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Rehospitalization and resource use after inpatient admission for extracorporeal life support in the United States

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ABSTRACT

Background: With increasing dissemination and improved survival after extracorporeal life support, also called extracorporeal membrane oxygenation, the decrease in readmissions after hospitalization involving extracorporeal life support is an emerging priority. The present study aimed to identify predictors of early readmission after extracorporeal life support at a national level.
Methods: This was a retrospective cohort study using the Nationwide Readmissions Database. All patients ≥18 years who underwent extracorporeal life support from 2010 to 2015 were identified. Patients were stratified into the following categories of extracorporeal life support: postcardiotomy, primary cardiogenic shock, cardiopulmonary failure, respiratory failure, transplantation, and miscellaneous. The primary outcome of the study was the rate of 90-day rehospitalization after extracorporeal life support admission. A multivariable logistic regression model was developed to predict the odds of unplanned 90-day readmission. Kaplan-Meier analyses were also performed.
Results: An estimated 18,748 patients received extracorporeal life support with overall mortality of 50.2%. Of the patients who survived hospitalization, 30.2% were discharged to a skilled nursing facility, and 21.1% were readmitted within 90 days after discharge. After adjusting for patient and hospital characteristics, cardiogenic shock was associated with the greatest odds of mortality (adjusted odds ratio 1.6; 95% confidence interval, 1.09–1.46; C-statistic, 0.64). The cohort with respiratory failure had decreased odds of readmission (adjusted odds ratio 0.76; 95% confidence interval, 0.58–0.99). Discharge to skilled nursing facility (adjusted odds ratio 1.64; 95% confidence interval, 1.36–1.97) was independently associated with readmission. Cardiac and respiratory-related readmissions comprised the majority of unplanned 90-day rehospitalizations.
Conclusion: In this large analysis of readmissions after extracorporeal life support in adults, 21% of extracorporeal life support survivors were rehospitalized within 90 days of discharge. Disposition to a skilled nursing facility, but not advanced age nor female sex, was associated with readmission.

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Introduction

Extracorporeal life support (ECLS, also called extracorporeal membrane oxygenation [ECMO]) is being used increasingly in the management of patients with acute cardiopulmonary decompensation.[1,2] Although its use was first reported >4 decades ago, ECLS utilization has experienced a major surge in the past decade.[2–4] As reported previously by our group, annual US hospitalizations for ECLS have increased 368% from 1,000 in 2008 to nearly 5,000 in 2014.[3] Advances in miniaturization of ECLS cannulas and circuits have allowed for safer deployment of this technology and have resulted in improved survival and decreased hemorrhagic, infectious, and thromboembolic complications.[5–8] Nevertheless, survivors of ECLS often retain many of their comorbidities and require extensive medical and rehabilitative care after hospital discharge.

With renewed emphasis on value-based delivery of healthcare in the United States, quality of care is often measured beyond acute survival. Combes et al reported on a small cohort of ECLS survivors and found substantially lower scores for general health and physical and social functions compared with healthy controls at 1 year.[9] One might therefore expect

Table I
ECLS indication based on ICD9 and ICD10

ECLS indication group	Diagnosis code
Postcardiotomy	• Any available pr code: 35.x, 36.1x, 36.2, 36.9, 37.1, 37.3x, 37.49
	• Any available i10_pr code: 021xxxx, 025xxxx, 027xxxx, 02Bxxxx, 02Cxxxx, 02Lxxxx, 02Nxxxx, 02Qxxxx, 02Txxxx, 02Wxxxx
Primary cardiogenic shock	• dxccs1: 96, 97, 100, 101, 103, 107, 108
Primary respiratory failure	• dxccs1: 003, 122-123, 126, 130-132
Cardiopulmonary failure	• dxccs1 does not contain cardiogenic shock or respiratory failure code but contains cardiogenic or respiratory related codes in any field from dxccs2-dxccs30. Excludes heart transplant, lung transplant, and postcardiotomy.
Heart or lung transplant dysfunction	• pr: 37.51, 335, 3751, 3352, 3350, 336
	• i10_pr: 02YAxxx, 0BYKxxx, 0BYLxxx, 0BYCxxx, 0BYDxxx, 0BYFxxx, 0BYGxxx, 0BYHxxx, 0BYJxxx, 0BYKxxx, 0BYLxxx, 0BYMxxx
Miscellaneous	• If patient did not meet above criteria, grouped into miscellaneous. Diagnoses included (sepsis, malignancy, trauma, poisoning, obstetric related) diagnosis clinical classification software codes i10_pr, ICD10 PR; pr, ICD9 procedure code, dxccs.

