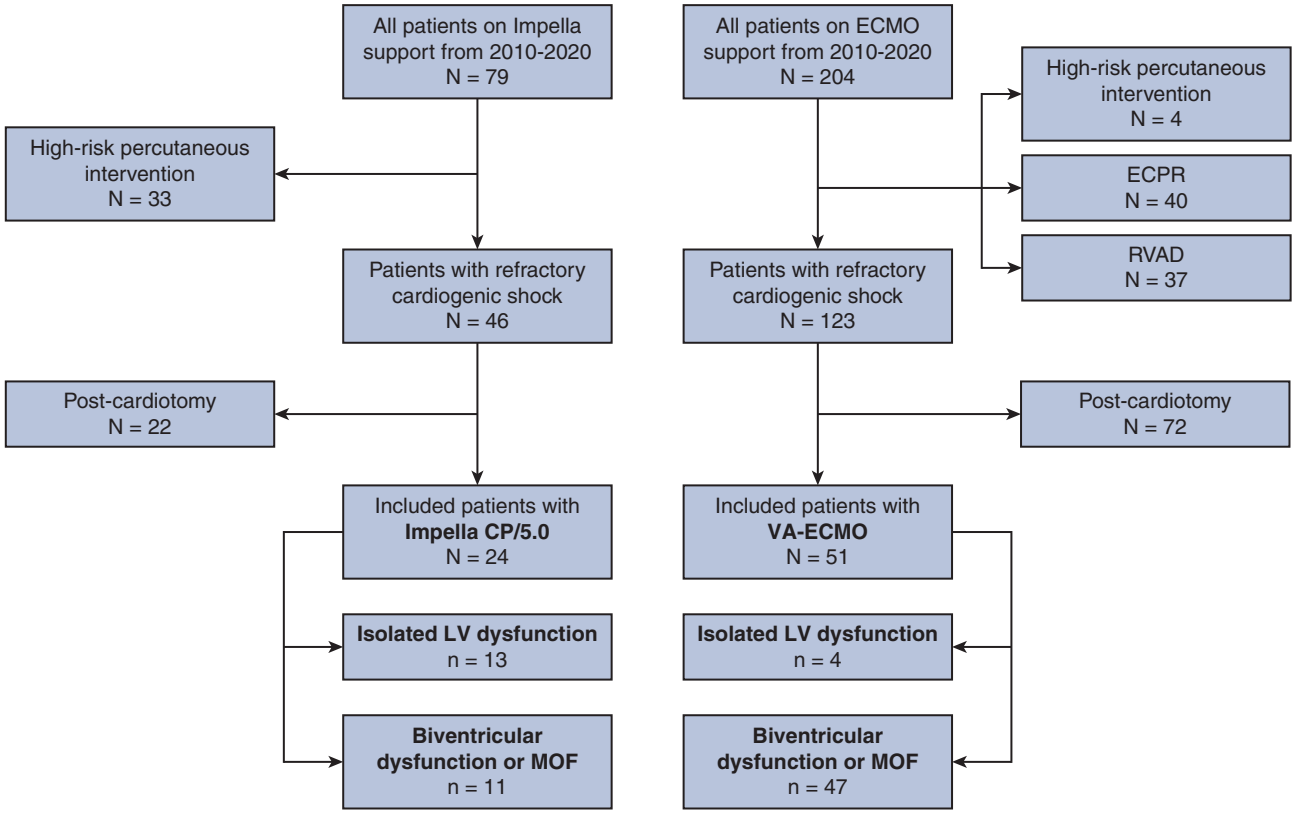


FIGURE 1. Flowchart of included patients in the study. *ECMO*, Extracorporeal membrane oxygenation; *ECPR*, extracorporeal cardiopulmonary resuscitation; *RVAD*, right ventricular assist device; *VA-ECMO*, venoarterial extracorporeal membrane oxygenation; *LV*, left ventricular; *MOF*, multiple organ failure.

Device-related vascular complications were more frequent in the Impella group compared with the ECMO group (31 vs 25%, respectively). The Bleeding Academic Research Consortium type 4 bleeding in the Impella was related to the emergent conversion to VA-ECMO. In the Impella group, 62% (n = 8) of patients were weaned successfully, compared with 100% in the ECMO group. Thirty-day survival was greater in the ECMO group compared with the Impella group (75% vs 46%, respectively). The cause of death for the 3 patients in the Impella group was irreversible MOF.

Patients with biventricular dysfunction or MOF. Among patients with biventricular dysfunction or MOF who were supported by Impella (n = 11), 36% received an Impella CP and 64% an Impella 5.0 (Table 2). One patient with Impella CP required escalation to VA-ECMO. Median peak creatine kinase-MB was greater in the Impella group compared with the ECMO group (65 vs 57 IU/L). The proportion of patients requiring RRT was greater in the ECMO group compared with the Impella group (49% vs 36%, respectively). Patients supported with Impella developed thrombocytopenia and hemolysis more frequently than patients under ECMO. Median duration of device support was slightly greater in the ECMO group (4.0 vs 3.7 days). Device-related vascular complications were more frequent in the ECMO group compared with the Impella group (34% vs 27%. respectively, $P = 1.0$). Furthermore, access site–related bleedings were more severe (Bleeding Academic Research Consortium types 4, 5a, and 5b) in patients supported by ECMO. In the ECMO group, 34% of patients were successfully weaned, compared with 9% in the Impella group ($P = .15$). Thirty-day survival was greater in the ECMO group compared with the Impella group, without reaching statistical significance (respectively 28% vs 9%, $P = .27$).

Impella CP Versus 5.0

Patients who received Impella CP had a greater median age compared with those supported by Impella 5.0 (59.8 vs 54.1 years, respectively) (Table 3). They also had a greater proportion of cardiovascular risk factors, including a significantly greater proportion of dyslipidemia ($P = .01$) and previous myocardial infarction ($P < .01$). Patients' SCAI stage distribution was comparable in both groups: the majority were in SCAI stage D, followed by stage C then E. Compared with patients with Impella CP, patients with Impella 5.0 more often had MOF or biventricular dysfunction and a greater proportion received IABP support (62% vs 55%) as a first device before MCS.

