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A 2007 Survey of Extracorporeal Life Support Members: Personnel and Equipment

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Abstract: Extracorporeal membrane oxygenation (ECMO) is used to support patients with cardiopulmonary failure in the intensive care unit. The purpose of this study is to determine what professional qualifications, equipment, and tests are used by established ECMO programs registered with the Extracorporeal Life Support Organization (ELSO). A survey link (Survey-Monkey) was e-mailed to the 110 registered ELSO program coordinators. Forty-nine responses were received. A test of binomial portions showed that nurses were more likely to be ECMO providers than respiratory therapists or perfusionists ($p < .05$). A χ^2 test identified a difference in the type of pump (roller or centrifugal) based on patient age ($p < .005$). The most common monitoring/safety devices were battery back-up (84%), pre- and post-oxygenator pressure (82%), mixed venous oxygen saturation (80%), venous line pressure (76%), blood flowmeter (63%), bubble detector (61%), point-of-care blood gases (59%), and in-line blood gas monitoring (47%). Laboratory tests available included d-dimer (65%), plasma-free hemoglobin (63%), anti-Xa plasma heparin concentration (43%), thromboelastograph (37%), and heparin concentration using protamine titration (35%). This survey of ELSO-registered centers represents an overview of current ECMO practices. **Keywords:** extracorporeal membrane oxygenation, survey. *JECT. 2009;41:172–179*

Extracorporeal membrane oxygenation (ECMO) is cardiopulmonary bypass (CPB) that is used to support patients who require long-term heart-lung or lung support in the intensive care unit. ECMO became a viable support option for this population after a 1985 randomized study by Bartlett et al. (1) reported successful ECMO outcomes in infants. In the wake of this report, ECMO programs opened across the nation (2–4). The increased number of ECMO programs created the need for continuing education and a forum for exchange of ideas to improve quality and outcomes for patients receiving ECMO. In response to this need, the Extracorporeal Life Support Organization (ELSO) was established in 1989. The ELSO Registry maintains a voluntary database for its members. Registered centers send ELSO detailed information on each ECMO patient. ELSO annually provides subscribers with compiled data regarding outcomes and complications. Registries such as this can provide a source of practice and outcome data that will advance improvements in clinical practice. In August 2007, there were 110 programs registered ELSO members in the United States.

As hospitals expand the complexity and high-risk nature of their services, the likelihood of a patient needing ECMO increases. Because extracorporeal technology changes rapidly, it is important to continuously evaluate and share strategies for staffing, monitoring, and equipment.

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MATERIALS AND METHODS

Design

This study was a prospective cohort analysis that examined the personnel characteristics, ECMO pump type, and use of safety devices in ELSO-registered programs in the United States. The data for this study were collected through an online survey instrument that was developed in Survey Monkey (Monkey Headquarters, Portland, OR).

Sample

The sample for this study was drawn from the 110 registered ELSO programs in the United States in August 2007. A link to the survey was e-mailed to 110 registered ELSO programs. The survey was completed by 49 programs, a survey response rate of 45%. The sample of respondents is a geographically representative group of 44 hospitals

that includes hospitals in Arizona, Arkansas, California, District of Columbia, Florida, Georgia, Illinois, Kentucky, Louisiana, Maryland, Massachusetts, Minnesota, Missouri, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Washington, and Wisconsin. The hospitals also represent teaching and non-teaching hospitals as well as children-only hospitals and children and adult hospitals. Table 1 provides a description of the characteristics of the survey respondents.

Measures

The online survey included questions regarding: the medical background of the ECMO specialists (nurses, respiratory therapists, perfusionists, or other); the type of pumps used for ECMO for each patient population (neonate, infant, pediatric, and adult); and the use of various monitoring and safety devices. An example of the survey is shown in Appendix A.

Procedures

A link to the online survey was e-mailed to the coordinator for each of the 110 registered ELSO programs in the United States in August 2007. The e-mail address for the coordinator was obtained from the ELSO website member directory. A second reminder e-mail containing the survey link was resent to directors who had not completed the survey 1 month after the initial e-mail.

