Original Article

Multivariate Analysis of Risk Factor for Mortality and Feasibility of Extracorporeal Membrane Oxygenation in High-Risk Thoracic Surgery

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Background: Extracorporeal membrane oxygenation (ECMO) as intraoperative cardiorespiratory support during lung transplantation is well known, but use for other types of surgery are limited. To assess risk factor for mortality after high-risk thoracic surgery and feasibility of ECMO, we reviewed.

Methods: This study was an observational study. Between January 2011 and October 2018, 63 patients underwent thoracic surgery with ECMO for severe airway disease, pulmonary insufficiency requiring lung surgery, and other conditions.

Results: In all, 46 patients remained alive at 30 days after surgery. The mean patient age was 50.38 ± 16.16 years. ECMO was most commonly used to prevent a lethal event (34 [73.9%]) in the Survival (S) group and rescue intervention (13 [76.5%]) in the Non-survival (N) group. In all, 11 patients experienced arrest during surgery (S vs N: 2 [4.3%] vs 9 [52.9%], $p \leq 0.001$). The multivariate analysis revealed that arrest during surgery (odds ratio [OR], 24.44; 95% confidence interval [CI], 1.82–327.60; $p = 0.016$) and age (OR, 7.47; 95% CI, 1.17–47.85; $p = 0.034$) were independently associated with mortality.

Conclusions: ECMO provides a safe environment during thoracic surgery, and its complication rate is acceptable except for extracorporeal cardiopulmonary resuscitation (ECPR).

Keywords: thoracic surgery, extracorporeal membrane oxygenation, cardiopulmonary resuscitation

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Introduction

Extracorporeal membrane oxygenation (ECMO) is widely used in patients with respiratory or cardiac failure who do not respond to conventional life support therapy. The feasibility of ECMO as intraoperative cardiorespiratory support during lung transplantation is well known; however, there were rare reports of ECMO used for thoracic surgery.[1–7] These reports have analyzed only 10–20 cases and simply confirmed the surgical results. In many cases, it is difficult to achieve clinical significance beyond the expansion of ECMO indications, and there are no reports of efficacy in specific areas.[3,8–11]

We have experienced various advantages and problems since the introduction of ECMO in thoracic surgery in 2006. Here, we present our experience and analyze the clinical outcomes of ECMO support in thoracic surgery to report tips on its use, factors influencing surgical outcomes, and indications for ideal ECMO support. The purpose of this study is to be used as basic data for risk factors related to mortality after high-risk thoracic surgery and ECMO indications. Please indicate at the end of the Introduction section: We present the following article in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting checklist.

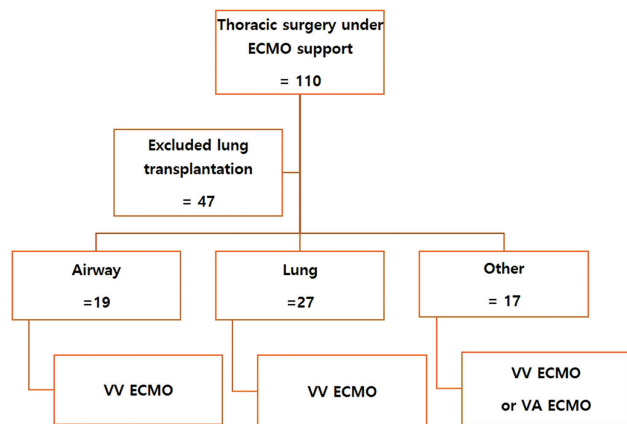## Materials and Methods

Patient selection

Between January 2011 and October 2018, 110 patients underwent thoracic surgery under ECMO support. Of them, 47 who underwent lung transplantation were excluded; thus, a total of 63 patients supported on ECMO were analyzed in this report. The indications for ECMO were needed for surgical correction to solve problems related to clinical disease as follows: severe airway disease such as trachea stenosis, pulmonary insufficiency requiring lung surgery such as hemoptysis due to the destroyed lung, pneumonia, sepsis, ventilator-induced lung injury (VILI), and other conditions that can cause cardiac arrest during surgery such as advanced huge thoracic cancer and major vessel injury leading to hypovolemic shock or tamponade (**Fig. 1**). We did not randomly remove all patients who met the selection criteria to reduce selection bias.

