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Extracorporeal membrane oxygenation in Korea – Trends and impact of hospital volume on outcome: Analysis of national insurance data 2009–2014

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ABSTRACT

Purpose: ECMO use has increased lately. However, differences between adult ECMO and non-ECMO patients admitted to the ICU remain unstudied. In terms of volume-outcome relationship, the impact of ECMO volume on survival has not been validated in a real world cohort.
Materials and methods: Retrospective analysis of data from the Korean Health Insurance Review and Assessment Service over 5 years, between August 1, 2009 and July 31, 2014. The ECMO group comprised patients who received ≥1 ECMO run. Data on patient demographics, ICU and hospital length of stay, cost, treatments, and in-hospital mortality were collected. Usage trends were analyzed by 5 one-year periods.
Results: Among 1, 265, 508 ICU patients, 6078 underwent ECMO during the study period. The number of ECMO patients rose by 2.5 times, and ECMO hospitals from 50 to 86 between periods 1 and 5. Compared to non-ECMO patients, the ECMO group was younger (59 years vs. 64 years, $p < .0001$) with more comorbidities. Healthcare expenditure and in-hospital mortality in the ECMO group were higher (US $23,600 vs. $5100; 63.4% vs. 12.6%; $p < .0001$). Using multivariable analysis, age ≥ 50 years, CRRT, and annual hospital ECMO volume < 20 negatively impacted survival to discharge.
Conclusion: The prevalence of ECMO among ICU patients was 0.5%. The expenditure and in-hospital mortality of the ECMO group were four and five times higher than non-ECMO group respectively. An annual hospital ECMO volume ≥ 20 may improve survival to hospital discharge.

1. Purpose

Extracorporeal membrane oxygenation (ECMO) has a long history spanning three decades in the treatment of neonatal respiratory failure. In recent years, promising evidence that argues in favor of ECMO has emerged for adult respiratory and cardiac failure. Two studies conducted in the United Kingdom have suggested that transferring patients with severe acute respiratory distress syndrome (ARDS) or severe H1N1 influenza to a designated ECMO center leads to better survival [1,2]. The 2009 H1N1 influenza pandemic also saw the Australasians achieve favorable survival outcomes with ECMO [3]. In resuscitation research, 2 observational studies have reported lower mortality with

Abbreviations: CI, confidence interval; ECMO, extracorporeal membrane oxygenation; ECMONet, ECMO Network; ELSO, Extracorporeal Life Support Organization; HIRA, Health Insurance Review & Assessment; ICD-10, International Classification of Diseases 10th revision; IRB, Institutional Review Board; KCD-6, Korean Classification of Diseases 6th edition; LOS, length of stay; MAP, Medical Aid Program; NA, not applicable; NHI, National Health Insurance; OR, odds ratio.

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extracorporeal cardiopulmonary resuscitation in in-hospital cardiac arrests compared to conventional therapy [4,5]. It is therefore unsurprising that global utilization is on the rise, with an increasing number of ECMO centers and runs [6]. However, a great proportion of ECMO studies may be skewed by data derived from highly selected databases. Real-world differences in characteristics, healthcare utilization and expenditure between ECMO patients and the general critical care population – data that is crucial from a clinical, economic, and healthcare delivery standpoint, have also not been studied. As ECMO is a costly and highly specialized intervention, it is imperative to examine such data in order to provide high-value, cost-conscious healthcare, especially in resource-limited environments. Lastly, a higher annual hospital ECMO volume appears to be linked to lower mortality but the association has not yet been validated in a nationwide database [7]. In this study, we aimed to evaluate ECMO utilization, trends and outcomes in Korea during the 5-year period between August of 2009 and July of 2014. In addition, we sought to determine if a volume-outcome relationship exists in this real-world national ECMO database.

2. Materials and methods

2.1. Study population

A retrospective cohort analysis was conducted of individuals aged 18 years and above with ≥1 ICU admission covered under the Korean National Health System between August 1, 2009 and July 31, 2014. The Republic of Korea operates on a single payer national health system. The Korean National Health Insurance (NHI) covers approximately 97% of Koreans, while the remaining 3% of Koreans who cannot afford national insurance are covered by the Medical Aid Program (MAP) [8]. The Health Insurance Review and Assessment (HIRA) Service, a central office in the Korean Ministry of Health, maintains an electronic database that covers information on inpatient and outpatient visits in all Korean healthcare institution, healthcare billing, and reimbursement claims submitted to the Korean NHI and MAP. This data, which is meticulously maintained by the office, is publicly accessible for research purposes [9]. Our database was retrieved from HIRA, and captured virtually all ICU admissions in Korea during the study period.

