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Performance and Safety of an Integrated Portable Extracorporeal Life Support System for Adults

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Abstract: Extracorporeal membrane oxygenation (ECMO) is indicated when conventional measures fail to support a patient during cardiac or respiratory failure. Due to the complicated nature of ECMO, patients often require transport to a tertiary care center. This study retrospectively compared the performance of the Cardiohelp™ (Maquet) life support system with a previously used ECMO circuit when transporting adult patients on venoarterial ECMO between facilities. Two ECMO circuits were compared for performance: 1) the Cardiohelp™ (Maquet) life support system and 2) the "standard" circuit consisting of a Thoratec CentriMag centrifugal pump, Maquet Quadrox-D oxygenator, and a Terumo CDI-500 in-line blood gas analyzer. After analyzing data from 16 patients (eight patients supported with each ECMO system), no differences in patient demographics, percentage of patients successfully weaned from ECMO, percentage of patients surviving to discharge, duration supported on the initial ECMO system, or total duration of ECMO were noted. No patient deaths were related to circuit failure or circuit disruptions in either group. Analysis of the performance of the ECMO circuits and the resulting patient status showed few significant differences between ECMO groups (Cardiohelp™ vs. standard circuit) and time points (the first 8 hours vs. a 24-hour time point). The statistically significant differences were not concerning in terms of appropriate medical support or patient safety. Of interest, the transmembrane pressure was significantly lower for the Cardiohelp™ module vs. the standard oxygenator during the first 8 hours (20.1 [5.3] vs. 37.1 [7.1] mmHg; $p < .001$) and at 24 hours (21.3 [3.8] vs. 34.8 [7.9] mmHg; $p = .001$). The Cardiohelp™ portable life support system provides safe and reliable support for adult patients on ECMO during interhospital patient transport as compared to the standard circuit. **Keywords:** ECMO, extracorporeal, extra corporeal life support, extracorporeal membrane oxygenation, transport. *JECT. 2015;47:38–43*

Extracorporeal membrane oxygenation (ECMO) is indicated when conventional medical and surgical measures fail to support a patient during cardiac or respiratory failure. Many primary care centers are unable or unwilling to perform ECMO, and patients often require transport to a tertiary care center. Multiple reports have shown that transporting high-risk patients on ECMO is beneficial if the risk of transporting them without extracorporeal support is life-threatening (1,2). It has been demonstrated that the survival of transported ECMO patients is comparable to patients not transported on ECMO (3). Also, adult patients transported on mechanical circulatory support may have improved outcomes when a dedicated team travels to initiate support and stabilize the patient before transport (4,5).

Recent improvements in technology have aimed to improve the safety and ease of transporting patients supported with ECMO. In particular, the size and simplicity of the Cardiohelp™ portable life support system (Maquet Cardiovascular, Bridgewater, NJ) may add convenience when initiating and/or transporting patients on ECMO. The Cardiohelp™ system is fully integrated and offers simple setup and priming techniques. These unique features may provide significant improvements over more traditional or "homemade" ECMO circuits, particularly when patient transport is required.

Several studies have documented the effective use of the Cardiohelp™ system for transporting patients with ECMO support (6–8). The Cardiohelp™ system has replaced the previous ECMO system used at our institution for facilitating interhospital transport of patients. The aim of this study was to determine the safety and performance of the Cardiohelp™ portable life support system in patients supported with venoarterial (VA) ECMO. We compared the performance of the Cardiohelp™ life

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support system with that of our previously used ECMO circuit when transporting adult patients on VA ECMO between facilities. The hypothesis of this study is that Cardiohelp™ life support system is a safe alternative to more traditional systems for the transport of adult patients on VA ECMO.

MATERIALS AND METHODS

After obtaining approval from the institutional review board (no. 14–000772), patients who were transported to our institution on VA ECMO between March 1, 2008 and July 31, 2014 were selected for analysis. All patients were older than 16 years and were placed on ECMO by our surgical team at the referring facility. Patients were excluded from analysis if they were placed on ECMO at the referring facility prior to the arrival of our team or if the total length of ECMO support was less than 20 hours. This is because we wanted to analyze data over time and analyze data using only our circuits. A total of 16 patients were identified, 8 of whom were transported using the Cardiohelp™ life support system and 8 transported using our traditional, or standard, circuit (Table 1). ECMO was initiated at the referring facility in either the operating room or the intensive care unit, and all patients were stabilized in the intensive care unit before transport to our facility. All 16 patients were transported via ground transportation in a commercial ambulance with a standard gurney.