TABLE 1. Baseline characteristics of patients in cardiogenic shock requiring Impella CP/5.0 or VA-ECMO, grouped according to severity of illness and adherence to local protocol

Variables	Isolated LV dysfunction				Biventricular dysfunction or MOF			
	All	Impella	ECMO		All	ECMO	Impella	
Median (IQR) or n (%)	(n = 17)	(n = 13)	(n = 4)	*P* value	(n = 58)	(n = 47)	(n = 11)	*P* value
Age, y	48.1 (39.2-59.8)	48.1 (37.9-63.9)	49.2 (41.5-58.4)	1.0	57.1 (43.5-63.2)	55.7 (40.6-60.6)	60.4 (57.4-67.6)	**.01**
Male	14 (82)	12 (92)	2 (50)	.12	43 (74)	35 (74)	8 (73)	1.0
Body mass index, kg/m^2	25.9 (23.2-29.5)	27.7 (23.2-29.9)	24.6 (23.3-27.7)	.46	27.4 (24.1-31.0)	26.8 (23.5-29.9)	30.0 (26.2-32.9)	.07
Cardiovascular risk factors								
Obesity	3 (18)	3 (23)	0	.54	17 (29)	11 (23)	6 (55)	.052
Active smoking	7 (41)	5 (38)	2 (50)	1.0	21 (36)	16 (34)	5 (45)	.50
Hypertension	5 (29)	4 (31)	1 (25)	1.0	22 (38)	19 (40)	3 (27)	.51
Dyslipidemia	4 (24)	4 (31)	0	.52	22 (38)	16 (34)	6 (55)	.21
Diabetes mellitus	4 (24)	3 (23)	1 (25)	1.0	11 (19)	8 (17)	3 (27)	.42
Chronic kidney disease	1 (6)	1 (8)	0	1.0	7 (12)	4 (9)	3 (27)	.12
Cardiovascular history								
Myocardial infarction	4 (24)	4 (31)	0	.52	8 (14)	4 (9)	4 (36)	**.04**
Stroke	0	0	0		2 (3)	0	2 (18)	**.03**
Peripheral vascular disease	1 (6)	1 (8)	0	1.0	3 (5)	2 (4)	1 (9)	.47
Shock etiology				.26				.24
Acute coronary syndrome	10 (59)	7 (54)	3 (75)		29 (50)	22 (47)	7 (64)	
Ischemic cardiomyopathy	1 (6)	1 (8)	0		2 (3)	1 (2)	1 (9)	
Idiopathic cardiomyopathy	3 (18)	3 (23)	0		13 (23)	11 (23)	2 (18)	
Familial cardiomyopathy	0	0	0		3 (5)	3 (6)	0	
Ongoing arrhythmias	1 (6)	0	1 (25)		4 (7)	4 (9)	0	
Other	2 (11)	2 (15)	0		7 (12)	6 (13)	1 (9)	
Hemodynamic variables								
Heart rate, beats/min	117 (99-130)	110 (84-130)	125 (120-135)	.14	108 (94-122)	107 (93-125)	110 (94-110)	.88
Mean arterial pressure, mm Hg	70 (64-82)	70 (63-79)	82 (69-95)	.19	65 (60-72)	65 (60-72)	65 (60-71)	.77
Shock index	1.2 (0.9-1.3)	1.2 (0.9-1.3)	1.2 (1.2-1.2)	.47	1.2 (1.0-1.4)	1.2 (1.0-1.4)	1.1 (1.0-1.2)	.61
Cardiac index, L/min per m^2	1.77 (1.47-2.10)	1.77 (1.47-2.10)	–	–	1.90 (1.45-2.40)	2.15 (1.53-2.50)	1.77 (1.46-1.79)	.19
Cardiac output, L/min	3.64 (2.87-4.50)	3.64 (2.87-4.50)	–	–	3.66 (2.45-4.41)	4.12 (2.47-4.50)	3.42 (2.71-3.61)	.31
CPI, W/m^2	0.28 (0.25-0.30)	0.28 (0.25-0.30)	–	–	0.25 (0.21-0.41)	0.33 (0.21-0.41)	0.20 (0.18-0.22)	.13
CPO, W	0.60 (0.51-0.63)	0.60 (0.51-0.63)	–	–	0.48 (0.43-0.69)	0.62 (0.45-0.71)	0.42 (0.34-0.45)	.15
Vasopressors or inotropes	16 (94)	12 (92)	4 (100)	1.0	58 (100)	47 (100)	11 (100)	–
Biventricular dysfunction	0	0	0	–	37 (64)	35 (74)	2 (18)	**<.001**
LVEF, %	10 (10-20)	15 (10-20)	10 (10-36)	.62	10 (10-15)	10 (5-15)	15 (10-25)	.07
SCAI Shock classification				.57				.07
SCAI stage C	7 (41)	6 (46)	1 (25)		5 (9)	4 (8)	1 (9)	
SCAI stage D	8 (48)	6 (46)	2 (50)		20 (34)	13 (28)	7 (64)	
SCAI stage E	2 (11)	1 (8)	1 (25)		33 (57)	30 (64)	3 (27)	
Arrest modifier	5 (29)	3 (23)	2 (50)	.54	22 (38)	20 (43)	2 (18)	.18
IABP support before high-output MCS	10 (59)	7 (54)	3 (75)	.60	37 (64)	30 (64)	7 (64)	1.0

(Continued)

TABLE 1. Continued

Variables	Isolated LV dysfunction				Biventricular dysfunction or MOF			
	All	Impella	ECMO		All	ECMO	Impella	
Median (IQR) or n (%)	(n = 17)	(n = 13)	(n = 4)	*P* value	(n = 58)	(n = 47)	(n = 11)	*P* value
Precannulation biochemistry								
Hemoglobin, g/L	138 (122-149)	141 (123-152)	127 (120-139)	.26	131 (112-147)	131 (115-146)	104 (82-152)	.36
Arterial pH	7.38 (7.29-7.44)	7.40 (7.32-7.44)	7.32 (7.21-7.43)	.36	7.22 (7.12-7.32)	7.22 (7.12-7.32)	7.22 (7.04-7.43)	.95
Arterial lactate, mmol/L	3.8 (1.1-5.8)	3.8 (1.2-5.8)	2.7 (0.8-7.9)	.91	7.9 (2.9-11.8)	8.9 (4.0-11.5)	3.0 (2.0-15.1)	.56
Creatinine, mg/dL	1.15 (0.98-1.67)	1.28 (1.02-1.72)	1.02 (0.76-1.14)	.09	2.09 (1.45-2.65)	1.88 (1.35-2.54)	2.59 (2.25-3.61)	**.009**
eGFR, mL/min	73 (60-102)	64 (57-102)	87 (74-108)	.17	39 (25-61)	40 (28-76)	24 (20-39)	**.005**
Bilirubin, mmol/L	13.4 (8.2-24.8)	15 (10.7-35.5)	7.4 (5.4-8.3)	**.01**	21.0 (12.7-30.7)	21.5 (12.9-32.3)	16.8 (10.0-30.3)	.38
ALT, units/L	108 (55-280)	125 (39-306)	80 (71-141)	.50	386 (73-1580)	365 (80-1650)	758 (77-1367)	.49
BNP, ng/L	4517 (2076-23,406)	4456 (2608-21,508)	3593 (3100-4085)	.64	14,418 (7724-34,525)	12,322 (7605-34,815)	25,969 (4648-34,328)	.87

Values in bold indicate statistical significance, as defined by a 2-sided $P < .05$. *LV*, Left ventricular; *MOF*, multiple organ failure; *ECMO*, extracorporeal membrane oxygenation; *IQR*, interquartile range; *CPI*, cardiac power index; *CPO*, cardiac power output; *LVEF*, left ventricular ejection fraction; *SCAI*, The Society for Cardiovascular Angiography and Interventions; *IABP*, intra-aortic balloon pump; *MCS*, mechanical circulatory support; *eGFR*, estimated glomerular filtration rate; *ALT*, alanine aminotransferase; *BNP*, B-type natriuretic peptide.

