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CLINICAL INVESTIGATION

Impact of Left Ventricular Venting on Acute Brain Injury in Patients With Cardiogenic Shock: An Extracorporeal Life Support Organization Registry Analysis

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OBJECTIVES: While left ventricular (LV) venting reduces LV distension in cardiogenic shock patients on venoarterial extracorporeal membrane oxygenation (ECMO), it may also amplify risk of acute brain injury (ABI). We investigated the hypothesis that LV venting is associated with increased risk of ABI. We also compared ABI risk of the two most common LV venting strategies, percutaneous microaxial flow pump (mAFP) and intra-aortic balloon pump (IABP).

DESIGN: Retrospective observational cohort study.

SETTING: The Extracorporeal Life Support Organization registry.

PATIENTS: Adult patients on peripheral venoarterial ECMO for cardiogenic shock (2013–2024).

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: ABI was defined as hypoxic-ischemic brain injury, ischemic stroke, or intracranial hemorrhage. Secondary outcome was hospital mortality. We compared no LV venting with: 1) LV venting, 2) mAFP, and 3) IABP using multivariable logistic regression. To compare ABI risk of mAFP vs. IABP, propensity-score matching was performed. Of 13,276 patients (median age = 58.2, 69.9% male), 1,456 (11.0%) received LV venting (65.5% mAFP and 29.9% IABP), and 525 (4.0%) had ABI. After multivariable regression, LV-vented patients had increased odds of ABI (adjusted odds ratio [aOR], 1.67; 95% CI, 1.22–2.26; $p = 0.001$) but no difference in mortality (aOR, 1.07; 95% CI, 0.90–1.27; $p = 0.45$) compared with non-LV-vented patients. In the propensity-matched cohort of IABP ($n = 231$) vs. mAFP ($n = 231$) patients, there was no significant difference in odds of ABI (aOR, 1.35; 95% CI, 0.69–2.71; $p = 0.39$) or mortality (aOR, 0.88; 95% CI, 0.58–1.31; $p = 0.52$).

CONCLUSIONS: LV venting was associated with increased odds of ABI but not mortality in patients receiving peripheral venoarterial ECMO for cardiogenic shock. There was no difference in odds of ABI or mortality for IABP vs. mAFP patients.

KEYWORDS: acute brain injury; cardiogenic shock; intra-aortic balloon pump; left ventricular venting; percutaneous microaxial flow pump

Cardiogenic shock is a life-threatening condition characterized by low cardiac output, end-organ hypoperfusion, and high mortality (1, 2). In recent years, venoarterial extracorporeal membrane oxygenation (ECMO) has been increasingly employed as a short-term rescue strategy in patients with cardiogenic shock, offering hemodynamic and respiratory support

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KEY POINTS

Question: We investigated the association between left ventricular (LV) venting and risk of acute brain injury (ABI) in patients receiving venoarterial extracorporeal membrane oxygenation for cardiogenic shock. We compared ABI risk of the two most common LV venting strategies, percutaneous microaxial flow pump (mAFP) and intra-aortic balloon pump (IABP).

Findings: LV venting was associated with increased odds of ABI but not mortality. However, IABP vs. mAFP did not impact either odds of ABI or mortality.

Meanings: Clinicians must weigh the benefits of venting against ABI risk when managing neurocritically ill patients. Additionally, IABP and mAFP may offer comparable neurologic safety profiles.

while reducing myocardial workload (3). However, this has not always translated to reduced mortality (4).

Notably, the ECMO circuit can strain the left ventricle (LV) by increasing afterload and altering normal blood flow, and LV distension is a serious complication occurring in up to 60% of patients (5–8). This weakened ejection can lead to blood pooling, elevated LV pressures, and increased risk of pulmonary edema, myocardial ischemia, cerebral hypoxia, and LV failure. Given these risks, dual mechanical support using a secondary device for LV venting has been explored to offload LV intraventricular pressure (7, 9). The two most common mechanical LV venting devices are the percutaneous microaxial flow pump (mAFP) and the intra-aortic balloon pump (IABP). The mAFP actively pumps blood from the LV to the ascending aorta, lowering LV pressure, and myocardial wall stress (10). The IABP inflates during diastole and deflates before systole, reducing afterload and assisting LV blood ejection (5, 11, 12).

While LV venting can mitigate the risk of myocardial damage, studies suggest that LV venting may increase risk of acute brain injury (ABI), which can occur in up to 11–20% of venoarterial ECMO patients and represents a leading cause of mortality (13). In particular, studies have associated the use of mAFP for LV unloading during venoarterial ECMO (i.e., ECMO combined with Impella, or ECMELLA) with higher rates of ABI compared with venoarterial ECMO alone, although findings are mixed regarding whether ischemic stroke (IS) or intracranial hemorrhage (ICH) risk is elevated (11, 14). Despite these risks and the increasing use of LV venting, the interplay between circulatory support devices, cerebral perfusion, and the risk of ABI remains poorly understood and there is a lack of clarity on which venoarterial ECMO patients should receive LV venting (12).

