Title: Efficacy of a single day mannequin-based extracorporeal membrane oxygenation (ECMO) training course

Running title: Efficacy of mannequin-based ECMO course

Authors: Joseph K. Maddry, MD[1,2,3,4,5,*]; R. Madelaine Paredes, PhD[3]; Timur Abdurashidov, DO[2]; William T. Davis, MD[2,4]; Joni A. Paciocco, RN[4]; Maria Castaneda MS[3]; Allyson A. Araña, PhD[4]; Crystal A. Perez, RN[4]; Darren S. Baldwin RN[4]; Dylan C. Rodriguez [3]; Kimberly L Medellin RN[4]; Patrick Ng, MD[2,4]

[1] United States Army Institute of Surgical Research, Ft Sam Houston, TX, USA

[2] Department of Emergency Medicine, Brooke Army Military Medical Center, Ft Sam Houston, TX, USA

[3] United States Air Force, 59th Medical Wing, Clinical Resuscitation, Emergency Science, Triage and Toxicology, Lackland AFB, TX, USA

[4] United States Air Force, 59th Medical Wing, En route Care Research Center, Lackland AFB, TX, USA

[5]Department of Military and Emergency Medicine, Uniformed Services University

*Corresponding author: Joseph K. Maddry, MD, joseph.k.maddry.mil@mail.mil

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ABSTRACT

Background: Extracorporeal membrane oxygenation (ECMO) is an advanced medical technology used to treat respiratory and heart failure. The coronavirus pandemic has resulted in significantly more ECMO patients. However, the number of hospitals with ECMO capabilities and ECMO trained staff are limited. Training of personnel in ECMO could supplement this demand.

Objective: To evaluate our previously developed ECMO course using a mannequin-based training, as opposed to an existing live-tissue training model and determine if such a program was adequate and could be expanded to other facilities.

Methods: Seventeen teams, each consisting of a physician and nurse, underwent a 5-hour accelerated ECMO course in which they watched pre-recorded ECMO training lectures, primed circuit, cannulated, initiated ECMO and corrected common complications. Training success was evaluated via knowledge and confidence assessments, observation of each team attempting to initiate ECMO while troubleshooting complications on a Yorkshire swine.

Results: Seventeen teams successfully completed the course. Sixteen teams (94%, 95% CI = 71% - 100%) successfully placed the swine on veno-arterial ECMO. Of those 16 teams, 15 successfully transitioned to veno-arterial-venous ECMO. The knowledge assessments and confidence levels of physicians and nurses increased by 24.3% from pre-test (mean of 65.3%, SD 14.4%) to post-test (mean of 89.6%, SD 10.3%), $p<0.0001$; similar to the success in the previous live-tissue training model.

Conclusions: An abbreviated one-day lecture and hands-on mannequin-based ECMO course resulted in a high rate of successful skill demonstration and improvement of physicians' and

nurses' knowledge assessments and confidence levels, similar to a previous live-tissue training protocol.

Introduction

Background

Extracorporeal membrane oxygenation (ECMO) is an advanced medical intervention used to treat refractory respiratory failure, heart failure, or both. In the case of respiratory failure, venovenous (VV) ECMO pumps deoxygenated blood out of a central vein, oxygenates the blood, and returns it via a central vein. Conversely, venoarterial (VA) ECMO can support heart failure patients by pumping blood out of a central vein and into an artery. Finally, venoarterial-venous (VAV) ECMO can support patients with both pulmonary and cardiac failure by pumping blood out of a vein, oxygenating the blood, and pumping it into both a central artery and vein via separate cannulas. Studies have demonstrated the efficacy of VV ECMO for the management of severe Acute Respiratory Distress Syndrome (ARDS).[1-4] Several authors have indicated the importance of ECMO use and properly trained ECMO clinicians on rescuing patients from cardiopulmonary complications, including COVID-19 patients.[5-8] Of relevance to emergency physicians, is the use of VA ECMO for the management of out-of-hospital cardiac arrest.[9-12] Recently, a study was prematurely terminated by reviewers given that survival in the ECMO arm was greater compared to standard therapy (33% versus 7%) and thus, enrollment of patients into the control arm was considered unethical.[13]

Importance

Despite evidence for the benefit of ECMO, its availability (ECMO specialty teams and equipment) remains limited to major medical centers. In phase I of our ECMO protocol, we developed and validated an abbreviated single-day "Teach, Train, Test" ECMO course, to train teams of one physician and either a nurse or respiratory therapist to prime the circuit, initiate VA ECMO, transition to VAV ECMO, and troubleshoot common ECMO complications.[14] In the previous

study, we taught participants using pre-recorded audiovisual lectures, performed hands-on training using a live-tissue model (Yorkshire swine), and tested on a second live-tissue model. However, since most training facilities lack access to live-tissue models, we opted to utilize mannequins in phase II for training of participants prior to their live-tissue model (swine) testing.