Table II
Patient demographics for the readmitted and nonreadmitted ECLS cohorts who survived to discharge

	Nonreadmitted N = 5,967	Readmitted N = 3,366	*P* value
Age, y (SE)	51.5 (0.5)	52.8 (.7)	.13
Female (%)	35.4	38.3	.009
Heart failure (%)	31.0	26.7	.83
Chronic lung disease (%)	16.2	16.5	.20
Depression (%)	9.4	11.0	.36
Hypertension (%)	48.8	46.9	.86
Chronic liver disease (%)	3.2	3.0	.01
Malignancy (%)	2.3	3.6	.01
Chronic kidney disease (%)	15.8	24.0	.005
History of coagulopathy (%)	41.2	46.9	.15
Diabetes with complications (%)	4.5	5.9	.15
Hospital status			
Large metropolitan (%)	71.9	76.6	.03
Small metropolitan (%)	27.4	23.1	
Micropolitan (%)	0.7	.3	
Hospital control			
Government (%)	11.4	13.2	.22
Private, not-for-profit (%)	86.6	85.2	
Private (%)	2.0	1.6	
Bedsize			.50
Small (%)	3.5	3.2	
Medium (%)	8.1	7.0	
Large (%)	88.4	89.7	
Teaching status			.23
Metropolitan, teaching (%)	7.5	7.1	
Metropolitan, nonteaching (%)	91.8	92.5	
Nonmetropolitan (%)	0.8	0.3	

Malignancy includes lymphoma, solid tumor of any organ type, and evidence of metastases.

these survivors to require more intensive medical care in both the inpatient and outpatient settings. Rehospitalizations in particular are considered a marker for quality of care in various conditions and are being used for benchmarking and purposes of cost-containment.[10] Although ECLS survivors generally carry several major comorbidities after hospital discharge, the magnitude of hospital readmissions and costs of care for this population remain poorly characterized.

The present study was performed to characterize the national burden of readmission and costs for care of patients surviving hospital discharge after ECLS. We further evaluated the principle causes of readmission and sought to identify factors independently associated with unplanned rehospitalization in this cohort.

Methods

Data were obtained from the 2010 to 2015 Nationwide Readmissions Database (NRD), the largest publicly available all-payer discharge database maintained by the Agency for Healthcare Research and Quality.[11] It should be noted that the episodes of hospitalization in the NRD are accrued from individual state inpatient databases containing patient identifiers that allow for linked visits to inpatient facilities and specifically exclude rehabilitation and long-term acute hospitals.[11] The NRD accounts for up to 57.8% of all US discharges. Each sampled institution has assigned discharge weights allowing for survey-weighted national estimates.

The study cohort was derived from approximately 17 million annual unweighted discharges in the NRD using International Classification of Disease, ninth (ICD9) and 10th (ICD10) editions, administrative coding. All adult patients (≥18 years) who underwent ECLS (ICD9 39.65 and 39.66; ICD10 5A15223, 5A1522F, 5A1522G, 5A1522H) were identified, and those who were <18 years of age were excluded. Indications for ECLS were categorized as postcardiotomy (any patient requiring extracorporeal life support following cardiac surgery), cardiogenic shock, respiratory failure, cardiopulmonary failure, transplantation graft dysfunction, and miscellaneous using a combination of diagnosis (DX), procedure (PR), and clinical classification software (DXCCS) codes described in Table I.[2] Costs of hospitalization were obtained by using the