The disposable pack for the Cardiohelp™ system is all-inclusive and contains all supplies necessary for ECMO support. Briefly, the kit consists of pre-connected arterial and venous 3/8″ tubing and an oxygenator/heat exchanger with an integrated blood pump. All temperature, pressure, and blood gas measurement technology is integrated into the oxygenator/centrifugal blood pump module, and values are displayed on the Cardiohelp™ drive unit. All Cardiohelp™ packs were coated with either Bioline or Softline biocoating. The standard circuit consisted of an X-coated custom 3/8″ tubing pack (Terumo, Ann Arbor, MI), a Quadrox-D oxygenator (Maquet Cardiovascular, Bridgewater, NJ), and a CentriMag blood pump (Thoratec Corp., Pleasanton, CA). For this circuit, a CDI-500 (Terumo Medical Corp., Ann Arbor, MI) in-line blood gas analyzer was incorporated to measure blood gases and electrolytes on the arterial side (via intra-circuit shunt) and a venous cuvette was used to measure hemoglobin, hematocrit, and venous saturation. Circuit pressures were monitored

Table 1. Patient demographics and outcomes.

Circuit	Primary Diagnosis	Pt Sex/ Age, y	Height, cm	Weight, kg	BSA, m^2	Cannulation Site	Successful Wean from ECMO?	Survived to Discharge?	Time on Initial Circuit, hours	Duration of ECMO Support
Standard	Cardiogenic shock	F/16	155	57	1.55	RFV/RFA	Yes	No	23*	334
	Cardiogenic shock	M/50	175	88	2.04	LFV/LFA	No	No	22	22
	Cardiogenic shock	M/54	192	120	2.49	LFV/LFA	No	No	123†	162
	Cardiogenic shock	M/59	184	109	2.31	RFV/RFA	Yes	Yes	138	138
	Ischemic cardiomyopathy	M/54	178	117	2.33	RFV/RFA	No	No	131*	140
	Giant cell myocarditis	M/32	185	84	2.08	LFV/LFA	Yes	Yes	113*	567
	Cardiac arrest	M/36	183	85	2.07	LFV/LFA	Yes	Yes	43	43
	Acute myocardial infarction	M/56	172	73	1.86	LFV/LFA	Yes	Yes	56	56
	Mean values	87.5% M/44.6	178.0	91.6	2.09		62.5%	50%	81.1	182.8
Cardiohelp™	Cardiogenic shock	F/33	171	121	2.29	RFV/RFA	Yes	Yes	124*	161
	Acute heart failure	M/47	155	81	1.80	RA/Ao	No	No	225*	348
	Cardiogenic shock	M/27	171	72	1.84	LFV/LFA	Yes	Yes	67	67
	Cardiac arrest	M/64	185	102	2.26	RFV/RFA	Yes	Yes	186	186
	Cardiogenic shock	M/50	190	96	2.24	RA/Ao	No	No	48*	290
	Failure to wean from CPB	M/66	178	82	2.00	RA/Ao	No	No	63‡	316
	Acute myocardial infarction	F/52	160	53	1.54	RA/Ao	Yes	No	191	191
	Failure to wean from CPB	M/34	165	77	1.84	RA/Ao	Yes	Yes	97	97
	Mean values	75% M/46.6	171.9	85.5	1.98		62.5%	50%	125.1	207.0

*Circuit replaced because of conversion to another type of extracorporeal support.
†Oxygenator replaced because of decreasing ECMO PO_2.
‡Circuit replaced because of clot formation in oxygenator outflow.
No statistically significant differences ($p \leq .05$) were found between groups in any of the measures shown.
BSA, body surface area; CPB, cardiopulmonary bypass; RFV, right femoral vein; RFA, right femoral artery; LFV, left femoral vein; LFA, left femoral artery; RA, right atrium; Ao, ascending aorta; ECMO, extracorporeal membrane oxygenation.

at the inlet and outlet of the oxygenator and were transduced to the CentriMag console.