Patients with Impella CP had a lower median hemoglobin (129 vs 141 g/L), and greater median lactate (5.2 and 2.7 mmol/L) and ALT levels (279 vs 150 units/L) compared with patients with Impella 5.0. The Impella 5.0 group had a greater median creatinine (2.23 vs 1.64 mg/dL, $P = .11$) and bilirubin levels (22.4 vs 13.4 mmol/L, $P = 11$) compared with Impella CP.

A slightly greater proportion of patients supported by Impella CP required RRT compared with those supported by Impella 5.0 (45 vs 38%, $P = .73$) (Table 4). Thrombocytopenia, hemolysis, and device-related vascular complications occurred more frequently in the Impella CP group compared with the Impella 5.0 group. Nondevice-related bleeding was greater in the Impella 5.0 group (23% vs 9%, $P = .60$). Thirty-day survival was greater in the Impella 5.0 group compared with the Impella CP group, for both CS phenotypes (isolated LV dysfunction: 83% vs 14% and biventricular dysfunction or MOF: 14% vs 0%, respectively) (Table E1).

Severity Score

Table E2 compares 30-day survival according to the type of MCS device (VA-ECMO, Impella CP, or Impella 5.0) and the SCAI stage at precannulation. Patients in SCAI stage E had lower survival rates than those in stage C or D, for all 3 devices.

DISCUSSION

This small, single-center and retrospective study showed that phenotyping CS when selecting high-output MCS device (Figure 2) can help achieve acceptable short-term survival in patients with refractory CS. These findings are concordant with recently reported cohorts.[13,14] In this small cohort, using an Impella for MOF or biventricular dysfunction led to dismal outcomes. In addition, patients supported with Impella CP had a lower 30-day survival compared with those supported with Impella 5.0, irrespective of CS phenotype. In contrast, the 4 patients with isolated LV dysfunction who were oversupported by VA-ECMO were all alive and discharged home at 30 days.

It is generally accepted that VA-ECMO should be selected over Impella in refractory CS associated with more severe features (cardiorespiratory failure, biventricular dysfunction, severe hemodynamic instability, etc).[15] In contrast, previous studies have questioned whether VA-ECMO is the right device for isolated LV dysfunction. A retrospective analysis of 132 patients supported with VA-ECMO for CS of different causes found that isolated LV dysfunction was an independent predictor for 90-day mortality.[16] In that cohort, 90-day survival was 32% for isolated LV dysfunction, 62% for isolated RV dysfunction, and 55% for biventricular dysfunction ($P = .04$).[16] It is unclear why our findings differ. The lower proportion of LV venting in the study by den Uil and colleagues compared with our cohort might have

TABLE 2. Clinical course and outcomes among patients supported with Impella CP/5.0 and VA-ECMO, grouped according to severity of illness and adherence to protocol

Variables	Isolated LV dysfunction				Biventricular dysfunction or MOF			
	All	Impella	ECMO		All	ECMO	Impella	
Median (IQR) or n (%)	(n = 17)	(n = 13)	(n = 4)	*P* value	(n = 58)	(n = 47)	(n = 11)	*P* value
Mechanical support device								
Impella CP	7 (41)	7 (54)	–	–	4 (7)	–	4 (36)	–
Impella 5.0	6 (35)	6 (46)	–	–	7 (12)	–	7 (64)	–
Upgrade mechanical support								
Upgrade from Impella CP to 5.0	0	0	–	–	0	–	0	–
Upgrade from Impella to ECMO	1 (6)	1 (8)	–	–	1 (2)	–	1 (9)	–
During admission								
Mechanical ventilation	16 (94)	12 (92)	4 (100)	1.0	58 (100)	47 (100)	11 (100)	–
Renal-replacement therapy	6 (35)	6 (46)	0	.24	27 (47)	23 (49)	4 (36)	.45
Thrombocytopenia	2 (12)	2 (15)	0	1.0	10 (17)	7 (15)	3 (27)	.38
Hemolysis	3 (18)	3 (23)	0	.54	2 (3)	1 (2)	1 (9)	.35
Duration of device support, d	4.0 (3.0-6.6)	4.0 (3.0-6.6)	4.0 (1.4-7.8)	1.0	3.9 (1.7-6.1)	4.0 (1.8-6.0)	3.7 (0.9-6.7)	.56
Device-related vascular complications	5 (29)	4 (31)	1 (25)	1.0	19 (33)	16 (34)	3 (27)	1.0
Access site-related bleeding	4 (24)	3 (23)	1 (25)		16 (28)	14 (30)	2 (18)	
BARC 2	1 (25)	1 (33)	0		1 (6)	1 (7)	0	
BARC 3a	0	0	0		2 (13)	1 (7)	1 (50)	
BARC 3b	1 (25)	1 (33)	0		8 (50)	7 (50)	1 (50)	
BARC 4	2 (50)	1 (33)	1 (100)		3 (19)	3 (21)	0	
BARC 5a	0	0	0		1 (6)	1 (7)	0	
BARC 5b	0	0	0		1 (6)	1 (7)	0	
Limb ischaemia	1 (6)	1 (8)	0		3 (5)	2 (4)	1 (9)	
Clinical end points								
Successfully weaned from device	12 (71)	8 (62)	4 (100)	.26	17 (29)	16 (34)	1 (9)	.15
Durable LVAD placement	0	0	0	–	3 (5)	2 (4)	1 (9)	.47
Heart transplantation	1 (6)	1 (8)	0	1.0	10 (17)	9 (19)	1 (9)	.67
LVAD and heart transplantation	2 (12)	2 (15)	0	1.0	2 (3)	2 (4)	0	1.0
In-hospital mortality	3 (18)	3 (23)	0	0.54	32 (55)	24 (51)	8 (73)	.31
Causes of death								
MOF	3 (18)	3 (23)	–		15 (47)	11 (46)	4 (50)	
Postanoxic brain injury	0	0	–		5 (16)	5 (21)	0	
Superimposed sepsis	0	0	–		5 (16)	3 (12)	2 (25)	
Other reason	0	0	–		7 (21)	5 (21)	2 (25)	
30-d survival	9 (53)	6 (46)	3 (75)	0.58	14 (24)	13 (28)	1 (9)	.27

LV, Left ventricular; *MOF*, multiple organ failure; *ECMO*, extracorporeal membrane oxygenation; *IQR*, interquartile range; *LVAD*, left ventricular assist device; *BARC*, Bleeding Academic Research Consortium.

