JCS
Journal of Chest Surgery
https://doi.org/10.5090/jcs.23.118
pISSN: 2765-1606 eISSN: 2765-1614
J Chest Surg. 2024;57(3):281-288

Clinical Research

Differences in Treatment Outcomes According to the Insertion Method Used in Extracorporeal Cardiopulmonary Resuscitation: A Single-Center Experience

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ARTICLE INFO
Received August 22, 2023
Revised December 19, 2023
Accepted January 18, 2024

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See Commentary page 289.

Background: Venoarterial extracorporeal membrane oxygenation (ECMO) is a key treatment method used with patients in cardiac arrest who do not respond to medical treatment. A critical step in initiating therapy is the insertion of ECMO cannulas. Peripheral ECMO cannulation methods have been preferred for extracorporeal cardiopulmonary resuscitation (ECPR).
Methods: Patients who underwent ECPR at Daegu Catholic University Medical Center between January 2017 and May 2023 were included in this study. We analyzed the impact of 2 different peripheral cannulation strategies (surgical cutdown vs. percutaneous cannulation) on various factors, including survival rate.
Results: Among the 99 patients included in this study, 66 underwent surgical cutdown, and 33 underwent percutaneous insertion. The survival to discharge rates were 36.4% for the surgical cutdown group and 30.3% for the percutaneous group (p=0.708). The ECMO insertion times were 21.3 minutes for the surgical cutdown group and 10.3 minutes for the percutaneous group (p<0.001). The factors associated with overall mortality included a shorter low-flow time (hazard ratio [HR], 1.045; 95% confidence interval [CI], 1.019–1.071; p=0.001) and whether return of spontaneous circulation was achieved (HR, 0.317; 95% CI, 0.127–0.787; p=0.013). Low-flow time was defined as the time from the start of cardiopulmonary resuscitation to the completion of ECMO cannula insertion.
Conclusion: No statistically significant difference in in-hospital mortality was observed between the surgical and percutaneous groups. However, regardless of the chosen cannulation strategy, reducing ECMO cannulation time was beneficial, as a shorter low-flow time was associated with significant benefits in terms of survival.

Keywords: Extracorporeal membrane oxygenation, Extracorporeal cardiopulmonary resuscitation, ECMO cannulation

Introduction

Extracorporeal membrane oxygenation (ECMO) is a lifesaving therapy that provides mechanical circulatory support to patients with severe respiratory and/or cardiac failure [1-4]. The use of ECMO has increased over the years due to advancements in technology and improved outcomes. Venoarterial ECMO (VA ECMO), in particular, has been a key treatment method in patients with cardiac arrest who do not respond to medical treatment [1-5]. Cannula insertion is a critical step in initiating ECMO therapy and requires careful consideration of patient anatomy, cannula size, and site selection [1,6-9].

There are several techniques, including percutaneous and open surgical approaches, available for insertion of the ECMO cannulas [1,6-9]. Percutaneous cannulation involves insertion of a cannula through the skin into a vessel, whereas open surgical cannulation involves a surgical incision to expose the vessel for cannula insertion. Both approaches have advantages and disadvantages, and the choice of technique depends on the patient's clinical status, availability of resources, and experience of the ECMO team.

https://doi.org/10.5090/jcs.23.118

Although several studies have reported on the outcomes of ECMO, few have studied the difference in extracorporeal cardiopulmonary resuscitation (ECPR) outcomes according to the insertion method. Therefore, this study investigated the complications and treatment outcomes of ECPR according to the insertion method.

Methods

Patients

Patients who underwent ECPR at Daegu Catholic University Medical Center between January 2017 and May 2023 were included. Ninety-seven consecutive patients treated in the intensive care unit after ECMO support were included in the study. Two patients who expired due to ECMO cannulation failure were excluded from the data.

This study was approved by the Institutional Review Board (IRB) of Daegu Catholic University Medical Center (IRB no., CR-23-080-L). The requirement for obtaining individual informed consent was waived.