Analysis

Data for this study were managed using SPSS for Windows Version 14 (Chicago, IL) and Microsoft Excel 2003 (Redmond, WA). Frequencies were used to describe nominal data, and descriptive statistics were used to describe continuous data. Hypothesis testing was performed using the χ^2 test for binomial proportions and the Friedman test of ranks.

Table 1. Respondent characteristics.

	N (%)	
Hospital type		
Stand-alone children	14 (32%)	
General	30 (68%)	
Neonate patient		
Roller pump use	37 (88%)	
Centrifugal pump use	5 (12%)	
Infant patient		
Roller pump use	27 (75%)	
Centrifugal pump use	9 (25%)	
Pediatric patient		
Roller pump use	25 (64%)	
Centrifugal pump use	14 (35%)	
Adult patient		
Roller pump use	13 (50%)	
Centrifugal pump use	13 (50%)	
ECMO team includes	Yes	No
Nurses	32 (84%)	17 (16%)
Respiratory therapists	27 (71%)	22 (29%)
Perfusionists	12 (32%)	37 (68%)
Other	1 (3%)	48 (97%)

RESULTS

Respondents were asked what percent of their ECMO specialists are comprised of nurses, respiratory therapists, perfusionists, and other. The difference in team composition was examined with a Friedman test to determine whether the distribution of rank of ECMO specialists: nurses (78%, 29.5%, and 94.5% for median, 25% quartile, and 75% quartile, respectively), respiratory therapists (21%, 4.25%, and 54%), perfusionists (0%, 0%, and 10%), and other (0%, 0%, and 0%) is statistically significant. The results showed that there is a significant difference in the type of provider used at each ECMO center to comprise their ECMO team of specialists, where nurses are being used more often than other healthcare workers in this role($\chi^2 = 12.806$, $p = .005$). Sixteen percent of programs in this survey used only nurses, 8.8% use respiratory therapists only, and 3.8% use only perfusionists.

The survey questions asked the respondents to identify what type of ECMO pump, roller or centrifugal, they used when performing ECMO on the following patient subsets: neonate, infant, pediatric, and adult. Of the 49 respondents, 42 identified what type of pump they primarily used for the neonate patient, 36 identified what type of pump they primarily used for the infant patient, 39 identified what type of pump they primarily used for the pediatric patient, and 26 identified what type of pump they primarily used for the adult patient. The adult patient subset has a lower number (26) because many of the respondents worked at stand-alone children's hospitals where ECMO was not performed on adults.

χ^2 analysis was used to first determine whether there was an association between the type of pump used for each patient subset. The results indicated that there is a statistically significant relationship between the type of pump used and the patient subset ($\chi^2 = 12.790$, $p = .005$). Next, a binomial test for proportions was run to examine whether the proportion of pump type used differs within each patient subset group. The test proportion was set at 50%. The results indicated that there is a statistically significant difference in the neonate patient subset ($p < .001$) and the infant patient subset ($p = .004$). In both the neonate and infant groups, the roller method was used as the ECMO pump significantly more often than the centrifugal method. Neither the pediatric ($p = .108$) nor adult ($p = 1.000$) subsets were statistically different.

The survey also asked the program coordinators to identify which of the following monitoring/safety devices they use during ECMO; CDI in-line blood gas monitoring, point-of-care blood gases, oxygen analyzer, in-line venous/arterial oxygen saturation, venous line pressure, arterial line pressure, blood flowmeter, pre- and post-oxygenator pressure, bubble detector, expired CO_2, battery back-up, data management system (computerized charting system),

and cerebral oximetry. Table 2 represents the frequencies of monitoring/safety device utilization excluding those who did not respond to the question. The monitoring/safety devices that >90% of respondents used were in-line venous/arterial oxygen saturation; venous line pressure; pre- and post-oxygenator pressure; and battery back-up. Expired CO_2 and data management systems were the only two monitoring/safety devices that had <50% utilization.

Last, the survey asked the respondents whether they have the following instruments available for laboratory analysis: thromboelastograph, plasma-free hemoglobin, heparin concentration using anti-Xa, heparin concentration protamine titration, and d-dimer. Table 3 represents what instruments the respondents have available for laboratory analysis. Most respondents had plasma-free hemoglobin and d-dimer instruments available for laboratory analysis.