Table III
Demographics, index, and readmission outcomes by support type of ECLS

	PC (N = 7,741)	CS (N = 3,862)	RF (N = 2,539)	CPF (N = 2,608)	TX (N = 984)	MISC (N = 1,015)	All ECLS (N = 18,748)	P value
Proportion of ECLS	41.3%	20.6%	13.5%	13.9%	5.2%	5.4%		
Age in y (SE)	60.2 (0.4)	51.7 (0.6)	42.9 (0.6)	48.1 (0.6)	51.5 (0.8)	51.6 (0.8)	53.5 (0.3)	<.001
Female (%)	34.0	31.5	42.7	37.6	31.2	36.2	35.1	<.001
Heart failure (%)	48.5	58.2	8.3	35.3	72.2	—	41.9	<.001
CPD (%)	18.0	13.4	18.8	18.3	9.7	12.4	16.6	.002
Depression (%)	7.3	7.1	9.6	8.7	10.2	13.0	8.0	.08
Hypertension (%)	56.2	46.5	33.9	38.5	31.8	44.7	46.8	<.001
CLD (%)	4.0	4.5	5.5	5.0	5.1	3.8	4.5	.52
CKD (%)	23.5	21.4	9.7	19.0	37.2	11.7	20.8	<.001
Diabetes (%)	6.3	4.6	2.6	3.7	3.2	0.0	19.1	.07
Index mortality (%)	50.7	56.7	44.3	50.7	44.0	41.2	50.2	<.001
DC to SNF (%)	29.8	30.2	35.5	25.9	25.9	34.1	30.2	.13
Index costs ($K)	155.1 ± 5.6	212.0 ± 9.3	216.6 ± 9.6	219.6 ± 8.2	385.8 ± 35.5	99.7 ± 22.3	195.4 ± 184.4	<.001
Index LOS (d)	26.7 ± 1.0	36.5 ± 1.6	42.5 ± 2.1	41.6 ± 1.7	79.9 ± 5.6	29.6 ± 2.3	36.2 ± 1.1	<.001
Days to Readm	46.4	63.1	49.7	51.9	36.5	51.9	50.4	.1033
Readmitted (%)	34.7	38.0	32.6	44.8	47.6	18.1	36.1	<.001
90-d Readm (%)	20.8	22.7	21.1	26.0	25.2	3.7	21.1	<.001
Readm Costs ($K)	26.9 ± 2.5	28.2 ± 3.9	34.7 ± 6.5	35.2 ± 5.0	39.5 ± 9.0	77.4 ± 32.3	31.8 ± 2.2	.19
Readm LOS (Days, SE)	8.9 ± 0.7	9.2 ± 1.0	10.2 ± 1.1	11.4 ± 1.4	12.0 ± 2.4	15.4 ± 5.4	9.9 ± 0.5	.075

CKD, chronic kidney disease; *CLD*, chronic liver disease; *CPD*, chronic pulmonary parenchymal disease; *CPF*, cardiopulmonary failure; *CS*, cardiogenic shock; *DC to SNF*, discharge to skilled nursing facility; *LOS*, length of stay; *MISC*, miscellaneous; *PC*, postcardiotomy; *Readm*, Readmission; *RF*, respiratory failure; *SE*, standard error; *TX*, transplantation graft dysfunction.
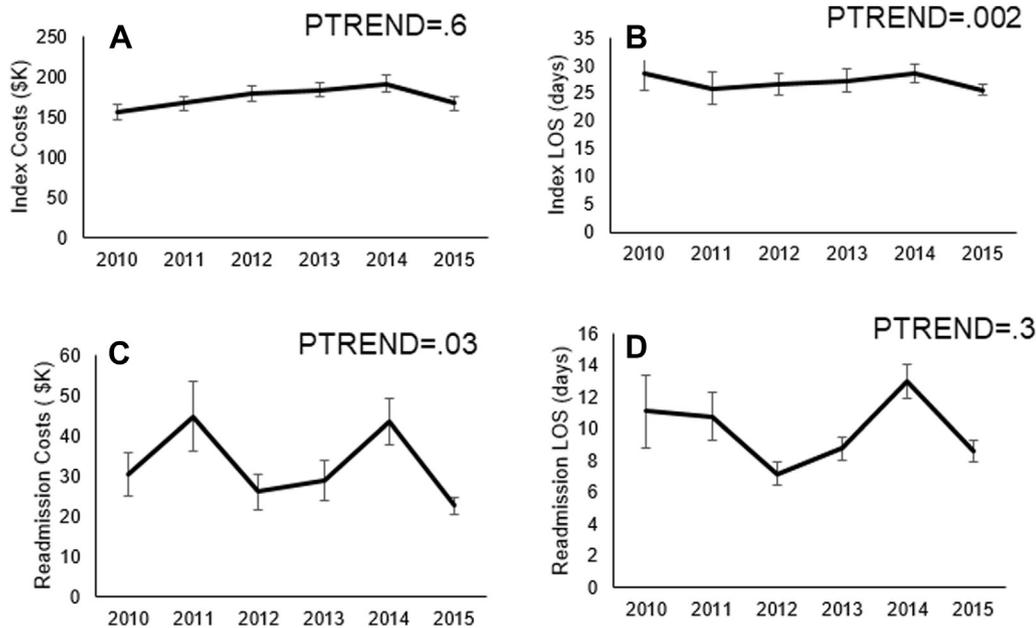