Extracorporeal membrane oxygenation cannulation strategy and procedure

The indications for ECMO cannulation followed the guidelines of the Korea Health Insurance Review and Assessment Service. Eligible patients had a witnessed cardiac arrest with bystander CPR. Exclusion criteria included irreversible cardiac diseases, cardiopulmonary resuscitation for over 60 minutes without adequate tissue perfusion, absolute contraindication of anticoagulant therapy due to recent cerebral hemorrhage or uncontrollable bleeding, progressive hematologic malignancy, bone marrow transplantation failure with an absolute neutrophil count <400/mm^3, and severe immunodeficiency states. In addition, individuals with irreversible brain damage, irreversible central nervous system disorders, terminal cancer, and irreversible severe end-stage organ failure with no possibility of recovery were excluded. Elderly patients deemed futile for the procedure were also excluded.

The ECMO cannulation method was determined by a surgeon. If ultrasonography (USG) was not available, the procedure was performed using an open technique. There are several open techniques, including direct cannulation after an open cutdown, using the Seldinger technique after exposing the target vessel (semi-Seldinger technique), and cannulation through a Dacron graft anastomosis at the target vessels [9]. This study employed only the open cutdown Seldinger technique for open surgical cannulation.

The femoral vessels were used for open surgical cannulation during simultaneous chest compressions. The skin incision was dissected using a Bovie or scissors to identify the arteries and veins, and ECMO was started after cannulation using the Seldinger technique. A distal perfusion catheter (5F angio sheath) was inserted, the wound was closed, and the cannula was fixed to the skin.

For the percutaneous technique, USG was performed in all possible cases. Simultaneous chest compressions were continued as the femoral area was draped, the sonoprobe was wrapped with sterilized vinyl, and the area was explored. Upon locating the femoral artery and vein, the vein was punctured first, followed by guidewire insertion, arterial puncture, cannulation using the Seldinger technique, and connection of the ECMO device. Chest compressions were stopped when sufficient blood flow was achieved. A distal perfusion catheter was sequentially inserted into the superficial femoral artery under USG guidance.

Definitions

Low-flow time was measured from the start of cardiopulmonary resuscitation (CPR) to the completion of ECMO cannula insertion with adequate flow established and chest compressions stopped. Return of spontaneous circulation (ROSC) was defined as restoration of spontaneous circulation at least once during CPR. The ECMO cannula insertion time was measured from draping to completion of ECMO cannula insertion and cessation of chest compressions. Transfusion totals were measured in units of blood products transfused (unit: pint) during the first 3 days after ECMO cannulation.

Statistical analysis

All statistical analyses were performed using IBM SPSS ver. 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were analyzed using the Student t-test, and categorical variables were analyzed using the chi-square test or Fisher exact test.

Multivariate analysis of the influence on survival was performed using the Cox proportional hazards model. The variables used were those with a p-value <0.2 in the univariate analysis of survival. Survival curves were generated using the Kaplan-Meier method, and the differences between groups were determined using the log-rank test. Statistical significance was set at $p<0.05$.

Results

The basic patient characteristics are presented in Table 1. Of the total 99 patients, 66 were in the open surgery group and 33 were in the percutaneous group. There were no significant differences between the 2 groups for histories of hypertension, diabetes mellitus, or hyperlipidemia.

Results of the ECMO procedure are shown in Table 2. The percutaneous method significantly shortened insertion time. The size of the cannula used was significantly different between the 2 groups, particularly the size of the venous cannula. The maximum pump flow measured while maintaining ECMO was significantly different between the 2 groups, with the percutaneous group measuring as high as 3.4 L/min.

The complications and short-term outcomes of ECMO are shown in Table 3. No statistically significant differences were observed between the 2 groups for (1) cases requiring continuous renal replacement therapy during ECMO (p=0.246), (2) ECMO weaning rates (p=0.943), and (3) survival-to-discharge rates (p=0.708).

The amount of blood transfused over 3 days after ECMO cannulation is compared in Table 4. Thirteen patients underwent surgery after receiving ECMO. The amount of blood transfused was high in patients who underwent surgery due to blood transfusions for cardiopulmonary bypass during surgery and postoperative bleeding. Among the patients who did not undergo surgery after ECMO cannulation, the number of red blood cell, fresh frozen plasma, and platelet transfusions in the open surgical group was higher than that in the percutaneous group, though the difference was not statistically significant.