This study aims to characterize the association between LV venting and ABI in patients with cardiogenic shock receiving peripheral venoarterial ECMO. In comparing the effects of mAFP and IABP on ABI outcomes using the largest registry of ECMO patients globally, our work seeks to clarify the impact of LV venting strategies on ABI risk.

METHODS

Patients

We conducted a retrospective analysis of the Extracorporeal Life Support Organization (ELSO) registry for adult patients who received peripheral venoarterial ECMO for cardiogenic shock from January 1, 2013, to June 21, 2024. We excluded patients who were treated with venovenous ECMO, were centrally cannulated, who received more than one ECMO run, who had conversions in ECMO mode, and who were with missing demographic, LV venting, or ABI data.

Patients were subgrouped by LV venting vs. LV venting. LV venting was defined using Current Procedural Terminology (CPT) codes (15) (**Supplemental Table 1**, https://links.lww.com/CCM/H814). Procedure timing for LV-vented patients was limited to "On-ECLS" and "Pre-ECLS" within 1 hour of ECMO cannulation/patients who received LV venting "Pre-ECLS" or "Post-ECLS" were categorized as no LV venting.

This retrospective observational cohort study was approved by the Johns Hopkins Hospital Institutional Review Board with a waiver of informed consent on October 22, 2019 (IRB00216321, "Retrospective Analysis of Outcomes of Patients on Extracorporeal Membrane Oxygenation"), conducted in accordance with the Declaration of Helsinki, and reported using Strengthening the Reporting of Observational Studies in Epidemiology guidelines (16).

Data Source

The ELSO registry is a voluntary international database that collects information on use, indications, and outcomes of ECMO support in patients from more than 50 countries (17). Diagnoses and medical history are reported according to the *International Classification of Diseases*, 9th Edition (ICD-9) and *International Classification of Diseases*, 10th Edition (ICD-10) codes.

We extracted the following information: pre-ECMO demographic information; pre-ECMO clinical variables; laboratory values; on-ECMO clinical variables including LV venting procedures; and ECMO-associated morbidity and mortality, including renal replacement therapy (RRT), hemolysis, arrhythmia, gastrointestinal hemorrhage, and ABI.

A heat map representing variable missingness is included in **Supplemental Figure 1** (https://links.lww.com/CCM/H814). Variable percent missingness can be located in **Supplemental Table 2** (https://links.lww.com/CCM/H814).

Definitions

ABI was defined as hypoxic-ischemic brain injury (HIBI), IS, and ICH including intraventricular hemorrhage. In the ELSO registry, IS is defined as CNS infarction determined by ultrasound, CT, or MRI. ICH is defined as intraparenchymal or extraparenchymal CNS hemorrhage or intraventricular CNS hemorrhage determined by ultrasound, CT, or MRI. HIBI is defined as CNS diffuse ischemia.

LV venting strategies were grouped into three categories: mAFP, IABP, and other LV venting. mAFP included all Impella (Abiomed, Inc., Danvers, MA) CPT codes (Supplemental Table 1, https://links.lww.com/CCM/H814). Other LV venting included closed heart atrial septostomy, open heart atrial septostomy with cardiopulmonary bypass, insertion of left heart vent by thoracic incision, insertion of catheter into right pulmonary artery, and transvenous atrial septectomy or septostomy with balloon including cardiac catheterization. Cardiogenic shock was defined as ICD-9 code 785.51 and ICD-10 code R57.0.

Arterial blood gases (ABGs) were collected at baseline/pre-ECMO and at 24 hours, and $Paco_2$ difference was defined as $Paco_2$ at 24 hours–$Paco_2$ at baseline/pre-ECMO. The pre-ECLS hemodynamics and ABG values were measured no more than 6 hours before ECLS. Twenty-four-hour ABG values were drawn between 18 and 30 hours after ECLS start time. RRT occurred during ECMO support.

Outcomes

The primary outcome was ABI during ECMO support. ABI outcome was assigned if the injury occurred during ECMO support and after LV venting procedure time. The secondary outcome was in-hospital mortality.

Statistical Analysis

Patient characteristics and outcomes data were summarized as medians and interquartile range (IQR) for continuous variables. Numbers and percentages were calculated for categorical variables. Continuous baseline characteristics were compared using the Wilcoxon rank-sum test, and discrete characteristics were compared using the chi-square test. Normality of variables was assessed using Shapiro-Wilk testing and histogram visualization. A p value of less than 0.05 was considered to be statistically significant. Statistical analyses were performed using R Studio (R 4.1.2, 2022; R Studio, PBC, Boston, MA).