For all patients, the following ECMO parameters were recorded hourly in the electronic medical record by the ECMO specialist (either a perfusionist or an ECMO-trained nurse): fraction of inspired oxygen (FIO_2), sweep rate, ECMO blood flow, and transmembrane pressure. Mean arterial pressure was either documented in the transport record of automatically captured from the patient monitor to the electronic medical record at 15-minute intervals. Arterial blood samples were drawn from both the patient and the ECMO circuit as needed. Samples were drawn as needed (at least once every 4 hours) for analysis of blood gases, activated clotting time (ACT), and other hematologic values. Upon returning to our facility, arterial blood gases, electrolytes, and hematocrit values reported were analyzed using the RapidPoint 405 (Siemens Medical Solutions, Malvern, PA) blood gas analyzer and ACTs were analyzed using the HMS plus (Medtronic, Minneapolis, MN). Venous oxygen saturation (SvO_2) was not analyzed using standard laboratory equipment. Instead, these values were collected from the CDI-500 (for the standard circuit) or from the integrated Cardiohelp™ values. For all patients, a loading dose of heparin (typically 80–100 U/kg) was given directly to the patient before cannulation for ECMO to induce a therapeutic ACT (typical target of 160–200 seconds). All circuits were primed with Plasmalyte A, and in some cases a small amount of heparin (3000 U or less). No other drugs were added to the primed circuits. The final priming volume of the Cardiohelp™ system was approximately 600 mL, and the final priming volume of the standard system was approximately 750 mL. On initiation of ECMO, patient temperatures were allowed to drift during transport. No patient temperatures below 35°C were recorded during this period. After arrival at our facility, the ECMO circuit's heat exchanger was connected to an ECMO heater (Model 333W; Cincinnati Sub-Zero, Cincinnati, OH), and patient temperatures were maintained between 36°C and 37°C.

All parameters investigated were averaged over the first 8 hours of ECMO support and also reported as a single time point approximately 24 hours (±2 hours) after initiation of support (Table 2). All patients in this investigation had a minimum of two blood samples used for analysis over the first 8 hours of ECMO support. The electronic medical record was also reviewed to determine any ECMO complications related to equipment malfunction or failure.

The mean (SD) values for the first 8 hours and the 24-hour time point of ECMO support were used for data analysis. Groups (Cardiohelp™ vs. standard) were compared for statistical differences using the student *t* test. $p < .05$ was considered statistically significant.

RESULTS

The demographics and outcomes for all patients are shown in Table 1. The groups were similar in age, body size, percentage of patients successfully weaned from ECMO, percentage of patients surviving to discharge, duration supported on the initial ECMO system, and total duration of ECMO. Of the patients supported with our standard circuit, one patient required an oxygenator change after 123 hours of support because of reduced oxygen exchange by the oxygenator. Although that patient had therapeutic ACTs (mean, 200 seconds) during the first 8 hours of support, the heparin was turned off shortly thereafter, and the patient's ACT had decreased to 148 seconds at 24 hours. Also, one patient supported with Cardiohelp™ required circuit replacement after 63 hours due to clot formation at the outflow connector from the oxygenator. This patient did not receive any anticoagulation prior to formation of the clot aside from the pre-ECMO

Table 2. ECMO circuit settings and performance.

Measure	First 8 Hours		24 Hours		*p*-Values			
	Standard	Cardiohelp™	Standard	Cardiohelp™	ST8 vs. CH8	ST24 vs. CH24	ST8 vs. ST24	CH8 vs. CH24
ECMO blood flow, L/min	5.53 (.65)	4.95 (1.03)	5.52 (.72)	5.46 (.89)	.20	.89	.98	.30
Sweep rate, L/min	4.30 (1.23)	3.76 (1.04)	3.34 (1.52)	3.56 (1.08)	.35	.74	.18	.72
ECMO FIO_2, %	89.0 (1.0)	83.0 (1.0)	79.4 (1.1)	73.8 (2.0)	.27	.50	.10	.24
ΔP, mmHg	37.1 (7.1)	20.1 (5.3)	34.8 (7.9)	21.3 (3.8)	**<.001**	**.001**	.55	.62
ECMO arterial pH	7.38 (.07)	7.34 (.07)	7.40 (.04)	7.41 (.06)	.36	.60	.46	**.05**
ECMO $PaCO_2$, mmHg	36.5 (2.1)	37.6 (4.1)	38.8 (5.1)	39.6 (7.0)	.51	.80	.26	.50
ECMO SaO_2, %	99.4 (.8)	99.4 (.3)	99.3 (.4)	99.0 (.4)	.85	.19	.66	.51
ECMO PaO_2, mmHg	347 (98)	312 (73)	258 (118)	234 (93)	.44	.66	.12	.08
PaO_2/FIO_2	385 (72)	376 (75)	321 (120)	317 (73)	.80	.94	.21	.13