DISCUSSION

This survey examined the qualifications of ECMO specialists and the type of ECMO equipment used at ECMO Centers across the United States. The study showed that there was a variety in the credentials of ECMO team members and that the majority of team members were nurses. There was a difference in the type of equipment used by patient age, with higher use of the roller method for neonate and infant patients. Last, there was variety in the type of monitoring/safety devices and laboratory equipment used at centers. These findings indicate that there is more variation in the type of provider and equipment used today compared with the first discussions of ECMO by Dr. Robert Bartlett in the mid-1970s (5,6).

ELSO "ECMO guidelines" state that ECMO specialists should have subspecialty credentialing in nursing, respiratory therapy, or perfusion. The findings from this survey support this statement and show more diversity compared with two previously published ECMO center surveys by Allison et al. (7) in 1990 and Lawson et al. in 2002 (8). The results from this study showed that nurses were the primary subspecialty represented, and 16% of programs surveyed use only nurses. The study of Lawson et al. reported that 18% of ECMO programs used only nurse providers (8) and the study of Allison et al. reported that >50% of the ECMO programs only use nurses as ECMO specialists (7). Our data indicated a trend toward a more diverse group of ECMO specialists, possibly realizing that all subspecialties offer some advantage to the patient and institution.

Respiratory therapists were the second most likely subspecialty of members of the ECMO team of specialists, with 8.8% of the programs using respiratory therapists only and 3.8% using perfusionists only. These survey results differ from the study of Lawson et al. that reported 4% of programs used respiratory therapists only and 7% used perfusionists only. Although perfusionists are often part of the ECMO team and are responsible for priming, component change out as well as other management issues, very few perfusionists are considered to be ECMO specialists, likely because of the high manpower demand ECMO requires compared with the relatively small number of perfusionists.

Dr. Bartlett's first series of ECMO patients used a roller pump, which by 1976 had emerged as the type of pump used on most heart-lung machines (9). As centrifugal blood pump technology developed, it seemed to offer a great advantage in the ECMO circuit. Centrifugal pumps are afterload dependent; they do not create spallation emboli from the compression of the tubing and may be less susceptible to macro air emboli. One study suggested that some designs are superior to others (10). Roller pumps offer the advantage of lower cost and, if the pump was to stop, the roller pump would not allow the blood to be shunted from the arterial side to the venous as could potentially happen with the centrifugal pump. Because the centrifugal pump is afterload dependent, line separation caused by high line pressure is less likely. However, without adjustments in revolutions per minute (RPM), changes in afterload will affect blood flow. The 1990 Allison et al. survey showed that <5% of the centers used centrifugal pumps (7), and this trend continued in the 2002 study of Lawson et al. (8). The current survey agrees with previous surveys regarding neonatal and infant ECMO, where the majority of centers are using roller pumps. However, in the pediatric and adult population, centrifugal pumps and roller pumps are used equally.

Table 2. Frequencies of monitoring and safety devices utilization.

Monitoring/Safety Device	Yes [*N* (%)]	No [*N* (%)]
CDI in-line blood gas monitoring	23 (55%)	19 (45%)
Point-of-care blood gases	29 (67%)	14 (33%)
Oxygen analyzer	20 (50%)	20 (50%)
In-line venous/arterial oxygen saturation	39 (95%)	2 (5%)
Venous line pressure	37 (90%)	4 (10%)
Arterial line pressure	33 (83%)	7 (17%)
Blood flowmeter	31 (76%)	10 (24%)
Pre and post oxygenator pressure	40 (93%)	3 (7%)
Bubble detector	30 (71%)	12 (29%)
Expired CO_2	18 (46%)	21 (54%)
Battery back-up	41 (98%)	1 (2%)
Data management system (computerized charting)	18 (45%)	22 (55%)
Cerebral oximetry	28 (70%)	12 (30%)

Table 3. Instruments available for laboratory analysis.