contributed to their poorer outcomes.[16] Indeed, LV unloading was found to be associated with improved survival in patients with VA-ECMO.[17,18] Another explanation could be that our small sample size led to biased results. Nevertheless, these findings remain hypothesis-generating. However, they shouldn't be interpreted as an argument for a more aggressive initiation of VA-ECMO over other MCS devices. ECMO is often associated with an increased use of allogenic blood product transfusions, greater thromboembolic complications, and increased bleeding compared with Impella.[19] Indeed, patient selection is framed by a number of contraindications,[20] and ECMO candidacy might be declined depending on the burden of comorbidities. The latter point might explain the selection of Impella for patients with MOF or biventricular dysfunction in our cohort, but this is difficult to confirm, given the retrospective design of the study. Another reason that could have explained the use of Impella in the presence of MOF is that the shock team may have made the decision to insert an Impella before the patient's biochemistry truly reflected the MOF. In addition, the use of BiPella (biventricular Impella) has recently emerged, but further studies are needed to prove its efficacy in managing biventricular dysfunction.[21]

As technologies and interventions improve, in parallel with an increase in patients' burden of comorbidities and disease complexity, it is crucial that systems of care for

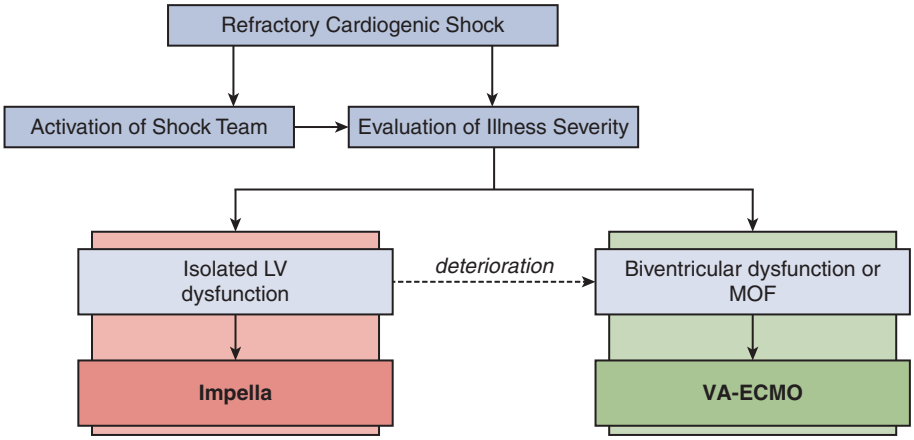


FIGURE 2. Proposed algorithm to guide mechanical circulatory support device selection based on phenotype of cardiogenic shock. *LV*, Left ventricular; *MOF*, multiple organ failure; *VA-ECMO*, venoarterial extracorporeal membrane oxygenation.

patients with CS evolve toward a standardized and validated approach.[22-24] Studies have demonstrated that initiatives to standardize management of CS within an integrated care system were associated with improved clinical outcomes.[25,26] The current version of our local algorithm for MCS selection, which post-dated this study, is shown in Figure E1. Several other institutions have reported their algorithmic approach based on currently available practice recommendations.[27,28] However, solid evidence such as of well-powered randomized trials for MCS device selection is still lacking.[29] As a result, these decisions remain largely based on institutional experience and local availability.

In the meantime, the emphasis should be turned toward the importance of rapid recognition of refractory CS, an early initiation of the shock care pathway, and a more accurate determination of severity of illness. Our care pathway

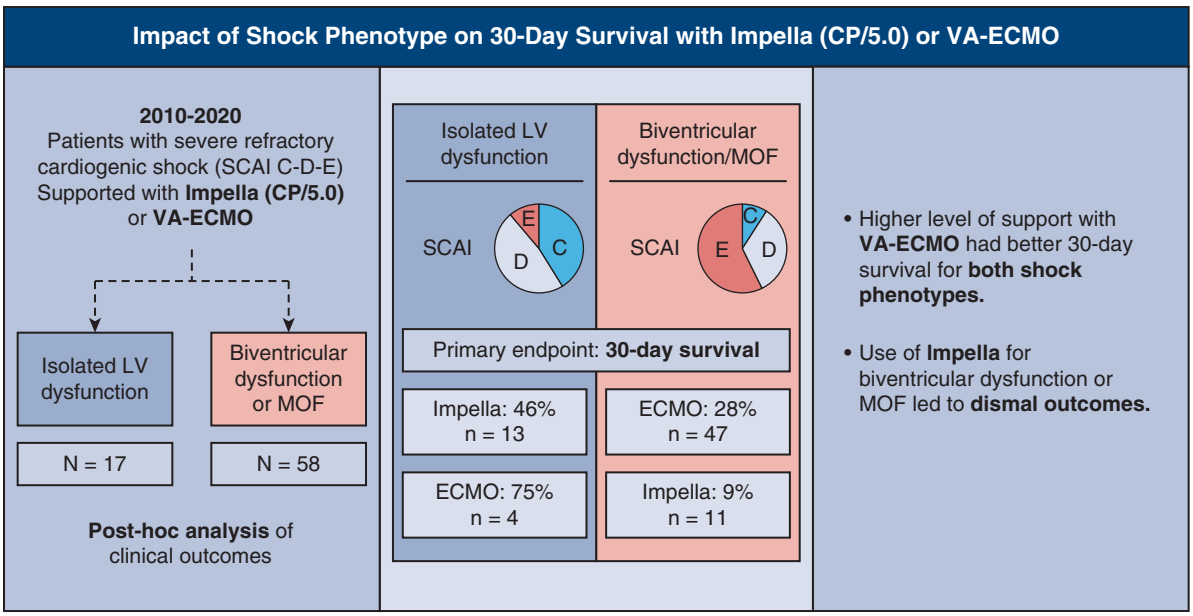


FIGURE 3. Impact of shock phenotype on 30-day survival with Impella (CP/5.0) or VA-ECMO. A support strategy that distinguishes cardiac phenotypes can streamline clinical decision-making in patients with SCAI stages C-D-E. The approach studied favors Impella for isolated LV dysfunction and VA-ECMO for biventricular dysfunction or MOF. Patients with biventricular dysfunction or MOF failure supported with Impella had worse 30-day survival. Patients with isolated LV dysfunction who were supported by Impella or VA-ECMO had good 30-day survival. *VA-ECMO*, Venoarterial extracorporeal membrane oxygenation; *SCAI*, Society for Cardiovascular Angiography and Interventions; *LV*, left ventricular; *MOF*, multiple organ failure.