CH8, Cardiohelp™ group, first 8 hours; CH24, Cardiohelp™ group, at 24 hours; ECMO, extracorporeal membrane oxygenation; FIO_2, fraction of inspired oxygen; ΔP, transmembrane pressure; $PaCO_2$, partial arterial carbon dioxide pressure; PaO_2, partial arterial oxygen pressure; SaO_2, arterial oxygen saturation; ST8, standard group, first 8 hours; ST24, standard group, at 24 hours.
Significant differences shown in bold.

bolus. Aside from those patients, there were no other circuit complications or failures requiring circuit change. Six patients (3 Cardiohelp™ and 3 standard) were converted to another type of support (i.e., conversion to cardiopulmonary bypass [CPB] or another mode of ECMO) for reasons not related to circuit failure or circuit complications.

Data regarding ECMO circuit settings and performance are shown in Table 2. There were no significant differences between groups or time points in ECMO blood flow, sweep rate, ECMO FIO_2, circuit carbon dioxide removal (ECMO partial arterial carbon dioxide pressure [$PaCO_2$]), circuit oxygenation (ECMO arterial oxygen saturation [SaO_2] and ECMO partial arterial oxygen pressure [PaO_2]), or the ECMO PaO_2/FIO_2 ratio. In the Cardiohelp™ group, the ECMO arterial pH was significantly higher at 24 hours than during the first 8 hours of ECMO support (7.41 [.06] vs. 7.34 [.07]; $p = .048$). The transmembrane pressure was significantly lower for the Cardiohelp™ circuit than the standard circuit during the first 8 hours (20.1 [5.3] vs. 37.1 [7.1]; $p < .001$) and at 24 hours (21.3 [3.8] vs. 34.8 [7.9]; $p = .001$).

Patient and ECMO parameters for both groups at both time points are shown in Table 3. Compared with patients on the standard circuit, Cardiohelp™ patients had significantly lower hematocrit (26.6 [3.3] vs. 32.6 [7.0]; $p = .046$), ACT (165 [22] vs. 211 [41]; $p = .01$) and oxygen delivery index (317 [48] vs. 414 [89]; $p = .02$) during the first 8 hours of ECMO support. Of these parameters, only the hematocrit remained significantly different between groups at 24 hours (26.5 [1.5] vs. 30.6 [1.9]; $p < .001$). When comparing differences over time, patients on the standard circuit had significantly lower SvO_2 (78.6 [3.2] vs. 82.2 [1.9]; $p = .03$) and ACT values (165 [25] vs. 211 [41]; $p = .02$) at 24 hours than during the first 8 hours. Patients on the Cardiohelp™ system had a higher pH (7.42 [.06] vs. 7.33 [.06]; $p = .01$) and a lower PaO_2 (142 [67] vs. 290 [58]; $p < .001$) at 24 hours than during the first 8 hours of support.

DISCUSSION

The aim of this study was to determine the safety and performance of the Cardiohelp™ portable life support system for transport of adult patients supported on VA ECMO. This study also investigated whether the Cardiohelp™ system is an adequate replacement for our standard system in both the peri-transport period (the first 8 hours) and for the initial period after returning to our facility (at 24 hours). The limited data suggest that patient outcomes were not affected by the system used. The percentage of patients successfully weaned from ECMO support (62.5%) and surviving to discharge (50%) were identical between groups. The ELSO International Registry reports an average survival-to-discharge rate of 39% for adult cardiac ECMO patients (9). Bryner et al. (3) reported that 30% (6/20) of adult patients transported to their center on cardiac ECMO survived to discharge. In this same manuscript, their review of 27 articles showed that 50% (143/286) of adult patients transported on cardiac ECMO survived (3). The present study compared favorably with these reported outcomes for adult VA ECMO. The nonsurvivors in the present study all died of their primary disease and not due to complications related to ECMO support.