The association between LV venting and ABI was examined using multivariable logistic regression to balance for clinically preselected covariates including demographic and clinical variables (age, sex, body mass index [BMI], hours on ECMO, pre-ECMO pH, pre-ECMO Pao_2, Pao_2 at 24 hr, $Paco_2$ difference, on-ECMO lactate, pump flow, RRT), pre-ECMO risk factors (cardiopulmonary bypass, transplant, cardiac arrest), and complications on ECMO (gastrointestinal hemorrhage, arrhythmia, and hemolysis). The use of: 1) LV venting vs. no LV venting, 2) mAFP vs. no LV venting, and 3) IABP vs. no LV venting was compared. To examine the risk of ABI for patients receiving mAFP vs. IABP, propensity-score matching was performed using 1:1 nearest neighbor matching without replacement within a caliper width of 0.2, with IABP as the dependent variable. Listwise deletion of cases with missing covariates or independent variables was used. Satisfactory matching was defined as an absolute value of the standardized mean difference of less than 0.10. Propensity scores were obtained by logistic regression. Participants

were matched by variables recorded in the ELSO registry including age, sex, BMI, hours on ECMO, pre-ECMO pH, pre-ECMO Pao_2, Pao_2 at 24 hours, $Paco_2$ difference, lactate at 24 hours post-ECMO cannulation, pre-ECLS cardiac arrest, pump flow at 4 hours post-ECMO cannulation, on-ECMO RRT, and on-ECMO complications including gastrointestinal hemorrhage, arrhythmia, and hemolysis. Covariate selection for multivariable models was guided by literature review and clinical relevance of candidate predictors.

After matching, multivariable logistic regression was used to compare ABI risk for mAFP vs. IABP groups. In our analyses comparing mAFP vs. IABP, mAFP support was used as the reference group since it was the most frequently used type of LV venting in our population. Odds ratios (ORs) with 95% CIs were calculated. Collinearity between confounders was assessed, with a variance inflation factor greater than 5 considered problematic multicollinearity.

RESULTS

Study Population

Of the 34,013 patients, 13,276 patients (median [IQR] age = 58.2 [47.20–66.20], 69.9% male) met the inclusion criteria (**Fig. 1**). The median (IQR) time on ECMO support was 119 hours (65–199 hr). In total, 4.0% of patients (n = 525) developed ABI, 2.3% (n = 307) IS, 1.1% (n = 145) ICH, and 0.6% (n = 73) HIBI. Hospital mortality was 50.5% (n = 6709; **Supplemental Table 3**, https://links.lww.com/CCM/H814).

One thousand four hundred fifty-six patients (11.0%) received LV venting while on venoarterial ECMO. Of these patients, 954 (65.5%) received mAFP, 436 (29.9%) received IABP, and 66 (4.6%) received another type of LV venting. **Supplemental Figure 2** (https://links.lww.com/CCM/H814) shows the utilization of different LV venting types by study year. **Figure 2** shows the proportions of ABI subtypes stratified by LV venting procedure type. Patients who received LV venting were more likely to be male (73% vs. 69.5%; p = 0.006). LV-vented patients also spent longer on ECMO (median [IQR] = 139.5 hr [86–216 hr] vs. 117 hr [64–196 hr]; p < 0.001) and had more RRT (30.8% vs. 25.8%; p < 0.001), hemolysis (7.8% vs. 3.6%; p < 0.001), and arrhythmia (20.7% vs. 14.5%; p < 0.001). Notably, LV-vented patients had lower MAP (mean arterial pressure) while on ECMO compared with non-LV-vented patients (67 mm Hg [58–78 mm Hg] vs. 70 mm Hg [62–81 mm Hg]; p < 0.001), although this difference disappeared after 24 hours post-cannulation (**Table 1**).

Similar findings emerged when patients were stratified into no LV venting vs. mAFP. Patients who received mAFP were also more likely to be male and spend longer on ECMO (p < 0.05). They also had more RRT, hemolysis, and arrhythmia (p < 0.05; **Supplemental Table 4**, https://links.lww.com/CCM/H814). Patients who received LV venting using IABP were comparable in sex and BMI to their non-LV-vented counterparts, but spent longer on ECMO (p = 0.008) and had more RRT and hemolysis (p < 0.05; **Supplemental Table 5**, https://links.lww.com/CCM/H814).