TABLE 3. Baseline characteristics of patients in cardiogenic shock supported with Impella (CP vs 5.0)

Variables Median (IQR) or n (%)	All (n = 24)	Impella CP (n = 11)	Impella 5.0 (n = 13)	*P* value
Age, y	58.4 (45.3-67.5)	59.8 (56.8-67.3)	54.1 (43.7-68.1)	.58
Male	20 (83)	8 (72)	12 (92)	.30
Body mass index, kg/m^2	29.1 (24.5-31.5)	25.9 (22.9-31.6)	29.4 (26.9-32.3)	.27
Cardiovascular risk factors				
Obesity	9 (38)	4 (36)	5 (38)	1.0
Active smoking	10 (42)	6 (55)	4 (31)	.41
Hypertension	7 (29)	5 (45)	2 (15)	.18
Dyslipidemia	10 (42)	8 (72)	2 (15)	**.01**
Diabetes mellitus	6 (25)	5 (45)	1 (8)	.06
Chronic kidney disease	4 (17)	2 (18)	2 (15)	1.0
Cardiovascular history				
Myocardial infarction	8 (33)	7 (64)	1 (8)	**.008**
Stroke	2 (8)	1 (9)	1 (8)	1.0
Peripheral vascular disease	2 (8)	2 (18)	0	.20
Shock etiology				.10
Acute coronary syndrome	14 (58)	9 (82)	5 (38)	
Ischemic cardiomyopathy	2 (8)	1 (9)	1 (8)	
Idiopathic cardiomyopathy	5 (21)	0	5 (38)	
Familial cardiomyopathy	0	0	0	
Ongoing arrhythmias	0	0	0	
Other	3 (13)	1 (9)	2 (15)	
Hemodynamic variables				
Heart rate, beats/min	110 (92-119)	110 (91-130)	110 (95-115)	.93
Mean arterial pressure, mm Hg	67 (62-76)	71 (61-80)	65 (63-70)	.26
Shock index	1.2 (0.9-1.3)	1.2 (0.9-1.3)	1.2 (1.0-1.3)	.81
Cardiac index, L/min per m^2	1.77 (1.46-1.88)	1.46 (1.41-1.48)	1.80 (1.77-2.12)	**.041**
Cardiac output, L/min	3.56 (2.86-4.31)	2.84 (2.74-3.03)	4.02 (3.58-4.50)	.062
CPI, W/m^2	0.25 (0.22-0.29)	0.24 (0.22-0.26)	0.26 (0.24-0.31)	.44
CPO, W	0.54 (0.46-0.62)	0.51 (0.48-0.53)	0.59 (0.46-0.65)	.40
Vasopressors or inotropes	23 (96)	10 (42)	13 (100)	.46
Isolated LV dysfunction	13 (54)	7 (64)	6 (46)	.44
Biventricular failure	2 (8)	0	2 (15)	.48
Multiple organ dysfunction	11 (46)	4 (36)	7 (54)	.39
LVEF, %	15 (10-20)	15 (10-25)	10 (10-18)	.24
SCAI shock classification				
SCAI stage C	7 (29)	3 (27)	4 (31)	.97
SCAI stage D	13 (54)	6 (55)	7 (54)	
SCAI stage E	4 (17)	2 (18)	2 (15)	
Arrest modifier	5 (21)	2 (18)	3 (23)	1.0
IABP support before high-output MCS	14 (58)	6 (55)	8 (62)	.73
Precannulation biochemistry				
Hemoglobin, g/L	137 (100-152)	129 (77-152)	141 (111-159)	.16
Arterial pH	7.36 (7.19-7.43)	7.38 (7.15-7.44)	7.28 (7.20-7.43)	.86
Arterial lactate, mmol/L	3.4 (1.9-7.9)	5.2 (2.6-15.1)	2.7 (1.2-7.3)	.11
Creatinine, mg/dL	1.8 (1.22-2.57)	1.64 (1.01-2.25)	2.23 (1.58-3.48)	.11
eGFR, mL/min	52 (25-68)	60 (42-87)	39 (24-62)	.25
Bilirubin, mmol/L	16.2 (10.8-30.0)	13.4 (10.0-17.4)	22.4 (14.2-37.0)	.11
ALT, units/L	215 (73-809)	279 (72-1215)	150 (88-795)	.75
BNP, ng/L	21,508 (2837-31,378)	21,508 (2837-32,050)	17,024 (2380-31,734)	.81

Values in bold indicate statistical significance, as defined by a 2-sided $P < .05$. *IQR*, Interquartile range; *CPI*, cardiac power index; *CPO*, cardiac power output; *LV*, left ventricular; *LVEF*, left ventricular ejection fraction; *SCAI*, The Society for Cardiovascular Angiography and Interventions; *IABP*, intra-aortic balloon pump; *MCS*, mechanical circulatory support; *eGFR*, estimated glomerular filtration rate; *ALT*, alanine aminotransferase; *BNP*, B-type natriuretic peptide.

TABLE 4. Clinical course and outcomes of patients in cardiogenic shock supported with Impella (CP vs 5.0)

Variables Median (IQR) or n (%)	All (n = 24)	Impella CP (n = 11)	Impella 5.0 (n = 13)	*P* value
During admission				
Upgrade from Impella to ECMO	2 (8)	2 (18)	0	
Mechanical ventilation	23 (96)	10 (91)	13 (100)	.46
Renal-replacement therapy	10 (42)	5 (45)	5 (38)	.73
Thrombocytopenia	5 (21)	3 (27)	2 (15)	.63
Hemolysis	4 (16)	3 (27)	1 (8)	.30
Duration of device support, d	3.8 (2.6-6.5)	3.4 (0.9-7.4)	4.0 (3.0-6.3)	.34
Device-related vascular complications	7 (29)	4 (36)	3 (23)	.66
Access site–related bleeding	5 (21)	3 (27)	2 (15)	
BARC 2	1 (20)	1 (33)	0	
BARC 3a	1 (20)	1 (33)	0	
BARC 3b	2 (40)	0	2 (100)	
BARC 4	1 (20)	1 (33)	0	
Limb ischemia	2 (8)	1 (9)	1 (8)	
Clinical end points				
Successfully weaned from device	9 (38)	3 (27)	6 (46)	.42
Durable LVAD placement	1 (4)	0	1 (8)	1.0
Heart transplantation	2 (8)	0	2 (15)	.48
LVAD and heart transplantation	2 (8)	2 (18)	0	.20
In-hospital mortality	11 (46)	6 (55)	5 (38)	.43
Causes of death				
MOF	7 (64)	5 (83)	2 (40)	
Postanoxic brain injury	0	0	0	
Superimposed sepsis	2 (18)	1 (17)	1 (10)	
Other reason	2 (18)	0	2 (40)	
30-d survival	7 (29)	1 (9)	6 (46)	.078

IQR, Interquartile range; *ECMO*, extracorporeal membrane oxygenation; *BARC*, Bleeding Academic Research Consortium; *LVAD*, left ventricular assist device; *MOF*, multiple organ failure.

can certainly be improved. First, hemodynamic and echocardiographic parameters should be gathered promptly, within the first hour of CS diagnosis. Given the decisional weight attributed to characterization of ventricular dysfunction, it is vital to collect a precise evaluation of the RV. Regardless of the quantitative methods used, thresholds of severity levels for RV failure should be more clearly defined. The same applies to the severity criteria of MOF. Lastly, the prognostic value of clinical scores could help define severity of illness and should be implemented in decision algorithms. Data from the CS Working Group registry showed a strong association between the SCAI staging system and incremental in-hospital mortality.[30] Shock phenotype including organ system failure were also reported as strong predictors of outcomes.[13] Reports also showed that increasing age was associated with higher mortality that was additive to the effect of SCAI shock severity, suggesting that age should have an important weighting factor during patient selection for device support in CS.[31] Other groups have evaluated the validity of the Survival after Veno-Arterial ECMO (SAVE) and prEdictioN of Cardiogenic shock OUtcome foR Acute myocardial infarction patients salvaGed by VA-ECMO (ENCOURAGE scores) for predicting mortality in patients with CS post-myocardial infarction supported by ECMO.[32-34] Further studies are needed to assess the performance of these predictive models to correct for disease severity in patients with CS.