ECMO settings and oxygenator performance were similar between the Cardiohelp™ and standard groups, as were parameters such as blood flow, sweep rate, and the FIO_2. Both systems delivered blood that was similarly oxygenated and ventilated, as shown by the ECMO arterial blood gases in Table 2. The ECMO arterial pH

Table 3. Patient parameters and ECMO support levels.

Measure	First 8 Hours		24 Hours		*p*-Values			
	Standard	Cardiohelp™	Standard	Cardiohelp™	ST8 vs. CH8	ST24 vs. CH24	ST8 vs. ST24	CH8 vs. CH24
ECMO pump index, $L/m^2/min$	2.67 (.34)	2.46 (.46)	2.67 (.40)	2.77 (.36)	.33	.60	>.99	.16
MAP, mmHg	71.9 (9.3)	69.0 (7.5)	77.0 (9.4)	74.1 (9.1)	.50	.54	.29	.24
SvO_2, %	82.2 (1.9)	77.0 (7.6)	78.6 (3.2)	74.1 (9.1)	.10	.66	**.03**	.96
Patient arterial pH	7.37 (.08)	7.33 (.06)	7.423 (.07)	7.42 (.06)	.27	.86	.20	**.01**
Patient $PaCO_2$, mmHg	35.8 (5.2)	38.5 (4.8)	35.9 (8.7)	40.4 (8.1)	.30	.30	.97	.57
Patient SaO_2, %	98.5 (2.2)	99.4 (.2)	98.1 (1.9)	97.5 (3.1)	.30	.67	.71	.12
Patient PaO_2, mmHg	241 (124)	290 (58)	160 (67)	142 (67)	.32	.59	.13	**<.001**
Hematocrit, %	32.6 (7.0)	26.6 (3.3)	30.6 (1.9)	26.5 (1.5)	**.05**	**<.001**	.45	.92
ACT, seconds	211 (41)	165 (22)	165 (25)	152 (16)	**.01**	.21	**.02**	.17
O_2 delivery index, $mL/m^2/min$	414 (89)	317 (48)	383 (57)	344 (44)	**.02**	.15	.41	.27

ACT, activated clotting time; CH8, Cardiohelp™ group, first 8 hours; CH24, Cardiohelp™ group, at 24 hours; ECMO, extracorporeal membrane oxygenation; MAP, mean arterial pressure; $PaCO_2$, partial arterial carbon dioxide pressure; PaO_2, partial arterial oxygen pressure; SaO_2, arterial oxygen saturation; SvO_2, venous oxygen saturation; ST8, standard group, first 8 hours; ST24, standard group, at 24 hours.
Significant differences shown in bold.

was significantly higher in the Cardiohelp™ group after 24 hours than the first 8 hours. This difference in pH is most likely due to buffering capacity (sodium bicarbonate and base excess values not recorded) since $PaCO_2$ values were not different between groups. Ultimately, the ECMO arterial pH was physiologically appropriate for safe patient support in all groups.

Although not statistically significant, the data suggest a slight decrease in oxygenation capability of both oxygenators over time, as illustrated by the PaO_2/FIO_2 ratio. This finding would be expected since even the newest generation of oxygenators become less efficient over time due to accumulation of cellular and thrombotic deposits (10). Interestingly, the transmembrane pressure was significantly lower with the Cardiohelp™ than the standard oxygenator. This might be explained by the design of the blood pump outlets. The standard system CentriMag blood pump has a single blood outlet, but the blood pump incorporated into the Cardiohelp™ module has four evenly spaced blood outlets, resulting in a more even distribution of blood entering the oxygenator. A higher transmembrane pressure may result in higher levels of blood trauma (11,12).