An ICU admission was identified as any hospital admission with Korean Classification of Diseases 6th edition (KCD-6) codes AJ001-AJ590900. KCD-6 is a modified version of the International Classification of Diseases 10th revision (ICD-10) that has been specifically adapted for use in the Korean Health System [10]. All ICU stays during the same hospitalization were considered as a single ICU admission. Similarly, hospital stays separated by <2 days were regarded as the same hospital admission. A total of 1,556,475 ICU admissions in 1,267,761 patients were retrieved. ICU admissions that occurred before August 1, 2009 were excluded. A final cohort comprising 1,553,673 ICU admissions in 1,226,566 patients was analyzed. The Institutional Review Board (IRB) of Samsung Medical Center (IRB protocol 2015–11-017) approved the study protocol. An exemption of informed consent was granted as only de-identified administrative data from a pre-existing repository was extracted.

3. Measurements

To retrieve patient factors, ICD-10 codes together with Korean NHI procedure and material codes were used. Korean NHI coding was able to capture medical treatments as the insurance claims database contained information on the breakdown of medical bills submitted by medical service providers. Patients who received ≥1 ECMO run were identified via claim codes (Korean NHI procedure codes: O1901-O1904; material codes: CAPIOX EBS CIRCUIT [G5401008], QUADROX PLS [G5501050], and CAPIOX EBS PMP CIRCUIT [G5501008]). If the patient received >1 ECMO run, only the first session was included in the analysis. Due to multiple, overlapping ICD codes and intrinsic limitations of the HIRA database, the mode of ECMO i.e. venoarterial or venovenous could not be reliably derived. Preliminary validation analysis on our cohort was performed, which did not achieve an acceptable degree of accuracy. ECMO mode was thus excluded from analysis in order to preserve data integrity. Relevant information, including demographic characteristics, comorbidities, procedures and medications was obtained via claim codes. Comorbidities such as diabetes mellitus, cardiovascular disease, cerebrovascular disease, chronic kidney disease, chronic liver disease, cancer, peptic ulcer disease and HIV/AIDS were identified via ICD-10 codes, and summarized using the Charlson Comorbidity Index [11-13]. Procedures of interest included mechanical ventilation (Korean NHI procedure codes: M5857, M5858, M5860), intermittent hemodialysis (O7020), peritoneal dialysis (O7062), and continuous renal replacement therapy [CRRT] (O7051–7054). The use of vasoactive drugs was ascertained by Korea drug and anatomical therapeutic chemical codes [14].

To evaluate hospital factors, we accessed the medical care institution database and collected information regarding bed capacity, range of facilities and number of physician employees. To study ECMO trends, all hospitals that had performed at ≥1 ECMO run were included in the analysis. In addition to ECMO volume, we included experience as a hospital factor. An experienced ECMO center was defined as one that had at least a year of experience since its first ECMO case. In contrast, a newly established ECMO center was identified from any ECMO initiation at a hospital within the first year of captured data (set as one year from the date of first ECMO case performed) In addition, hospitals were sub-classified according to their level of support, which was based on bed capacity and range of specialties as stipulated by the Korean Health Law [15]. A hospital was defined as a healthcare institution with >30 inpatient beds. A general hospital was one with >100 beds and >7 specialty departments that must include Internal Medicine, Surgery, Pediatrics, Obstetrics and Gynecology, Anesthesiology, Pathology, and Laboratory Medicine. A tertiary hospital had >20 specialty departments and serves as a teaching hospital to medical students and nurses.

Study outcomes were ICU length of stay (LOS), hospital LOS, in-hospital mortality, and total hospitalization cost. Total hospitalization cost was the amount of money reimbursed by the Korean NHI to hospitals and patients for medical services endorsed by HIRA.

