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Original Research

Feasibility and Outcomes of a Cardiovascular Medicine Inclusive Extracorporeal Membrane Oxygenation (ECMO) Service

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ABSTRACT

Background: There has been a significant increase in the utilization of venoarterial extracorporeal membrane oxygenation (VA-ECMO) in recent years. Cardiothoracic surgery teams have historically led VA-ECMO care teams, with little data available on alternative care models.

Methods: We performed a retrospective review of a cardiovascular medicine inclusive VA-ECMO service, analyzing patients treated with peripheral VA-ECMO at a large quaternary care center from 2018 to 2022. The primary outcome was death while on VA-ECMO or within 24 hours of decannulation. Univariate and multivariate analyses were used to identify predictors of the primary outcome.

Results: Two hundred forty-four patients were included in the analysis (median age 61 years; 28.7% female), of whom 91.8% were cannulated by interventional cardiologists, and 84.4% were managed by a cardiology service comprised of interventional cardiologists, cardiac intensivists or advanced heart failure cardiologists. Indications for VA-ECMO included acute myocardial infarction (34.8%), decompensated heart failure (30.3%), and refractory cardiac arrest (10.2%). VA-ECMO was utilized during cardiopulmonary resuscitation in 26.6% of cases, 48% of which were peri-procedural arrest. Of the patients, 46% survived to decannulation, the majority of whom were decannulated percutaneously in the cardiac catheterization laboratory. There was no difference in survival following cannulation by a cardiac surgeon vs interventional cardiologist (50% vs 45%; $P = .90$). Complications included arterial injury (3.7%), compartment syndrome (4.1%), cannulation site infection (1.2%), stroke (14.8%), acute kidney injury (52.5%), access site bleeding (16%) and need for blood transfusion (83.2%). Elevated baseline lactate (odds ratio [OR], 1.13 per unit increase) and sequential organ failure assessment score (OR, 1.27 per unit increase) were independently associated with the primary outcome. Conversely, an elevated baseline survival after VA ECMO score (OR, 0.92 per unit increase) and 8-hour serum lactate clearance (OR, 0.98 per % increase) were independently associated with survival.

Conclusions: The use of a cardiovascular medicine inclusive ECMO service is feasible and may be practical in select centers as indications for VA-ECMO expand.

Introduction

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) provides temporary cardiopulmonary support to patients with circulatory collapse and is utilized both as a bridge to definitive therapy and recovery. There has been a significant increase in the utilization of ECMO over the past decade.[1] Sauer et al[2] reported a 422% increase in the use of ECMO from 2006 to 2011 in the United States whereas Becher et al[3] reported a similar 30-fold increase from 2007 to 2015 in Germany.

Abbreviations: AKI, acute kidney injury; AMI, acute myocardial infarction; CA, cardiac arrest; ECMO, extracorporeal membrane oxygenation; HF, heart failure; MCS, mechanical circulatory support; OR, odds ratio; SAVE, survival after VA ECMO; SOFA, sequential organ failure assessment; VA-ECMO, venoarterial extracorporeal membrane oxygenation.

Keywords: cardiogenic shock; extracorporeal membrane oxygenation; mechanical circulatory support.

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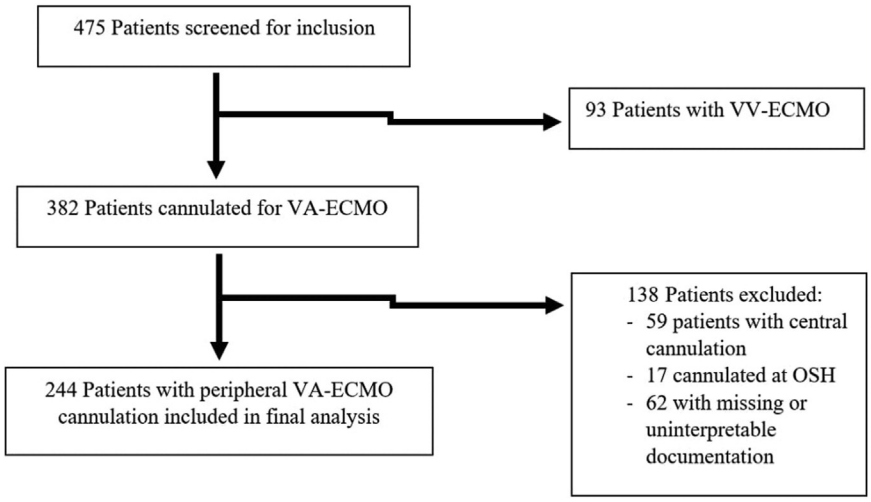


Figure 1.
Patient screening and inclusion. OSH, outside hospital; VA-ECMO, venoarterial extracorporeal membrane oxygenation; VV-ECMO, veno-venous extracorporeal membrane oxygenation.

The clinical utility of ECMO has expanded well beyond the operating room. ECMO is commonly utilized in the management of patients with cardiogenic shock, including those with acute myocardial infarction (AMI), cardiac arrest (CA), decompensated heart failure, and pulmonary embolism.[4–7] With the growing indications and use of ECMO, health care systems may benefit by diversifying the clinicians providing ECMO care including granting privileges to cardiovascular-medicine physicians to implant, manage, and explant ECMO.

Our report highlights the experience of a cardiovascular medicine inclusive VA-ECMO service within a larger comprehensive acute mechanical circulatory support (MCS) program. Since the inclusion of cardiologists in our ECMO program in 2017, our program has seen steady growth which can serve as a blueprint for select centers.

Methods

Study design and population

We performed a retrospective review of patients admitted to a quaternary care center from January 2018 through September 2022. All patients admitted to the cardiac intensive care unit on an ECMO circuit were reviewed for inclusion in this analysis. Patients were included if they were $\geq$18 years old and required peripheral VA-ECMO. Patients were excluded if ECMO cannulation occurred at an outside hospital, if ECMO cannulation occurred via central access, if patients died before being admitted to the cardiac intensive care unit, or if there were missing data regarding the indication for ECMO, procedural details, or outcomes.

Data collection and missing data

All data were gathered through chart review and manual abstraction from the electronic health record. Baseline demographics, comorbidities, severity scores, and outcomes were evaluated by the research team and adjudicated by study investigators. Information on ECMO cannulation, including indication, procedural details, and complications, was manually abstracted from procedural documentation and follow-up.