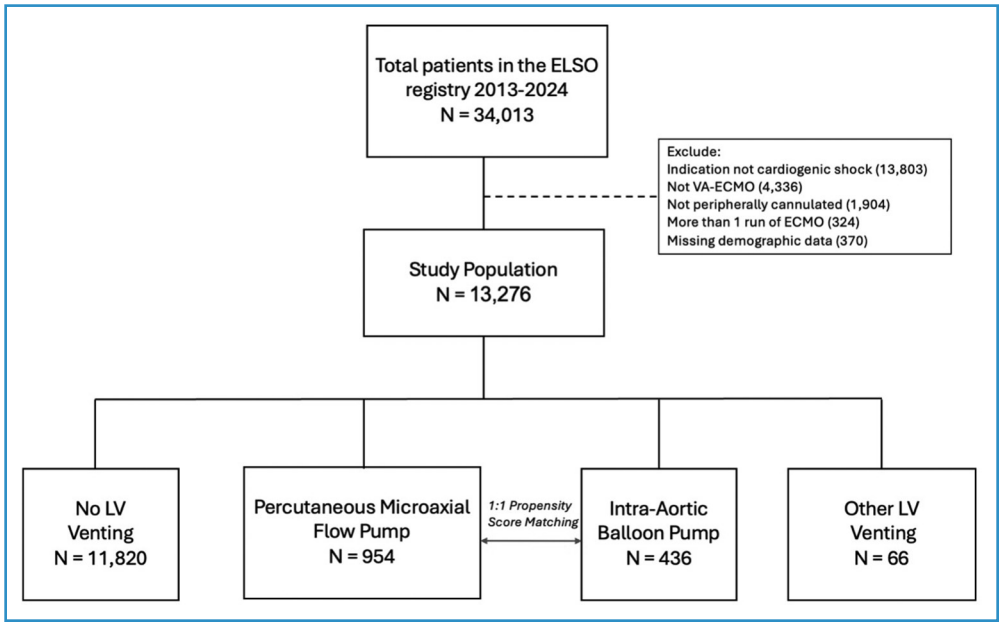

Figure 1. Consolidated Standards of Reporting Trials diagram for the study cohort.
ECMO = extracorporeal membrane oxygenation, ELSO = Extracorporeal Life Support Organization, LV = left ventricular, VA = venoarterial.

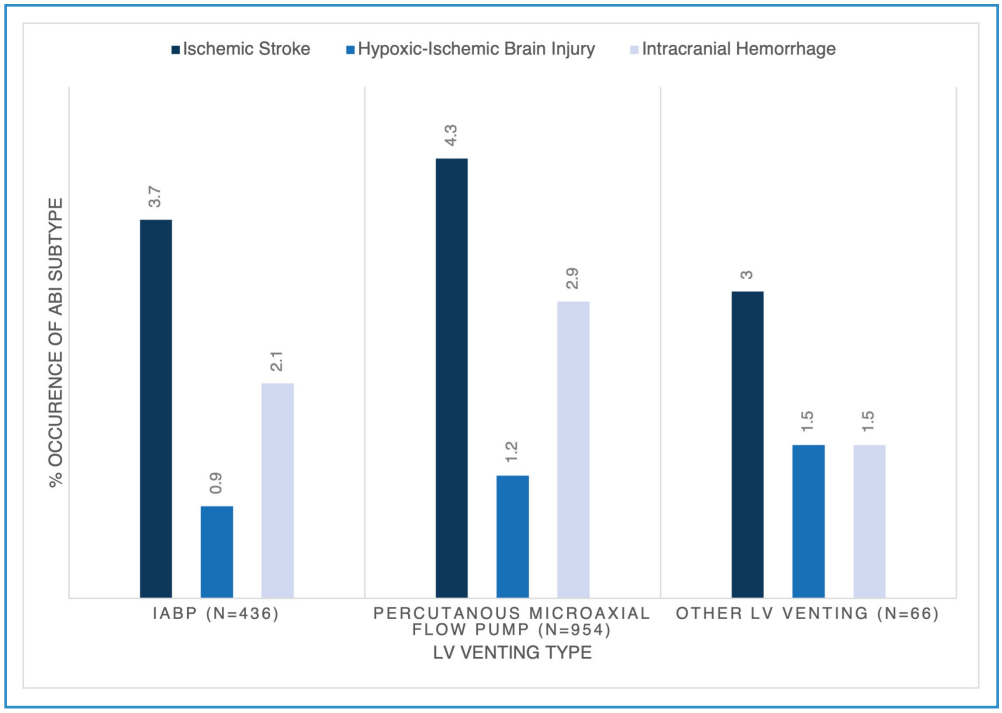

Figure 2. Distribution of acute brain injury (ABI) for left ventricular (LV) venting patients stratified by procedure type. IABP = intra-aortic balloon pump.

Acute Brain Injury

LV Venting vs. No LV Venting. Of LV-vented patients, 7.8% (n = 113) developed ABI compared with 3.6% (n = 412) of non-LV-vented patients ($p < 0.001$; Table 1). The distribution of different types of ABI stratified by LV venting procedure type is shown in Figure 1. Compared with non-LV-vented patients, LV-vented patients had higher prevalence of each type of ABI, including IS (4.1% vs. 2.1%; $p < 0.001$), ICH (2.6% vs. 0.9%; $p < 0.001$), and HIBI (1.1% vs. 0.5%; $p = 0.005$; Table 1). After adjusting for covariates in the multivariable regression, patients who received LV venting were found to have higher odds of ABI (adjusted OR [aOR], 1.67; 95% CI, 1.22–2.26; $p = 0.001$), ICH (aOR, 1.93; 95% CI, 1.11–3.22; $p = 0.015$), and HIBI (aOR, 2.92; 95% CI, 1.21–6.59; $p = 0.012$; **Table 2**).

mAFP vs. No LV Venting. Patients who received mAFP had more ABI than patients who did not receive LV venting while on venoarterial ECMO (8.4% [n = 80] vs. 3.6% [n = 412]; $p < 0.001$; Supplemental Table 4, https://links.lww.com/CCM/H814). mAFP patients had higher prevalence of all ABI types including IS (4.3% vs. 2.1%; $p < 0.001$), ICH (2.9% vs. 0.9%; $p < 0.001$), and HIBI (1.2% vs. 0.5%; $p < 0.013$). Multivariable regression revealed higher odds of ABI (aOR, 1.53; 95% CI, 1.04–2.20; $p = 0.02$) and HIBI (aOR, 2.99; 95% CI, 1.04–7.58; $p = 0.03$) for mAFP patients compared with non-LV-vented patients (Table 2).