3.1. Data analysis

Descriptive statistics were used to summarize characteristics of general ICU patients, and those who received ECMO. To evaluate the longitudinal trend in ECMO utilization, we divided the 5-year study duration into 5 periods: August 2009 to July 2010 (period 1); August 2010 to July 2011 (period 2); August 2011 to July 2012 (period 3); August 2012 to July 2013 (period 4); and August 2013 to July 2014 (period 5). In order to evaluate the effect of annual hospital ECMO volume, we calculated the average case volume for each hospital since the inception of ECMO service. Multivariable logistic regression was used to derive risk factors associated with in-hospital mortality for patients who received ECMO. Two models with increasing degrees of adjustment were used to attenuate potential confounding by metabolic factors on chronic kidney and liver diseases. Model 1 was only adjusted for patient factors, which included age, sex, Charlson Comorbidity Index and the need for CRRT. Model 2 was further adjusted for hospital factors, including type of hospital (tertiary or general), and experience. In Model 2, we used multilevel logistic regression so that odds ratios for risk factors were further adjusted to account for unobserved hospital-level characteristics due to random effect. All reported P values were two-sided and the significance level was set at 0.05. All analyses were performed using SAS Visual Analytics.

4. Results

4.1. Comparison between ECMO and non-ECMO groups

During the 5-year study period, 6078 patients (0.5% of total ICU admissions) received ECMO. Patients who received ECMO were younger (59.0 vs. 64.3 years), and had more comorbidities than general ICU patients who did not, as evident by a higher Charlson Comorbidity Index (3.4 vs. 3.2). The median duration of ECMO was 4 days. The ECMO group had a higher proportion of patients that received vasoactive drugs (64.6% vs. 10.9%), and renal replacement therapy (51.0% vs. 5.9%) than the non-ECMO group. ECMO patients also incurred longer ICU LOS (14 vs. 4 days) and hospital LOS (16 vs. 13 days), and higher total hospitalization cost (US $23,600 vs. $5100) than non-ECMO patients. General ICU patients had an overall mortality of 12.6%. Among those who underwent ECMO, mortality was 63.4% (Table 1).

Table 1
Comparison of General ICU and ECMO Patients.

	General ICU Patients[a]	ECMO Patients	p value
	(n = 1,220,488)	(n = 6078)	
	N (%)	N (%)	
Age, mean (SD)	64.3 (15.5)	59 (15.5)	<0.0001
Sex			<0.0001
Male	700,421 (57.4)	3939 (64.8)	
Female	520,067 (42.6)	2139 (35.2)	
Comorbidity			
Diabetes mellitus	530,115 (43.4)	3169 (52.1)	<0.0001
Cardiovascular disease	249,199 (20.4)	3257 (53.6)	<0.0001
Cerebrovascular disease	338,384 (27.7)	905 (14.9)	<0.0001
Chronic kidney disease	70,976 (5.8)	549 (9.0)	<0.0001
Chronic liver disease	19,819 (1.6)	257 (4.2)	<0.0001
Cancer	236,924 (19.4)	820 (13.5)	<0.0001
Peptic ulcer disease	186,779 (15.3)	1037 (17.1)	0.0118
HIV/AIDS	855 (0.07)	9 (0.15)	0.0016
Charlson Comorbidity Index, mean (SD)	3.2 (3.4)	3.4 (3)	0.0313
Hospital setting			<0.0001
Tertiary hospital	477,212 (39.1)	4165 (68.5)	
General hospital	703,682 (57.7)	1913 (31.5)	
Primary hospital	38,745 (3.2)		
Vasoactive drug use	133,347 (10.9)	3925 (64.6)	<0.0001
Need for renal replacement therapy			
Total	71,579 (5.9)	3102 (51.0)	<0.0001
Continuous renal replacement therapy	40,616 (3.3)	3052 (50.2)	<0.0001
Intermittent hemodialysis	45,106 (3.7)	574 (9.4)	<0.0001
Peritoneal dialysis	162 (0.01)	6 (0.1)	0.0097
Duration of ECMO run, median (IQR)	NA	4 (2, 7)	
Hospital length of stay (days), median (IQR)	13 (6, 24)	16(5, 35)	0.071
ICU length of stay (days), median (IQR)	4 (2, 8)	14 (5, 34)	<0.0001
Hospitalization cost (1000 USD), median (IQR)	5.1 (2.5, 8.8)	23.6 (13.2, 40.9)	<0.0001
In-hospital mortality	153,542 (12.6)	3853 (63.4)	<0.0001

[a] Only the first ICU admission was analyzed, if patients had more than one admission.
NA: not applicable.

