Original Article

The economic burden and long-term mortality in survivors of extracorporeal membrane oxygenation in South Korea

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Background: The economic burden for extracorporeal membrane oxygenation (ECMO) survivors is a critical issue. We investigated the total healthcare costs for one year following ECMO support and its association with three-year all-cause mortality.

Methods: This population-based cohort study used data from the National Health Insurance Service (NHIS) in South Korea. Adult ECMO survivors (age ≥18 years who were alive ≥365 days following ECMO support) from January 1, 2005, to December 31, 2018, were included. The total healthcare costs for one year included all the expenses for hospital and outpatient clinic visits after discharge.

Results: In total, 6,044 patients were included in the final analysis comprising 3,566 (59.0%) in the cardiac indication group, 658 (10.9%) in the respiratory indication group, and 1,820 (30.1%) in the "other" group. The median total healthcare cost was United States Dollars (USD) 46,308.0 [interquartile range (IQR): 25,727.0–86,924.8]. The median ECMO support and hospital stay durations were three (IQR: 1–7) days and 25 (IQR: 15–31) days. In the multivariable Cox regression model, a USD 1,000 increase in the total healthcare cost was associated with an increase in the three-year all-cause mortality (hazard ratio, 1.01; 95% CI: 1.00–1.01; P=0.015).

Conclusions: After one year, ECMO survivors accrued USD 46,308 in healthcare costs in South Korea. An increase in the total healthcare cost was associated with a higher risk of three-year all-cause mortality among ECMO survivors.

Keywords: Circulatory support; cardiorespiratory failure; extracorporeal membrane oxygenation (ECMO); artificial lung & respiratory support; cardiac assist & artificial heart

Submitted May 24, 2022. Accepted for publication Sep 30, 2022.
doi: 10.21037/atm-22-2721
View this article at: https://dx.doi.org/10.21037/atm-22-2721

Introduction

Extracorporeal membrane oxygenation (ECMO) is a rescue therapy for patients with refractory respiratory or cardiac failure in the intensive care unit (ICU) (1,2). ECMO support has increased globally from 2006 to 2017, according to an Extracorporeal Life Support Organization registry report (3).

In South Korea, as the number of hospitals providing ECMO support is increasing, the number of cases receiving ECMO support is also increasing, although gradually (4,5). General indications for ECMO include (I) refractory heart failure; (II) severe acute respiratory failure or acute respiratory distress syndrome (ARDS); (III) patients awaiting heart or lung transplant; and (IV) patients who had cardiac arrest or have cardiac arrest that

is potentially reversible by ECMO support. However, there are some relative contraindications as stipulated by the government, including (I) irreversible heart failure after transplantation; (II) patient refusal of cardiopulmonary resuscitation; (III) recent brain hemorrhage; (IV) absolute contraindications to anticoagulation therapy during ECMO support; (V) advanced multiple organ failure; (VI) severe immunodepression; (VII) irreversible neurologic disorders; (VIII) terminal stages of cancer; and (IX) very old age.

For ICU survivors, the socio-economic burden of critical illness affects their quality of life (QOL) after hospital discharge as observed by unemployment or need for hospital care after the initial discharge (6). A recent study reported that financial stress after a critical illness was a common and serious issue, as it can cause anxiety and depression in survivors (7). The economic burden of treatment can be more significant for patients who require ECMO support because of its high cost (8,9). In Norway, the median cost of ECMO is United States Dollar (USD) 62,545 [interquartile range (IQR): 34,121–154,817] (9). In the United States, the total in-hospital cost of critically ill patients who undergo ECMO is USD 42,554–537,554 (8). The previous studies focused on the cost of the ECMO procedure itself or the total hospitalization cost at the time of ECMO support (8,9). Another recent cohort study from Canada reported that the median value of the total healthcare cost for ECMO survivors following admission was approximately USD 102,320.5 (IQR: 46,102.7–189,271.5) (10). However, this study did not evaluate the association between the total healthcare cost after admission and the long-term outcomes of ECMO survivors (10).