Preoperative characteristics

The medical records of these 63 patients were reviewed. The following routine clinical baseline data were collected: age, sex, body mass index (BMI), diagnosis, purpose for ECMO, type of ECMO support, and preoperative clinical condition (such as major multiple trauma, advanced thoracic malignancy, infectious disease, airway obstruction, bleeding before surgery, diabetes, hypertension, renal failure, and coagulopathy).

### ECMO and anticoagulation protocol

ECMO was administered based on guidelines from the Extracorporeal Life Support Organization. The ECMO system consisted of an EBS (Terumo, Tokyo, Japan) or PLS (Maquet, Mahwah, NJ, USA) machine, centrifugal

Fig. 1 Patient enrollment process. A total of 63 patients were included. Between January 2011 and October 2018, 110 patients underwent thoracic surgery under ECMO support. Of them, 47 who underwent lung transplantation were excluded. We divided the patients into three groups by condition. In all, 19 patients underwent ECMO due to severe airway disease such as trachea stenosis. In all, 27 patients underwent ECMO for pulmonary insufficiency requiring lung surgery such as hemoptysis due to a destroyed lung, pneumonia, sepsis, and VILI. In all, 17 patients underwent ECMO for other conditions that can cause cardiac arrest during surgery such as advanced huge thoracic cancer and major vessel injury leading to hypovolemic shock or tamponade. ECMO: extracorporeal membrane oxygenation; VILI: ventilator-induced lung injury

pumps (Maquet, Rastatt, Germany), and simplified Bioline-coated circuits (Maquet). All patients were cannulated peripherally through the femoral vein and artery or internal jugular vein using the Seldinger technique under ultrasound guidance. Venovenous (VV) ECMO was used for respiratory support. In the majority of cases involving VV ECMO, the right femoral vein was used for venous drainage and the internal jugular vein for venous return; if additional heart support was necessary during VV ECMO, a return cannula was added to the femoral artery and VVA ECMO was implemented. If hemodynamic support was required rather than respiratory support, venoarterial (VA) ECMO was performed. Cannulation mainly used the configuration of femoral vein drain and femoral artery return. If cardiac arrest occurred, VA ECMO was performed regardless of the cause of arrest.

Preoperative extracorporeal cardiopulmonary resuscitation (ECPR) or preoperative elective ECMO was performed once with a 50–70 IU/kg heparin bolus immediately before insertion of the cannula for ECMO; no additional heparin was injected until the end of the operation. Patients with ongoing bleeding did not start anticoagulation therapy. After the end of the operation, if
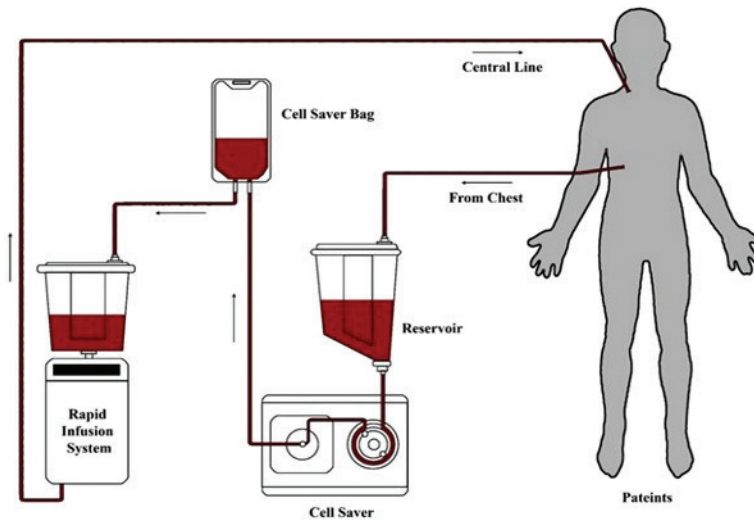
Fig. 2 Configuration of autologous transfusion using a cell saver with a rapid infusion system. We applied an autologous transfusion to prevent hypovolemic shock in trauma patients. After the blood was suctioned into the reservoir, it was sent from the reservoir to the cell saver and recycled. The collected blood in the cell saver bag was directly connected to the Rapid Infusion System for infusion directly through the patient's central line.

support of ECMO was needed, anticoagulation was initiated after 24 hours. Anticoagulation was monitored by activated clotting time (ACT) and activated partial thromboplastin time (aPTT). ACT was maintained for approximately 160–190 s.

