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Rapid Training in Extracorporeal Membrane Oxygenation for a Large Health System

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ABSTRACT

Background: Despite the rapid integration of extracorporeal membrane oxygenation (ECMO) into intensive care units over the past decade, established programs for training critical care clinicians to provide ECMO are lacking.

Objective: To evaluate the development and implementation of a multidisciplinary ECMO training program for the rapid deployment of ECMO training for a high volume of critical care clinicians.

Methods: We performed a prospective cohort study examining a program for rapid training of multiple disciplines of critical care clinicians to deliver ECMO during the implementation of ECMO services across the intensive care units of an academic tertiary care center between October 2018 and January 2019. The multidisciplinary ECMO training program included didactic and simulation-based teaching and emphasized new, universal clinical protocols to improve consistency of care across the institution. Pre- and post-program written examinations evaluated knowledge acquisition, and an electronically distributed program evaluation assessed perceptions of content and delivery.

Results: Among the 97 clinicians who completed the program, 49 (51%) were physicians and 48 (49%) were advanced practice providers from the departments of surgery ($n = 42$), medicine ($n = 29$), and anesthesia ($n = 26$). There was a significant difference in knowledge about ECMO between the pre- and post-program examination score (median [interquartile range] 70% [60–80%] vs. 90% [80–90%], respectively, $P < 0.001$). The median (interquartile range) individual gain from pre- to post-program score was 20% (10–30%). The program was perceived as useful and applicable to safe care.

Conclusion: Rapid deployment of a multidisciplinary ECMO training program across a large academic center was feasible, achieved knowledge acquisition, and was positively perceived.

Keywords:
education; critical care; intensive care units

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The use of extracorporeal membrane oxygenation (ECMO) in adult intensive care units (ICUs) has grown rapidly over the past decade (1–4) owing to evolving indications (5–8), technological improvements (9–11), and increasing data informing the effect of ECMO on patient outcomes (12–15). Despite this growth, established approaches to training different disciplines of clinicians across a health system to deliver ECMO are lacking (16, 17).

Management of ECMO patients in the ICU requires a combined understanding of patient and circuit physiology and critical care (18). As ECMO may occur in different types of ICUs based on the indication, a wide range of clinicians may need to understand ECMO to leverage local expertise and optimize clinical outcomes. The paucity of standardized training and clinical protocols for ECMO may lead to a siloed approach to ECMO management, limiting its integration into clinical care in some environments, and produce unintentional variation in management between clinicians.

The Extracorporeal Life Support Organization (ELSO) provides guidelines for ECMO specialist training (19) and regional courses for clinicians. The extensive ECMO specialist training program includes animal laboratory sessions that are logistically challenging, and some clinicians may struggle to find the resources to attend the multiday regionally based courses. These impediments are highlighted when charged with building and maintaining hospital-wide competence in clinical management of ECMO. Prior work suggests that simulation-based ECMO training is beneficial (20–24) and favorable when compared with traditional strategies (25). The standardization of simulation-based training in ECMO has not been well established.

We combined elements of ELSO's training guidelines, simulation-based training, and new clinical protocols to develop a local multidisciplinary ECMO training program targeted at critical care physicians, advanced practice nurses, and physician's assistants. We evaluated our program using pre- and post-program examination data and program evaluations. We hypothesized that the training program would be feasible and increase knowledge acquisition.

METHODS

Study Design and Oversight

We performed a prospectively planned analysis of the development and implementation of a multidisciplinary ECMO training program offered to critical care clinicians across multiple departments between October 2018 and January 2019 at Vanderbilt University Medical Center. This study was approved by the Vanderbilt University Institutional Review Board (IRB: 190,620). Reporting conforms to the SQUIRE 2.0 guidelines (26).