IABP vs. No LV Venting. Overall, 6.7% of IABP patients (n = 29) developed ABI compared with 3.6% of non-LV-vented patients (n = 412; p = 0.001; Supplemental Table 5, https://links.lww.com/CCM/H814). Specifically, patients who received IABP had higher prevalence of ICH (2.1% vs. 0.9%; p = 0.029), while rates of IS and HIBI were similar between groups. After multivariable regression, odds of ABI in IABP patients was 2.09 times as high (aOR, 2.09; 95% CI, 1.27–3.30; $p = 0.002$) compared with non-LV-vented patients (Table 2). With respect to ABI subtype, patients who received IABP were more likely to develop ICH (aOR, 2.69; 95% CI, 1.13–5.65; $p = 0.014$).

mAFP vs. IABP. Of patients who received IABP, 6.7% (n = 29) developed ABI compared with 8.4% of patients (n = 80) who received mAFP ($p = 0.31$; **Table 3**). IABP supported patients had lower frequency of ABI subtypes, including IS (3.7% vs. 4.3%; p = 0.69), ICH (2.1% vs. 2.9%; p = 0.45), and HIBI (0.9% vs. 1.2%; p = 0.91). No differences in odds of ABI or ABI subtype were found after adjusting for covariates (**Supplemental Table 6**, https://links.lww.com/CCM/H814).

In the propensity-matched cohort (n = 514), 10.0% (n = 23) of IABP patients developed ABI compared with 7.8% (n = 18) of mAFP patients. With respect to ABI subtypes, 5.2% of IABP patients developed IS, 3.5% developed ICH, and 1.3% developed HIBI. In the mAFP group, 3.9% developed IS, 2.6% developed ICH, and 1.3% developed HIBI. Patient characteristics of the mAFP and IABP propensity-matched cohort are provided in Table 3. The distribution of propensity scores

TABLE 1.
Patient Characteristics Stratified by Left Ventricular Venting

Characteristic	No LV Venting (*n* = 11,820)	LV Venting (*n* = 1,456)	*p*
Demographics			
Age, median (IQR)	58.2 (47.2–66.3)	57.7 (46.4–65.6)	0.177
Male sex (%)	8,213 (69.5)	1,063 (73.0)	0.006
Body mass index, median (IQR)	28.24 (24.51–32.88)	28.98 (25.31–33.28)	0.001
Hours on ECMO, median (IQR)	117 (64.0–196)	139.5 (86.0–216)	< 0.001
Ventilation type (%)			< 0.001
Conventional	7,615 (87.3)	913 (82.9)	
High-frequency oscillatory	13 (0.1)	0 (0.0)	
No ventilator	972 (11.1)	171 (15.5)	
Other	116 (1.3)	16 (1.5)	
Other high-frequency ventilation	2 (0.0)	1 (0.1)	
Transplant (%)	782 (6.9)	111 (7.7)	0.33
Ventilation, median (IQR)			
Positive end-expiratory pressure	8.0 (5.0–10.0)	8.0 (5.0–10.0)	0.375
Rate	18.0 (14.0–23.0)	18.0 (15.0–24.0)	0.057
F_{IO_2}	100 (60.0–100)	100 (60.0–100)	0.714
Pa_{O_2}	104 (73.0–191)	111 (74.0–204)	0.122
pH	7.29 (7.19–7.38)	7.30 (7.19–7.39)	0.590
Delta P_{CO_2}	−2.0 (−10.2 to 6.0)	−1.0 (−10.0 to 7.0)	0.093
Hemodynamics, median (IQR)			
SBP (mm Hg)	90 (76–105)	92 (80–107)	< 0.001
DBP (mm Hg)	56 (46–67)	59 (50–71)	< 0.001
MAP (mm Hg)	67 (58–78)	70 (62–81)	< 0.001
SBP 24-hr post-ECMO (mm Hg)	95 (83–108)	92 (81–105)	< 0.001
DBP 24-hr post-ECMO (mm Hg)	64 (57–72)	66 (57–74)	0.056
MAP 24-hr post-ECMO (mm Hg)	74 (67–81)	74 (68–81)	0.2
Outcomes (%)			
Renal replacement therapy required	3,054 (25.8)	449 (30.8)	< 0.001
Hemolysis	427 (3.6)	113 (7.8)	< 0.001
Arrhythmia	1,714 (14.5)	302 (20.7)	< 0.001
Gastrointestinal hemorrhage	565 (4.8)	85 (5.8)	0.089
Acute brain injury	412 (3.6)	113 (7.8)	< 0.001
Ischemic stroke	248 (2.1)	59 (4.1)	< 0.001
Intracranial hemorrhage	107 (0.9)	38 (2.6)	< 0.001
Hypoxic-ischemic brain injury	57 (0.5)	16 (1.1)	0.005
Mortality	5,980 (50.6)	729 (50.1)	0.73