This study examined the total healthcare cost for ECMO survivors following admission and investigated whether the total cost was associated with poorer long-term survival outcomes among ECMO survivors. We present the following article in accordance with the STROBE reporting checklist (11) (available at https://atm.amegroups.com/article/view/10.21037/atm-22-2721/rc).

Methods

Study design and ethics statement

The institutional review board (IRB) of Seoul National University approved the study protocol (approval No. X-2001-586-902), and the National Health Insurance Service (NHIS) approved and provided the data (NHIS-2020-1-125). The informed consent requirement was waived by the IRB. Data were retrospectively analyzed in an anonymized form. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Data source and the study population

The NHIS database was used for data extraction. As the sole public health insurance system in South Korea, the NHIS contains demographic, socio-economic status, and healthcare use information for all the citizens. Diagnoses are registered in the database using the International Classification of Diseases 10th Revision (ICD-10) codes along with the procedure and drug prescription information.

All critically ill patients aged ≥18 years who received ECMO support in the ICU from January 1, 2005, to December 31, 2018, in South Korea were included. ECMO survivors were patients who were alive ≥365 days after ECMO support initiation. In South Korea, the death of an individual is registered in the NHIS database regardless of where the patient died (ICU, hospital, or home). As venoarterial (VA) and venovenous (VV) ECMO are registered with the same prescription code in the NHIS database, the ECMO survivors were divided using the main diagnoses at ECMO support, representing VA and VV ECMO. The cardiac indication group (cardiovascular disease, post-cardiac arrest, and shock) represented VA and the respiratory indication group (ARDS, and respiratory failure) represented VV; all other main diagnoses were classified into the "other" group. The "other" group comprised cancer, gastrointestinal tract diseases, sepsis, post-surgery, connective tissue disease, cerebrovascular disease, urinary tract disease, nervous system disease, endocrine disease, musculoskeletal disease, event at pregnancy and childbirth, poisoning and drug intoxication, trauma, hematologic disorder, and congenital malformation. The "other" group included patients with secondary respiratory or cardiac failure requiring VA or VV ECMO support as a consequence of the abovementioned conditions and diseases. For example, if a patient was diagnosed with both cardiac failure and a main diagnosis of sepsis and was provided VA ECMO support, the patient was included in the "other" group. The NHIS defines the main diagnosis as the patient's most prominent disease demanding treatment or examination during hospitalization. For example, for a patient admitted to the hospital with an initial pneumonia diagnosis but during hospitalization was diagnosed with ARDS and required ECMO support, the NHIS registered

ARDS as the main diagnosis.

The economic burden for ECMO survivors

The economic burden for ECMO survivors was defined as the total healthcare costs for one year following ECMO support, including the total ECMO-related hospital costs and all expenses accrued through hospital and outpatient clinic visits after discharge. The total cost was divided into self-payment (paid by the patient) and NHIS insurance coverage (paid by the NHIS). In general, South Korean citizens pay approximately 1/3 of their total medical expenses, and the rest (approximately 67%) are subsidized by the government (12). However, those who cannot afford insurance premiums or have difficulty financially supporting themselves are included in the Medical Aid Program, where the South Korean government pays almost all medical expenses. In a recent Profile of the National Cohort in South Korea, the percentage of men and women enrolled in the total Medical Aid Program was 2.5% and 3.4%, respectively (13). Additionally, the South Korean government pays almost all medical expenses (approximately 90–95%) if any individual is diagnosed with severe and rare diseases, which may otherwise cause a higher economic burden. These severe and rare diseases include cancer, severe burn, severe trauma, cerebrovascular and cardiovascular diseases. For this study, all costs were first extracted in Korean currency (won, ₩) then converted to USD based on the exchange rate of ₩1,080 = $1 USD. Additionally, all expenses incurred by the patient for treatment in a hospital, outpatient clinic, at home, in a nursing home, etc. are registered in the NHIS database.