4.2. Temporal trends in ECMO: nationwide usage, number of centers, and newly established services

The total number of patients who received ECMO increased by 2.5 times between period 1 and period 5 (674 vs. 1683, respectively) (Fig. 1A). No overt seasonal variation in ECMO runs was observed (Fig. 1B). The number of hospitals performing ECMO increased with each consecutive period during the study duration (50, 67, 76, 83 and 86 in period 1, 2, 3, 4 and 5, respectively) (Fig. 2). Among hospitals with newly established ECMO service, the proportion represented by tertiary hospitals showed a declining trend while that of general hospitals rose continuously until period 4 (Fig. 3).

4.3. Annual hospital ECMO volume and crude in-hospital mortality

Overall in-hospital mortality in the ECMO group was 63.4%. When the data was stratified by ECMO volume, there were 58, 14, and 5 hospitals with a corresponding annual ECMO volume of 1–19, 20–39, and ≥ 40. The total number of patients who received ECMO in those hospitals was 2186, 1818 and 1747, respectively. Unadjusted in-hospital mortality was highest in the volume category of 1–19 (67.9% vs. 59.6% vs. 62.1%) (Table 2A).

4.4. ECMO experience and crude in-hospital mortality

When stratified by experience, there were 50 experienced ECMO and 27 newly established ECMO centers. Unadjusted in-hospital mortality in experienced and newly established ECMO centers was 63.4% and 65.6% respectively (Table 2B).

4.5. Factors associated with in-hospital mortality

During the 5-year follow up period, 3853 cases of in-hospital deaths occurred among patients treated with ECMO. As expressed earlier, the cumulative incidence of in-hospital mortality in ECMO patients was higher in hospitals with an annual volume of 1–19 cases than those with ≥40 cases. The crude odds ratio (OR) for in-hospital mortality of ECMO patients in hospitals with an annual volume of 1–19 cases compared to those in hospitals with a yearly volume of ≥40 cases was not statistically significant (OR: 1.41, 95% confidence interval [CI]: 0.88–2.25, p = .1499). However, the association was rendered significant after adjusting for patient (OR: 1.70, 95% CI: 1.01–2.88, p = .0475) and in addition, hospital factors (OR 1.82; 95% CI: 1.05–3.16, p = .0334) (Tables 3 and 4).

5. Discussion

In this study, we found four important observations. 1) The prevalence of ECMO patients was 0.5% of our nationwide ICU cohort. 2) Although younger by an average of 5 years, the ECMO patient's median expenditure and overall mortality were four and five times higher than a non-ECMO patient. 3) The annual national ECMO patient load, and the number of centers performing ECMO increased at a magnitude in the region of two-fold during the study period. This increase in the number of centers was preferentially influenced by general hospitals performing ECMO rather than tertiary institutions in the latter years of the study period. 4) An annual institutional ECMO case load of <20 was an independent risk factor for in-hospital mortality.

A rapid increase in the number of ICU patients treated with ECMO was observed during the study period, with a prevalence of 0.5%. With increasing ECMO utilization, this figure is expected to rise further. To date, no published study relying on nationwide ECMO data has compared characteristics between critically ill patients who received ECMO and those who did not. We found that the average ECMO patient was younger but had more comorbidities than a non-ECMO patient. However, cerebrovascular and malignant diseases were less frequently