Because most surgeries are accompanied by massive bleeding, we applied autologous transfusion using a cell saver to prevent hypovolemic shock in trauma patients. Generally, cardiopulmonary bypass (CPB) with sucker could be used for direct infusion of blood loss, but to operate CPB which is an open circuit, sufficient dose of heparin and ACT prolong must be needed, which causes more bleeding. We decided to create a configuration of autologous transfusion circuit using ECMO which is a closed circuit. The circuit was configured as follows to quickly replenish the blood loss. After the blood was suctioned into the reservoir, it was sent from the reservoir to the cell saver and recycled. Then, to reduce the amount of transfusion and fluid, the collected blood in the cell saver bag was directly connected to the Rapid Infusion System to infusion directly through the patient's central line (**Fig. 2**). After surgery, obstruction of femoral artery by the cannula was suspected, a small additional cannula was inserted for distal leg perfusion.

Statistical analysis

Continuous variables are expressed as mean ± standard deviation, and differences between continuous variables were analyzed using the unpaired Student's t-test. Categorical variables are expressed as numbers and their percentages were compared by the Pearson's chi-squared test or Fisher's exact test as appropriate. According to the latest European Association of Cardio-Thoracic Surgery statistical and data reporting guidelines, we entered the threshold value of dichotomous variables with univariable p values <0.20 into a multivariable binary logistic-regression model to identify the independent risk factors for 30-day mortality. To provide concise and informative factors for the prediction of 30-day mortality, the continuous variables in the multivariate logistic regression model were dichotomized according to the clinically meaningful cutoffs widely accepted for risk stratification in routine clinical practice, including geriatric state, age >65 years; and overweight/obese state, BMI >25 kg/m². Results are expressed as odds ratios (ORs) with 95% confidence intervals (CIs), and two-tailed p values <0.05 were considered significant. We used SPSS for Windows (version 21.0, IBM Corp., Armonk, NY, USA) for the statistical analysis.

Results

During the study period, 63 patients underwent thoracic surgery under ECMO support for hemodynamic or respiratory support. Their baseline characteristics are

presented in **Table 1**. To assess risk factors affecting mortality, we divided the patients into two groups according to mortality status: 46 patients survived, while 17 died by 30 days after surgery.

Patient characteristics of survival patients

Our study consisted of 42 (66.7%) male patients (Survival group (S) vs Non-survival group (N): 28 [60.9%] vs 14 [82.4%], p = 0.139) with a mean age of 50.38 ± 16.16 years (S vs N: 47.4 ± 15.8 vs 58.35 ± 14.7, p = 0.016). ECMO was often applied to prevent a lethal event (34 [73.9%]) in the Survival group and to rescue life (13 [76.5%]) in the Non-survival group (p <0.001). There were significant intergroup differences. ECMO support types included VV (only respiration support) ECMO (37 [80.4%]) in the Survival group and VA (cardiopulmonary support) ECMO (12 [70.6%]) in the Non-survival group (p <0.001). There were significant intergroup differences. Surgery types and preoperative clinical conditions did not differ significantly between the two groups.

Postoperative results of survival patients

In all, 11 patients experienced arrest during surgery (S vs N: 2 [4.3%] vs 9 [52.9%], p <0.001). The mean operation time was 250.56 ± 125.77 min (S vs N: 249.0 ± 115.6 vs 254.7 ± 153.9, p = 0.875). Surgery-related complications did not differ significantly between the two groups. There were no significant intergroup differences.

Multivariate analysis of risk factors for mortality

We entered the threshold value of dichotomous variables with a univariate p value <0.20 into a multivariate binary logistic regression model to identify the independent risk factors for mortality. A multivariate logistic regression model involving age, sex, ECMO indication, ECMO support type, intraoperative arrest, and postoperative bleeding is shown in **Table 2**. Multivariate analysis including these factors showed that age (OR, 7.47; 95% CI, 1.17–47.85; p = 0.034), arrest during operation (OR, 24.44; 95% CI, 1.82–327.60; p = 0.016) were independently associated with complications for mortality (**Table 2**).