Endpoint

The endpoint was the three-year all-cause mortality rate of ECMO survivors. The survival time was calculated from the ECMO support initiation date to the death date. All death dates were extracted until December 31, 2019. As we included ECMO patients who survived ≥365 days after ECMO initiation, we considered three-year all-cause mortality (two additional years) as an endpoint.

Covariates

Age and sex were collected as demographic information. The residence and annual income level at ECMO support reflected the socioeconomic status of ECMO survivors. Seoul (the capital city) and other metropolitan cities were considered urban areas; elsewhere was considered rural. The annual income level was divided into four groups using the quartile ratio. High-volume medical centers were associated with improved survival outcomes among ECMO patients (14). Therefore, we collected the annual case volume of ECMO support in South Korea during the study period then divided it into four groups using quartile ratios (Q1: <15, Q2: 15–28, Q3: 29–63, and Q4: >63). The Charlson Comorbidity Index (CCI) was calculated using individual underlying diseases by ICD-10 codes to reflect the comorbidity status of all ECMO survivors (15). The length of hospital stay during ECMO support and ECMO support duration were collected as covariates. Additionally, we collected the total number of hospital-visit days for one year, defined as the total number of outpatient clinic visits and hospital inpatient days. For example, if an ECMO survivor was hospitalized for 25 days surrounding ECMO support, visited the outpatient clinic ten times, and was admitted to the hospital for seven days within one year, the total number of hospital-visit days for one year was 42. The follow-up after hospital discharge from ECMO support was classified as a follow-up in the same hospital in which ECMO support was performed, transfer to other long-term care centers, discharge to home, or outpatient clinic follow-up. The period of ECMO support from 2005 to 2018 was divided into four groups, namely 2005–2008, 2009–2012, 2013–2015, and 2016–2018, because the prevalence and cost related to ECMO support have increased in South Korea (16).

Statistical analysis

The clinico-epidemiological characteristics of all ECMO survivors were presented as median with IQR for continuous variables and number with percentage for categorical variables. A one-way analysis of variance test and chi-square test were used for continuous and categorical variables, respectively, to compare characteristics based on the main diagnosis at ECMO support. A generalized linear regression model (GLM) was constructed to examine factors independently associated with the total healthcare cost incurred in one year among ECMO survivors. In this model, the gamma distribution and the log-link function were assumed for the dependent variable (total healthcare cost for one year). All covariates were included in the GLM for the multivariate adjustment. Next, we fitted a multivariable Cox regression model for three-year all-cause

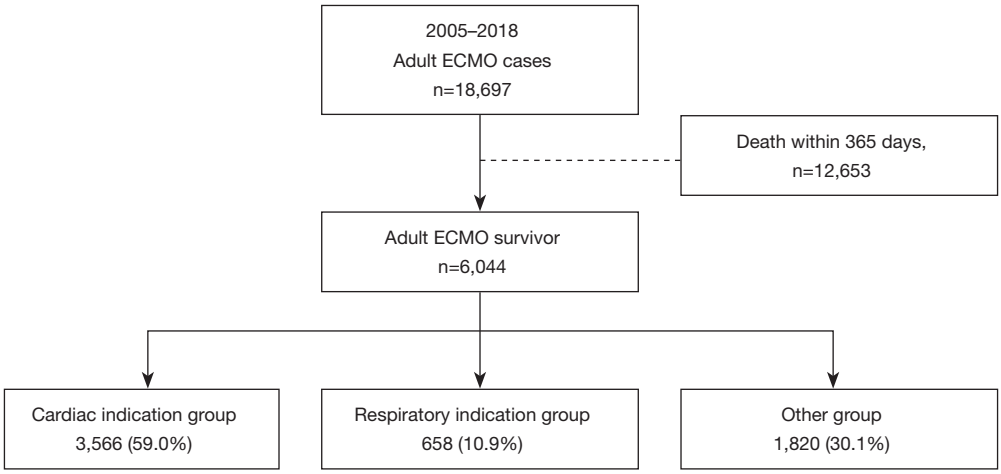

Figure 1 The ECMO survivor selection process. ECMO, extracorporeal membrane oxygenation.