When comparing medical training mannequins to live-tissue, there are considerable differences in malleability, elasticity, anatomy, and tensile strength.[15-16] For example, some mannequins use plastic tubing to mimic vascular structures. This tubing is generally not as collapsible and lacks the pulse-to-pulse change in diameter seen in live tissue models and humans. Since laceration of the central artery or vein was one of the more serious and common complications encountered in phase I during ECMO cannulations, we were concerned that the use of a mannequin model alone would be too simple for students and result in a false sense of confidence. Conversely, a swine model presents a greater challenge to clinicians since the femoral artery and vein are smaller, more tortuous, and covered by a greater quantity of muscular tissue when compared to human central vessels. Therefore, we aimed to develop a mannequin-based ECMO course to use within facilities and training programs lacking access to live-tissue models and determine its efficacy as our previous live-tissue training protocol.

Goals of this investigation:

Our objective was to evaluate a team consisting of one physician and one nurse or respiratory therapist, who completed the accelerated training on the mannequin, on their ability to successfully initiate ECMO and troubleshoot ECMO complications on the live tissue model (swine).

Methods

Study Design

As in the previous phase I ECMO study, we continued with the "Teach, Train, Test" method, to evaluate the efficacy of our abbreviated ECMO course to provide the physicians and nurses the necessary skills to initiate and maintain ECMO therapy and troubleshoot common complications.[14] However, in this phase II study, a mannequin was used for the "Train" section as opposed to the live swine in phase I. To determine the effectiveness of mannequin training, the "Test" section, was conducted on live swine as per the phase I study (Figure 1). The study was determined to be exempt by the 59th Medical Wing (MDW) Institutional Review Board and was approved by the 59th MDW Clinical Investigation and Research Support (CIRS) Institutional Animal Care and Use Committee (IACUC).

Study Setting and Selection of Participants

Similar to the phase I study, we solicited volunteer students from the San Antonio Military Medical Center (SAMMC), the Department of Defense's only Level I trauma center, via e-mail, word of mouth, and presentations at department grand rounds. Eligible study participants included attending emergency medicine (EM) physicians, third-year EM residents (from a single 3-year emergency medicine residency), critical care attending physicians, critical care fellowship physicians, third-year or later general surgery residents, EM nurses, critical care nurses, and respiratory therapists, who had no previous formal ECMO training or ECMO cannulation experience. Participants in phase I of this study were not eligible for phase II given prior ECMO training. We adhered to the regulations and guidelines of the Animal Welfare Act, the National Institutes of Health Guide for the Care and Use of Laboratory Animals, and the American

Association for the Accreditation of Laboratory Animal Care. The Congressionally Directed Medical Research Program (CDMRP) Joint Program Committee 6 (JPC-6) /Combat Casualty Care Research Program funded the study.

Materials

As in the previous phase I study, the CARDIOHELP ECMO pump (Maquet Getinge Group CARDIOHELP-I REF 70104-8012), circuit (Maquet HLS Set Advanced 7.0, HLS 7050 USA, 701052794) and the Maquet arterial and venous cannulas (PAL 1523, PVS 1938, and PVL 2155) were used.[14]

Course Materials

The course was set up in a "Teach, Train, Test" model in which the students first reviewed a total of 1.5 hours of narrated lectures with visual slides covering the following ECMO topics: indications, contraindications, physiology, patient management, cannula selection, cannulation strategies, routine circuit management, and troubleshooting circuit emergencies. Following lectures' completion, subjects were given hands-on training on the ECMO circuit and mannequins (2–3 hours). Previously developed procedural checklists (supplementary Table) were used for training and assessment for each the following tasks: set-up and priming of the ECMO circuit, patient cannulation, and management of ECMO complications.

Hands-on Training with Mannequins

Hands-on training was provided to each team by an ECMO-trained physician, a nurse, and nurse assistants. The training included verbal and hands-on instruction to the subjects as they assembled and primed the ECMO circuit and cannulated the vessels (two femoral veins and one femoral artery) of the ECMO Vascular Access Model mannequin (Christopher Ho, MD, Inc.). The ECMO Vascular mannequin resembles a human pelvis containing bilateral femoral artery and vein

access (tubing), connected to a saline bag system allowing for the continuous circulation of fluid upon ECMO initiation.