Operative and postoperative results as groups of ECMO indications

The operation time did not differ significantly among groups. Intraoperative arrest was more common in the Other group than the other groups (Airway group (A) vs Lung group (L) vs Other group (O), 2 [10.5%] vs 3 [11.1%] vs 6 [35.3%], p = 0.940), but there were no significant differences. The Other group included advanced malignancy patients and great vessel injury patients. Thus, this group showed larger estimated blood losses (A vs L vs O: 590.63 ± 474.77 vs 2308.00 ± 4847.69 vs 7728.57 ± 8728.33, p = 0.003), red blood cell transfusions (A vs L vs O: 3.11 ± 6.67 vs 9.70 ± 15.78 vs 25.41 ± 23.66, p <0.001), and fresh frozen plasma transfusions (A vs L vs O: 1.89 ± 5.69 vs 7.48 ± 13.29 vs 13.94 ± 13.38, p = 0.011) than the other groups. The O group had more case of bleeding after surgery due to a large amount of estimated blood loss and transfusion leading to a bleeding tendency (A vs L vs O: 1 [5.3%] vs 3 [11.1%] vs 7 [41.2%], p = 0.014). The L group included preoperative respiratory failure due to pneumonia, sepsis, and VILI. Thus, these groups showed a longer duration of ventilator and ECMO use and longer mean hospital stay than the other groups. Lung failure after surgery was more common in the L group than the other groups (A vs L vs O: 0 [0%] vs 15 [55.6%] vs 5 [29.4%], p <0.001) (**Table 3**).

Discussion

Most thoracic surgeries could be performed with continuous one-lung ventilation and a triple-lumen central line. However, surgery is impossible if continuous ventilation is difficult, lung function is poor, or a large amount of bleeding occurs. It was recently reported that surgery is possible with ECMO use.[1–7] The usefulness of ECMO in thoracic surgery is divided into three categories.[3,11] First, the most useful indication of ECMO is airway obstructive disease.[7,12–14] Most causes of death in patients with airway disease are respiratory failure due to airway obstruction. ECMO helps maintain life before surgical correction. The airway surgery is highly risky and very difficult despite being performed by an expert surgeon, because most conventional airway surgeries should be performed alternately between ventilation and non-ventilation for a limited time and the surgical field is poor due to endotracheal tube insertion into the distal trachea. However, ECMO can provide oxygen support and CO_2 removal without ventilation, making it possible to perform airway surgery with or without ventilation.[11] ECMO enables safe airway surgery in an emergency state, even for inexpert trachea surgeons.

The second indication for ECMO support for thoracic surgery is the state of lung failure due to pneumonia, sepsis, and VILI.[9] These patients are generally contraindicated for thoracic surgery by traditional criteria. It is

Table 1 Clinical value according to mortality

Variables	Total (n=63)	Survivor (n = 46)	Non-survivor (n = 17)	p value
Age (years)	50.38 ± 16.16	47.4 ± 15.8	58.35 ± 14.7	0.016
Sex (male)	42 (66.7%)	28 (60.9%)	14 (82.4%)	0.139
BMI (kg/m$^{2)}$)	23.07 ± 4.04	22.9 ± 4.3	23.7 ± 3.0	0.523
Purpose of ECMO				<0.001
Prevention of lethal event	38 (60.3%)	34 (73.9%)	4 (23.5%)	
Rescue of life	25 (39.7%)	12 (26.1%)	13 (76.5%)	
Types of support				<0.001
VA Cardiopulmonary support)	21 (33.3%)	9 (19.6%)	12 (70.6%)	
VV (Only respiration support)	42 (66.7%)	37 (80.4%)	5 (29.4%)	
Types of operation				0.153
Airway surgery	19 (30.2%)	17 (37.0%)	2 (11.8%)	
Lung	27 (42.9%)	18 (39.1%)	9 (52.9%)	
Others (mediastinum, major vessel)	17 (27.0%)	11 (23.9%)	6 (35.3%)	
Preoperative clinical conditions				
Major multiple trauma	22 (34.9%)	14 (30.4%)	8 (47.1%)	0.246
Advanced thoracic malignancy	15 (23.8%)	10 (21.7%)	5 (29.4%)	0.740
Infectious disease	12 (19.0%)	10 (21.7%)	2 (11.8%)	0.487
Airway obstruction	14 (22.2%)	12 (26.1%)	2 (11.8%)	0.316
Bleeding before surgery	26 (41.3%)	18 (39.1%)	8 (47.1%)	0.388
Diabetes	13 (20.6%)	9 (19.6%)	4 (23.5%)	1.000
Hypertension	15 (23.8%)	10 (21.7%)	5 (29.4%)	0.740
Renal failure	1 (1.6%)	0 (0%)	1 (5.9%)	0.270
Coagulopathy	27 (42.9%)	16 (34.8%)	11 (64.7%)	0.460
Postoperative results				
Arrest during operation	11 (17.5%)	2 (4.3%)	9 (52.9%)	<0.001
Operation time	250.56 ± 125.77	249.0 ± 115.6	254.7 ± 153.9	0.875
Operation-related complications				
Bleeding	11 (17.5%)	6 (13.0%)	5 (29.4%)	0.149
Cerebral injury	8 (12.7%)	3 (6.5%)	5 (29.4%)	0.280
Lung failure	20 (31.7%)	10 (21.7%)	10 (58.8%)	0.191
Other	7 (11.1%)	4 (8.7%)	3 (17.6%)	0.375