DBP = diastolic blood pressure, ECMO = extracorporeal membrane oxygenation, IQR = interquartile range, LV = left ventricular, MAP = mean arterial pressure, SBP = systolic blood pressure

TABLE 2.
Multivariable Logistic Regression for Acute Brain Injury and Mortality by Left Ventricular Venting

Outcome (Reference: No LV Venting)	OR (95% CI)	*p*
LV venting		
ABI	1.67 (1.22–2.26)	0.001
Ischemic stroke	1.35 (0.88–1.99)	0.15
Intracranial hemorrhage	1.93 (1.11–3.22)	0.015
HIBI	2.92 (1.21–6.59)	0.012
Mortality	1.07 (0.90–1.27)	0.45
Percutaneous microaxial flow pump		
ABI	1.53 (1.04–2.20)	0.026
Ischemic stroke	1.26 (0.74–2.03)	0.37
Intracranial hemorrhage	1.67 (0.82–3.13)	0.13
HIBI	2.99 (1.04–7.58)	0.03
Mortality	1.09 (0.89–1.35)	0.41
Intra-aortic balloon pump		
ABI	2.09 (1.27–3.30)	0.002
Ischemic stroke	1.59 (0.80–2.86)	0.15
Intracranial hemorrhage	2.69 (1.13–5.65)	0.014
HIBI	3.17 (0.72–9.88)	0.074
Mortality	1.02 (0.76–1.36)	0.91

ABI = acute brain injury, HIBI = hypoxic-ischemic brain injury, LV = left ventricular, OR = odds ratio.

for patients who received mAFP vs. IABP is visualized in **Supplemental Figure 3** (https://links.lww.com/CCM/H814).

After propensity matching, odds of ABI remained similar in patients who received IABP and patients who received mAFP (aOR, 1.35; 95% CI, 0.69–2.71; $p = 0.39$; Supplemental Table 6, https://links.lww.com/CCM/H814). Odds of IS (aOR, 1.47; 95% CI, 0.56–5.00; $p = 0.43$), ICH (aOR, 1.37; 95% CI, 0.45–4.37; $p = 0.58$), and HIBI (aOR, 1.24; 95% CI, 0.15–10.7; $p = 0.83$) were also similar between groups.

Mortality

In-hospital mortality was similar for LV-vented vs. non-LV-vented patients (50.1% vs. 50.6%; $p = 0.73$; Table 1), mAFP vs. non-LV-vented patients (50.8% vs. 50.6%; $p = 0.91$; Supplemental Table 4, https://links.lww.com/CCM/H814), and IABP vs. non-LV-vented patients (49.3% vs. 50.6%; $p = 0.63$; Supplemental Table 5, https://links.lww.com/CCM/H814). After multivariable regression, there were no statistically significant differences in mortality between any LV venting group and the no LV venting group (Table 2).

In the propensity-matched cohort, in-hospital mortality was 49.4% for patients who received IABP compared with 51.5% for patients who received mAFP ($p = 0.710$). Odds of mortality for IABP supported patients compared with mAFP supported patients did not differ significantly in the propensity-matched cohort (aOR, 0.88; 95% CI, 0.58–1.31; $p = 0.52$; Supplemental Table 6, https://links.lww.com/CCM/H814).

DISCUSSION

In this multicenter ELSO registry analysis, we found that LV venting was associated with increased odds of ABI but not mortality in patients receiving peripheral venoarterial ECMO for cardiogenic shock. Notably, odds of IS were comparable across LV venting, mAFP, and IABP vs. no LV venting groups, while odds of ICH were elevated for both LV-vented patients and IABP supported patients compared with the no LV venting group. Additionally, odds of HIBI were increased in LV-vented patients compared with non-LV-vented patients. Finally, we found that after propensity matching, there was no significant difference in odds of ABI or mortality for patients who received IABP vs. mAFP during venoarterial ECMO.

Our results are consistent with the few existing studies that have linked LV venting to increased risk of ABI in patients receiving venoarterial ECMO, particularly the heightened risk of bleeding complications (11, 14). However, one study that examined outcomes of LV venting in patients undergoing venoarterial ECMO from 2010 to 2019 found both similar rates of ICH and comparable odds of IS in vented vs. nonvented patients (6). Importantly, that study categorized venting strategies broadly and lacked granular data on device-specific impacts, particularly regarding mAFP and IABP vs. no LV venting. In contrast, our study benefits from more recent data and greater granularity, allowing us to evaluate the differential effects of specific LV venting modalities on specific types of ABI. Notably, the same study compared patients who received IABP vs. percutaneous ventricular assist device and found that IABP

TABLE 3.