Educational Intervention

This study was designed to evaluate a multidisciplinary ECMO training program developed to accompany the transition of a single, large academic medical center from a care model in which ECMO was provided by a small number of experienced personnel in a single cardiovascular ICU to a care model in which ECMO is provided in each of the locations in which patients receiving ECMO would be cared for otherwise were they not receiving ECMO, including a 35-bed medical ICU, a 14-bed trauma ICU, and a 27-bed cardiovascular ICU. The multidisciplinary ECMO training program comprised in-person didactics and simulation plus written clinical protocols introduced into each of the practice settings.

Vanderbilt University's Center for Experiential Learning and Assessment laboratory was used for all training. The 6-hour multidisciplinary ECMO training program included a didactic portion that emphasized medical management of ECMO patients and incorporated the following lectures: *1*) Why ECMO Matters, *2*) History of ECMO, *3*) The ECMO Circuit and Physiology, *4*) ECMO Indications and Selection Criteria, *5*) ECMO Configurations, *6*) ECMO in Hypoxemic Respiratory Failure, *7*) ECMO in Hypercapnic Respiratory Failure, *8*) ECMO in Cardiogenic Shock, and *9*) Weaning, Decannulation and Post-Decannulation. Program content and list of lecture references are available in an additional document file (Document E1 in the data supplement). Didactic was followed by simulation and small group exercises that included three rotating stations: review of the circuit components, ECMO circuit emergencies, and an interactive case study. The program was offered twice each month over a period of 4 months and advertised through e-mail distribution lists. Class sizes were limited to 15 participants to maintain a small cohort to provide focused training and adequate hands-on experience. Instructor-to-participant ratio was 15:1 during the didactic and 4:1 or 3:1 during the simulation and small group exercises.

Didactic material, guided by ELSO's training guidelines, were newly developed and delivered by a multidisciplinary team composed of ECMO program directors, ECMO surgical fellow physician, perfusionists, and ECMO specialists. An ECMO circuit connected to a mannequin was used to review circuit components and the circuit safety checklist with the following materials: adult Quadrox-I oxygenator (Maquet Cardiopulmonary), centrifugal pump (Affinity CP; Medtronic) adapted to the Sorin centrifugal pump console system (Sorin Group), three-eighths-inch tubing (Balance Biosurface-coated; Medtronic), 23-F Bio-Medicus Nextgen femoral venous cannula (Medtronic), 20-F Elongated One-Piece arterial cannula (Medtronic), and 15-F Bio-Medicus Nextgen femoral arterial cannula (Medtronic). A separate, identical circuit was connected to the Califia 3.0 (Biomed Simulation, Inc.), a high-fidelity bypass simulator system with dynamic feedback of patient hemodynamics, laboratory values, circuit flows, and pressures.

ECMO clinical protocols considered important to initial learning and maintenance of consistent evidence-based practice across the institution were developed, presented during the program, and distributed to the learners. Protocols included stepwise instructions for initiation and ongoing ventilator management for patients with acute respiratory distress syndrome and weaning from venovenous ECMO. Protocols were generated using existing literature and ELSO guidelines, and each included an algorithm for easy bedside viewing (Document E2 and E3). The initial ventilator and ECMO setup algorithm are shown in Figure 1.

Evaluation and Study Outcomes

To assess the effect of the multidisciplinary ECMO training program on knowledge acquisition, pre- and post-program examinations were developed by the multidisciplinary team using a modified Delphi technique (27, 28) and distributed to participants at the beginning and conclusion of the program to evaluate the assimilation of knowledge and program delivery (additional document file Document E4). Examination questions were