Multiple imputation was used for specific missing variables and values in order to calculate baseline survival after VA ECMO (SAVE) and sequential organ failure assessment (SOFA) scores, as well as to calculate 8-hour lactate clearance. The following laboratory values required imputation for missing data points: baseline creatinine (2/244 patients), baseline bicarbonate (2/244 patients), baseline bilirubin (21/244 patients), baseline platelet count (4/244 patients), baseline serum lactate (33/244 patients), post-ECMO cannulation 0-hour (12/244 patients) and 8-hour (28/244 patients) lactate levels.

Study definitions and calculations

The primary end point of "ECMO death" was defined as death while on ECMO or within 24 hours of decannulation. This end point allowed better characterization of ECMO management characteristics including ECMO decannulation. Secondary end points included inpatient death, defined as any death occurring during the index hospitalization. Death postdischarge was defined as death from any cause after discharge from the index hospitalization. Acute kidney injury (AKI), defined by the Kidney Disease Improving Global Outcomes 2012 guidelines, based on creatinine elevation and a reduction in urine output, was recorded as mL/kg/h. Thrombocytopenia was defined as a drop in platelets by $\geq$50% of baseline or to a nadir of $<$100,000/μL. ECMO days were calculated from the day of cannulation to decannulation or death. Hospital length of stay was calculated as time from index admission to discharge or death.

Statistical analysis

Continuous variables were described by medians (with interquartile ranges) and categorical variables by frequency rates and percentages. The Mann-Whitney *U* test or *t* test was used for continuous variables, whereas χ^2 or Fisher exact tests were used for categorical variables. A univariate analysis was performed to determine the association of underlying risk factors with the primary outcome of ECMO death. A multivariate logistic regression analysis was then performed with ECMO death as the dependent variable. The risk factors chosen for the model were based on association with the dependent variable by univariate analysis with a $P < .05$ on 2-sided alpha testing. The adjusted odds ratio (OR) and CI were reported for each risk factor. Kaplan-Meier analysis was used to analyze 30-day mortality depending on the indication for VA-ECMO. SPSS Statistics software (IBM) was used for imputation of missing variables and all statistical analysis.

Results

Baseline demographics, indications, medical history

A total of 475 patients were screened for inclusion and 244 patients were included in the final analysis, 132 (54%) patients died while on

Table 1. Baseline demographics, ECMO indication, and medical history.

Variable	Overall (N = 244)	ECMO death (n = 132)	Survival to decannulation (n = 112)	*P* value
Baseline demographics				
Age, y	61.0 (49.8-69.0)	62.0 (53.5-69.3)	58.0 (47.8-68.0)	.139
Body mass index, kg/m^2	26.7 (23.1-31.4)	27.1 (23.3-31.7)	26.5 (22.9-30.8)	.661
Male sex	174.0 (71.3)	97.0 (73.5)	77.0 (68.8)	.417
Ethnicity				.088
White	142.0 (58.2)	72.0 (54.5)	70.0 (62.5)	
Black	71.0 (29.1)	39.0 (29.5)	32.0 (28.6)	
Latino	3.0 (1.2)	2.0 (1.5)	1.0 (0.9)	
Other	28.0 (11.5)	19.0 (14.4)	9.0 (8.0)	
Index hospitalization				
Outside hospital transfer	131.0 (53.7)	73.0 (55.3)	58.0 (51.8)	.585
ECMO indication[b]				.356
Acute myocardial infarction	85 (35.0)	48 (36.4)	37 (33.0)	
Heart failure	74 (30.3)	42 (31.8)	32 (28.6)	
Refractory VT/VF	25 (10.2)	12 (9.09)	13 (11.6)	
Acute valvular disease	15 (6.1)	4 (3.0)	11 (9.8)	
SHD procedure complication	15 (6.1)	8 (6.1)	7 (6.3)	
PCI/LHC complication	6 (2.5)	3 (2.3)	3 (2.7)	
ECMO implanter				.910
Interventional cardiologist	222.0 (91.0)	121 (91.7)	101 (90.2)	
Cardiac surgeon	22.0 (9.0)	11 (8.3)	11 (9.8)	
Primary management team				.638
Interventional cardiology	166.0 (68.0)	94.0 (71.2)	72.0 (64.3)	
Heart failure	40.0 (16.4)	16.0 (12.1)	24.0 (21.4)	
Cardiac surgery/anesthesia	38.0 (15.6)	22.0 (16.7)	16.0 (14.3)	
Cardiac arrest	127.0 (52.0)	82.0 (62.1)	45.0 (40.2)	.001[d]
Arrest site				.002[d]
Out-of-hospital	16.0 (6.6)	11.0 (8.3)	5.0 (4.5)	
Emergency department	4.0 (1.6)	3.0 (2.3)	1.0 (0.9)	
In-hospital	107.0 (43.9)	68.0 (51.5)	39.0 (34.8)	
Arrest rhythm				<.001[d]
VF	35.0 (14.3)	21.0 (15.9)	14.0 (12.5)	
VT	13.0 (5.3)	7.0 (5.3)	6.0 (5.4)	
Pulseless electrical activity	67.0 (27.5)	48.0 (36.4)	19.0 (17.0)	
Asystole	9.0 (3.7)	5.0 (3.8)	4.0 (3.6)	
Total CPR time, min	20.0 (10.0-30.0)	20.0 (10.0-40.0)	15.0 (10.0-25.0)	.043[d]
ECPR[c]	65.0 (26.6)	44.0 (33.3)	21.0 (18.8)	.010[d]
Primary cardiac arrest	23.0 (9.4)	18.0 (13.6)	5.0 (4.5)	
Procedural complication	31.0 (12.7)	16.0 (12.1)	15.0 (13.4)	
Medical history				
Hypertension	171.0 (70.1)	90.0 (68.2)	81.0 (72.3)	.484
Diabetes mellitus	87.0 (35.7)	46.0 (34.8)	41.0 (36.6)	.776
COPD	23.0 (9.4)	12.0 (9.1)	11.0 (9.8)	.846
On home oxygen	9.0 (3.7)	8.0 (6.1)	1.0 (0.9)	.033[d]
Cirrhosis	7.0 (2.9)	4.0 (3.0)	3.0 (2.7)	.870
Chronic kidney disease	63.0 (25.8)	32.0 (24.2)	31.0 (27.7)	.543
On dialysis	9.0 (3.7)	3.0 (2.3)	6.0 (5.4)	.204
Venous thromboembolism	26.0 (10.7)	13.0 (9.8)	13.0 (11.6)	.659
Tobacco use	85.0 (34.8)	46.0 (34.8)	39.0 (34.8)	.996
Coronary artery disease	109.0 (44.7)	58.0 (43.9)	51.0 (45.5)	.804
Prior MI	61.0 (25.0)	34.0 (25.8)	27.0 (24.1)	.768
Prior PCI	51.0 (20.9)	26.0 (19.7)	25.0 (22.3)	.617
Prior CABG	32.0 (13.1)	17.0 (12.9)	15.0 (13.4)	.906
Arrhythmia	62.0 (25.4)	29.0 (22.0)	33.0 (29.5)	.182
VT/VF	17.0 (7.0)			
Atrial fibrillation	45.0 (18.4)			
SSS/CHB	7.0 (2.9)			
ICD implanted	32.0 (13.1)	17.0 (12.9)	15.0 (13.4)	0.906
MCS prior to index event[a]	38.0 (15.6)	24.0 (18.2)	14.0 (12.5)	0.224
Intraaortic balloon pump	9.0 (3.7)			
Impella	24.0 (9.8)			
VV-ECMO	1.0 (0.4)			
Left ventricular assist device	4.0 (1.6)			

Values are median (IQR) or n (%).