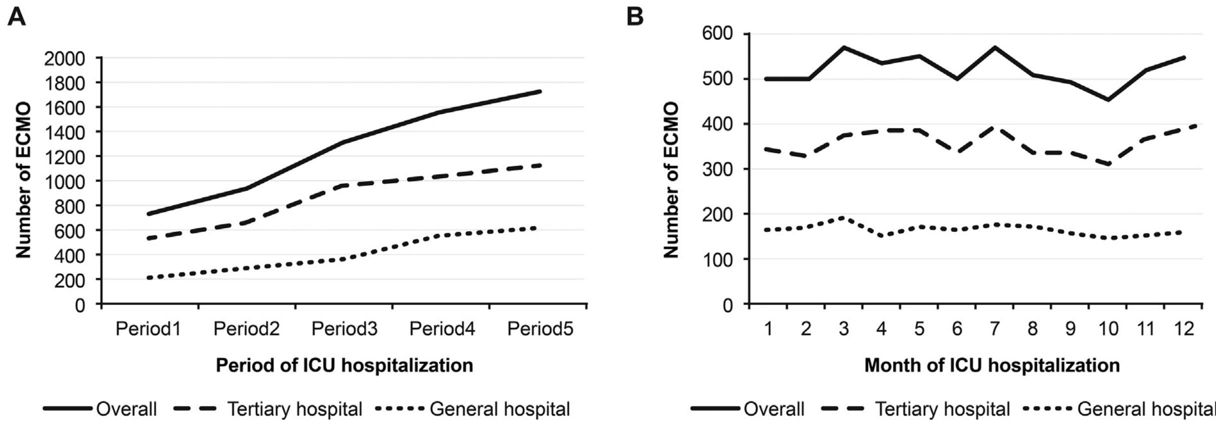

Fig. 1. Number of patients who received ECMO by A, period and B, month. Definition of periods: 1: from August 1, 2009 to July 31, 2010; 2: from August 1, 2010 to July 31, 2011; 3: from August 1, 2011 to July 31, 2012; 4: from August 1, 2012 to July 31, 2013; 5: from August 1, 2013 to July 31, 2014.

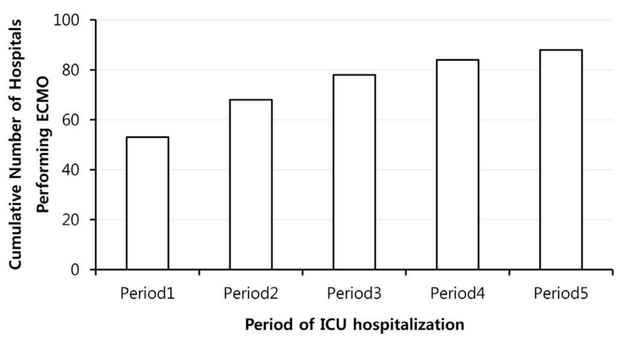

Fig. 2. Number of hospitals performing ECMO by period. Definition of periods: 1: from August 1, 2009 to July 31, 2010; 2: from August 1, 2010 to July 31, 2011; 3: from August 1, 2011 to July 31, 2012; 4: from August 1, 2012 to July 31, 2013; 5: from August 1, 2013 to July 31, 2014.

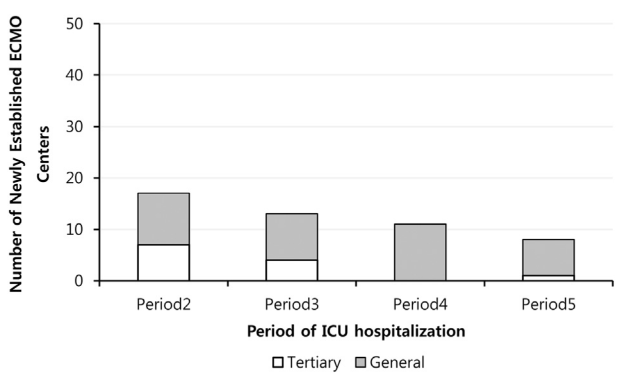

Fig. 3. Number of hospitals with newly established ECMO service starting August 1, 2010. Definition of periods: 2: from August 1, 2010 to July 31, 2011; 3: from August 1, 2011 to July 31, 2012; 4: from August 1, 2012 to July 31, 2013; 5: from August 1, 2013 to July 31, 2014.

Table 2A
Crude mortality rates of ECMO patients by annual hospital ECMO volume

	Overall		
Annual hospital ECMO volume	1–19	20–39	40+
Number of hospitals	58	14	5
Number of patients	2186	1818	1747
Mortality (%)	1484 (67.9)	1090 (59.6)	1085 (62.1)

Table 2B
Crude mortality rates of experienced versus newly established ECMO centers.

	Experienced ECMO Center	Newly Established ECMO Center
Number of hospitals	50	27
Number of patients	5411	410
Mortality	3432 (63.4)	269 (65.6)

observed in the ECMO group, suggesting that they had likely been subject to some degree of pre-intervention selection. The yearly ECMO usage in the Republic of Korea appeared to show an upward trend between 2009 and 2014 but overall survival to discharge rates remained stable at an average of 37%. The in-hospital mortality of ECMO patients was four times higher than non-ECMO patients, and the median incurred expenditure was five times higher. This is an important observation, especially in an era where healthcare economics and value-based care is very likely to gain more prominence in national healthcare models [16]. Although we believe this to be the first study to have compared expenditure and survival in critically ill patients who received ECMO to those who did not, downstream implications such as cost-effectiveness and the impact/burden of increased ECMO use on the healthcare system remain unknown and warrant further investigation.