We analyzed the risk factors for in-hospital deaths. Using univariate analysis, ROSC and low-flow times were found to be statistically significant factors influencing in-hospital death. However, the method of ECMO insertion was not a statistically significant factor for mortality (p=0.550). Low-flow times were also shown to be statistically significant in the multivariate analysis (hazard ratio, 1.055; p<0.001), while cannulation type had no significant

Table 1. Patient characteristics in a comparison of peripheral extracorporeal membrane oxygenation cannula insertion methods (n=99)

Characteristic	Surgical insertion group (n=66)	Percutaneous insertion group (n=33)	p-value
Age (yr)	59.4±13.5	58.8±13.8	0.822
Sex			0.766
Female	11 (16.7)	4 (12.1)	
Male	55 (83.3)	29 (87.9)	
Initial rhythm			0.695
VT/VF	41 (62.1)	19 (57.6)	
Pulseless electrical activity	19 (28.8)	12 (36.4)	
Asystole	6 (9.1)	2 (6.1)	
Body mass index (kg/m^2)	24.7±3.4	24.7±2.4	0.977
Hypertension	30 (45.5)	15 (45.5)	1.000
Diabetes mellitus	20 (30.3)	9 (27.3)	0.938
Dyslipidemia	6 (9.1)	5 (15.2)	0.572
Current smoker	20 (30.3)	10 (30.3)	1.000
Malignancy	1 (1.5)	0	1.000
Liver disease	1 (1.5)	2 (6.1)	0.534
Chronic kidney disease	5 (7.6)	3 (9.1)	1.000
Chronic obstructive pulmonary disease	0	1 (3.0)	0.722
Heart failure	5 (7.6)	1 (3.0)	0.655
Valvular heart disease	3 (4.5)	0	0.534
Arrhythmia	2 (3.0)	2 (6.1)	0.857
Peripheral arterial occlusive disease	1 (1.5)	1 (3.0)	1.000
Angina	6 (9.2)	2 (6.1)	0.880
Previous myocardial infarction	5 (7.6)	5 (15.2)	0.409
Previous percutaneous coronary intervention	5 (7.6)	4 (12.1)	0.711
Previous coronary artery bypass grafting	3 (4.5)	0	0.534
Old cerebrovascular accident	5 (7.6)	1 (3.0)	0.655

Values are presented as mean±standard deviation or number (%).
VT, ventricular tachycardia; VF, ventricular fibrillation.

https://doi.org/10.5090/jcs.23.118

Table 2. Characteristics of ECMO procedures according to peripheral cannula insertion method

Variable	Surgical insertion group (n=66)	Percutaneous insertion group (n=33)	p-value
Low-flow time (min)	38.4±22.6	35.7±22.8	0.578
Cardiac arrest			0.825
In-hospital cardiac arrest	41 (62.1)	22 (66.7)	
Out-of-hospital cardiac arrest	25 (37.9)	11 (33.3)	
ECMO insertion time (min)	21.3±9.4	10.3±5.2	<0.001
Arterial cannula size			0.017
15F	4 (6.1)	9 (27.3)	
16F	51 (77.3)	17 (51.5)	
17F	2 (3.0)	2 (6.1)	
18F	9 (13.6)	5 (15.2)	
Venous cannula size			0.012
20F	5 (7.6)	1 (3.0)	
21F	3 (4.5)	2 (6.1)	
22F	39 (59.1)	9 (27.3)	
23F	4 (6.1)	7 (21.2)	
24F	15 (22.7)	14 (42.4)	
Max pump flow (L/min)	3.0±0.6	3.4±0.8	0.018
ECMO duration (day)	5.1±4.7	5.0±5.2	0.942

Values are presented as mean±standard deviation or number (%).
ECMO, extracorporeal membrane oxygenation.

Table 3. Complications and short-term outcomes of ECMO according to peripheral cannula insertion method

Variable	Surgical group (N=66)	Percutaneous group (N=33)	p-value
Wound complication	7 (10.6)	0	0.127
Continuous renal replacement therapy	17 (25.8)	13 (39.4)	0.246
Distal perfusion	62 (93.9)	31 (93.9)	1.000
ECMO weaning success			0.943
No	30 (45.5)	16 (48.5)	
Yes	36 (54.5)	17 (51.5)	
Survival discharge			0.708
No	42 (63.6)	23 (69.7)	
Yes	24 (36.4)	10 (30.3)	

Values are presented as number (%).
ECMO, extracorporeal membrane oxygenation.