mortality among ECMO survivors. ECMO survivors who received ECMO support from 2017 to 2018 were excluded from the analysis because their three-year mortality could not be evaluated before December 31, 2019. The total healthcare cost was included in the model as a continuous variable per USD 1,000. To avoid multicollinearity with the total healthcare cost, a separate multivariable model was fitted with self-payment for one year, confirming that the central assumption of the multivariable Cox regression model was satisfied (using log-log plots), and there was no collinearity between the variables in the model (variance inflation factor <2.0). The GLM results were presented as exponential regression coefficients (Exp Coef) with 95% CIs, and the multivariable Cox regression model results were presented as hazard ratios (HRs) with 95% CIs.

Results

Study population

During the study period, 18,697 adults (≥18 years old) received ECMO support from 110 ECMO centers. Among them, 6,044 patients (32.3%) were alive after 365 days and included in the final analysis as ECMO survivors. The ECMO survivors were 3,566 (59.0%) in the cardiac indication group, 658 (10.9%) in the respiratory indication group, and 1,820 (30.1%) in the "other" group. *Figure 1* presents a flow chart depicting the study participant selection process, and *Table 1* presents the clinicopathological characteristics of all ECMO survivors. The median value of the total healthcare cost for one year was USD 46,308.0 (IQR: 25,727.0–86,924.8). The median self-payment cost was USD 3,960.3 (IQR: 1,875.9–8,101.7). The median ECMO support and hospital stay durations were 3 (IQR: 1–7) days and 25 (IQR: 15–31) days, respectively. *Table 2* compares the clinicopathological characteristics between the main diagnosis at ECMO support (i.e., cardiovascular, respiratory, and "other").

Associated factors for total healthcare cost for one year

Table 3 presents the multivariable GLM results for the total healthcare cost for one year among ECMO survivors. Older age (Exp Coef: 1.01; 95% CI: 1.00–1.01; P<0.001), male sex (Exp Coef: 1.07; 95% CI: 1.04–1.10; P<0.001), a longer ECMO support duration (Exp Coef: 1.02; 95% CI: 1.01–1.02; P<0.001), the hospital stay length (Exp Coef: 1.01; 95% CI: 1.01–1.02; P<0.001), and the total number of hospital-visit days for one year (Exp Coef: 1.01; 95% CI: 1.00–1.01; P<0.001) were associated with increased total healthcare costs. The respiratory indication group had 12% less healthcare costs (Exp Coef: 0.89; 95% CI: 0.86–0.93; P<0.001) than the cardiac indication group. The "other" group had 31% more costs (Exp Coef: 1.31; 95% CI: 1.27–1.35; P<0.001) than the cardiac indication group.

The three-year all-cause mortality rate

Table 4 presents the multivariable Cox regression model results for the three-year all-cause mortality rate among ECMO survivors from 2005 to 2016 (n=4,255). There were 449 patients who died within three years. In multivariable

Table 1 The clinicopathological characteristics of all ECMO survivors

Variables	Median [IQR] or number (%)
Age, years	56 [45, 65]
Sex, male	4,028 (66.6)
Residence at ECMO support	
Urban area	2,740 (45.3)
Rural area	3,304 (54.7)
Year of ECMO support	
2005–2008	492 (8.1)
2009–2012	1,169 (19.3)
2013–2015	1,784 (29.5)
2016–2018	2,599 (43.0)
Annual income level at ECMO support	
Q1 (lowest)	1,481 (24.5)
Q2	1,166 (19.3)
Q3	1,468 (24.3)
Q4 (highest)	1,929 (31.9)
Annual case volume of ECMO support	
Q1 <15	1,194 (19.8)
Q2: 15–28	1,346 (22.3)
Q3: 29–63	1,862 (30.8)
Q4 >63	1,642 (27.2)
Charlson comorbidity index	3 [1,4]
Total number of hospital-visit days for 1-year, days	81 [48, 141]
Duration of ECMO support, day	3 [1,7]
Length of hospital stay at ECMO support, days	25 [15, 31]
Total healthcare cost for one year, USD	46,308.0 [25,727.0, 86,924.8]
Self-payment by patient for 1-year	3,960.3 [1,875.9, 8,101.7]
NHIS insurance coverage for 1-year	41,592.6 [23,035.0, 77,810.8]
Follow up after discharge	
Follow up in the same hospital	3,048 (50.4)
Transfer to other long-term facility care center	230 (3.8)
Discharge to home, and outpatient clinic follow up	2,766 (45.8)
Main diagnosis at ECMO treatment	
Cardiac indication group	3,566 (59.0)
Respiratory indication group	658 (10.9)
Other	1,820 (30.1)