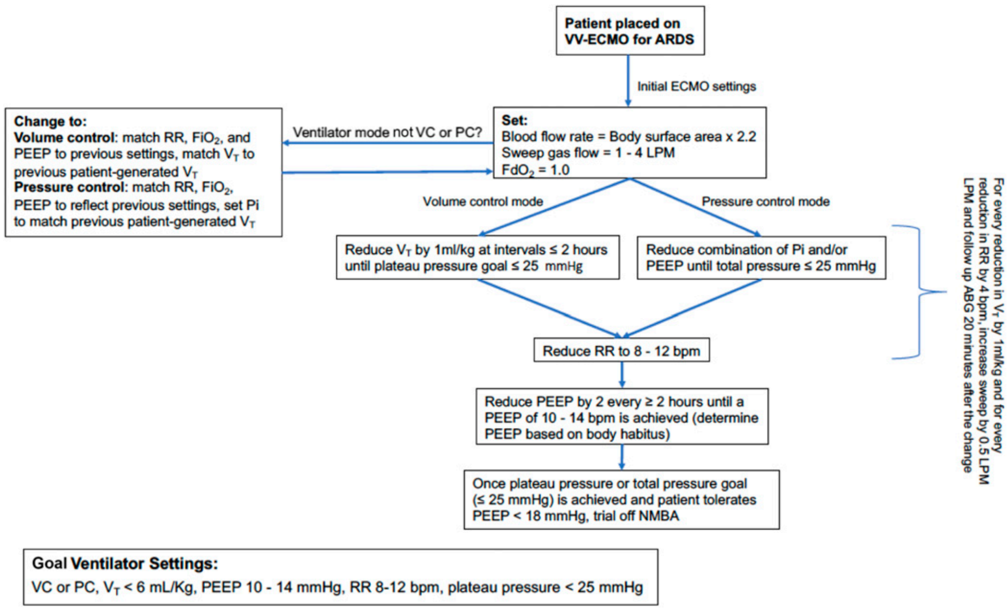

Figure 1. Clinical algorithm for initial ventilator and extracorporeal membrane oxygenation setup for patients receiving venovenous extracorporeal membrane oxygenation for acute respiratory distress syndrome. ABG = arterial blood gas; ARDS = acute respiratory distress syndrome; bpm = breaths per minute; F_{DO_2} = fraction of delivered oxygenation; F_{IO_2} = fraction of inspired oxygen; LPM = liters per minute; NMBA = neuromuscular blocking agent; PC = pressure control; PEEP = peak end-expiratory pressure; Pi = driving pressure; RR = respiratory rate; VC = volume control; V_T = tidal volume; VV-ECMO = venovenous extracorporeal membrane oxygenation.

analyzed on a per-question basis to identify those that did not show improvement from preprogram to post-program to expose potential areas of deficit in the training program. Examinations were not introduced until the third training. There were five preprogram examinations without a corresponding post-program examination that were omitted from the analyses. Examinations were uniquely identified to maintain anonymity but allow tracking of individual score differentials.

To assess learners' perceptions of the multidisciplinary ECMO training program, a 14-question evaluation was distributed electronically at the completion of the program. Each lecture was subjectively measured using a 4-point Likert scale of "not at all useful," "somewhat useful," "useful," and "very useful." Perception of program content difficulty and appropriateness of program duration was evaluated using a 3-point Likert scale of "too basic," "appropriate," and "too advanced," and "too short," "appropriate length," and "too long," respectively. A subjective measure of program application to safe practice was captured in the question, "this program provides me the information necessary to care for my ECMO patient" using a binary "yes" or "no" response.

Statistical Analysis

The number of learners who received the multidisciplinary ECMO training program and participated in the assessment was determined by the number of personnel working in the clinical locations into which care for patients with ECMO was being integrated. As such, a prospective sample size calculation was not performed. Continuous variables were expressed as median and interquartile range (IQR), and categorical variables were expressed as numbers and percentages. Continuous variables within the same learner were compared using a Wilcoxon signed-rank test. A P value of less than 0.05 was considered significant. No adjustments were made for multiple comparisons. Statistical analyses were performed using STATA 14.2.

RESULTS

Participant Characteristics

Ninety-seven clinicians attended the multidisciplinary ECMO training program over 8 different days. This included 15 (15.5%) attending physicians, 32 (33.0%) fellow physicians, 2 (2.1%) resident physicians, 44 (45.4%) advanced practice nurses, 2 (2.1%) physician's assistants, and 2 (2.1%) nurses from the departments of medicine ($n = 29$), surgery ($n = 42$), and anesthesia ($n = 26$). Participants stratified by department are shown in Table 1.