Patient Characteristics Stratified by Intra-Aortic Balloon Pump Versus Percutaneous Microaxial Flow Pump Before and After Matching

	Before Matching			After Matching			
Characteristic	**Percutaneous Microaxial Flow Pump ($n = 954$)**	**IABP ($n = 436$)**	***p***	**Percutaneous Microaxial Flow Pump ($n = 257$)**	**IABP ($n = 257$)**	***p***	**Standardized Mean Difference**
Demographics							
Age, median (IQR)	58.0 (47.5–65.7)	57.7 (45.9–65.7)	0.873	58.4 (47.4–66.8)	58.1 (47.7–65.2)	0.893	0.03
Male sex (%)	714 (74.8)	302 (69.3)	0.035	158 (68.4)	169 (73.2)	0.31	0.10
Body mass index, median (IQR)	29.0 (25.5–33.2)	28.8 (25.2–33.7)	0.926	29.44 (26.07–34.54)	28.68 (24.96–33.30)	0.083	0.05
Extracorporeal membrane oxygenation hours, median (IQR)	144 (87.0–224.8)	126 (86.0–197.0)	0.015	141 (86.5–206)	134 (92.0–204)	0.746	0.05
Ventilation type (%)			< 0.001			0.27	0.16
Conventional	593 (82.4)	274 (83.3)		180 (84.5)	177 (88.9)		
No ventilator	118 (16.4)	47 (14.3)		31 (14.6)	19 (9.5)		
Other	8 (1.1)	8 (2.4)		2 (0.9)	3 (1.5)		
Other high-frequency ventilation	1 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)		
Transplant (%)	71 (7.5)	32 (7.4)	< 0.001	5 (2.2)	16 (7.0)	0.001	0.45
Ventilation, median (IQR)							
Positive end-expiratory pressure	8.0 (5.0–10.0)	8.0 (5.0–10.0)	0.471	8.0 (5.0–10.0)	8.0 (5.0–10.0)	0.879	0.008
Rate	18.0 (16.0–24.0)	18.0 (14.0–24.0)	0.126	18.0 (16.0–24.3)	18.0 (14.0–24.0)	0.704	0.05
F_{IO_2}	100 (60.0–100)	92.0 (50.0–100)	0.001	100 (60.0–100)	93.0 (50.0–100)	0.047	0.18
Pa_{O_2}	115 (75.0–208)	104 (72.0–199)	0.155	108 (77.0–197)	102 (71.6–199)	0.48	0.03
pH	7.30 (7.18–7.38)	7.29 (7.20–7.39)	0.986	7.30 (7.18–7.38)	7.29 (7.20–7.38)	0.85	0.04
Delta P_{CO_2}	–0.60 (–10.0 to 7.0)	–1.0 (–8.0 to 7.0)	0.947	0.0 (–9.0 to 7.0)	–1.0 (–8.3 to 7.0)	0.743	0.001
MAP (mm Hg)							
MAP 24 hr (mm Hg)							
Outcomes (%)							
Renal replacement therapy required	285 (29.9)	140 (32.1)	0.44	79 (34.2)	82 (35.5)	0.845	0.03
Hemolysis	79 (8.3)	30 (6.9)	0.43	23 (10.0)	21 (9.1)	0.874	0.03

(*Continued*)

TABLE 3. (*Continued*)
Patient Characteristics Stratified by Intra-Aortic Balloon Pump Versus Percutaneous Microaxial Flow Pump Before and After Matching

Characteristic	Before Matching			After Matching			
	Percutaneous Microaxial Flow Pump (*n* = 954)	IABP (*n* = 436)	*p*	Percutaneous Microaxial Flow Pump (*n* = 257)	IABP (*n* = 257)	*p*	Standardized Mean Difference
Arrhythmia	216 (22.6)	73 (16.7)	0.015	42 (18.2)	40 (17.3)	0.903	0.02
Gastrointestinal hemorrhage	58 (6.1)	19 (4.4)	0.24	12 (5.2)	12 (5.2)	1.000	0.001
Acute brain injury	80 (8.4)	29 (6.7)	0.31	18 (7.8)	23 (10.0)	0.513	0.076
Ischemic stroke	41 (4.3)	16 (3.7)	0.69	9 (3.9)	12 (5.2)	0.655	0.062
Intracranial hemorrhage	28 (2.9)	9 (2.1)	0.45	6 (2.6)	8 (3.5)	0.786	0.05
Hypoxic-ischemic brain injury	11 (1.2)	4 (0.9)	0.91	3 (1.3)	3 (1.3)	1.000	0.001
Mortality	485 (50.8)	215 (49.3)	0.64	119 (51.5)	114 (49.4)	0.710	0.04

IABP = intra-aortic balloon pump, IQR = interquartile range, MAP = mean arterial pressure.

patients had comparable rates of ICH and IS, which is consistent with our findings. **Supplemental Table 7** (https://links.lww.com/CCM/H814) presents more details on prior literature regarding ABI risk in the setting of LV venting.