Limitations

This study used a retrospective design to explore short-term outcomes over a 10-year period while the science and available devices were changing rapidly. The sample size remained small, especially for the group with isolated LV dysfunction supported with ECMO (4 patients). This significantly limited the statistical power, the use of multivariate analysis, and the ability to analyze data at a more granular level. In addition, given the small sample size of the study, adjustment with propensity matching was not feasible. Therefore, the comparative effectiveness results cannot rule out unmeasured confounding bias and cannot prove causation. As there are currently no randomized-controlled trials evaluating Impella versus ECMO for CS, this observational study is subject to inherent selection bias regarding choice of MCS device. The discretionary selection of Impella for patients admitted directly for cardiac catheterization

after an acute coronary syndrome represents the greatest potential bias. Avoiding VA-ECMO support in older patients and those perceived as having a low chance of survival might be another implicit bias. Of note, our local MCS selection strategy does not consider age nor the crude estimate of a patient's survival at preimplantation as a criterion for MCS selection but rather the patient and family's wishes with respect to level of care. Given these limitations, our conclusions can only be hypothesis-generating. Another limitation was that echocardiographic images weren't recorded and, therefore, couldn't be reassessed to confirm ventricular dysfunction for the purpose of this analysis. The study was, however, performed at an experienced cardiac and MCS center. Lastly, only short-term follow-up and survival were reported, due to care transition to other institutions that don't share a common electronic health record system.

CONCLUSIONS

In this small cohort, the use of Impella 5.0 for isolated LV dysfunction and VA-ECMO for MOF or biventricular dysfunction was associated with favorable 30-day survival (Figure 3). Supporting patients who have MOF or biventricular dysfunction with Impella led to dismal outcomes. Patients with isolated LV dysfunction supported with VA-ECMO had good outcomes. Further data are needed to explore the potential benefits of early escalation to VA-ECMO in patients with isolated LV failure who are rapidly deteriorating.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/1358.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. *N Engl J Med*. 2012;367:1287-96.
2. Perera D, Stables R, Thomas M, Booth J, Pitt M, Blackman D, et al. Elective intra-aortic balloon counterpulsation during high-risk percutaneous coronary intervention: a randomized controlled trial. *JAMA*. 2010;304:867-74.
3. Patel MR, Smalling RW, Thiele H, Barnhart HX, Zhou Y, Chandra P, et al. Intra-aortic balloon counterpulsation and infarct size in patients with acute anterior myocardial infarction without shock: the CRISP AMI randomized trial. *JAMA*. 2011;306:1329-37.
4. Mandawat A, Rao SV. Percutaneous mechanical circulatory support devices in cardiogenic shock. *Circ Cardiovasc Interv*. 2017;10:e004337.
5. Osman M, Syed M, Patibandla S, Sulaiman S, Kheiri B, Shah MK, et al. Fifteen-year trends in incidence of cardiogenic shock hospitalization and in-hospital mortality in the United States. *J Am Heart Assoc*. 2021;10:e021061.
6. Vahdatpour C, Collins D, Goldberg S. Cardiogenic shock. *J Am Heart Assoc*. 2019;8:e011991.
7. Taleb I, Koliopoulou AG, Tandar A, McKellar SH, Tonna JE, Nativi-Nicolau J, et al. Shock team approach in refractory cardiogenic shock requiring short-term mechanical circulatory support: a Proof of Concept. *Circulation*. 2019; 140:98-100.
8. Strom JB, Zhao Y, Shen C, Chung M, Pinto DS, Popma JJ, et al. Hospital variation in the utilization of short-term nondurable mechanical circulatory support in myocardial infarction complicated by cardiogenic shock. *Circ Cardiovasc Interv*. 2019;12:e007270.
9. Mebazaa A, Combes A, van Diepen S, Hollinger A, Katz JN, Landoni G, et al. Management of cardiogenic shock complicating myocardial infarction. *Intensive Care Med*. 2018;44:760-73.
10. Rastan AJ, Dege A, Mohr M, Doll N, Falk V, Walther T, et al. Early and late outcomes of 517 consecutive adult patients treated with extracorporeal membrane oxygenation for refractory postcardiotomy cardiogenic shock. *J Thorac Cardiovasc Surg*. 2010;139:302-11. 311.e301.
11. Jentzer JC, van Diepen S, Barsness GW, Henry TD, Menon V, Rihal CS, et al. Cardiogenic shock classification to predict mortality in the cardiac intensive care unit. *J Am Coll Cardiol*. 2019;74:2117-28.
12. Westrope C, Harvey C, Robinson S, Speggiorin S, Faulkner G, Peek GJ. Pump controlled retrograde trial off from VA-ECMO. *ASAIO J*. 2013;59:517-9.
13. Zweck E, Thayer KL, Helgestad OKL, Kanwar M, Ayouty M, Garan AR, et al. Phenotyping cardiogenic shock. *J Am Heart Assoc*. 2021;10:e020085.
14. Basir MB, Kapur NK, Patel K, Salam MA, Schreiber T, Kaki A, et al. Improved outcomes associated with the use of shock protocols: updates from the National Cardiogenic Shock Initiative. *Catheter Cardiovasc Interv*. 2019;93:1173-83.
15. Ezekowitz JA, Kaul P. The epidemiology and management of elderly patients with myocardial infarction or heart failure. *Heart Fail Rev*. 2010;15: 407-13.
16. den Uil CA, Jewbali LS, Heeren MJ, Constantinescu AA, Van Mieghem NM, Reis Miranda DD. Isolated left ventricular failure is a predictor of poor outcome in patients receiving veno-arterial extracorporeal membrane oxygenation. *Eur J Heart Fail*. 2017;19:104-9.
17. Al-Fares AA, Randhawa VK, Englesakis M, McDonald MA, Nagpal AD, Estep JD, et al. Optimal strategy and timing of left ventricular venting during veno-arterial extracorporeal life support for adults in cardiogenic shock: a systematic review and meta-analysis. *Circ Heart Fail*. 2019;12:e006486.
18. Schrage B, Becher PM, Bernhardt A, Bezerra H, Blankenberg S, Brunner S, et al. Left ventricular unloading is associated with lower mortality in patients with cardiogenic shock treated with venoarterial extracorporeal membrane oxygenation: results from an international, multicenter cohort study. *Circulation*. 2020; 142:2095-106.
19. Lamarche Y, Cheung A, Ignaszewski A, Higgins J, Kaan A, Griesdale DEG, et al. Comparative outcomes in cardiogenic shock patients managed with Impella microaxial pump or extracorporeal life support. *J Thorac Cardiovasc Surg*. 2011; 142:60-5.
20. Zangrillo A. The criteria of eligibility to the extracorporeal treatment. *HSR Proc Intensive Care Cardiovasc Anesth*. 2012;4:271-3.
21. Karaaslan DC, Mutlu D, Lendel V, Ates I, Kulaksizoglu S, Cilingiroglu M. Bi-Pella: mini review on a novel method to treat cardiogenic shock patients. *Acta Cardiol Sin*. 2021;37:312-7.
22. Wayangankar SA, Bangalore S, McCoy LA, Jneid H, Latif F, Karrowni W, et al. Temporal trends and outcomes of patients undergoing percutaneous coronary interventions for cardiogenic shock in the setting of acute myocardial infarction: a report from the CathPCI registry. *JACC Cardiovasc Interv*. 2016;9:341-51.
23. Patarroyo Aponte MM, Manrique C, Kar B. Systems of care in cardiogenic shock. *Methodist Debakey Cardiovasc J*. 2020;16:50-6.
24. Alvarez Villela M, Clark R, William P, Sims DB, Jorde UP. Systems of care in cardiogenic shock. *Front Cardiovasc Med*. 2021;8:712594.