Evaluation of Knowledge Acquisition

Fifty-nine participants took the preprogram examination and 54 participants took the post-program examination. There was a significant difference between the preprogram and post-program examination score (median [IQR] 70% [60–80%] vs. 90% [80–90%], respectively, $P < 0.001$) as shown in Figure 2. The median (IQR) individual increase in score from the preprogram examination to the post-program examination was 20% (95% confidence interval, 10–30%). Frequency distributions of changes in score from the preprogram examination to the post-program examination is shown in Figure E1.

Evaluation of Examination Questions

There was an improvement in the percentage of participants who answered correctly in most examination questions from preprogram to post-program ($P < 0.05$ in questions 1–7, Table 2). There was no significant improvement in questions 8, 9, and 10. More than 90% of participants answered questions 8 and 10 correctly in the preprogram examination, with a marginal increase in the percentage who answered correctly in the post-program examination. This might suggest these questions were relatively less challenging and might benefit from improved construct. Question 9 had the least improvement in the percentage of participants who answered correctly from preprogram to post-program (78.0% vs. 79.6%, respectively, $P = 1.0$). This may point toward a need to improve the content about selection of venoarterial configurations based on underlying physiology in the training program.

Evaluation of Learner Perceptions

Twenty-eight clinicians participated in the program evaluations. Overall, the multidisciplinary ECMO training program was well received. "ECMO Circuit and Physiology" and "Indications and Selection Criteria" were the didactic components perceived to be most useful; 27/28 responders selected "useful" or "very useful" for each. Of 28 responders, 27 (96.4%) answered "yes" when asked if this program provided the information necessary to safely care for ECMO patients. Program difficulty was perceived as "appropriate" in 24/28 (87.5%) of responders. Length was perceived as "appropriate" in 19/28 (67.9%) of responders. Full results of the program evaluation are shown in Table E1.

DISCUSSION

This is the first study to evaluate the development and implementation of a

Table 1. Participant characteristics

	Total (*n* = 97)	Department Medicine (*n* = 29)	Surgery (*n* = 42)	Anesthesia (*n* = 26)
Physicians	49 (50.5)	19 (65.5)	15 (35.7)	15 (57.7)
Attendings	15 (15.5)	5 (17.2)	5 (11.9)	5 (19.2)
Fellows	32 (32.0)	14 (48.3)	8 (19.1)	10 (38.5)
Residents	2 (2.1)	—	2 (4.8)	—
Nonphysicians	48 (49.5)	10 (34.5)	27 (64.3)	11 (42.3)
Advanced practice nurses	44 (45.4)	10 (34.5)	25 (59.5)	9 (34.6
Physician's assistants	2 (2.1)	—	—	2 (7.7)
Nurses	2 (2.1)	—	2 (4.8)	—

Data are expressed as number of participants (%). Percentages may not add to 100 because of rounding.

multidisciplinary ECMO training program for the rapid deployment of ECMO training for a high volume of diverse critical care clinicians within a hospital system. We found that development of a multidisciplinary ECMO training program was feasible, increased knowledge acquisition across a broad range of critical care clinicians, and was positively perceived by learners. These findings are important because the rapid expansion of ECMO means many health systems are faced with the challenge of rapidly training a large, diverse group of clinicians, and few other data exist to inform this effort.

ECMO training and education for critical care clinicians is not standardized across ECMO programs, and limited guidance from professional organizations exists (17). Proficiency in the medical, surgical, and device management of ECMO patients requires considerable training (23). As the volume of ECMO use increases (4), the demand for adequate training continues to grow.