Instrument	Number of Respondents Who Responded Yes (%)
Thromboelastograph	18 (37%)
Plasma-free hemoglobin	30 (61%)
Heparin concentration using anti-Xa	21 (43%)
Heparin concentration protamine titration	17 (35%)
d-dimer	32 (65%)

This survey identified that centers are using more patient safety devices than previously published. This study showed that 55% of the respondents identified using an in-line CDI device, which measures pH, pCO_2, pO_2, potassium, and hemoglobin, and 67% of the respondents reported the use of point-of care blood gases. These values are an increase over both previously published use rates. Allison et al. (7) reported that 8.5% of centers monitored in-line pO_2 and pCO_2. The number of centers using in-line blood gases increased in the survey of Lawson et al. to 43% (8). In this study, venous and arterial saturation are used at 95% of the centers, whereas in 1990, Allison et al. reported 70% (7) and, in 2002, Lawson et al. (8) reported only 60%. The venous oxygen saturation of the ECMO circuit blood can be used to evaluate patient condition and ECMO system function. In the study of Allison et al. (7), 50% of the reporting centers used an oxygen analyzer in the gas sweep line, which was similar in this study (50%). These devices will make the clinician aware of any acute changes in patient blood gas values, avoiding delays in treatment. Use of an in-line sweep gas oxygen analyzer will help to quickly rule out any changes in the FiO_2. The ability to detect potentially detrimental patient conditions in real time should improve patient outcomes.

Pump negative pressure must be limited in the ECMO circuit to avoid pulling air around the cannula or out of solution. Limiting the negative pump in-flow pressure also helps to minimize hemolysis. Early in the ECMO literature, a bladder bag was used with servo-regulation. A pressure-regulated system was introduced in 1989 (11). Eighty-seven percent used the servo-regulated bladder box in the study of Allison et al. (7) and 10% used the pressure-regulated system. In the study of Lawson et al. (8), all centers used either pressure servo-regulation (71%) or the bladder box (29%). In this study, 90% of the respondents used pressure-regulated servo-regulation. Pressure servo-regulation seems to have replaced most of the bladder servo-regulated systems. Although not addressed in this study, based on previous surveys, it would seem that the remaining 10% either use a bladder servo-regulated system or a centrifugal pump.

A blood flow meter was used in 76% of the centers in this study, whereas the study of Allison et al. (7) reported only 17%. This positive trend reflects that centers are aware of the variable difference between the pumphead flow reading and the actual patient blood flow caused by circuit shunting or occlusion setting.

Pre- and post-oxygenator pressures were measured in 93% of the respondents. In the study of Allison et al. (7), nearly 80% of the responses monitored these pressures. Because the oxygenator presents the most significant surface area of the circuit, it is one of the more likely areas to find clot. Because it is difficult to visualize clots in the oxygenator, an increase in the pressure drop across the oxygenator can assist in the diagnosis of this problem.

Air can enter the ECMO circuit in a number of ways. The most likely is through a loose connection or open stopcock on the negative side of the pump; air can also be introduced through a patient's central venous line and the oxygenator. Seventeen percent of the centers in the study of Allison et al. (7) reported using a bubble detector. The Lawson et al. (8) survey showed a 48% increase (65%) in the number of respondents using an air bubble detector. This study showed a modest increase in the use of an air bubble detector to 71%.

Only one center in the study reported that they did not use a battery back-up for the ECMO pump. Not only is the battery back-up crucial in the event of power failure but is also important if the patient would need to be transported. Expired CO_2 and data management systems were used at 46% and 45% of the centers, respectively. Expired CO_2 is an inexpensive way to monitor the oxygenator outlet pCO_2 in a hollow fiber membrane oxygenator. As hospitals progress toward paperless systems, the use of data management systems should increase. The detailed data collection will allow teams to examine the ECMO run more thoroughly, enabling them to address changes in protocol that could improve outcomes. Cerebral oximetry was used at 70% of the centers.

Most centers are using d-dimer and plasma-free hemoglobin levels to manage ECMO patients (65% and 61%, respectively). ECMO patients are at a high risk of bleeding, and there is also the risk of clotting the circuit, making anticoagulation management crucial. However, only 37% of the centers use a thromboelastograph and 43% use anti-Xa heparin concentration.