25. Tehrani B, Truesdell A, Singh R, Murphy C, Saulino P. Implementation of a cardiogenic shock team and clinical outcomes (INOVA-SHOCK registry): observational and retrospective study. *JMIR Res Protoc*. 2018;7:e160.
26. Tehrani BN, Truesdell AG, Sherwood MW, Desai S, Tran HA, Epps KC, et al. Standardized team-based care for cardiogenic shock. *J Am Coll Cardiol*. 2019; 73:1659-69.
27. Rab T, Ratanapo S, Kern KB, Babar Basir M, McDaniel M, Meraj P, et al. Cardiac shock care centers: JACC Review Topic of the Week. *J Am Coll Cardiol*. 2018; 72:1972-80.
28. Rao V, Fillio B. When NOT to use short-term mechanical circulatory support. *JTCVS Open*. 2020;3:106-10.
29. Thiele H, Desch S, Freund A. Microaxial left ventricular assist devices: in search of an appropriate indication. *JAMA*. 2020;323:716-8.
30. Thayer KL, Zweck E, Ayouty M, Garan AR, Hernandez-Montfort J, Mahr C, et al. Invasive hemodynamic assessment and classification of in-hospital mortality risk among patients with cardiogenic shock. *Circ Heart Fail*. 2020;13: e007099.
31. Semaan C, Charbonnier A, Pasco J, Darwiche W, Saint Etienne C, Bailleul X, et al. Risk scores in ST-segment elevation myocardial infarction patients with refractory cardiogenic shock and veno-arterial extracorporeal membrane oxygenation. *J Clin Med*. 2021;10:956.
32. Amin F, Lombardi J, Alhussein M, Duero Posada J, Suszko A, Koo M, et al. Predicting survival after VA-ECMO for refractory cardiogenic shock: validating the SAVE score. *CJC Open*. 2021;3:71-81.
33. Muller G, Flecher E, Lebreton G, Luyt CE, Trouillet JL, Bréchot N, et al. The ENCOURAGE mortality risk score and analysis of long-term outcomes after VA-ECMO for acute myocardial infarction with cardiogenic shock. *Intensive Care Med*. 2016;42:370-8.
34. Kanwar M, Thayer KL, Garan AR, Hernandez-Montfort J, Whitehead E, Mahr C, et al. Impact of age on outcomes in patients with cardiogenic shock. *Front Cardiovasc Med*. 2021;8:688098.

Key Words: cardiogenic shock, mechanical circulatory support, Impella, VA-ECMO

Discussion

Presenter: Olina Dagher

Dr M. Faraz Masood *(St. Louis, Mo)*. Thank you so much. Thanks so much for the panelists and the association for allowing me to do the discussion on this paper. I would like to congratulate you and your coauthors for assimilating these data and presenting this important data in a surgical meeting because we hear this a lot in the medical society, but less so in the surgical society, that a protocolized approach to high-output mechanical circulatory support device selection can help achieve acceptable outcomes. I also appreciate that you sent me the paper for review in due time. I have a couple questions and a few comments. Why did you think that the patients in the venoarterial extracorporeal membrane oxygenation (VA-ECMO) group were younger in age? Do you have an age cutoff in which—because it looked like, in your paper, older people got more so Impella. And the old is not really old from St Louis criteria. The 50-year-old or 55-year-old or older patients more got Impella, and 55-year-olds or younger got VA-ECMO. Is there a cutoff at your institute for that?

Dr Olina Dagher *(Montreal, Canada)*. First of all, thank you, Dr Masood, for taking the time to review our manuscript and for the feedback. At our institution, we don't typically use age as a threshold for decision-making. It's a multidisciplinary discussion, and I am sure it is taken into consideration, but we don't have the same criteria as your institution. Age is increasingly recognized as an independent predictor for mortality. Therefore, it's definitely something that we should take into consideration in the future iterations of our protocol. And then, when it comes to why the VA-ECMO group were younger, that's a difficult question. We included all shock etiologies, so it wasn't just the acute myocardial infarctions. It was also the familial cardiomyopathies. It was the shock caused by ongoing arrhythmias. So maybe that's why we saw this lower age tendency. And then, again, that's difficult to gather from reviewing the charts, but maybe was the team more tempted to go toward VA-ECMO in younger patients because they really wanted them to make sure that they had all the chances?

Dr Masood. And in your presentation and in your comments now, as well, you mention about the team. And it's really important to have a shock team approach. It looks like you do, on the paper. I have a question about your left ventricular (LV) venting strategy. In your paper, you mention various LV venting strategies, from pharmacologic to mechanical. My questions are, is mechanical LV loading done in all patients? Because I couldn't really pinpoint from your paper.

Dr Dagher. So great question, and I'll just—

Dr Masood. One second. I got—

Dr Dagher. Oh, sorry.

Dr Masood. I got a few more. And what is your preferred strategy of LV venting? Is it a balloon, like we saw in the first talk, or is it Impella unloading only at your center? And what are the timings of the LV vent? Because you also mention in your paper that not everybody gets ECMO Impella at the same time. Maybe we can sleep at night and wake up in the morning and do the Impella 5.0?