The Cardiohelp™ system performed adequately to support patients during the first 24 hours of ECMO. Mean arterial pressure, ECMO pump index, and patient blood gases were all in ranges considered appropriate for safe patient support. Although the oxygen delivery index was significantly lower with the Cardiohelp™ than with the standard circuit during the first 8 hours of support, this is explained by the lower hematocrit in those patients, since the blood flow and oxygenator performance were similar between groups. However, the oxygen delivery of the Cardiohelp™ group (317 [48] mL/min/m^2) was still appropriate for safe ECMO support. Also, although not statistically different between the groups, changes in oxygen delivery may have contributed to the significant difference in SvO_2 in the standard group at the different time points. Patient hematocrits were lower in patients on Cardiohelp™ than the standard circuit at both time points. Because the Cardiohelp™ requires a lower priming volume (and less hemodilution) than the standard circuit, it is possible that the lower hematocrits may reflect differences in pre-ECMO values, rates of transfusion, or increased bleeding in Cardiohelp™ patients. These data were not always available (given the transfer from a referring hospital) and therefore was not included in this study.

Although the arterial blood gases in each group were appropriate for safe patient support, there were some differences worth mentioning. The higher arterial pH in the Cardiohelp™ group at 24 hours vs. 8 hours is likely due to the buffering capacity of the blood since the $PaCO_2$ values were not different between groups. Interestingly, in the Cardiohelp™ group, the PaO_2 was lower at 24 hours (142 [67] mmHg) than during the first 8 hours (290 [58] mmHg). This could be explained by two factors. First, even though not statistically significant, both the ECMO arterial PaO_2 and FIO_2 showed a similar pattern of lower values at 24 hours than during the first 8 hours. Second, the ejection of blood from the left ventricle and the resulting effect on blood gases may be a factor. Left ventricular ejection has been shown to result in substantial differences in blood gases measured at the ECMO arterial line vs. a patient's radial artery (13). The patients' PaO_2 values in this study were consistently lower than the PaO_2 values at the ECMO arterial line in all groups, lending credibility to the hypothesis that left ventricular ejection could be at least partially responsible for these differences.

Regarding circuit longevity, one patient in each group required circuit replacement because of failure or complication, but neither of these events occurred during the first 24 hours. The scope and duration of our study do not allow determination of conclusions about the effect of anticoagulation on longevity of circuits, but it is often presumed that higher levels of anticoagulation may prolong the viability of ECMO circuits. Our anecdotal experience suggests that the Cardiohelp™ circuit can be used for more than 2 weeks without incident.

In addition to the obvious advantages (such as size and weight) of the Cardiohelp™ system for patient transport, the Cardiohelp™ system may also preferred for any patients requiring rapid deployment of ECMO. Because the priming techniques of the Cardiohelp™ system are simple, we no longer keep an ECMO circuit set up at all times in case of emergent procedures. The Cardiohelp™ system can be entirely set up and primed within 15 minutes by all staff. This has been financially beneficial to our program (by reducing waste) and also may decrease the contamination risk associated with keeping a circuit set up for longer periods of time. Our ECMO specialists (both nurses and perfusionists) also prefer the Cardiohelp™ system to the standard system in terms of routine monitoring such as hourly charting and circuit checks.

We believe the component integration of the Cardiohelp™ system provides added safety and convenience for several reasons. First, the Cardiohelp™ system reduces the amount of equipment necessary to perform ECMO. For the standard circuit used in the present study, the ECMO carts consist of a CentriMag primary console, a CentriMag backup console, a pump motor, an oxygenator holder, and a CDI-500 monitor. For Cardiohelp™, only one unit (the drive console) is necessary, since the Cardiohelp™ module can be attached to a hand crank in the event of console failure. This component integration is therefore convenient for personnel, particularly during the loading and ambulance transport of the system. The console can easily be carried alongside the patient into the ambulance and placed

on a shelf next to the patient and strapped into or placed in a location that is accessible to the ECMO specialist. Second, the Cardiohelp™ disposable kit has fewer connectors, shunts, and stopcocks in the system, resulting in fewer points that are susceptible to leaks and disconnections. Third, the Cardiohelp™ console is very user-friendly and convenient for specialists to monitor. It also has the ability to alarm or to intervene by changing or stopping pump speed based on changes in parameters such as circuit pressures or bubble detection. We do not activate such interventions in our practice, just audible and visual alarms to alert the ECMO specialist to a condition. Despite these advantages, the standard circuit may still be considered for use when patient transport is not necessary or when an exceptionally long duration of ECMO support is anticipated. For this type of scenario, a more traditional circuit may be considered due to decreased cost of simply changing out an oxygenator vs. changing out an entire Cardiohelp™ module.