ECMO, extracorporeal membrane oxygenation; IQR, interquartile range; NHIS, National Health Insurance Service; USD, United States Dollar.

Table 2 Comparison the clinicopathological characteristics between the main diagnosis at ECMO support

Variables	Cardiac indication group (n=3,566)	Respiratory indication group (n=658)	Other (n=1,820)	P
Age, years, median [IQR]	58 [47, 68]	54 [42, 62]	53 [44, 60]	<0.001
Sex, male, n (%)	2,435 (68.3)	436 (66.3)	1,157 (63.6)	0.002
Residence at ECMO support, n (%)				<0.001
Urban area	1,725 (48.4)	299 (45.4)	716 (39.3)	
Rural area	1,841 (51.6)	359 (54.6)	1,104 (60.7)	
Year of ECMO support, n (%)				<0.001
2005–2008	395 (11.1)	8 (1.2)	89 (4.9)	
2009–2012	761 (21.3)	81 (12.3)	327 (18.0)	
2013–2015	980 (27.5)	200 (30.4)	604 (33.2)	
2016–2018	1,430 (40.1)	369 (56.1)	800 (44.0)	
Annual income level at ECMO support, n (%)				0.206
Q1 (lowest)	858 (24.1)	184 (28.0)	439 (24.1)	
Q2	682 (19.1)	138 (21.0)	346 (19.0)	
Q3	868 (24.3)	148 (22.5)	452 (24.8)	
Q4 (highest)	1,158 (32.5)	188 (28.6)	583 (32.0)	
Annual case volume of ECMO support, n (%)				<0.001
Q1 <15	818 (22.9)	189 (28.7)	187 (10.3)	
Q2: 15–28	974 (27.3)	138 (21.0)	234 (12.9)	
Q3: 29–63	996 (27.9)	178 (27.1)	688 (37.8)	
Q4 >63	778 (21.8)	153 (23.3)	711 (39.1)	
Charlson comorbidity index, median [IQR]	3 [1, 4]	2 [1, 4]	3 [1, 5]	<0.001
Total hospital-visit days for 1-year, median [IQR]	68 [47, 127]	90 [53, 156]	101 [67.3, 161.0]	<0.001
Duration of ECMO support, days, median [IQR]	4 [2, 6]	7.5 [4.0, 12.0]	1 [1, 4]	<0.001
LOS at ECMO support, median [IQR]	21 [13, 30]	26.5 [15.8, 36.0]	31 [19, 44]	<0.001
Total healthcare cost for one year, USD, median [IQR]	37,239.3 [22,871.5, 63,280.1]	48,165.4 [28,021.7, 89,224.9]	80,946.2 [40,988.3, 115,502.5]	<0.001
Self-payment by patient for 1-year	2,791.0 [1,661.0, 5,449.2]	7,786.7 [4,290.2, 12,848.0]	6,471.3 [2,844.3, 10,527.9]	<0.001
NHIS insurance coverage for 1-year	34,105.5 [21,008.8, 57,636.4]	39,523.8 [22,212.9, 74,795.5]	73,558.1 [36,414.9, 105,644.3]	<0.001
Follow up after discharge, n (%)				<0.001
Follow up in the same hospital	1,814 (50.9)	406 (61.7)	828 (45.5)	
Transfer to other long-term facility care center	152 (4.3)	27 (4.1)	51 (2.8)	
Discharge to home, and outpatient clinic follow up	1,600 (44.9)	225 (34.2)	941 (51.7)	

IQR, interquartile range; ECMO, extracorporeal membrane oxygenation; LOS, length of hospital stay; USD, United States Dollar; NHIS, National Health Insurance Service.