A 1993 study by Schumacher et al. (12) showed that ECMO had a positive cost–benefit ratio. This study examined the trends in ECMO equipment and personnel and can be useful to hospitals that are planning an ECMO program. As the use of centrifugal pumps increase, the pump inflow pressure should still be monitored to avoid excessive negative pressure, resulting in hemolysis. Retraining personnel from the roller pump to the centrifugal pump must be done to ensure that the ECMO specialists understand the pump-flow/afterload relationship; the potential for A-V shunt should the pump be shut off without clamping; and the high hemolysis at "zero flow" when the pump is generating RPM. Positive trends in the study include an increase in the use of in-line blood gas monitoring, blood flowmeters, pre- and post-oxygenator pressures, and bubble detectors.

In conclusion, this survey represents a point in time and may not reflect the current status or even trends in areas of staffing and equipment. An inherent source of error in all surveys is the group of non-responders. In this case, some ECMO coordinators were likely not contacted because of the inaccurate ELSO-registered center coordinator list, and certainly, all non–ELSO-registered centers were not included. In addition, when surveys become more complex, opportunities for misunderstandings by the person completing the survey can result in errors of measurement.

Finally, responders may feel that some questions are sensitive or proprietary. By keeping the survey short and editing the survey to remove potential sensitive questions, this survey attempted to limit these biases.

This survey suggested that ELSO-registered ECMO programs are moving in the right direction by providing more variety in the ECMO specialist's specialty and the increase in safety devices. These changes should lead to improved patient care, but more work must be done to show these relationships.

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Demographics

Demographics

1. Please provide the following information regarding your program.

Institution	
City	
State	
Person completing survey	
Email address (If you would like to receive the compiled data)	

2. How many ECMO cases to you perform each year in each subset of patients?

Neonate	
Infant	
Pediatric	
Adult	

3. For each subset of patients, do you primarily use roller or centrifugal pumps

	Type of pump
Neonate	
Infant	
Pediatric	
Adult	

Other (please specify)

4. What manufacturers and models of ECMO pump(s) do you use? How many of each do you have?

5. Which oxygenators(manufacturer and model) do you use for each subset of patients?

Neonate	
Infant	
Pediatric	
Adult	
Comments	

6. Which of the following monitoring/safety devices do you utilize during ECMO?

	Yes	No	Sometimes
CDI in-line blood gas monitoring	☐	☐	☐
Point-of-care blood gases	☐	☐	☐
Oxygen analyzer	☐	☐	☐
In-line venous/arterial oxygen saturation	☐	☐	☐
Venous line pressure	☐	☐	☐
Arterial line pressure	☐	☐	☐
Blood flowmeter	☐	☐	☐
Pre and post oxygenator pressure	☐	☐	☐
Bubble detector	☐	☐	☐
Expired CO2	☐	☐	☐
Battery back-up	☐	☐	☐
Data management system (computerized charting)	☐	☐	☐
Cerebral oximetry	☐	☐	☐

Other (please specify)

7. Do you have any of the following instruments available for laboratory analysis?

	Yes
Thromboelastograph	◯
Plasma-free hemoglobin	◯
Heparin concentration using anti-Xa	◯
Heparin concentration protimine titration	◯
D-dimer	◯

Other instrumentation you find helpful?

8. Answer the following questions related to your ECMO team.

Number of ECMO specialists	
Hours of didactic training	
Hours of wet lab training	
Hours of animal lab training	
Hours of preceptoring	

9. Do you utilize a simulator for ECMO training?

◯ Yes ◯ No

If yes please decribe

10. What percent of your team is comprised of:

Nurses

Respiratory therapists

Perfusionsists

Other

11. How are your ECMO specialists compensated?

- ◯ Fixed increase in hourly rate
- ◯ Fixed increase in hourly rate ONLY while managing ECMO
- ◯ Percent increase in hourly rate
- ◯ Percent increase in hourly rate ONLY while sitting ECMO
- ◯ Other (please specify)

12. How long are ECMO specialists shifts?

- ◯ 8-hours
- ◯ 12-hours
- ◯ Other (please specify)

13. Related to the questions on this survey what changes do you foresee taking place in the next year?