BP, blood pressure; CABG, coronary artery bypass graft; CHB, complete heart block; CICU, cardiac intensive care unit; COPD, chronic obstructive pulmonary disease; CPR, cardiopulmonary resuscitation; DM, diabetes mellitus; ECPR, extracorporeal membrane oxygenation (ECMO) cardiopulmonary resuscitation; HF, heart failure; ICD, implantable cardioverter defibrillator; MCS, mechanical support; MI, myocardial infarction; PCI, percutaneous coronary intervention; SHD, structural heart disease; SICU, surgical intensive care unit; SSS, sick sinus syndrome; VF, ventricular fibrillation; VT, ventricular tachycardia; VV-ECMO, veno-venous extracorporeal membrane oxygenation.

[a] Highest recorded value prior to VA ECMO cannulation. [b] See Supplemental Table S1 for the full list of indications. [c] See Supplemental Table S2 for the full list of ECPR indications. [d] Significant *P* values.

Table 2. Pre-ECMO laboratory and hemodynamic assessment, and severity scores.

Variable	Overall (N = 244)	ECMO death (n = 132)	Survival to decannulation (n = 112)	*P* value
Pre-ECMO labs				
Creatinine, mg/dL[a,b]	1.7 (1.2-2.5)	1.8 (1.2-2.5)	1.6 (1.1-2.5)	.933
AKI prior to VA ECMO	142.0 (58.2)	79.0 (59.8)	63.0 (56.3)	.572
Bicarbonate, mEq/L[a]	20.0 (16.0-24.0)	19.0 (14.5-24.0)	21.0 (17.0-25.0)	.221
Bilirubin, mg/dL [a,b]	1.2 (0.6-2.3)	1.2 (0.7-2.4)	1.0 (0.6-2.2)	.109
Lactate, mmol/L [a,b]	4.1 (1.9-9.7)	6.6 (2.8-12.0)	2.5 (1.6-6.0)	<.001[e]
Platelet count, K/μL [a,b]	183.5 (130.0-253.3)	169.5 (118.5-247.0)	197.0 (150.0-258.3)	.010[e]
PaO_2, mm Hg [a,b]	113.0 (78.8-246.0)	106.5 (69.0-198.0)	128.0 (84.9-284.0)	.096
Pre-ECMO imaging and hemodynamics				
Echo prior to ECMO				
Baseline LVEF, %	43.0 (20.0-60.0)	45.0 (22.0-60.0)	40.5 (20.0-60.0)	.509
MR (mod-severe)	68.0 (27.9)	23.0 (17.4)	45.0 (40.2)	.269
MS (mod-severe)	11.0 (4.5)	5.0 (3.8)	6.0 (5.4)	.727
TR (mod-severe)	51.0 (20.9)	26.0 (19.7)	25.0 (22.3)	.946
AI (mod-severe)	14.0 (5.7)	4.0 (3.0)	10.0 (8.9)	.087
AS (mod-severe)	24.0 (9.8)	12.0 (9.1)	12.0 (10.7)	.951
LA dilation	69.0 (28.3)	33.0 (25.0)	36.0 (32.1)	.557
RV dysfunction	86.0 (35.2)	46.0 (34.8)	40.0 (35.7)	.449
LVED diameter, cm	5.1 (4.5-6.1)	4.8 (4.1-6.0)	5.3 (4.8-6.2)	.101
Estimated PAP, mm Hg	42.0 (29.0-55.0)	42.5 (32.8-57.3)	41.0 (26.0-53.0)	.050[e]
TAPSE, cm	1.7 (1.3-2.2)	1.6 (1.2-2.1)	1.7 (1.4-2.3)	.298
RHC hemodynamics peri-ECMO[c]	215.0 (88.1)	—	—	—
RA mean, mm Hg	15.0 (10.0-20.0)	14.0 (9.0-18.0)	17.0 (11.3-22.0)	.115
PA systolic, mm Hg	51.5 (40.3-64.3)	54.0 (42.0-65.0)	51.0 (39.0-62.0)	.959
PA diastolic, mm Hg	25.5 (20.0-30.8)	25.0 (20.0-32.0)	26.0 (20.0-30.0)	.785
PA mean, mm Hg	35.0 (28.3-44.0)	36.0 (28.0-45.0)	34.0 (29.0-42.0)	.765
PCWP mean, mm Hg	24.5 (16.0-30.8)	24.0 (16.0-30.0)	25.0 (17.0-31.0)	.801
Mixed venous O_2, %	54.0 (44.0-60.5)	52.0 (42.0-61.0)	55.5 (45.8-60.0)	.605
Cardiac output, L/min	4.0 (3.0-5.1)	3.8 (3.1-5.5)	4.4 (2.9-5.1)	.349
Cardiac index, L/min/m^2	1.8 (1.5-2.3)	1.7 (1.5-2.5)	2.0 (1.4-2.3)	.682
Intubated prior to VA ECMO	209.0 (85.7)	124.0 (93.9)	85.0 (75.9)	<.001[e]
PIP prior to VA ECMO, cm H_2O	24.0 (20.0-30.0)	25.0 (21.0-31.0)	23.0 (18.3-27.0)	.014[e]
Systolic BP, mm Hg[a]	90.5 (79.0-107.0)	87.5 (76.0-105.0)	93.5 (83.8-109.0)	.050[e]
Diastolic BP, mm Hg[a]	59.0 (49.0-68.0)	57.5 (49.0-65.0)	63.0 (50.8-69.3)	.152
Requiring vasopressor	196.0 (80.3)	115.0 (87.1)	81.0 (72.3)	.004[e]
Number of vasopressors required				<.001[e]
0	48.0 (19.7)	17.0 (12.9)	31.0 (27.7)	
1	78.0 (32.0)	38.0 (28.8)	40.0 (35.7)	
2	59.0 (24.2)	38.0 (28.8)	21.0 (18.8)	
3	54.0 (22.1)	34.0 (25.8)	20.0 (17.9)	
4	5.0 (2.0)	5.0 (3.8)	0 (0)	
Requiring inotropic support	73.0 (29.9)	36.0 (27.3)	37.0 (33.0)	.329
Dobutamine	47.0 (19.3)	26.0 (19.7)	21.0 (18.8)	
Milrinone	26.0 (10.7)	10.0 (7.6)	16.0 (14.3)	
Severity scores				
SAVE score[a,d]	0.0 (–4.0 to 3.0)	–2.0 (–6.0 to 2.0)	0.5 (–4.0 to 4.3)	<.001[e]
SOFA score[a,d]	13.0 (10.0-16.0)	15.0 (12.0-17.0)	12.0 (8.0-14.0)	<.001[e]