Table 3 Multivariable GLM results for the total healthcare cost for one year among ECMO survivors

Variables	Multivariable model, Exp (B) (95% CI)	P
Age, years	1.01 (1.00, 1.01)	<0.001
Sex, male	1.07 (1.04, 1.10)	<0.001
Residence at ECMO support		
Urban area	1	
Rural area	1.02 (1.00, 1.04)	0.189
Year of ECMO support		
2005–2008	1	
2009–2012	1.34 (1.28, 1.40)	<0.001
2013–2015	1.65 (1.57, 1.72)	<0.001
2016–2018	2.07 (1.98, 2.16)	<0.001
Annual income level at ECMO support		
Q1 (lowest)	1	
Q2	1.01 (0.97, 1.04)	0.673
Q3	1.02 (0.99, 1.06)	0.174
Q4 (highest)	1.00 (0.97, 1.03)	0.957
Annual case volume of ECMO support		
Q1 <15	1	
Q2: 15–28	1.06 (1.02, 1.10)	0.002
Q3: 29–63	1.18 (1.14, 1.22)	<0.001
Q4 >63	1.59 (1.53, 1.64)	<0.001
Charlson comorbidity index	1.01 (1.01, 1.02)	<0.001
Total number of hospital-visit days for 1-year	1.01 (1.00, 1.01)	<0.001
Duration of ECMO support	1.02 (1.01, 1.02)	<0.001
Length of hospital stay at ECMO support	1.01 (1.01, 1.02)	<0.001
Follow up after discharge		
Follow up in the same hospital	1	
Transfer to other long-term facility care center	0.92 (0.86, 0.97)	0.004
Discharge to home, and outpatient clinic follow up	1.31 (1.27, 1.35)	<0.001
Main diagnosis at ECMO treatment		
Cardiac indication group	1	
Respiratory indication group	0.89 (0.86, 0.93)	<0.001
Other	1.31 (1.27, 1.35)	<0.001

GLM, generalized linear regression model; ECMO, extracorporeal membrane oxygenation.

Table 4 Multivariable Cox regression model results for three-year all-cause mortality rate among ECMO survivors from 2005 to 2016 (n=4,255, event =449)

Variables	Multivariable model, HR (95% CI)	P
Total healthcare cost for one year, 1,000 USD (model 1)	1.01 (1.00, 1.01)	0.015
Self-payment for one year, 1,000 USD (model 2)	1.00 (0.98, 1.01)	0.665
Age, years	1.04 (1.03, 1.05)	<0.001
Sex, male	1.19 (0.98, 1.45)	0.084
Residence at ECMO support		
Urban area	1	
Rural area	1.07 (0.88, 1.29)	0.496
Year of ECMO support		
2005–2008	1	
2009–2012	0.83 (0.61, 1.12)	0.224
2013–2016	0.60 (0.45, 0.81)	0.001
Annual income level at ECMO support		
Q1 (lowest)	1	
Q2	0.93 (0.70, 1.25)	0.636
Q3	0.73 (0.56, 0.96)	0.026
Q4 (highest)	0.88 (0.69, 1.12)	0.285
Annual case volume of ECMO support		
Q1 <15	1	
Q2: 15–28	0.87 (0.64, 1.18)	0.358
Q3: 29–63	0.98 (0.74, 1.29)	0.884
Q4 >63	0.83 (0.61, 1.12)	0.223
Charlson comorbidity index	1.05 (1.01, 1.09)	0.021
Total number of hospital-visit days for 1-year	1.01 (1.01, 1.01)	<0.001
Duration of ECMO support	1.01 (1.00, 1.02)	0.067
Length of hospital stay at ECMO support	1.00 (1.00, 1.00)	0.532
Follow up after discharge		
Follow up in the same hospital	1	
Transfer to other long-term facility care center	1.08 (0.65, 1.80)	0.760
Discharge to home, and outpatient clinic follow up	1.02 (0.82, 1.26)	0.871
Main diagnosis at ECMO treatment		
Cardiac indication group	1	
Respiratory indication group	0.98 (0.67, 1.43)	0.926
Other	1.94 (1.55, 2.43)	<0.001