Several studies have reported that a higher age was associated with higher mortality in ECMO patients [17,18]. However, we found that age only began to exert a negative effect on survival from 50 years onward. Acute kidney injury frequently occurs during ECMO support, and the need for CRRT has already been described in previous studies to portend an adverse outcome [19-22]. Our study also reaffirms the association between higher annual hospital ECMO volumes and lower in-hospital mortality rates. This finding is consistent with the positive volume-outcome relationship reported in a study that analyzed data from the Extracorporeal Life Support Organization (ELSO) registry [7]. More importantly, we have evaluated both ECMO experience and annual ECMO volume as hospital factors in this study. The fact that experience was rendered insignificant as an independent variable in regression analysis suggests two crucial points. First, a newly established ECMO center could gain experience and achieve desired survival outcomes with a minimum case volume in its incipient year. Second, experienced ECMO centers would still need to maintain a minimum annual case volume for optimal survival outcomes. Finally, we found this ECMO volume-outcome relationship to be significant at an annual cut-off volume of at least 20. Higher volumes of 40 and above did not result in additional significant reduction in in-hospital mortality. The results of our study lend strength to the alternate recommendation put forth by the International ECMO Network (ECMONet) expert panel – that ECMO

Table 3
Univariate and Multivariable Logistic Regression Models for Factors Associated With In-Hospital Mortality Among ECMO Patients in Korea From 2009 to 2014.

Annual hospital ECMO volume	Crude	p value	Model 1	p value	Model 2	p value
	OR (95% CI)		OR (95% CI)		OR (95% CI)	
1–19	1.41 (0.88–2.25)	0.1499	1.70 (1.01–2.88)	0.0475	1.82 (1.05–3.16)	0.0334
20–39	0.99 (0.86–1.66)	0.9859	1.07 (0.60–1.91)	0.8158	1.15 (0.65–2.05)	0.6317
40+	Reference		Reference		Reference	

OR indicates odds ratio; CI: confidence interval.
Model 1: Adjusted for patient factors: age, sex, Charlson Comorbidity Index and need for continuous renal replacement therapy.
Model 2: Further adjusted for hospital factors: hospital type (tertiary and general) and experience.

Table 4
Multivariable Logistic Regression Models for Factors associated with In-hospital Mortality Among ECMO Patients in Korea from 2009 to 2014.

	Crude OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Age				
18–29	Reference		Reference	
30–39	1.16 (0.86–1.56)	0.3402	1.18 (0.86–1.63)	0.3082
40–49	1.28 (0.98–1.67)	0.0742	1.4 (1.05–1.88)	0.0233
50–59	1.51 (1.17–1.94)	0.0015	1.78 (1.35–2.35)	<0.001
60–69	2.18 (1.69–2.81)	<0.001	2.78 (2.11–3.67)	<0.001
70–79	2.6 (2.02–3.36)	<0.001	3.38 (2.56–4.47)	<0.001
80 and above	2.36 (1.7–3.27)	<0.001	3.46 (2.42–4.93)	<0.001
Sex				
Male	Reference		Reference	
Female	1.12 (1–1.26)	0.0457	1.11 (0.98–1.26)	0.0917
Charlson Comorbidity Index	0.95 (0.93–0.96)	<0.001	0.91 (0.89–0.93)	<0.001
Annual hospital ECMO volume				
1–19	1.41 (0.88–2.25)	0.0199	1.94 (1.14–3.31)	0.0147
20–39	0.99 (0.86–1.66)	0.9859	1.17 (0.66–2.07)	0.5853
40 +	Reference		Reference	
Newly established ECMO center[a]				
No	Reference		Reference	
Yes	0.9 (0.66–1.22)	0.4838	0.88 (0.63–1.23)	0.1149
Need for CRRT				
No	Reference		Reference	
Yes	2.65 (2.37–2.96)	<0.001	3.5 (3.09–3.97)	<0.001
Hospital type				
Tertiary hospital	Reference		Reference	
General hospital	0.9 (0.8–1.02)	0.0935	0.82 (0.65–1.05)	0.1149