Table 4. Comparison of blood transfusions during the first 3 days after extracorporeal membrane oxygenation cannulation according to insertion method and whether further surgery was performed (n=99)

Blood product (pints)	Medical treatment only			Definitive surgery		
	Surgical insertion group (N=59)	Percutaneous insertion group (N=27)	p-value	Surgical insertion group (N=7)	Percutaneous insertion group (N=6)	p-value
RBC transfusion	3.9±4.8	3.0±3.8	0.471	11.7±7.1	12.0±3.4	0.930
FFP transfusion	1.6±3.1	1.3±2.2	0.701	6.0±6.8	7.7±5.8	0.645
PLT transfusion	4.5±7.7	2.7±4.1	0.153	9.6±4.6	14.7±6.1	0.113

Values are presented as mean±standard deviation.
RBC, red blood cell; FFP, fresh frozen plasma; PLT, platelet.

influence on mortality (p=0.550) (Table 5). In the standardized log-rank statistical analysis, a significant increase in the mortality rate was observed after 38 minutes of low-flow time (Fig. 1). The Kaplan-Meier analysis of mortality during hospitalization showed no significant difference between the 2 insertion types (p=0.97) (Fig. 2).

Table 5. Risk factors for in-hospital death among patients who received ECMO for ECPR (n=99)

Characteristic	Univariate analysis		Multivariate analysis	
	HR (95% CI)	p-value	HR (95% CI)	p-value
Age	1.005 (0.975–1.036)	0.750		
Male sex	1.613 (0.543–4.794)	0.390		
Body mass index	0.949 (0.829–1.086)	0.445		
Return of spontaneous circulation	0.317 (0.127–0.787)	0.013	0.494 (0.143–1.699)	0.263
Surgical insertion of ECMO cannulas	1.314 (0.537–3.219)	0.550		
ECMO insertion time	1.00 (0.958–1.044)	0.990		
Low-flow time	1.045 (1.019–1.071)	0.001	1.055 (1.026–1.086)	<0.001
Max pump flow	0.641 (0.345–1.190)	0.159	0.536 (0.251–1.142)	0.106

ECMO, extracorporeal membrane oxygenation; ECPR, extracorporeal cardiopulmonary resuscitation; HR, hazard ratio; CI, confidence interval.

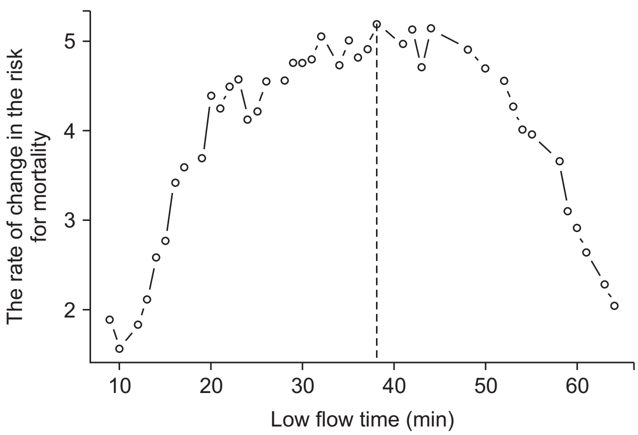

Fig. 1. Standardized log-rank analysis of mortality rate after extracorporeal membrane oxygenation.

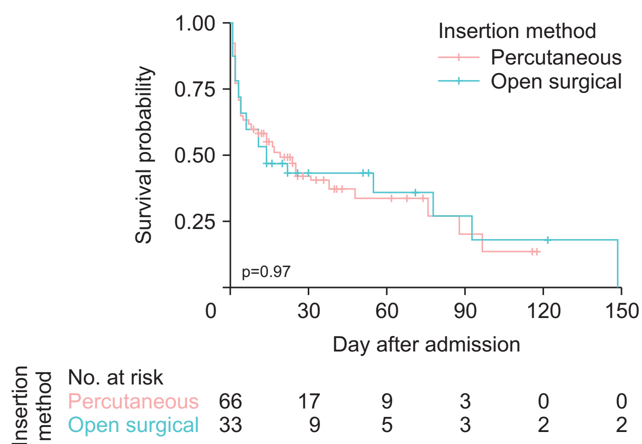

Fig. 2. Kaplan-Meier curve showing mortality rates according to the method of insertion in extracorporeal membrane oxygenation.