ECMO, extracorporeal membrane oxygenation; USD, United States Dollar; HR, hazard ratio.

model 1, a USD 1,000 increase in the total healthcare cost for one year was associated with an increase in the three-year all-cause mortality rate (HR: 1.01; 95% CI: 1.00–1.01; P=0.015). However, a USD 1,000 increase in self-payment for one year was not associated (P=0.665). Furthermore, a CCI increase (HR: 1.05; 95% CI: 1.01–1.09; P=0.021), and the total number of hospital-visit days for one year (HR: 1.01; 95% CI: 1.01–1.01; P<0.001) were associated with an increase in three-year all-cause mortality rate among ECMO survivors. The three-year all-cause mortality rate did not differ between the respiratory indication group and cardiac indication group (P=0.926), but the "other" group had a 1.94-fold higher three-year all-cause mortality rate (HR: 1.94; 95% CI: 1.55–2.43; P<0.001) than the cardiac indication group.

Discussion

This nationwide cohort study in South Korea demonstrated that various factors were associated with higher healthcare costs one year after ECMO, such as older age, male sex, a higher CCI score, an increase in the total number of hospital-visit days, the ECMO duration, and the hospital stay length. Furthermore, the potential VV ECMO group (i.e., the respiratory indication group) was associated with lower total healthcare costs compared to the potential VA ECMO group (i.e., the cardiac indication group). An increase in total healthcare costs for one year after ECMO was associated with a higher risk of three-year all-cause mortality among ECMO survivors.

Compared to the cost of ECMO support in Norway, Canada, and the United States (8-10), the economic burden among ECMO survivors in South Korea was relatively low. In South Korea, the government determines the cost of all patient care at hospitals (17). Specifically, the government can enforce hospitals to adhere to low rates of medical services, even if it means that hospitals run at a deficit because of this. This compulsory and public system made it possible for patients to receive relatively expensive treatments, including ECMO support, at a low price in South Korea. For example, a previous study reported that the median value of total hospitalization cost was USD 2,555.6 (IQR: 1,335.2–5,757.4) among patients with sepsis in South Korea in 2005–2012 (18). Moreover, we reported recently that the mean expense of hospitalization among survivors of ARDS was USD 9,714.1 (standard deviation: 12,266.7) in South Korea (19). Therefore, the differences in ECMO support cost should be interpreted and compared carefully with previous studies (8-10), considering the unique feature of the South Korean NHIS system.

We recently reported that 50% of ECMO survivors experience worsening QOL, including less income or unemployment, with a mean total ECMO-related hospitalization cost of USD 34,453 (20). Considering that the median total healthcare cost for one year among ECMO survivors was USD 46,308.0 in this study, approximately USD 11,800 was used after the initial hospital discharge for healthcare. Ruhl *et al.* reported that 98% of ARDS survivors require healthcare services after the initial hospital discharge, and 40% of ARDS survivors reported hospital re-admission at least once, with a median estimated hospital cost of USD 18,756 (IQR: 7,852–46,174) (21). In South Korea, most essential healthcare costs including ECMO support are determined by the government, and the overall healthcare costs are cheaper (17).