Values are median (IQR) or n (%).

AI, aortic insufficiency; AKI, acute kidney injury; AS, aortic stenosis; LA, left atrium; LVED, left ventricular end diastolic; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; MS, mitral stenosis; PA, pulmonary artery; PaO_2, partial pressure of arterial oxygen; PAP, pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PI, pulmonary insufficiency; RA, right atrium; RHC, right heart catheterization; RV, right ventricle; SaO_2, oxygen saturation; SAVE, survival after VA ECMO; SOFA, sequential organ failure assessment; TAPSE, tricuspid annular plane systolic excursion; TR, tricuspid regurgitation; TS, tricuspid stenosis; VA ECMO, venoarterial extracorporeal membrane oxygenation.

[a] Highest or worst recorded value prior to VA ECMO cannulation. [b] Data available for baseline creatinine (2/244 patients), baseline bicarbonate (2/244 patients), baseline bilirubin (21/244 patients), baseline platelet count (4/244 patients), baseline serum lactate (33/244 patients), post-ECMO cannulation 0-h (12/244 patients) and 8-h (28/244 patients). [c] Values obtained prior to, during, or immediately after ECMO cannulation, to guide clinical decision making for device selection lactate levels. Multiple imputation was used for missing variables as highlighted in the methods section. [d] SAVE and SOFA scores calculated with values that required imputation for missing variables as highlighted in the methods section. [e] Significant *P* values.

ECMO, and 112 (46%) survived 24 hours from decannulation. The primary reasons for exclusion were central ECMO cannulation and missing or incomplete data. Figure 1 includes the information on patient screening, inclusion, and exclusion.

Our patient cohort comprised 71.3% males and 58.2% White patients, with a median age of 61 years (IQR, 49.8-69.0) and a BMI of 26.7 kg/m^2 (IQR, 23.1-31.4). Indications for ECMO included AMI (34.8%), heart failure (HF) (30.3%), refractory ventricular tachycardia (VT)/ventricular fibrillation (VF) (10.2%), valvular disease (7.0%), structural heart disease complication (5.7%), and complication from a heart catheterization (4.9%). Patients frequently experienced CA (52%), with a median cardiopulmonary resuscitation time of 20 minutes (IQR, 10-30). ECMO was utilized for cardiopulmonary resuscitation in 26.6% of patients, including 9.4% for primary CA, and 12.7% for periprocedural arrest. A total of 224 (91.8%) patients were cannulated by an interventional cardiologist and 206 (84.4%) patients were managed by a primary cardiology service.

The most prevalent comorbidities included hypertension (70.1%), diabetes mellitus (35.7%), chronic kidney disease (25.8%), and prior myocardial infarction (25%), with 20.9% having received prior percutaneous coronary intervention and 13.1% having received prior CABG. Additionally, 25.4% of patients had a history of arrhythmia (7.0% VT/VF, 18.4% atrial fibrillation, 2.9% sick sinus syndrome/complete heart block),

Table 3. VA-ECMO cannulation procedural information.

Variable	Overall (N = 244)	ECMO death (n = 132)	Survival to decannulation (n = 112)	*P* value
LV venting	158.0 (64.7)	79 (59.9)	79 (70.5)	0.210
LAVA	43.0 (17.6)	15.0 (11.4)	28.0 (25.0)	0.005[a]
LV Impella	115.0 (47.1)	64.0 (48.5)	51.0 (45.5)	0.647
Venous cannula location				0.592
RFV	170.0 (69.7)	94.0 (71.2)	76.0 (67.9)	
LFV	68.0 (27.9)	35.0 (26.5)	33.0 (29.5)	
RIJV	6.0 (2.5)	3.0 (2.3)	3.0 (2.7)	
Arterial cannula location				0.266
RFA	131.0 (53.7)	70.0 (53.0)	61.0 (54.5)	
LFA	110.0 (45.1)	59.0 (44.7)	51.0 (45.5)	
Axillary	3.0 (1.2)	3.0 (2.3)	0 (0)	

Values are n (%).
LAVA, left-atrial venoarterial; LFA, left femoral artery; LFV, left femoral vein; LV, left ventricle; RFA, right femoral artery; RFV, right femoral vein; RIJV, right internal jugular vein; VA ECMO, venoarterial extracorporeal membrane oxygenation.
[a] Significant *P* values.

and 13.1% had an implantable cardioverter defibrillator implanted prior to the index hospitalization. Patients were frequently transferred from another health care facility (53.7%) and 15.6% had some form of MCS prior to ECMO cannulation (3.7% intraaortic balloon pump, 9.8% Impella, 0.4% veno-venous extracorporeal membrane oxygenation, 1.6% durable left ventricular assist device). Table 1 includes baseline demographics, indications for ECMO, and past medical history of the cohort. Supplemental Tables S1 and S2 expand on the indications for ECMO and the use of ECMO in the peri-arrest setting, respectively.

Pre-ECMO laboratory values, hemodynamics, and severity scores

Prior to ECMO cannulation, baseline laboratory markers and hemodynamic parameters were evaluated. Patients frequently presented with AKI prior to ECMO (58.2%), with a median creatinine of 1.7 mg/dL (IQR, 1.2-2.5). Baseline lactate was elevated at 4.1 mmol/L (IQR, 1.9-9.7). Baseline echocardiogram prior to ECMO cannulation was available in 70.5% of patients with a baseline LVEF of 43% (IQR, 20-60).

Patients were frequently intubated (85.7%), 80.3% required vasopressors, with 46.3% of patients requiring 2 or more vasopressors, and 29.9% required inotropes.