Fig 1. Trends of index and readmission costs and duration of stay for all ECLS. *PTREND*, P-for-trend.

cost-to-charge ratio files and personal healthcare price index adjustment to normalize costs for inflation over time.[12]

Demographics were compared between readmitted and non-readmitted patients using χ^2 analysis for categorical variables and Wald's adjusted test for continuous variables. Multivariable logistic models were generated for categorical outcomes of nonelective readmission within 90 days using survey-weighted analyses to account for effects of hospital clustering. Model selection was based on inclusion of clinically relevant variables to optimize the C-statistic. Odds ratios were reported with corresponding 95% confidence interval. A Kaplan-Meier analysis was performed to identify time to all-cause readmission. The Wilcoxon log-rank test was used to evaluate discrepancies in readmission performance among groups by indications for ECLS. Readmission diagnoses were categorized based on grouping of similar diagnoses-related group codes for all patients with a linked, nonelective second visit within the

remainder of the year after ECLS (Table II). Trend analysis of readmission and readmission mortality was performed using modified Cochran-Armitage test.[13] All statistical analyses were performed using Stata 15 (StataCorp, College Station, TX). This study was deemed exempt from review by the Institutional Review Board at the University of California, Los Angeles.

Results

During the study period, an estimated 18,748 patients received ECLS support, with an all-cause, inpatient mortality of 50.2%. Of the patients who survived hospitalization, 30.2% were discharged to a skilled nursing facility and 21.1% were readmitted to an acute care hospital within 90 days after discharge. All-cause mortality at the first readmission within 90 days was 5.4%. The baseline comorbidities of the patients and hospital characteristics associated with the
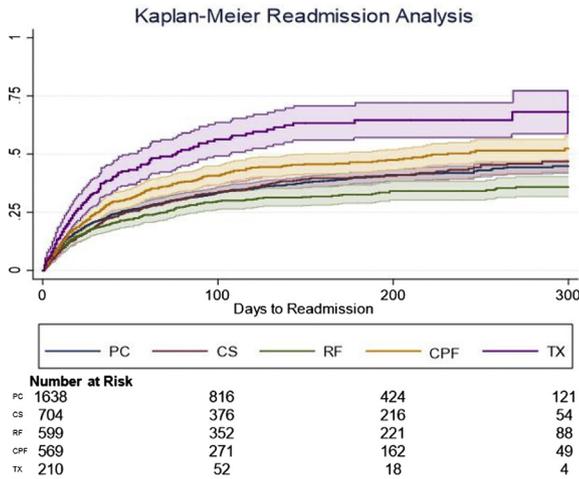
Fig 2. Kaplan-Meier readmission analysis. *Log-rank test: PC versus CS, P = .89; PC versus RF, P = .007; PC versus CPF, P = .0022; PC versus Tx, P < .0001. *CPF*, cardiopulmonary failure; *CS*, cardiogenic shock; *PC*, postcardiotomy; *RF*, respiratory failure; *TX*, transplantation graft dysfunction.