ECMO: extracorporeal membrane oxygenation; VA: venoarterial; VV: venovenous

difficult to decide to perform conventional surgery without ECMO support; even if the surgery is decided, there are many cases in which the vital signs are not maintained and the operation cannot be started, or if the surgery is performed, pulmonary insufficiency cannot be recovered after surgery. However, the use of ECMO allows maintenance of cardiopulmonary support during perioperative period. It is very helpful in patients who underwent ECMO support during preoperative period. If surgical risk factors have been eliminated, it is reasonable to perform surgery to resolve the disease focus. ECMO also prevents worsening of lung function or additional cardiopulmonary damage in VILI and reduces many risks (hypoxia, shock, or arrest during surgery) that can occur during surgery. Since 2012, aggressive surgical correction using ECMO has been performed with these concepts in our institute. Despite the very high operative risk group, the mortality rate was relatively reasonable (16.7%).

The third indication is ECMO support for cardiopulmonary support during thoracic surgery.[8,15,16] It is mainly used to maintain hemodynamic function in surgery for advanced huge thoracic cancer and thoracic trauma with major vessel injury. Intraoperative mass manipulation can deteriorate cardiac function. In severe cases, cardiac arrest may occur. Most intraoperative arrests lacking emergency preparation result in death. The hemodynamic support of ECMO prevents unexpected lethal events during surgery and ensures that surgery proceeds safely. ECMO is simultaneously possible rapid volume replacement during surgery. We already reported the effects of ECMO as a life-saving method in the treatment of shock from heart and major vessel injury.[17]

If indications have been determined, the next question is "When is it effective to apply ECMO?" In our risk factor analysis, the mortality was higher when the arrest occurred intraoperatively. Since ECPR is performed

Table 2   Multivariable analysis of risk factors for mortality

Estimated factors	Odds ratio	95% CI	p value
Age (years)	7.47	1.17–47.85	0.034
Sex	0.20	0.01–3.03	0.245
Types of support	4.60	0.48–43.93	0.185
Arrest during operation	24.44	1.82–327.60	0.016
Purpose of ECMO	0.64	0.09–4.52	0.652
Postoperative bleeding	0.45	0.05–3.97	0.470

ECMO: extracorporeal membrane oxygenation

preoperatively, ECMO can be performed relatively quickly. The operation can begin after the patient's vital signs have stabilized. However, if ECPR (as sudden cardiac arrest) during thoracic surgery occurs without femoral cannula site preparation, ECMO insertion and recovery of vital signs were delayed due to the lateral decubitus position of patients. Although ECMO was started, most patients presented with hypoxic brain damage or irreversible cardiopulmonary dysfunction due to delayed time to resuscitation. Min et al.[18] reported an overall success rate (i.e., neurological deficit-free operation) of 26% with intraoperative ECPR. In our study, only two of 11 (18.1%) intraoperative ECPR patients survived. One patient was in a supine position and the other had an event during surgical draping, so ECMO could be applied relatively quickly. Based on these results, preventive ECMO insertion comparing the intraoperative ECPR may have helped increase patient survival. In the patients who have a risk of developing cardiopulmonary failure during surgery, it is necessary to establish indications for preventive ECMO insertion. In our institute, indication of preventive ECMO insertion is as follows: (1) tachycardia occurs due to compression on the heart by a huge mass, (2) maintain of PaO_2 is difficult due to active and massive hemoptysis, (3) airway is collapsed below 5 mm, (4) maintain the airway is difficult due to bilateral thoracic surgery or carina surgery, and (5) maintain ventilation is difficult due to pneumonia or acute respiratory distress syndrome (ARDS) of the opposite lung.