Our finding that LV venting was associated with increased odds of ICH but not IS suggests that the primary mechanism of ABI in this clinical context may be related to bleeding risk and hemorrhagic conversion of IS. Notably, LV venting has been found to alter systemic pulsatility; in fact, a prior study in a porcine model showed that ECMO combined with LV support increased carotid artery perfusion compared with ECMO alone, suggesting that changes in pulsatility have the potential to influence cerebral perfusion dynamics (18). The absence of pulsatility index measured by transcranial Doppler has also been associated with higher rates of intraparenchymal hemorrhage in patients receiving venoarterial ECMO (19). Relatedly, our finding that LV venting was associated with increased risk of HIBI but not IS may reflect the greater severity of illness in LV-vented patients. The need for LV venting is often driven by low cardiac output or refractory shock, and these patients likely experienced more pronounced hemodynamic fluctuations both before and after cannulation. Notably, this interpretation is supported by the lower pre-ECMO MAP values and greater MAP variability observed in vented patients, raising the possibility of compromised cerebral perfusion that may have contributed to elevated risk of HIBI. Ultimately, the distinctions in risk of particular ABI subtypes underscore the need to better understand the balance between supporting cardiac function and maintaining optimal cerebral perfusion.

Furthermore, our study adds to the literature surrounding LV venting and mortality. One commonly cited study found LV venting to be associated with higher complication rates but lower 30-day mortality in patients with cardiogenic shock receiving venoarterial ECMO (14), and a meta-analysis of 3977 patients from 17 observational studies similarly found decreased mortality in this population (20).The international, multicenter, randomized DanGer Shock (Danish–German Cardiogenic Shock) trial also found improved 180-day mortality in patients receiving mAFP vs. standard of care (21). With respect to LV venting with mAFP vs. IABP, one study found no differences in mortality between the two groups (6).

Our study found that despite being associated with increased odds of ABI, hospital mortality was similar between LV-vented and non-LV-vented groups. These findings could represent a delayed mortality benefit associated with LV venting. Given that ABI is typically associated with increased mortality in ECMO patients (22) and that LV-vented patients tend to be more critically ill, it is possible that LV venting helped mitigate short-term mortality risk.

Taken together, our findings call for a more nuanced approach to patient selection for LV venting. While LV venting may provide valuable hemodynamic support, its potential to increase ABI risk warrants careful consideration, rather than broad, routine application as suggested by existing literature (23). However, our finding that there were no significant differences in odds of ABI or mortality for patients who received IABP vs. mAFP during venoarterial ECMO reassures clinicians that these devices may offer comparable neurologic safety profiles, suggesting that treatment decisions can be guided by device availability and patient-specific factors. Still, future studies incorporating more granular data such as cardiogenic shock etiology remain necessary.

This study has several limitations. First, the retrospective, observational nature of the dataset limited our ability to infer causality from our findings. Second, the voluntary nature of the ELSO dataset could have resulted in selection bias, and variations in data reporting between centers may affect generalizability. Missing data from the registry could also have limited our analyses, particularly as key physiologic variables such as blood pressure and lactate were frequently absent. We acknowledge that this missingness may disproportionately reflect differences in data completeness across centers, potentially favoring high-resource or high-volume institutions. To mitigate this, we used listwise deletion for cases with missing covariates in our propensity-matched analysis. Although our dataset did not contain a specific variable for post-cardiotomy shock, we adjusted for cardiopulmonary bypass (CBP) use as a surrogate to help account for the potential ABI risk associated with this subgroup. Third, our study lacked detailed hemodynamic and anticoagulation parameters, illness severity measures, and specific confounders—such as cardiac arrest characteristics—that may have influenced HIBI risk. Similarly, while percutaneous coronary intervention (PCI) may have served as a surrogate for antiplatelet exposure and vascular disease severity, this variable was not available in the dataset. Additionally, since our dataset lacked information on the different subtypes of cardiac arrhythmias, we were unable to explore the increased frequency of arrhythmia in the LV venting cohort. Our registry also does not distinguish between different types of Impella devices, which underwent technological updates during the study period. Earlier versions of the Impella are no longer commonly used, and lack of granularity in device type represents a significant limitation. Finally, the registry did not include data on the duration of LV venting support, and we were unable to identify patients who had LV venting devices placed pre-ECLS but maintained throughout ECMO support.

CONCLUSIONS

LV venting was associated with increased odds of ABI but not mortality in patients receiving peripheral veno-arterial ECMO for cardiogenic shock. Similar mortality between LV-vented and non-LV-vented patients despite increased ABI risk with LV venting may suggest an unmeasured survival benefit of LV venting. There was no difference in odds of ABI or mortality in patients who received IABP vs. mAFP. Further research is essential to validate these findings and better understand the mechanisms linking LV venting, ABI, and survival. Specifically, future studies should leverage larger, multicenter datasets with more granular data on cardiogenic shock etiology, illness severity, anticoagulation and hemodynamic parameters, and LV venting duration and timing.

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