Two factors associated with increased healthcare costs were older age and a higher CCI score, which reflect multimorbid patients who required more care than others (22). Longer ECMO support and hospital stay durations and the total number of hospital-visit days were positively correlated with healthcare costs in this study, suggesting that longer treatment duration increased the economic burden of ECMO survivors. In *Table 2*, the ECMO duration, hospital stay length, and total healthcare cost were higher in the respiratory indication group than in the cardiac indication group. However, after covariate adjustment in the GLM, the respiratory indication group (the potential VV ECMO group) was associated with a lower cost than the cardiac indication group (the potential VA ECMO group). In South Korea, procedural costs—particularly of cannulation and maintenance—of VA and VV ECMO are the same per day because a same prescription code is used for both types of ECMO in South Korea. Thus, the cardiac indication group received more expansive treatment per day than the respiratory indication group.

The increasing association between total healthcare costs for one year and the three-year all-cause mortality rate was also a notable finding. ICU survivors generally use more healthcare resources (accruing higher costs) and have a higher long-term mortality rate than other hospital survivors (23). A recent cohort study reported that ICU treatment was associated with increased healthcare and specialist service use and a higher medication intake (24), suggesting that survivors of critical illness will likely use healthcare resources. ECMO survivors spend more money

on healthcare after discharge; they might experience ECMO sequelae (25). Post-intensive care syndrome (PICS) is an important QOL issue in critical illness survivors (26), negatively affecting long-term survival. In our study, PICS could have impacted healthcare use and subsequent cost in the ECMO survivors, perhaps negatively affecting their long-term survival outcomes.

The results of our survival analyses regarding association of payment by patient and 3-year all-cause mortality should be interpreted carefully. Self-payment for one year was not associated with 3-year all-cause mortality among ECMO survivors. The South Korean government pays almost all medical expenses (approximately 90–95%) for individuals diagnosed with the severe and rare diseases, such as cancer, severe burn, severe trauma, cerebrovascular and cardiovascular diseases. Many ECMO survivors who experienced these diseases received financial compensation and paid only 5–10% themselves during hospitalization or outpatient clinic visits. Therefore, there might be a bias in the relationship between self-payment and 3-year all-cause mortality among ECMO survivors.

This study has some limitations. First, some variables, such as body mass index, smoking history, and alcohol consumption, were not included because our database did not contain this data. Second, our statistical adjustments only included measured and known confounders. However, there might be unmeasured confounders that affected our results. Third, the NHIS insurance system in South Korea is the sole public health insurance system in which the government subsidizes most healthcare costs for ECMO survivors, regardless of annual income level. Therefore, our findings might not generally apply to other countries. Fourth, we did not provide information regarding the cost of ECMO patients who died within 365 days or the cost of a comparator group such as patients with a prolonged ICU stay of >30 days). Thus, future research is needed to compare the healthcare cost of ECMO survivors and other comparator groups. Lastly, we did not accurately distinguish between VA and VV ECMO. However, we classified ECMO survivors into three groups using their main diagnosis at ECMO support. A recent report indicated that 98% of ARDS patients associated with coronavirus disease received VV ECMO support and only 2% received VA ECMO support (27). Therefore, our classification system might be helpful for those interested in the effects of ECMO type on this study's results.

Conclusions

One year after ECMO support, ECMO survivors accrued USD 46,308 on healthcare. Older and male patients and those with a higher CCI score, more total hospital-visit days, and longer ECMO and hospital stay durations were associated with higher healthcare costs. However, the potential VV ECMO (i.e., respiratory) group was associated with a lower total cost. Further, an increase in the total one-year healthcare cost was associated with a higher risk of three-year all-cause mortality among ECMO survivors.

Acknowledgments

Funding: None.

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-2721/rc

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-2721/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The institutional review board (IRB) of Seoul National University approved the study protocol (approval No. X-2001-586-902), and the National Health Insurance Service (NHIS) approved and provided the data (NHIS-2020-1-125). The study also conformed to the provisions of the Declaration of Helsinki (as revised in 2013). The informed consent requirement was waived by the IRB.

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Cite this article as: Oh TK, Song IA. The economic burden and long-term mortality in survivors of extracorporeal membrane oxygenation in South Korea. Ann Transl Med 2022;10(23):1266. doi: 10.21037/atm-22-2721