If thoracic surgery with ECMO support is chosen, the correction of preoperative coagulation defects is important for operation mortality. Anticoagulation should generally be used to prevent blood clots in extracorporeal circuits. However, it is important to consider whether it is reasonable to implement prophylactic anticoagulation in patients with major bleeding. In particular, when ECMO is inserted to support surgery, its short-term use is planned, so the probability of thromboembolic events is lower than the other ECMO applications.

There are many reports of surgery with heparin-free ECMO in trauma. Muellenbach et al.[19] first reported three cases of prolonged heparin-free VV ECMO in multiple-injury ARDS patients with severe traumatic brain injury in whom conventional mechanical ventilation had failed. Arlt et al.[20] reported that six of 10 multiple trauma patients with coexisting pulmonary failure or cardiopulmonary failure and hypovolemic shock due to bleeding survived with the use of heparin-free ECMO. Ried et al.[21] reported an overall survival rate of 79% in 52 patients with severe thoracic trauma and acute lung failure refractory to conventional therapy using extracorporeal lung support. Heparin-free ECMO was used in patients at high risk of further bleeding complications or showing signs of intracranial bleeding.

It is theoretically possible to support patients with ongoing massive bleeding by ECMO without anticoagulation. First, patients with massive bleeding often have coagulation defects prior to ECMO insertion because a mild coagulation defect is induced by blood loss and hemodilution due to massive crystalloid volume replacement. It is possible to maintain ECMO flow and function without anticoagulation during ECMO cannulation.[22] Second, newer circulatory systems utilizing heparin-bonded catheters, low-pressure oxygenators, and centrifugal pumps allow for the use of less anticoagulant during ECMO without circuit thrombotic complications.[23] Third, most thromboses occur at sites of stasis or turbulent flow in the circuit, that is, on the venous (pre-oxygenator) side of the circuit rather than on the arterial (post-oxygenator) side.[24,25] We performed ECMO intraoperatively without heparin except a loading dose during elective ECMO insertion to reduce bleeding due to anticoagulation use.

The last point to mention is that ECMO can be used postoperatively. All patients undergoing surgery with ECMO have a high-risk medical problem. Therefore, in many cases, cardiopulmonary failure occurs after surgery. Maintaining vital signs is often difficult despite maximal conventional support. In these cases, ECMO support is required to maintain cardiopulmonary

Table 3 Clinical value between three groups

Basic characteristics	Total (63)	Airway (19)	Lung (27)	Other (17)	p value
Age	50.38 ± 16.16	49.42 ± 20.06	54.33 ± 11.25	45.18 ± 17.27	0.180
Sex (male)	42 (66.7%)	6 (31.5%)	23 (85.2%)	13 (76.5%)	0.001
BMI	23.07 ± 4.04	23.87 ± 5.04	22.20 ± 3.57	23.61 ± 3.33	0.329
Purpose of ECMO					<0.001
Prevention of lethal event	38 (60.3%)	17 (89.5%)	20 (74.1%)	1 (5.9%)	
Rescue of life	25 (39.7%)	2 (10.5%)	7 (25.9%)	16 (94.1%)	
Type of support					<0.001
VA (cardiopulmonary)	21 (33.3%)	3 (15.8%)	5 (18.5%)	13 (76.5%)	
VV (pulmonary)	42 (66.7%)	16 (84.2%)	22 (81.5%)	4 (23.5%)	
Operation results					
Operation time	250.56 ± 125.77	263.9 ± 104.8	250.19 ± 104.84	236.18 ± 145.84	0.808
Arrest during operation	11 (17.5%)	2 (10.5%)	3 (11.1%)	6 (35.3%)	0.940
Estimated blood loss	3415.45 ± 6017.14	590.63 ± 474.77	2308.00 ± 4847.69	7728.57 ± 8728.33	0.003
Transfusion during operation					
RBC	11.95 ± 18.35	3.11 ± 6.67	9.70 ± 15.78	25.41 ± 23.66	<0.001
FFP	7.54 ± 12.28	1.89 ± 5.69	7.48 ± 13.29	13.94 ± 13.38	0.011
Platelet	6.86 ± 13.46	2.95 ± 8.92	6.59 ± 11.68	11.65 ± 18.65	0.153
Postoperative ventilator day	17.30 ± 25.01	6.68 ± 16.44	28.22 ± 30.00	11.82 ± 17.06	0.007
Postoperative ECMO day	4.54 ± 7.97	2.05 ± 4.42	8.22 ± 10.49	1.47 ± 2.35	0.005
Postoperative ICU stay	19.30 ± 26.38	10.84 ± 25.84	28.96 ± 28.81	13.41 ± 17.77	0.038
Postoperative hospital stay	44.83 ± 47.37	30.37 ± 37.85	61.74 ± 54.94	34.12 ± 36.38	0.045
Complications and mortality					
Bleeding	11 (17.5%)	1 (5.3%)	3 (11.1%)	7 (41.2%)	0.014
Cerebral injury	8 (12.7%)	2 (10.5%)	2 (7.4%)	4 (23.5%)	0.302
Lung failure	20 (31.7%)	0 (0%)	15 (55.6%)	5 (29.4%)	<0.001
Renal failure	14 (22.2%)	1 (5.3%)	9 (33.3%)	4 (23.5%)	0.070
Others	7 (11.1%)	0 (0%)	5 (18.5%)	2 (11.8%)	0.970
30-day mortality	17 (27.0%)	2 (10.5%)	9 (33.3%)	6 (35.3%)	0.160