The median SAVE score prior to VA-ECMO was 0.0 (IQR, –4.0 to 3.0), which correlates to predicted in-hospital mortality of 58%. Similarly, median baseline SOFA score was 13.0 (IQR, 10.0-16.0) which correlates to a predicted in-hospital mortality of >95%. Table 2 highlights the pre-VA-ECMO laboratory values, hemodynamic parameters, and severity scores.

Procedural characteristics

Patients were frequently treated using a venting strategy (64.7%), 17.6% via left-atrial VA-ECMO cannulation, and 47.1% via additional insertion of an Impella. The majority of patients received femoral vein (97.6%) and femoral artery cannulation (98.8%). Table 3 highlights the technical and procedural characteristics of ECMO cannulation.

Successful decannulation from ECMO occurred in 115 (47.1%) patients. Of the 115 decannulated, 75% were performed percutaneously with Perclose (55) or Manta (31), whereas 15 (13%) were performed surgically, and 14 (5.7%) cases lacked documentation on closure technique. Pre-Perclose was used in 29 patients. "Dry" closure technique using balloon tamponade from another access occurred in 43 patients. Table 4 highlights details of decannulation.

Complications

Complication rates postcannulation were similar between patients who died while on ECMO and those surviving decannulation, and included 3.7% arterial injury, 11.1% limb ischemia, 4.1% compartment syndrome, and 1.2% cannulation site infection. Bleeding from the access site occurred in 16% of patients and overall 83.2% of patients required blood transfusion. Thrombocytopenia occurred in 84.8% of patients and 26.2% of patients receiving platelet transfusion. A total of 36 (14.8%) patients developed stroke while on ECMO including 6.6% hemorrhagic stroke, and 8.2% ischemic stroke. The incidence of AKI post-ECMO was 52.5%, with 22.5% of patients requiring renal replacement therapy for renal failure. Complications during the hospitalization while on ECMO are highlighted in Table 5.

Outcomes

The median post-ECMO 0-hour lactate level was 7.0 mmol/L (IQR, 2.8-12.4), with a post-ECMO 8-hour lactate level of 4.1 mmol/L (IQR, 1.9-9.3), and 8-hour lactate clearance of 22.3% (1.1-42.4).

Table 4. Decannulation.

Variable	Overall (N = 244)	ECMO death (n = 132)	Survival to decannulation (n = 112)	*P* value
Decannulated	115.0 (47.1)	13.0 (9.8)	102.0 (91.1)	<.001[a]
Decannulation closure used	115.0 (47.1)	10 (7.6)	78 (69.6)	<.001[a]
Perclose	55.0 (22.5)	6.0 (4.5)	42.0 (37.5)	
MANTA	31.0 (12.7)	3.0 (2.3)	22.0 (19.6)	
Surgical	15.0 (6.1)	1.0 (0.8)	14.0 (12.5)	
Undocumented	14.0 (5.7)			
Dry closure technique used	43.0 (17.6)	8.0 (6.1)	35.0 (31.3)	
Pre-Perclose used	29.0 (11.9)	14.0 (10.6)	15.0 (13.4)	.505

Values are n (%).
[a] Significant *P* values.

Table 5. Complications.

Complications	Overall (N = 244)	ECMO death (n = 132)	Survival to decannulation (n = 112)	*P* value
Arterial injury	9.0 (3.7)	5.0 (3.8)	4.0 (3.6)	.929
Dissection	6.0 (2.5)	4.0 (3.0)	2.0 (1.8)	–
Pseudoaneurysm	2.0 (0.8)	0.0 (0.0)	2.0 (1.8)	–
Retroperitoneal bleed	1.0 (0.4)	1.0 (0.8)	0 (0)	–
Venous injury	16.0 (6.6)	11.0 (8.3)	5.0 (4.5)	.225
Dissection	1.0 (0.4)	0.0 (0.0)	1.0 (0.9)	–
Hematoma	15.0 (6.1)	11.0 (8.3)	4.0 (3.6)	–
Limb ischemia	27.0 (11.1)	19.0 (14.4)	8.0 (7.1)	.073
Compartment syndrome	10.0 (4.1)	7.0 (5.3)	3.0 (2.7)	.305
Return to cath lab	33.0 (13.5)	18.0 (13.6)	15.0 (13.4)	.956
Bleeding from access	39.0 (16.0)	24.0 (18.2)	15.0 (13.4)	.311
Thrombocytopenia	207.0 (84.8)	109.0 (82.6)	98.0 (87.5)	.287
Required platelet transfusion	64.0 (26.2)	29.0 (22.0)	35.0 (31.3)	.101
Required pRBC transfusion	203.0 (83.2)	103.0 (78.0)	100.0 (89.3)	.019[a]
Infected cannulation site	3.0 (1.2)	0 (0)	3.0 (2.7)	.059
Bacteremia	14.0 (5.7)	6.0 (4.5)	8.0 (7.1)	.387
Need for wound vac placement	10.0 (4.1)	5.0 (3.8)	5.0 (4.5)	.792
Stroke	36.0 (14.8)	17.0 (12.9)	19.0 (17.0)	.372
Hemorrhagic	16 (6.6)	—	—	–
Ischemic	20.0 (8.2)	—	—	–
AKI post VA ECMO	128.0 (52.5)	80.0 (60.6)	48.0 (42.9)	.006[a]
Required inpatient RRT	55.0 (22.5)	28.0 (21.2)	27.0 (24.1)	.591

Values are n (%).
AKI, acute kidney injury; pRBC, packed red blood cells; RRT, renal replacement therapy; SAH, subarachnoid hemorrhage; SDH, subdural hematoma; vac, vacuum; VA ECMO, venoarterial extracorporeal membrane oxygenation.
[a] Significant *P* values.

The median days on VA-ECMO was 4.0 days (IQR, 2.0-8.0). The median hospital length of stay was 10.5 days (IQR, 3.0-23.8). The 30-day mortality was 66.8%, and 90-day mortality was 70.9%. Overall, in-hospital mortality was 69.7%. Table 6 includes post-ECMO outcomes.

Predictors of outcomes

Factors associated with ECMO death on univariate analysis included the following: occurrence of CA prior to cannulation ($P = .001$); past medical history of chronic respiratory failure on home oxygen ($P = .033$); baseline serum lactate level ($P < .001$) and platelet count ($P = .010$); intubation prior to cannulation ($P < .001$); vasopressor use ($P = .004$); SAVE score ($P < .001$) and SOFA score ($P < .001$); major bleeding requiring blood transfusion ($P = .019$); AKI postcannulation ($P = .006$); and postcannulation 8-hour serum lactate clearance ($P = .002$).