There are limitations to this study. First, following the acquisition of the Cardiohelp™ system we no longer used our standard circuit for ECMO transport; therefore, the transport of all eight patients on our standard circuit occurred prior to the transport of all eight patients on Cardiohelp™. Given the length of the study (over 6 years), it is likely that our practice changed over time as we gained experience. An example of this is noted in our cannulation sites (Table 1). All patients transported on the standard circuit were cannulated peripherally, whereas only three of the eight patients transported using Cardiohelp™ were cannulated peripherally. Also, this study did not include any standardization of practices such as anticoagulation or management of blood gas parameters. Lastly, the short duration of the data collection allows us to make only limited conclusions regarding circuit longevity.

Based on the present study, we conclude that the Cardiohelp™ life support system is a safe and effective alternative to a previously used circuit for transporting adult patients on VA ECMO. In addition, the Cardiohelp™ system offers added convenience and improved component integration compared with other ECMO systems. These added features make the Cardiohelp™ system our preferred system for transport of patients on ECMO. Further studies should be done to determine the longer-term safety and performance of the Cardiohelp™ system for supporting patients on ECMO.

REFERENCES

1. Starck CT, Hasenclever P, Falk V, Wilhelm MJ. Interhospital transfer of seriously sick ARDS patients using veno-venous extracorporeal membrane oxygenation (ECMO): Concept of an ECMO transport team. Int J Crit Illn Inj Sci. 2013;1:46–50.
2. Peek GJ, Mugford M, Tiruvoipati R, et al. Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): A multicentre randomized controlled trial. Lancet. 2009;374:1351–63.
3. Bryner B, Cooley E, Copenhaver W, et al. Two decades' experience with interfacility transport on extracorporeal membrane oxygenation. Ann Thorac Surg. 2014;98:1363–70.
4. Staley LL, Dobberpuhl J, Pierce CN, Scott RL, Jaroszewski DE, Arabia FA. Bridge to decision: SWAT team approach used by Mayo Clinic Arizona's cardiac transport team. Prog Transplant. 2010;20:118–24.
5. Jaroszewski DE, Kleisli T, Staley L, et al. A traveling team concept to expedite the transfer and management of unstable patients in cardiopulmonary shock. J Heart Lung Transplant. 2011;30:618–23.
6. Haneya A, Philipp A, Foltan M, et al. First experience with the new portable extracorporeal membrane oxygenation system Cardiohelp for severe respiratory failure in adults. Perfusion. 2012;27:150–5.
7. Roncon-Albuquerque R, Basilio C, Figueiredo P, et al. Portable miniaturized extracorporeal oxygenation systems for H1N1-related severe acute respiratory distress syndrome: A case series. J Crit Care. 2012;27:454–63.
8. Philipp A, Arit M, Amann M, et al. First experience with the ultra compact mobile extracorporeal membrane oxygenation system Cardiohelp in interhospital transport. Interact Cardiovasc Thorac Surg. 2011;12:978–81.
9. Paden ML, Conrad SA, Rycus PT, Thiagarajan RR. Extracorporeal Life Support Organization Registry Report 2012. ASAIO J. 2013;59:202–10.
10. Lehle K, Philipp A, Gleich O, et al. Efficiency in extracorporeal membrane oxygenation-cellular deposits on polymethylpentene membranes increase resistance to blood flow and reduce gas exchange capacity. ASAIO J. 2008;54:612–7.
11. Gu YJ, Boonstra PW, Graaff R, Rijnsburger AA, Mungroop H, van Oeveren W. Pressure drop, shear stress, and activation of leukocytes during cardiopulmonary bypass: A comparison between hollow fiber and flat sheet membrane oxygenators. Artif Organs. 2000;24:43–8.
12. Dubois J, Jamaer L, Mees U, et al. Ex vivo evaluation of a new neonatal/infant oxygenator: Comparison of the Terumo CAPIOX Baby RX with Dideco Lilliput 1 and Polystan Safe Micro in the piglet model. Perfusion. 2004;19:315–21.
13. Alwardt CM, Patel BM, Lowell A, Dobberpuhl J, Riley JB, DeValeria PA. Regional perfusion during venoarterial extracorporeal membrane oxygenation: A case report and educational modules on the concept of dual circulations. J Extra Corpor Technol. 2013;45:187–94.