BMI: body mass index; ECMO: extracorporeal membrane oxygenation; FFP: fresh frozen plasma; ICU: intensive care unit; RBC: red cell blood; VA: venoarterial; VV: venovenous

function after surgery. Because ECMO rescues life or reduces respiratory dependence in the immediate postoperative critical period, patients who require maximal ventilator support could prevent VILI or diaphragm dysfunction by postoperative ECMO support. Yeo et al.[26] reported an 80% survival rate of postoperative ARDS through ECMO therapy. In general, the survival rate of postoperative ARDS is 50–60%, a high success rate.[27] If ECMO is used during surgery, it can be easily determined to which extent it should be used immediately after surgery; thereby, we can prevent secondary cardiopulmonary function damage from occurring after surgery. The limitation of this study was that it was a small case number and was not various thoracic surgery.

Conclusion

ECMO is useful during thoracic surgery in high-risk patients with respiratory or cardiac failure. ECMO provides a safe environment during thoracic surgery with acceptable mortality and complication rates. However, as shown in our results, unprepared ECMO insertion does not increase the survival rate due to delayed resuscitation in intraoperative arrest. For patients at high risk of surgery with a high chance of a lethal event, elective ECMO insertion to prevent a lethal event is recommended.

Acknowledgment

Disclosure Statement

None.

References

1) Aigner C, Wisser W, Taghavi S, et al. Institutional experience with extracorporeal membrane oxygenation in lung transplantation. Eur J Cardiothorac Surg 2007; **31**: 468–73; discussion 473-4.

2) Lang G, Ghanim B, Hötzenecker K, et al. Extracorporeal membrane oxygenation support for complex tracheo-bronchial procedures†. Eur J Cardiothorac Surg 2015; **47**: 250–5; discussion 256.

3) Rinieri P, Peillon C, Bessou JP, et al. National review of use of extracorporeal membrane oxygenation as respiratory support in thoracic surgery excluding lung transplantation. Eur J Cardiothorac Surg 2015; **47**: 87–94.

4) Lei J, Su K, Li XF, et al. ECMO-assisted carinal resection and reconstruction after left pneumonectomy. J Cardiothorac Surg 2010; **5**: 89.

5) Rosskopfova P, Perentes JY, Ris HB, et al. Extracorporeal support for pulmonary resection: current indications and results. World J Surg Oncol 2016; **14**: 25.

6) Keeyapaj W, Alfirevic A. Carinal resection using an airway exchange catheter-assisted venovenous ECMO technique. Can J Anaesth 2012; **59**: 1075–6.

7) Kim CW, Kim DH, Son BS, et al. The feasibility of extracorporeal membrane oxygenation in the variant airway problems. Ann Thorac Cardiovasc Surg 2015; **21**: 517–22.