Table IV
Adjusted predictors of readmission

	AOR	95% CI
Age >65 y	0.94	0.8–1.2
Female	1.16	1.0–1.4
Heart failure	0.71	0.6–0.9
Chronic kidney disease	1.62	1.3–2.0
Chronic liver disease	1.01	0.7–1.6
Hospital bedsize		
Small	Reference	
Medium	1.08	0.64–1.82
Large	1.10	0.67–1.76
Composite complication	1.23	0.99–1.52
Discharge to SNF	1.64	1.36–1.97
Indication		
PC	Reference	
CS	1.10	0.87–1.38
RF	0.76	0.58–0.99
CPF	1.43	1.11–1.83
C-statistic	0.60	

AOR, adjusted odds ratio; *CI*, confidence interval; *CPF*, cardiopulmonary failure; *CS*, cardiogenic shock; *PC*, postcardiotomy; *RF*, respiratory failure; *SNF*, skilled-nursing facility.

readmission are shown in Table II. Briefly, those readmitted after ECLS discharge were more commonly female and had greater rates of malignancy and chronic kidney disease.

Outcomes of the index and readmission are illustrated in Table III. Among all ECLS categories, cardiogenic shock was associated with the greatest rate of index mortality (P < .001). After adjusting for differences in patient and hospital characteristics, cardiogenic shock was associated with the greatest odds of mortality (adjusted odds ratio 1.6, 95% confidence interval, 1.09–1.46; C-statistic, 0.64). Annual expenditures for index ECLS hospitalizations were estimated at $275 million, with an average hospitalization cost of $177,046. ECLS for postcardiotomy was associated with the least costs and duration of stay among all indications (Table III, P < .001). During the study period, the costs of index ECLS hospitalization remained stable, whereas the average duration of stay across all indications decreased from 28 to 25 days (Fig 1, A and B).

Average time interval to first readmission for the entire cohort was 50 days without a statistically significant difference among various indications (Table III). Kaplan-Meier analysis demonstrated a greater readmission rate in patients receiving heart and lung transplants, followed by the cohort with cardiopulmonary failure (Fig 2). The respiratory failure group exhibited the lowest rates of readmission within 90 days of discharge and for the remainder of the year, as shown in Fig 2. Risk-adjusted predictors of readmission included the presence of chronic kidney disease and discharge to a skilled nursing facility (Table IV). Furthermore, compared with classification of postcardiotomy cohort, respiratory failure patients had a lesser odds of readmission, whereas mixed cardiopulmonary failure was associated with statistically greater odds of rehospitalization (Table IV).

During the study period, the incidence and mortality rates for readmission among ECLS patients did not change (Fig 3). Cardiac and respiratory-related readmissions comprised the majority of unplanned rehospitalizations for the first 90 days and the remainder of the year. Readmission for renal or genitourinary reasons comprised a greater proportion of rehospitalizations within the first 90 days compared with the remainder of the observation period (Table V). Subgroup analysis of major readmission categories revealed a greater proportion of cardiac-related readmissions for the postcardiotomy and cardiogenic shock cohorts and respiratory reasons for respiratory and cardiopulmonary
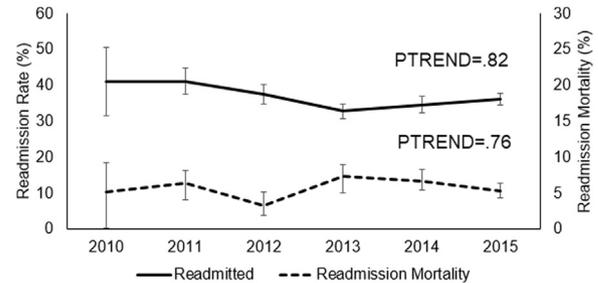

Fig 3. Readmission incidence and mortality for all ECLS. Annual readmission incidence (solid black line, left-sided y-axis) and readmission mortality (black dotted line, right-sided y-axis) shown with no significant change during the study period. *PTREND*, P-for-trend.

failure groups (Fig 4). There were no differences in rates of infectious or genitourinary readmissions among the various ECLS indications. Patients who received ECLS for respiratory failure exhibited a nearly 2-fold greater rate of gastrointestinal or hepatobiliary issues than the postcardiotomy cohort (14.2 vs 7.9%, P = .03).