Students were reminded to use the written instructions in a stepwise fashion throughout this process. As in our prior study, cannulation was accomplished using an ultrasound guided percutaneous Seldinger technique. Serial dilations of one of the femoral veins was performed using the Maquet percutaneous insertion kit (12Fr.-18Fr.; PIK 150-USA) followed by a final dilation with the 20-French Avalon Elite vascular dilator (20Fr.; #12210). A 21-French venous cannula (Maquet HLS cannula) was placed. Serial dilations of a femoral artery were performed up to 14 French, using the Maquet percutaneous insertion kit. A 15-French arterial cannula (Maquet arterial HLS cannula) was placed in the femoral artery. Cannulas were de-aired and attached to the ECMO circuit.

Following confirmation of successful VA ECMO initiation, cannulation of the second femoral vein in the ECMO Vascular Access Model mannequin was accomplished using an ultrasound guided percutaneous Seldinger technique. Serial dilations of the second femoral vein was performed using the Maquet percutaneous insertion kit up to 18-Fr. A 19-Fr. venous cannula (Maquet arterial HLS cannula) was used. The cannula was then deaired and a clamp was placed to ensure there was no entrainment of air or leaking of fluid (saline) from the cannula. To initiate VAV ECMO, the arterial line flowing out of the ECMO circuit was clamped and cut. A Y-connector (NovoSci, C330S) was placed allowing the saline pumped out of the ECMO circuit into the mannequin's artery to be diverted into the 15-Fr. Arterial cannula and the 19-Fr. venous cannula. Flow regulator clamps were placed on the tubing of the 19-Fr. femoral vein cannula, allowing the ECMO participants to regulate the blood flow from the Cardiohelp (Maquet Getinge Group) between the arterial and venous system.

Similar to phase I, following confirmation of successful VAV ECMO initiation on the ECMO Vascular Access Model mannequin, the participants were provided with hands-on training on the identification and management of common ECMO complications to include loss of electrical power, access insufficiency (often referred to as "chatter"), air in the ECMO circuit, and loss of circuit integrity (i.e., a hole in the tubing).

Participants were then instructed to practice the cannulation procedures using the ECMO Simulator Prototype mannequin (University of Illinois, Coordinated Science Laboratory, Health Care Engineering System Center, Urbana, Illinois). The ECMO Simulator prototype is a human torso with access to a unilateral femoral artery and vein connected to a peristaltic pump providing pulsatile fluid flow, similar to human systolic and diastolic blood flow.

Animal Preparation

Given the inability to evaluate mortality and physiology using a mannequin model and the lack of practical and ethical means of enrolling human volunteers, validation was performed using a live animal model. We elected to use a total of 17 Yorkshire swine (*Sus scrofa*) weighing between 70 and 90 kilograms (one swine per team) based on *a priori* power analysis. As in our previous study, each animal was sedated with ketamine at an intramuscular dose of 10 mg/kg, and endotracheal intubation was performed. Mechanical ventilation was commenced and adjusted to maintain the arterial partial pressure of carbon dioxide (PCO_2) between 38- and 42-mm Hg using a volume-limited, time-cycled ventilator (Fabius GS anesthesia machine, Drager-Siemens). Anesthesia was maintained by a qualified surgical technician throughout the procedure using isoflurane mixed with room air in a range between 1 and 3.5%. Our prior phase I publication can be referenced for further specifics regarding the animal preparation, instrumentation and sedation.[5] Following animal stabilization, a baseline arterial blood gas (ABG) was collected to obtain

measurements of oxygen saturation, PaO_2, $PaCO_2$, hemoglobin (Hb), pH, bicarbonate, base excess, and lactate (ABL 800 Flex blood gas analyzer, Radiometer America).

Training Validation and Testing in swine model

Identical to our prior study, upon completion of the hands-on training, the team, consisting of one physician and one nurse, was provided the supplies necessary to prime and prepare the circuit, access and cannulate the required blood vessels, initiate and maintain ECMO therapy, and troubleshoot common complications.

Two research assistants independently observed the students to evaluate and document performance and time to completion of each of the major tasks taught during the hands-on training. Any difference in documented information between the research assistants were clarified via consensus; if there was no consensus, the primary investigator made the final determination. In the event that students were unsuccessful in initiating ECMO therapy, an ECMO specialist would intervene and initiate ECMO. Failed ECMO initiation was documented and the students then proceeded to the following phase of the study.