Elevated baseline lactate (OR, 1.13 per mmol/L increase; 95% CI, 1.04-1.23; $P = .003$) and elevated baseline SOFA scores (OR, 1.27 per unit increase; 95% CI, 1.15-1.40; $P < .001$) were independently associated with the primary end point on multivariate logistic regression analysis. Conversely, elevated baseline SAVE score (OR, 0.923 per unit increase; 95% CI, 0.859-0.993; $P = .031$) and 8-hour serum lactate clearance (OR, 0.987 per % increase, 95% CI, 0.979-0.994, $P = .001$) were independently associated with survival. Table 7 demonstrates all factors included in the multivariate regression analysis.

Kaplan Meier analysis (Figure 2) demonstrates no significant difference in 30-day survival based on indication for VA-ECMO when comparing the major subgroups of AMI and HF-related cardiogenic shock.

Discussion

Our analysis highlights several important findings: (1) the majority of patients treated with peripheral ECMO were cannulated and decannulated by an interventional cardiologist demonstrating the

Table 6. Outcomes.

Outcomes	Overall (N = 244)	ECMO death (n = 132)	Survival to decannulation (n = 112)	*P* value
0-h lactate post VA ECMO	7.0 (2.8-12.4)	10.3 (5.2-14.8)	4.1 (2.0-8.5)	<.001[b]
8-h lactate post VA ECMO	4.1 (1.9-9.3)	8.4 (3.3-14.9)	2.7 (1.4-4.9)	<.001[b]
8-h lactate clearance, %	22.3 (1.1-42.4)	13.5 (–7.5 to 36.2)	33.3 (7.8-49.3)	.002[b]
24 h lactate post VA ECMO	1.9 (1.2-4.2)	3.9 (2.0-8.8)	1.3 (1.0-2.2)	<.001[b]
48 h lactate post VA ECMO	1.4 (1.0-2.2)	2.2 (1.4-3.1)	1.2 (0.9-1.6)	<.001[b]
72 h lactate post VA ECMO	1.2 (0.8-1.8)	1.7 (1.2-3.2)	1.0 (0.8-1.4)	<.001[b]
Total VA-ECMO d	4.0 (2.0-8.0)	2.0 (2.0-5.3)	6.0 (4.0-11.0)	<.001[b]
Hospital LOS, d	10.5 (3.0-23.8)			
Inpatient death[a]	170.0 (70.0)			
Death post discharge	4.0 (1.6)			
30-d survival[a]	81.0 (33.2)			
90-d survival[a]	71.0 (29.1)			
6-mo survival[a]	62.0 (25.4)			
1-y survival[a]	54.0 (22.1)			

Values are median (IQR) or n (%).
LOS, length of stay; VA ECMO, venoarterial extracorporeal membrane oxygenation.
[a] 1 patient still admitted at the time of data collection and analysis. [b] Significant *P* values.

Table 7. Multivariate logistic regression analysis of risk factors for ECMO death.

Variable	Adjusted odds ratio (95% CI)	*P* value
On home oxygen prior to admit	10.47 (0.8768-125.0555)	.063
Initial serum lactate (mmol/L)	1.13 (1.0416-1.2287)	.003[a]
Initial platelet count (1000)	1.00 (0.99-1.00)	.067
Cardiac arrest	1.56 (0.13-19.20)	.728
Arrest site	1.04 (0.47-2.32)	.920
Arrest rhythm	0.84 (0.51-1.38)	.488
Total CPR time (min)	1.02 (0.99-1.05)	.181
Intubated prior to VA ECMO	2.18 (0.57-8.31)	.252
Initial SBP prior to VA ECMO	1.00 (0.99-1.02)	.629
Required vasopressors prior to VA ECMO	1.12 (0.38-3.32)	.843
Required inotropes prior to VA ECMO	0.94 (0.45-1.96)	.871
SAVE score prior to VA ECMO (unit)	0.92 (0.86-0.99)	.031[a]
SOFA score prior to VA ECMO (unit)	1.27 (1.15-1.40)	<.001[a]
LAVA ECMO	0.43 (0.16-1.20)	.109
Required blood transfusion post VA ECMO	0.39 (0.15-1.03)	.057
8-h serum lactate clearance (%)	0.99 (0.98-0.99)	.001[a]
AKI post VA ECMO	1.16 (0.57-2.37)	.689

Model inclusive of risk factors associated with ECMO death with a *P* value of <.05 on univariate analysis (Tables 1-6). Dependent variable = ECMO death defined as inpatient mortality while on ECMO circuit, or within 24 h of decannulation.
AKI, acute kidney injury; CPR, cardiopulmonary resuscitation; LAVA, left-atrial venoarterial; SAVE, survival after VA ECMO; SOFA, sequential organ failure assessment; VA ECMO, venoarterial extracorporeal membrane oxygenation.
[a] Significant *P* values.

feasibility of such an approach; (2) the majority of patients were managed by a primary cardiology service comprising interventional, HF or critical care cardiologists, highlighting the potential role of a cardiology inclusive ECMO service; (3) there was no difference in survival between patients cannulated on ECMO by an interventional cardiologist compared to a cardiac surgeon, suggesting comparable safety with such an approach; (4) preoperative lactate and SOFA scores were independently associated with VA-ECMO death; (5) 8-hour lactate clearance and higher SAVE scores were independently associated with survival (Central Illustration).

The most important finding from our analysis is that use of a cardiovascular medicine inclusive ECMO service is feasible. Previous groups have highlighted the use of an intensivist inclusive service. Kouch et al[8] described their experience transitioning from a surgical-based model to an intensivist-based model in patients requiring veno-venous ECMO. Similarly, Kraai et al[9] have described their experience of an intensivist-led ECMO program encompassing both veno-venous and VA-ECMO. Our experience similarly supports the concept that cardiologists who are knowledgeable about ECMO and critical care management can serve as primary providers for this critically ill patient population. In our program, we utilized numerous pathways to define competency for implantation and explantation as well as management of ECMO. We utilized commonly available resources provided by Extracorporeal Life Support Organization (ELSO) for training in the management of ECMO. Additional hands-on experience was obtained by coscrubbing into early cases.

Although there is no doubt to the importance of cardiac surgeons in a successful ECMO program, there are distinct advantages of being inclusive of cardiologists in ECMO programs. Cardiologists are overall well suited for ECMO care, as they are knowledgeable of hemodynamic derangements, which are frequent in those with cardiogenic shock, allowing for assistance in MCS device selection and interpretation of invasive hemodynamics and cardiovascular imaging. Garan et al[10] for example demonstrated that in >1400 patients with cardiogenic shock, there was an improvement to in-hospital mortality when care was guided by a pulmonary artery catheter (PAC) monitoring. Similarly, Osman et al[11] demonstrated improved outcomes with the use of PAC monitoring which in their analysis was more frequently associated with delivery of advanced HF therapies. In our analysis, for 88% of the patients, a PAC was used to guide decision making for MCS device selection.