8) Felten M-L, Michel-Cherqui M, Puyo P, et al. Extracorporeal membrane oxygenation use for mediastinal tumor resection. Ann Thorac Surg 2010; **89**: 1012.

9) Brenner M, O'Connor JV, Scalea TM. Use of ECMO for resection of post-traumatic ruptured lung abscess with empyema. Ann Thorac Surg 2010; **90**: 2039–41.

10) Tsunezuka Y, Sato H, Tsubota M, et al. Significance of percutaneous cardiopulmonary bypass support for volume reduction surgery with severe hypercapnia. Artif Organs 2000; **24**: 70–3.

11) Redwan B, Ziegeler S, Freermann S, et al. Intraoperative veno-venous extracorporeal lung support in thoracic surgery: a single-centre experience. Interact Cardiovasc Thorac Surg 2015; **21**: 766–72.

12) Hong Y, Jo KW, Lyu J, et al. Use of venovenous extracorporeal membrane oxygenation in central airway obstruction to facilitate interventions leading to definitive airway security. J Crit Care 2013; **28**: 669–74.

13) Kim SH, Song S, Kim YD, et al. Outcomes of extracorporeal life support during surgery for the critical airway stenosis. ASAIO J 2017; **63**: 99–103.

14) Ko M, dos Santos PR, Machuca TN, et al. Use of single-cannula venous-venous extracorporeal life support in the management of life-threatening airway obstruction. Ann Thorac Surg 2015; **99**: e63–5.

15) Xu HC, Ye P, Bao FC, et al. ECMO-assisted esophagectomy after left pneumonectomy. Int J Artif Organs 2013; **36**: 259–62.

16) Byrne JG, Leacche M, Agnihotri AK, et al. The use of cardiopulmonary bypass during resection of locally advanced thoracic malignancies: a 10-year two-center experience. Chest 2004; **125**: 1581–6.

17) Park JM, Kim CW, Cho HM, et al. Induced airway obstruction under extracorporeal membrane oxygenation during treatment of life-threatening massive hemoptysis due to severe blunt chest trauma. J Thorac Dis 2014; **6**: E255–8.

18) Min JJ, Tay CK, Ryu DK, et al. Extracorporeal cardiopulmonary resuscitation in refractory intra-operative cardiac arrest: an observational study of 12-year outcomes in a single tertiary hospital. Anaesthesia 2018; **73**: 1515–23.

19) Muellenbach RM, Kredel M, Kunze E, et al. Prolonged heparin-free extracorporeal membrane oxygenation in multiple injured acute respiratory distress syndrome patients with traumatic brain injury. J Trauma Acute Care Surg 2012; **72**: 1444–7.

20) Arlt M, Philipp A, Voelkel S, et al. Extracorporeal membrane oxygenation in severe trauma patients with bleeding shock. Resuscitation 2010; **81**: 804–9.

21) Ried M, Bein T, Philipp A, et al. Extracorporeal lung support in trauma patients with severe chest injury and acute lung failure: a 10-year institutional experience. Crit Care 2013; **17**: R110.

22) Bedeir K, Seethala R, Kelly E. Extracorporeal life support in trauma: worth the risks? A systematic review of published series. J Trauma Acute Care Surg 2017; **82**: 400–6.

23) Petricevic M, Milicic D, Boban M, et al. Bleeding and thrombotic events in patients undergoing mechanical circulatory support: a review of literature. Thorac Cardiovasc Surg 2015; **63**: 636–46.

24) Wen PH, Chan WH, Chen YC, et al. Non-heparinized ECMO serves a rescue method in a multitrauma patient combining pulmonary contusion and nonoperative internal bleeding: a case report and literature review. World J Emerg Surg 2015; **10**: 15.

25) Zonies D, Merkel M. Advanced extracorporeal therapy in trauma. Curr Opin Crit Care 2016; **22**: 578–83.

26) Yeo HJ, Cho WH, Kim D. Awake extracorporeal membrane oxygenation in patients with severe postoperative acute respiratory distress syndrome. J Thorac Dis 2016; **8**: 37–42.

27) Serpa Neto A, Hemmes SN, Barbas CS, et al. Incidence of mortality and morbidity related to postoperative lung injury in patients who have undergone abdominal or thoracic surgery: a systematic review and meta-analysis. Lancet Respir Med 2014; **2**: 1007–15.