On readmission, there were differences in rehospitalization costs or duration of stay among ECLS groups (Table III). During the 6-year period, where ECLS experienced an increase in utilization, the costs of readmission modestly decreased modestly from $30,504 to $22,585 per episode (Fig 1, C, P = .03). Taken together, the overall financial burden of the first non-elective readmission within 90 days of discharge was in excess of $6.2 million in annual expenditures for ECLS patients.

Discussion

Advances in extracorporeal circulation and the H1N1 influenza epidemic of the past decade have resulted in the rapid adoption of ECLS technology in the United States.[14] Hospitalizations for ECLS are resource intensive, with an incremental increase in hospitalization costs as low as 100,000 for cardiogenic shock and >$450,000 for lung transplant patients.[1,3,15,16] Survivors of ECLS often require prolonged hospitalization and intensive follow-up after discharge. Thus far, however, the burden and risk factors for rehospitalization in this rapidly growing patient sector has not been reported. We

Table V
Overall readmission indication for all ECLS

DRG category	Percentage of first readmission (N = 3,370)	Percentage of 90-day readmission (N = 1,967)
Cardiac	26.6	29.5
Respiratory	14.37	14.1
Infectious	12.15	2.2
GI/biliary	9.8	12.0
Missing	9.76	2.8
Skin	4.44	2.5
Neurologic/psych	4.07	4.2
Other/misc	3.31	3.0
Vascular/amp	3.21	2.2
Complication	2.5	2.8
Renal/genitourinary	2.37	13.5
Hematologic	2.11	2.8
Endo/nutrition	1.85	2.1
Musculoskeletal	1.18	0.8
Chemotherapy	0.94	0.3
Gynecologic	0.92	0.7
Other unrelated operation	0.42	0.5

CPF, cardiopulmonary failure; *CS*, cardiogenic shock; *PC*, postcardiotomy; *RF*, respiratory failure; *SNF*, skilled nursing facility.
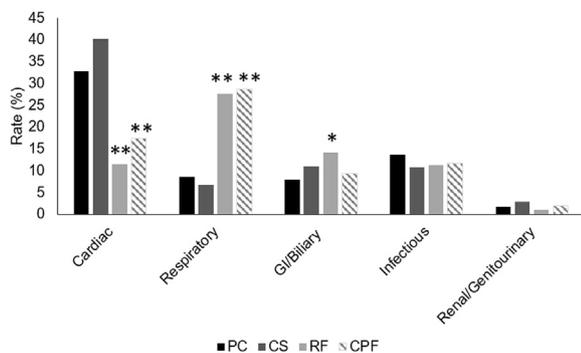

Fig 4. Comparison of readmission cause by indication for ECLS. *P = .03. **P < .001. *CS*, cardiogenic shock; *CPF*, cardiopulmonary failure; *PC*, postcardiotomy; *RF*, respiratory failure.

used the Nationwide Readmissions Database to examine the incidence, costs, and predictors for unplanned readmission in patients surviving to discharge after hospitalization for ECLS. We found that ECLS mortality remains high at 50%, with 21% of ECLS survivors requiring rehospitalization at least once within 90 days of discharge. ECLS patients with cardiopulmonary failure and transplant graft dysfunction had the greatest readmission burden, whereas patients with respiratory failure experienced decreased odds of readmission.

Overall, cardiopulmonary readmissions comprised the greatest burden of rehospitalization within 90 days after ECLS discharge. As expected, the indication for readmission correlated with primary indication for ECLS because patients in the categories of postcardiotomy and cardiogenic shock returned more commonly for cardiac-elated diagnoses, whereas respiratory failure and cardiopulmonary failure patients had a greater rate of respiratory-related rehospitalization. The congruence of indications for ECLS and primary readmission diagnoses within 90 days after discharge underscores the chronicity of processes that induce profound inpatient cardiopulmonary dysfunction. Therefore, consideration of specialized outpatient models, similar to the management of high-risk chronic liver disease, heart failure, and geriatric patient populations, might improve recovery after discharge after ECLS.[17–20]