Discussion

Since numerous studies have reported better outcomes with ECMO than with conventional treatments, ECMO during CPR has been increasingly implemented in many centers [1-4].

ECMO cannulation can be either central or peripheral. Opening the sternum is often not feasible in emergency situations or when chest compressions are being performed, making peripheral cannulation the preferred choice. Although peripheral cannulation sites can be selected from various locations, the femoral vessel is the most common choice due to its sufficient vessel size and ease of approach [5,10]. Peripheral ECMO cannulation can be performed by surgical cutdown or percutaneous cannulation.

ECMO cannula insertion has traditionally been performed by surgeons and surgical cutdown insertion has therefore been the predominant method in the past [6]. However, as ECMO has become more widely practiced, its use has expanded to internal medicine, emergency, and critical care settings, leading to an increasing proportion of percutaneous insertions [6-8]. Surgical cutdown involves the creation of a longitudinal or transverse incision at the femoral site, followed by tissue dissection to expose the target vessel. Subsequently, the Seldinger technique is used for cannulation. The advantage of the surgical cutdown method is that it allows precise identification of the blood vessel and facilitates accurate placement of the cannula at the desired location. In addition, the surgeon can easily establish distal perfusion at the time of cannulation [10]. However, it does require a level of expertise with an accurate understanding of vascular anatomy and the use of surgical instruments and equipment. This can be a limitation, as specialized skills and resources are required for successful cannulation. Furthermore, the potential for bleeding during the incision process and the time-consuming dissection required to locate the blood vessel are considered disadvantages of the surgical cutdown method.

Percutaneous cannulation involves USG guidance to

https://doi.org/10.5090/jcs.23.118

identify the target vessel, followed by application of the Seldinger technique for cannulation. If a USG machine is available, percutaneous cannulation offers the advantage of quick cannula insertion through a needle puncture [7]. Attempting blind insertion without USG guidance presents the risk of cannulation failure, making the USG machine essential and limiting the applicability of percutaneous cannulation.

There is limited research comparing the outcomes of these 2 methods (surgical cutdown and percutaneous cannulation) in the context of ECPR. According to our results, the time required for ECMO cannula insertion was 21.3 minutes and 10.3 minutes for the surgical cutdown and percutaneous methods, respectively. This difference was statistically significant (p<0.001). The observed difference in insertion times was likely a reflection of the advantages and limitations mentioned earlier. In practice, the process of incision and location of the blood vessel can take longer, depending on the operator's proficiency.

In our study, when the ECMO cannulas were percutaneously inserted, we observed a statistically higher maximum pump flow during the ECMO maintenance period than with the open surgical method (3.0 L/min versus 3.4 L/min, p=0.018). The observed difference was likely related to the ease with which the operator could assess the overall size of the blood vessels and determine the appropriate cannula size during percutaneous insertion. This advantage allows for better selection of the cannula size, potentially leading to improved pump flow rates during ECMO support. However, it did not appear to have a direct effect on mortality (p=0.159).

ECMO flow can be directly associated with systemic circulation in patients undergoing ECPR with severe heart dysfunction. However, higher ECMO flow rates can also lead to increased left ventricular (LV) afterload and elevated diastolic filling pressure, which in turn can result in a decrease in the transcoronary perfusion gradient and impaired coronary perfusion [2]. Excessive ECMO flow can cause progressive LV loading, ultimately leading to increased pulmonary artery pressure and the potential occurrence or worsening of pulmonary edema [11,12]. Furthermore, if LV venting is not performed sufficiently, stasis can occur within the LV chamber because of a poorly opened aortic valve. This stasis can lead to thrombosis, resulting in potentially fatal embolic events such as stroke [13]. Although adequate ECMO flow is essential for survival and recovery, a higher maximum ECMO flow does not necessarily indicate a better prognosis.

Since ECMO functions as a form of extracorporeal circulation, various complications such as bleeding, hemolysis leading to anemia, and consumption of coagulation factors can arise during its maintenance or removal [14-16]. In our study, we did not observe a statistically significant difference in bleeding-related complications according to the insertion method. However, when investigating the amount of blood transfused during the first 3 days after ECMO cannulation, transfusion requirements were slightly higher in patients who underwent open surgical insertion than in those who underwent percutaneous intervention. This can be attributed to external bleeding from the incision site [7,17].