Cardiologists also implant and manage other forms of MCS, such as intraaortic balloon pump, Impella, and Tandem Heart, and thus can carefully evaluate the risks and benefits of select devices. In our cohort, 64.8% of patients had some form of left ventricle venting when using ECMO. Use of LV venting has been associated with improved outcomes in patients treated with VA-ECMO.[12] In particular, there was growing use in patients receiving left-atrial VA-ECMO cannulation and these patients had increased likelihood of survival.

The cardiac catheterization laboratory is also well equipped for ECMO cannulation and decannulation. Cath labs are operational 24 hours a day, with systems in place for rapid activation, as is necessary for ST-segment elevation myocardial infarction (STEMI) care. Although investigators have previously described the use of VA-ECMO in the cath lab,[13-15] these cohorts have predominantly comprised patients with in-hospital CA admitted to a tertiary academic medical center[14]; in our cohort, we describe a comprehensive cohort of patients who were safely treated in the cath lab.

Interventional cardiologists are also well equipped to manage large bore MCS, including use of modern-day vascular access best practices, such as the use of ultrasound, fluoroscopy, micropuncture needles, peripheral angiography, the routine use of reperfusion sheaths and vascular access closure. This skill set is important not just for successful cannulation but more importantly to mitigate vascular access complications, all of which significantly impact survival.[16] In our study, 3.7% of patients suffered from arterial complications, 11.1% had limb ischemia, and 4.1% suffered compartment syndrome while on support. These complications are lower than prior reports.[17] Insertion of distal perfusion sheaths has also been shown to reduce the incidence of limb ischemia[18] and is routinely used in the majority of ECMO patients. Furthermore, only 13.5% of patients in the cohort required transport back to the catheterization lab due to complications, and though 16%

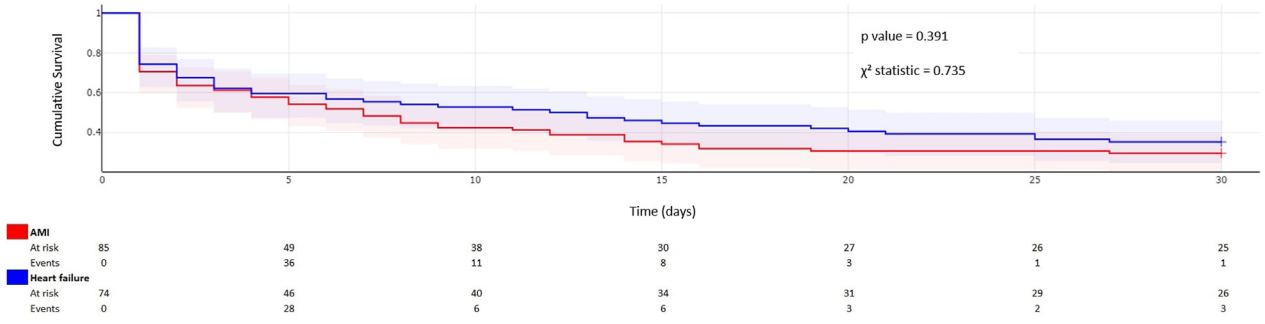
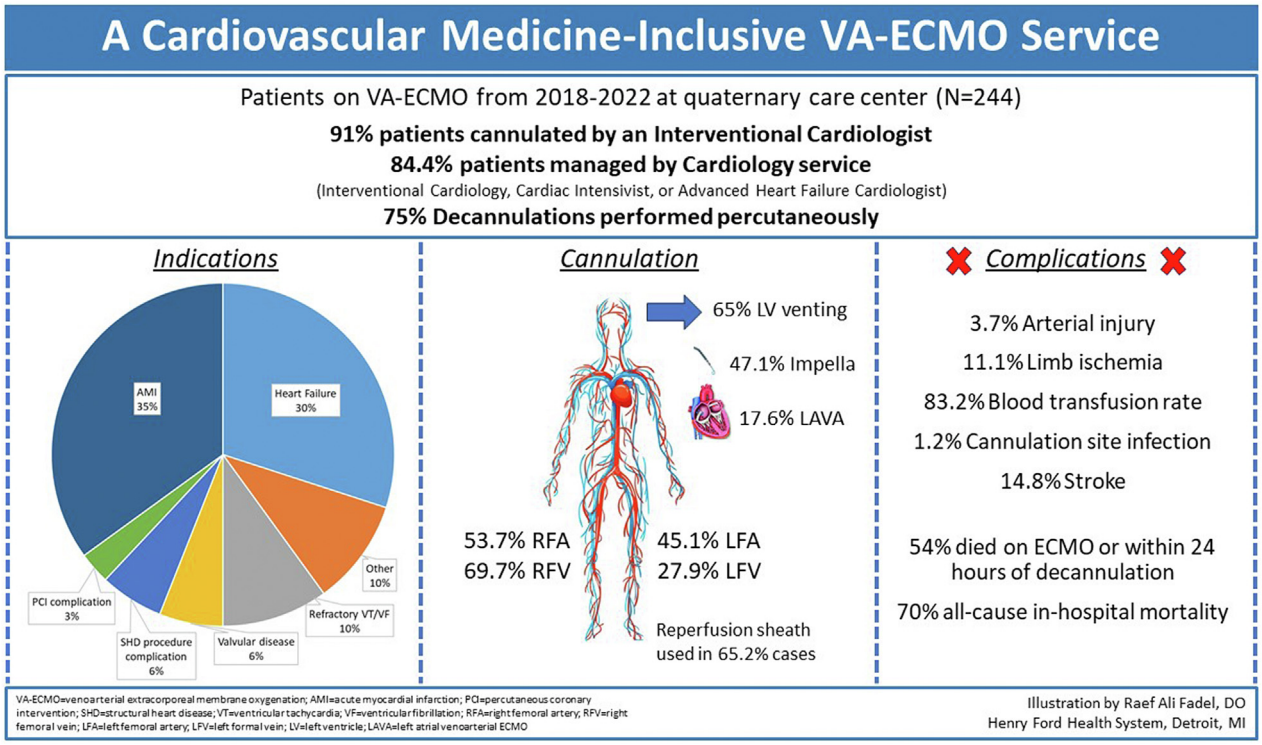


Figure 2.
Kaplan Meier analysis of 30-day mortality by indication for venoarterial extracorporeal membrane oxygenation. AMI, acute myocardial infarction.