Older age and the female sex, which are established risk factors for readmission after conventional operations, were not associated with increased odds of rehospitalization after ECLS.[21,22] Rather, discharge to a skilled-nursing facility was an independent predictor of readmission, likely a reflection of baseline patient frailty and ongoing intensive needs not well-captured with the administrative risk-adjustment model.[23] Discharge to short or long-term facilities has also been associated with increased readmission in operations involving percutaneous ventricular assist devices and several other cardiac operations.[21,24,25] Therefore, development and utilization of a method of assessment of patient frailty before discharge may aid in predicting and decreasing readmission better than pre-ECLS variables alone.[23,26] The observed decrease in readmission with baseline heart failure was unexpected owing to the large body of literature endorsing high readmission rates for patients with various etiologies of cardiomyopathy.[18,19,27] Given the prevalence of heart failure in the ECLS population, its presence might represent a improved inpatient recognition diagnosis and coding, thus exerting a protective effect against readmission.

Among all indications for ECLS, respiratory failure was independently associated with decreased odds of readmission, whereas mixed cardiopulmonary failure and transplant graft dysfunction yielded the greatest cumulative rates of rehospitalization. Our findings provide insight into the role of resilience, a substantial but previously underrecognized determinant of readmission. Patients with respiratory failure requiring ECLS are on average younger and are afflicted by an acute illness. Prior studies have also shown that ECLS for respiratory failure was associated with an increased rate of mortality and are also typically the youngest patient cohort.[2,3] Therefore, despite being critically ill and often requiring discharge to long-term facilities, patients with respiratory failure might possess more resilience and be less likely to be affected by chronic illnesses. Conversely, patients with cardiopulmonary failure or those requiring ECLS after transplantation often have chronic illnesses, lack physiologic reserve, and maybe immunosuppressed, thereby hampering their recovery. Although resilience and frailty are currently not captured in most databases, these metrics may serve as important predictors of complications and readmissions alike.[22]

As indications and availability of ECLS expand, the discussion surrounding hospital expenditures and life-years gained will evolve in complexity. This discussion is especially relevant given the estimated cost of $275 million per year with an additional $6 million in readmission costs within the first 3 months. Patient-level economic analyses with quality-adjusted life expectancy and long-term life expectancy for ECLS patients, such as those available for transcatheter aortic valve replacement, another burgeoning technology, are not available but are warranted.[28] Future prospective

studies of ECLS should focus on quality of life added on surviving ECLS to objectively characterize the cost-effectiveness of this life-saving modality.[29,30] Long-term follow-up of patient-centered outcomes are warranted to assess the true costs and benefits of ECLS beyond the acute hospitalization.

Several limitations of our study should be acknowledged. As one of the largest discharge databases available, the NRD allows for linkage of patients visits for each year. However, long-term outcomes are not feasible because patient identification is not consistent across years. Furthermore, the database lacked sufficient detail to delineate ECLS support and cannulation strategy, limiting specificity of our present analysis. Another limitation of our study is that we excluded patients who were discharged to rehabilitation and long-term acute hospitals, which would have their own economic costs of post discharge care. Despite more hospitals performing ECLS, it remains a highly specialized procedure that often requires regional transfer, increasing the risk of patients readmitted to a non-NRD sampled hospital. Absence of physiologic data also limits the extent to which risk-adjustment may be performed, although we have used rigorous methods to control cohort imbalance to the best of our ability by using diagnoses associated with critical illness, such as prolonged mechanical ventilation. Furthermore, patients were categorized using a combination of diagnosis and procedural administrative codes available in the NIS without hemodynamic information. There also exists a subset of patients who were admitted initially with cardiogenic shock and eventually required postoperative ECLS who are categorized in postcardiotomy cohort owing to limitations of NIS data structure.

In conclusion, this large, dedicated analysis showed the frequency and costs of readmissions after ECLS in adults using nationally representative data. With the rapid adoption of ECLS and improved survival, focus on care transitions and post-discharge monitoring for patients at high-risk for readmission might improve patient quality of life and value of care in this population.

Disclosure

All authors have no conflicts of interest to declare.

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