Dr Dagher. Thank you for your question. So, regarding the venting strategy, most of the patients had LV venting. And so I do mention it—I mentioned it in the manuscript, but so we had a balloon pump, we had a LV pigtail drainage catheter, we had a septostomy, so transeptal. The vast majority of patients on VA-ECMO had a venting strategy. Most often, it was a balloon pump, because it was actually already in. We did not have a VA-ECMO strategy. So, there was no combination. There was no patient who had an Impella as a venting strategy. And then, in terms of—so timing of the venting. So we typically do it in, especially in patients who have LV dilatation, pulmonary edema, high LV end-diastolic pressure, or no aortic valve opening. Does it mostly happen

at night? I don't know. But it's something, again it's an ongoing process. It's ongoing evaluation, discussion, again, to highlight the importance of multidisciplinary team, and serial assessments, reevaluations of the patient.

Dr Masood. So not everybody gets a mechanical LV unloading?

Dr Dagher. No. Not everybody.

Dr Masood. Got it.

Dr Dagher. The vast majority did.

Dr Masood. Got it. Congratulations and thank you for your answers.

Dr Dagher. Thank you so much. Thank you.

Unidentified Speaker 1. This paper's open for discussion.

Unidentified Speaker 2. Thank you. Very nice paper. Just looking forward in your decision-making process of the shock team, would you consider right ventricular assist device ECMO support, right ventricular assist device ECMO plus Impella instead of using VA-ECMO?

Dr Dagher. That's a very good question. So, with the development of new technology, we see new combinations of support. At our institution, we wouldn't typically do that. We would favor VA-ECMO. Thank you.

Unidentified Speaker 3. Hello. Thanks very much for your presentation. I guess one question for you, if you can kind of shed some light on is did you have data on the original sort of intention of the therapy? Because in some of these circumstances, for instance, you have someone in cardiogenic shock, where you try an Impella strategy but then their lactase continues to go up. And then, you're then crossing over to the VA-ECMO arm. I think that would be really helpful to better understand the original sort of intention to therapy, and then what happens with those patients. And then, certainly as a bridge strategy, looks like some of your patients got transplanted, for instance. Where your kind of, your thought process, about trying a therapy, maybe bridging them to transplant, or bridging them to VA-ECMO, ventricular assist device, those things, I think, would be really helpful to try to better understand kind of this treatment algorithm. Thank you.

Dr Dagher. Thank you. So, yeah. We might find a way to sort of include in the manuscript or get a sense of the treatment. Thank you.

Unidentified Speaker 4. So based on what your experience is, what do you think is a role of Impella CP? Should we just take it off the shelf? It should not be there anymore?

Dr Dagher. We're in a cardiac surgery congress. Maybe it would have been different if we had combined cardiology-cardiac surgery.

Unidentified Speaker 1. Great. I'll let my colleague, Dr LeMarsh, senior author, make the final comment on this paper.

Dr LeMarsh. Thank you. Excellent presentation. Thank you. To that last comment, one very interesting thing we saw, and that's why we had to evaluate the strategy as an intention to treat, when we did put Impella in, and we needed to escalate, these are the strategies in which we had the longest organ suffering and complication, access-site complication, because of the rush emergency insertion of VA-ECMO as a second support. So, this is why in our local [inaudible], which is at its eighth iteration, we are going toward an earlier, heavier support to make sure we don't undersupport patients. And deescalation is way less morbid than escalation, in our experience.

Unidentified Speaker 1. Great. Thank you.

Dr Dagher. Thank you.

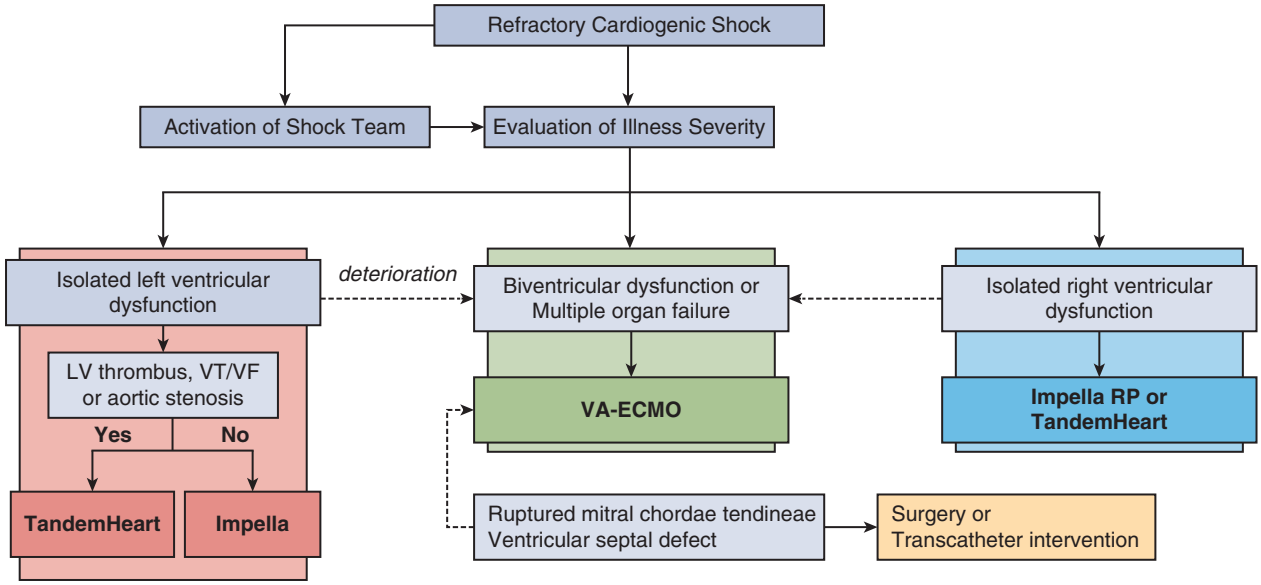


FIGURE E1. Current local algorithm used for mechanical circulatory support device selection in patients with refractory cardiogenic shock. *LV*, Left ventricular; *VT*, ventricular tachycardia; *VF*, ventricular fibrillation; *VA-ECMO*, venoarterial extracorporeal membrane oxygenation.

TABLE E1. Thirty-day survival of patients with cardiogenic shock supported with Impella CP and Impella 5.0, grouped according to shock phenotype

n/N (%)	Isolated LV dysfunction	Biventricular dysfunction or multiple organ failure
Impella CP	1/7 (14)	0/4 (0)
Impella 5.0	5/6 (83)	1/7 (14)

LV, Left ventricular.

TABLE E2. Thirty-day survival of patients with cardiogenic shock supported with Impella CP/5.0 and VA-ECMO, grouped according to the device type and SCAI shock stage

n/N (%)	SCAI stage C	SCAI stage D	SCAI stage E
VA-ECMO	2/5 (40)	6/15 (40)	8/31 (26)
Impella CP	1/3 (33)	0/6 (0)	0/2 (0)
Impella 5.0	4/4 (100)	2/7 (29)	0/2 (0)

SCAI, The Society for Cardiovascular Angiography and Interventions; *VA-ECMO*, venoarterial extracorporeal membrane oxygenation.