First, the students prepared and primed the ECMO circuit. Students then placed cannulation wires in each of the femoral veins and in one of the femoral arteries. Proper placement of the guidewires was verified via fluoroscopy. In the event the guidewires were not located in inferior vena cava and descending aorta, students removed the improperly placed wire and reattempted appropriate placement. Following confirmation of proper guidewire placement, 10,000 units of heparin was administered intravenously. The students then performed the aforementioned serial dilations of one of the femoral veins and the femoral artery, placed the appropriate cannulas, and connected the cannulas to the ECMO circuit.

As in our prior study, after initiation of VA ECMO the students were removed from the room and the research team induced a common complication. The students were then brought back into the room and instructed to "assess the patient and the Cardiohelp system, state what complication they encountered, and perform the necessary steps to correct the problem." This process was repeated for each of the following complications: loss of electrical power, excessive blood flow turbulence ("chatter"), diagnosis and removal of air from the venous side of the circuit, diagnosis and removal of air from the arterial side of the circuit, and loss of circuit integrity. Research assistants documented success vs failure and time to completion for each of these tasks.

After completion of the troubleshooting phase, the students were instructed to place the patient on VAV ECMO. Students then cannulated the second femoral vein and connected the femoral vein cannula to the arterial ECMO line. Then, used the flow regulator clamps to establish the balance of blood flow necessary to ensure swine's adequate oxygenation (pulse oximetry > 92%) and appropriate blood perfusion (mean arterial pressure > 55 mmHg). Research assistants documented success vs. failure and time to completion. Swine were euthanized (IV pentobarbital, 100 mg/kg) under veterinary guidance in accordance with the American Veterinary Medical Association Panel on Euthanasia guidelines.

Data Collection

As in our previous study, at the beginning of each abbreviated ECMO course, the physician and nurse participant completed a survey to obtain baseline demographic information, prior ECMO training and their ECMO comfort level (Table 1). Each participant completed a written assessment to determine their ECMO knowledge prior to receiving any course materials (Figure 1). At the completion of the hands-on skill validation, students completed post-training written assessments of ECMO knowledge and comfort level.

Measurements

For comparison of efficacy of our previous animal-based training to the new mannequin-based training, we used identical task completion assessment as well as comfort and knowledge assessment documents that were used in the previous study.

The confidence assessment consisted of 10 items that described necessary steps to initiate and maintain ECMO. Students also rated their confidence and experience level for each item on a scale from 0 (“no experience”) to 5 (“expert”). The knowledge assessment consisted of 20 questions (multiple choice and true/false) focused on ECMO procedures, indications, complications, and troubleshooting.

During the hands-on procedures, and as done in the prior study, blood from the carotid artery was collected at each blood draw (baseline, immediately post-ECMO initiation, and at study completion) and was used for ABGs analysis.

Data Analysis

In order to compare the results between the two studies, we performed the same type of analysis with the new data collected from this study. We reported categorical variables as frequencies and percentages and continuous variables as means with standard deviations. The primary endpoint was a binary outcome (successful ECMO initiation, yes vs. no). Other variables of interest include successful priming and preparation of the ECMO circuit (yes vs. no), preparation time (from start of lab to completion of circuit preparation), procedure time (from start of lab to completion of cannulation procedure), and lab time (from start of lab to completion of lab).

We performed descriptive analyses of swine physiological parameters. We evaluated inter-rater agreement on the procedure instruction checklist using percent agreement over all items and

teams (calculated as number of items in agreement across all teams divided by the total number of items across all teams) and Cronbach's alpha as a measure of internal consistency for the 10-item confidence assessment. Scores from each item on the confidence assessment were summed and a percentage score was calculated out of the 50 possible points. We also calculated the proportion of students who rated themselves as "competent" (a score of 3) or better on each item. For the knowledge assessment, we calculated the percentage of correct answers (out of 20 items). Proportions of successful ECMO initiation and troubleshooting were compared to that of the teams in our previous study which used a live animal model for hands-on training. Additionally, the students' comfort and knowledge assessments were compared 1) before and after the mannequin-based ECMO training course and 2) after animal-based versus mannequin-based training. Descriptive summaries of participant demographics and backgrounds were conducted. Analysis of these secondary outcomes included paired t-tests (for continuous variables) and McNemar tests (for nominal variables) comparing pre-training scores to post-training scores to assess improvements on the confidence and knowledge assessments. These results were then compared to the findings in our live-tissue based training study using chi-square and independent t-tests.