Central Illustration.
Important details and findings of our study.

of the cohort suffered bleeding at the site of cannulation it is still lower than in previous cohorts.[19] Lastly, 1.2% of patients in our study experienced infection at the site of cannulation, and 5.7% were found to have bacteremia during the entire time on ECMO. Prior reports have suggested rates of groin cannulation infection ranging from 10% to 20%, with obesity and malnourishment being 2 primary risk factors.[18,20] We saw far fewer infections and suspect this may be due to better sterile cannulation techniques used in the catheterization laboratory compared to the intensive care unit.

Another advantage of cardiology involvement in ECMO care is the ability to perform percutaneous decannulation. Kraai et al[9] have previously described their experience of intensivists implanting ECMO. In their cohort, 50% of the patients were cannulated with the use of transesophageal echocardiography at the bedside and the other 50% were cannulated using a portable fluoroscopy unit. Although the investigators reported safety of using such an approach, the majority of patients were decannulated in the operating room. In our cohort, 115 patients were decannulated, the vast majority of whom were decannulated percutaneously using suture-based closure, collagen-based closure, or "dry" closure using balloon tamponade and manual pressure. Previous reports have demonstrated that percutaneous closure, which interventional cardiologists are apt to perform, is associated with 80% less likelihood of limb complications and bleeding and therefore may be the preferred strategy when feasible.[21]

An inclusive ECMO program also allows surgeons to focus and have more time for the placement of durable left ventricular assist devices, cardiac transplants, and centrally placed temporary MCS devices including ECMO. This allows cardiologists to provide more complete care to patients they are already caring for. For example, in our cohort, 32% of patients required ECMO for AMI complicated by cardiogenic shock, 30% for decompensated heart failure, 10% for refractory arrhythmias, and 7% for severe valvular disease. Cardiologists are heavily involved in the care of these patients and the ability to use more robust MCS devices such as ECMO can often be lifesaving. However, caution is necessary when selecting appropriate ECMO candidates, as ECMO is a resource-heavy therapy. In our cohort, 10% of the patients required ECMO for intraprocedural complications, 26.6% were placed on ECMO in a peri-arrest setting, and of these patients, 67% died.

It is also important to emphasize that in our cohort, approximately 10% of patients were cannulated at a satellite hospital with no cardiothoracic surgery backup. Having ECMO cannulation capabilities at such facilities can be vitally important to patient care.[22] In fact, this highlights the need to expand the accessibility of ECMO, particularly as part of the treatment of patients with cardiogenic shock diagnosed at institutions without surgical teams.

Although recent clinical trials including ECLS-SHOCK and ECMO-CS have suggested no significant benefit in routine use of VA-ECMO in AMI-CS,[23,24] it is important to highlight that only a small portion of our current, real-world cohort would have met either trial inclusion criteria if applied at the time of cannulation (Supplemental Figure S1). Additionally, although we demonstrated no significant difference in overall 30-day survival on Kaplan Meier analysis between the major subgroups of AMI and HF-CS, the various other indications for ECMO show the heterogeneity of cardiogenic shock and highlight the utility of VA-ECMO beyond AMI-CS, particularly in cases of VT/VF, procedural complications, and HF shock as a bridge to durable support or transplant.

Lastly, our overall in-hospital mortality was 69.7%. This is comparable to the estimated mortality of 58% to 95% based on the patients' SAVE and SOFA scores, as well as the high rate of cannulation in the peri-arrest setting.[25–27] The difference between the rate of all-cause in-hospital mortality and survival to decannulation from ECMO was due to various reasons, but most notable was the fact that patients who were decannulated went on to undergo surgical procedures or developed infections/complications at which point they were no longer candidates for advanced therapies. This is an area of interest, which should be the focus of future studies.

Limitations

There are several limitations of our study. Our study was a retrospective single-center study, prone to selection and treatment bias which limits the generalizability of our results. Additionally, the determination for use of MCS was decided by the treatment team. However, the purpose of our study was to describe the outcomes of a cardiology inclusive ECMO service; so the selection of a support device does not alter the interpretation of results. In addition, data on the use of reperfusion catheters were omitted due to lack of confidence in the accuracy of the data. Regarding statistical analysis, it is worth noting that imputation was used for missing variables to calculate severity scores, and this should be considered when drawing conclusions. Although this is a validated and widely used method for missing data, it introduces a margin of error that must be considered. Furthermore, none of the patients who expired while on ECMO underwent autopsy, and thus may have had missing diagnoses for the cause of decompensation such as bleeding, infection, or thrombosis that was not previously identified, potentially impacting our results.

Looking ahead

As the accessibility of ECMO increases across health systems, there remains a need for continued studies. Clinical trials to identify patient cohorts who may benefit or be harmed by ECMO, as well as continued study of the processes of care that affect outcomes are necessary.

Declaration of competing interest

Mohammad Alqarqaz received research funding from Abiomed. Jennifer Cowger is a consultant for Abbott, Medtronic, CH Biomedical, Procyrion, BioVentrix, and CorWave. Khaldoon Alaswad is a consultant for Arrow, Cardiovascular Systems Inc, Teleflex, Abbott, and Boston Scientific. William O'Neill is a consultant for Abbott, Abiomed, Boston Scientific, Edwards Lifesciences, and Medtronic. Pedro Villablanca is a consultant for Edwards Lifesciences, Medtronic, Medicure Pharma, and Angiodynamics. Brian O'Neill is a consultant for Edwards Lifesciences, Abbott, Medtronic, Inari, Medicure Pharma, and Angiodynamics. Herb Aronow is a consultant for Philips. Hassan Nemeh is a consultant for Edwards Lifesciences and Abbott. Tiberio Frisoli is a consultant for Edwards Lifesciences, Abbott, Boston Scientific, and Angiodynamics. Celeste Williams is a consultant for Zoll, Abbott, Medtronic, and St. Jude. Mir Babar Basir is a consultant Abiomed, Boston Scientific, Chiesi, Saranas, and Zoll. All other authors report no conflicts of interest.

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Ethics statement and patient consent

The research was carried out in accordance with appropriate ethical guidelines. The Henry Ford Health System Institutional Review Board approved the study and waived the need for informed consent due to the retrospective nature of the study.

Supplementary material

To access the supplementary material accompanying this article, visit the online version of the *Journal of the Society for Cardiovascular Angiography & Interventions* at 10.1016/j.jscai.2024.101359

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