We aimed to *1*) provide content that we considered fundamental to the medical management of ECMO patients in an efficient, digestible, and retainable manner locally, *2*) lay the cultural foundation for the wider integration of ECMO services across specialties, and *3*) set an expectation for consistent clinical management across the institution by creating and distributing granular clinical protocols. We designed our multidisciplinary ECMO training program to include an in-person didactic and simulation training and limited class size to 15 participants to maximize the level of class interaction and engagement. We distilled the components of ELSO's training guidelines that we considered crucial to ICU clinicians. We sought to provide the education necessary for ECMO to integrate into usual adult critical care and teach ICU clinicians how to identify and respond to circuit problems that they would be expected to troubleshoot. Given this narrower focus, we omitted pediatric ECMO and technical procedures such as circuit priming, and component exchanges included in ELSO's training guidelines (19). We condensed the program to 6 hours and offered it multiple times, locally, to maximize the attendance of a broad range

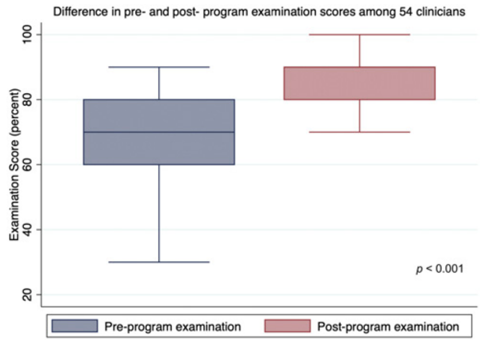

Figure 2. Box-and-whisker plots of pre- and post-program examination scores among 54 participants.

of learners while providing access to experienced clinicians. We did not design this program to supplant regional ELSO courses but rather to serve as a complementary, expedient source of education and a platform on which to standardize ECMO clinical management within the institution. The multidisciplinary ECMO training program is standardized, easily repeatable institutionally, translatable to other sites, and able to be given locally without necessitating travel for multiple days to a regional course. Our results demonstrating an increase in score between the pre- and post-program examinations suggest the multidisciplinary ECMO training program achieved the goal of short-term knowledge acquisition.

Our study has some important limitations. First, the training program had a greater focus on knowledge acquisition than hands-on skills and circuit management. Pre- and post-program examination questions were identical, so the increase in scores could be due to familiarity with the material from having taken the test previously, rather than from the effects of the program. Additionally, the examination used was not a validated instrument, and its construct, content, and

Table 2. Differences in proportion of each question answered correctly

	Preprogram Exam (*n* = *59*)	Post-program Exam (*n* = *54*)	*P* Value
Question 1	35 (59.3)	49 (90.7)	<0.001
Question 2	29 (49.2)	51 (94.4)	<0.001
Question 3	46 (78.0)	50 (92.6)	0.01
Question 4	39 (66.1)	45 (83.3)	0.03
Question 5	29 (49.2)	44 (81.5)	<0.001
Question 6	53 (89.8)	54 (100)	0.03
Question 7	16 (27.1)	26 (48.1)	0.01
Question 8	58 (98.3)	54 (100)	0.32
Question 9	46 (78.0)	43 (79.6)	1.0
Question 10	56 (94.9)	53 (98.1)	0.32

Data are expressed as number of participants answered correctly (%).

criterion validity are unknown. Although learners served as their own controls, the program represented only the educational activity, limiting the ability to compare the effect of the program with other educational means. Because the post-program evaluation occurred in close proximity to completion of the program, the study is unable to assess longer-term retention of learned material or application to practice. Finally, the effect of the program on patient outcomes was not measured. Future work is necessary to understand how ECMO training methods are most effectively incorporated into the broad population of critical care clinicians and to determine which methods translate into improved patient outcomes.

Conclusions

Development and implementation of a short, 6-hour multidisciplinary ECMO training program for a diverse group of critical care learners was feasible, achieved knowledge acquisition, was positively perceived, and may be a useful adjunct in areas that have limited time and availability for more robust, time-intensive training. Further work is necessary to determine the efficacy of different training methods across the spectrum of critical care clinicians and specialties to optimize ECMO training programs.

Author disclosures are available with the text of this article at www.atsjournals.org.

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