OR indicates odds ratio; CI: confidence interval; CRRT: continuous renal replacement therapy. Adjusted for age, sex, Charlson comorbidity index, annual hospital ECMO volume, experience, need for CRRT and hospital type.
[a] A newly established ECMO centre was defined as one that had less than one year of experience since its first ECMO case.

centers should have an annual volume of 20 and above [23]. Current evidence is conflicting with some studies reporting a somewhat "linear" relationship or none at all [7,18]. It has been postulated that centers reputed to have good ECMO outcomes receive more inter-hospital referrals, and this higher patient load translates to more experience and better results [2,24,25]. However, we believe that our study is more representative of the real-world situation. Data from all hospitals providing ECMO (of which only 3 are ELSO-affiliated) in Korea are captured by HIRA, as opposed to the potential data bias from a select global network of ELSO-affiliated ECMO centers [26]. However, it must be reiterated that the optimal outcome of an ECMO patient does not, and cannot rest on sheer volume alone. A dedicated multidisciplinary team comprising intensivists, cardiothoracic surgeons, perfusionists, nurse specialists, and allied health personnel, is pivotal in ensuring the best delivery of care. In Korea, where considerable discrepancy in healthcare expertise exists among its special cities and provinces, national policies must be implemented to ensure the strategic development of designated ECMO centers in various locales. This may hopefully lead to a more even and balanced provision of ECMO across the country, circumventing the unfavorable situation of oversupply in some areas and under provision in others. In instances whereby this cannot be achieved, a robust ECMO referral system structure ensuring expedient communication and prompt patient transfer for ECMO must be established.

There are several limitations to this study. First, we were unable to evaluate the clinical indications for ECMO. KCD-6, as with other disease-coding systems, was unable to differentiate the mode of ECMO support. We had intentionally avoided the derivation of ECMO indication via disease codes (which are often multiple and overlap) in order to better preserve big data integrity. Previous studies have found that the volume-outcome association was restricted only to patients who received cardiac ECMO, and therefore we could not determine if this was true in our study cohort (7). Second, the baseline disease severity of patients could not be determined due to the fact that useful clinical data e.g. arterial blood gas analysis, lactate, clotting profile etc. could not be retrieved from HIRA. Third, information on patient transfers between hospitals could not be obtained, and this could have inflated mortality rates in hospitals that received many inter-hospital transfer cases. Fourth, all expenditures were evaluated per se without any corrections made for inflation. As HIRA is an insurance claim database, non-claims – which might have included some non-standard medications, devices or services, could lead to underestimation of total expenditure. Lastly, HIRA does not provide any survival information extending beyond hospital discharge and long-term outcomes could not be evaluated.

6. Conclusion

The use of ECMO has increased markedly in the Republic of Korea in recent years. The prevalence of ECMO was 0.5% in our national ICU cohort. The expenditure and in-hospital mortality of an ECMO patient were four and five times higher than a non-ECMO patient in spite of a younger age. An age ≥ 50, the need for CRRT, and an annual ECMO volume of <20 are negative prognostic factors for survival. Taking our study findings into consideration, governmental policies should be made to ensure a strategic and more even provision of ECMO services across the country. If not, a robust nationwide referral protocol is mandated.

Ethics approval and consent to participate

The Institutional Review Board (IRB) of Samsung Medical Center (IRB protocol 2015-11-017) approved the study protocol. An exemption of informed consent was granted as only de-identified administrative data from a pre-existing repository was extracted.

Consent for publication

The authors have reviewed and approved the manuscript for publication.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Not applicable.

Authors' contributions

Substantial contribution to conception & design: CKT, YHC, JC, KS, GYS.

Substantial contribution to acquisition of data: DK, HP, CRC, JHY, JP.

Substantial contribution to analysis and interpretation of data: DK, HP, JC, CKT, YHC, KS, GYS.

Drafting the article: CKT, YHC, DK, JC, GYS.

Critically revising the article: CKT, YHC, CRC, JHY, JP, JC, DK, HP, KS, GYS.

Final approval of the version to be published: CKT, YHC, KS, GYS, JC, CRC, JHY, JP, DK, HP.

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