In cases of peripheral ECMO cannulation, there is a risk of lower-limb ischemia due to reduced blood flow towards the distal cannulation site [7,10,17]. This can result in the need for interventions such as thromboembolectomy, vascular repair, or fasciotomy to address these complications [10,17]. In this study, no cases of acute lower limb ischemia were identified in either the surgical or percutaneous group. This could be attributed to the higher proportion of distal perfusion catheter insertions, which may have maintained adequate blood flow and minimized the risk of ischemic complications in the lower limbs [18,19].

Among the patients in our study who underwent surgical cutdown, 7 experienced insertion site wound complications that required vacuum therapy or skin grafting. No wound complications were observed in the percutaneous group. However, in one case, a pseudoaneurysm was identified following ECMO removal, and a stent graft intervention was performed.

The ECMO weaning and survival rates were not significantly different between the groups in our study. Among several variables examined in this study, total low-flow time and ROSC demonstrated statistically significant associations with weaning success and in-hospital mortality. In the study by Nagao et al. [20], the survival rate was significantly decreased when the low-flow time exceeded 40 minutes. Although the ECMO insertion time in our study's percutaneous approach group was significantly shorter than the surgical approach group, no statistically significant difference was found in terms of in-hospital mortality between the 2 groups.

This study had several limitations. As a retrospective data analysis, this study inherently relied on available records. Despite the lack of significant differences in the patient characteristics of the 2 groups and the shorter ECMO insertion time in the percutaneous group, the total low-flow time remained similar. This suggests the existence of time-consuming processes beyond ECMO insertion time.

It is possible that the percutaneous group required more preparation in terms of USG guidance settings and other aspects of the insertion process. To conduct a more accurate comparison, data from the time of contact with the cardiovascular surgery team to ECMO initiation are necessary. However, obtaining such data in a retrospective study may be challenging. The choice between surgical and percutaneous cannulation strategies varies depending on the operator's preference and experience. This introduces potential operator bias that can affect the results and conclusions of the study. In a large data analysis comparing ECPR and conventional cardiopulmonary resuscitation (CCPR), Low et al. [21] reported that out-of-hospital cardiac arrest (OHCA) with ECPR revealed a survival rate similar to CCPR, while in-hospital cardiac arrest (IHCA) with ECPR demonstrated a higher survival rate than CCPR. Conversely, our study found that the ECPR survival rates for IHCA and OHCA were not significantly different. Several factors may explain this lack of a significant difference between the IHCA and OHCA survival rates with ECPR. First, there might be operator bias. Operator preferences in setting candidate criteria may differ. The abundance of ambiguous information often encountered in the OHCA cases might have led us to set more stringent criteria when selecting target patients from the OHCA ECPR cohort. Specifically, the standards of the Korea Health Insurance Review and Assessment Service only mention "old age" as a criteria, without specifying an exact age range. In fact, there was a significant difference in age between the 2 groups (IHCA versus OHCA; 61.7±12.0 versus 55.4±15.2; p=0.025). Opinions may also vary on other factors such as the definition of "irreversible." The survival rate of patients with OHCA ECPR at our institution appears to be higher than that reported in the large data analysis by Low et al. [21], which could be attributed to the more stringent patient selection criteria, as discussed above. There also may have been a preference for certain procedural methods. Therefore, the data may not be perfectly randomized.

In conclusion, in this study focusing on the VA ECMO cannulation strategy used in ECPR situations, no statistically significant difference in in-hospital mortality was observed between the surgical and percutaneous groups. Because CPR is performed in emergency settings, there can be variability in operator expertise and available resources. Therefore, selecting a cannulation strategy based on the situation and considering operator preferences may be appropriate. However, regardless of the chosen cannulation strategy, reducing the ECMO cannulation time is beneficial, as a shorter low-flow time is associated with significant benefits in terms of weaning success and mortality. Therefore, minimizing the ECMO insertion time whenever possible appears to be the key to achieving better outcomes.

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Conflict of interest

No potential conflict of interest relevant to this article was reported.

Funding

This work was supported by grant from the Korean Association of Mechanical Life Support (KAMEL 2024-002).

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