Power Analysis

To ensure ease of study comparison, we matched the prior sample size of 17 teams (two clinicians per animal).[14] This study can be referenced for further details of our a priori power analysis. In brief, a precision analysis was performed *a priori* and determined that a sample size of 17 teams (2 clinicians per animal) could produce a 95% confidence interval of 90% to 100% with the assumption of 99.9% success rate in ECMO initiation. Analyses were performed using SAS v9.4 (SAS Institute, Inc. Cary, North Carolina). Statistical tests are two-sided with a significance level of 5%.

Results

Characteristics of Study Subjects

As in our last study, a total of 34 clinicians (17 teams) completed the ECMO course. These teams consisted of 16 EM physicians, one surgery department physician, five emergency department nurses, 10 intensive care unit (ICU) nurses, one research nurse and one respiratory therapist. Most physicians (77%) and nurses/respiratory therapists (89%) had been in their current position for 5 years or fewer. Most students had less than 10 hours of experience caring for a patient on ECMO (91%) and none had ever completed formal ECMO training prior to this course (Table 1).

Primary Outcome

All 17 teams successfully primed and prepared the ECMO circuit with a mean time of 27:01 minutes (SD 5:06, 95% CI = 24:23-29:38 minutes) (Table 2). Sixteen of the 17 teams (94%, 95% CI = 71% - 100%) were able to complete the cannulation procedures (mean time from start of the lab: 65:34 minutes, SD 16:26, 95% CI 57:07-74:01 minutes). One team was unable to initiate ECMO due to an arterial laceration caused during the cannulation process. One team successfully initiated VA ECMO but lacerated the second femoral vein and was unable to transition to VAV ECMO. The mean total lab time (from start to finish) was 148:30 ± 26:11 minutes (SD 26:11, 95% CI =135:00 -161:54 minutes).

There were no significant differences in success rates between the previous live-tissue based study and the current study (Table 6). Students were able to prime and prepare the circuit more quickly in this study than in the previous study (difference of 4:26 minutes, 95% CI of the difference 0:26-8:26 minutes), but otherwise there were no differences in the time it took to initiate ECMO, convert to VAV ECMO, or in the total lab time.

Secondary Outcomes

The procedure validation checklist had 93% inter-rater agreement across all items and teams, and the confidence assessment showed good reliability (Cronbach's alpha = 0.92). All students showed an increase in confidence in completing ECMO tasks after the course. On average, their overall confidence scores improved with an absolute increase of 35.1% from pre-test (mean 17.5%, SD 14.4%) to post-test (mean 52.6%, SD 20.1%), with 95% CI of the increase = 29.1%-41.2%, $p<0.0001$. The proportion of students rating themselves as "competent" or better significantly improved for each item on the confidence assessment after the training course (Table 3). Post-course confidence scores ranged from 44% on two items (initiation of ECMO in a critical patient in a deployed setting and, trouble shooting and managing issues with circuit/equipment) to 74% (initiation of IV anticoagulation).

Students' mean knowledge assessment scores increased after training completion by 24.3% from pre-test (65.3% correct, SD 14.4%) to post-test (89.6% correct, SD 10.3%), 95% CI of the increase 18.6%-29.9%, $p<0.0001$. Nearly all teams who successfully initiated ECMO could troubleshoot ECMO complications (Table 4). These complications included venous air, arterial air, loss of circuit integrity, loss of power, and access insufficiency (chatter). Additionally, in those 16 animals successfully placed on ECMO, ABG values, and vital signs remained stable (Table 5).

We found no significant differences between this current study and the previous live-tissue study when comparing pre-test scores, post-test scores, and improvements for the confidence and knowledge assessments (Table 6). Similarly, there were no differences between the two studies with regards to the troubleshooting tasks.

Discussion

Most physician and nurse/respiratory therapist teams receiving a brief one-day lecture and mannequin-based hands-on ECMO training course successfully initiated ECMO on a swine model in this follow-on study. All student teams were successful at setting up and priming the ECMO circuit and troubleshooting common ECMO complications. The current study adds to findings from our prior live tissue training study by validating the use of a lecture and mannequin-based ECMO course for use in facilities lacking live-tissue training. Our study highlights the ability to train teams consisting of a physician and a nurse/respiratory therapist with emergency or critical care experience in the basics of ECMO initiation and troubleshooting. These findings offer an avenue for increased scale of ECMO training to address the increased demand for this specialized skill set due to the COVID-19 pandemic and the expansion of prehospital cardiac arrest ECMO.

In this hands-on training study, we continue to demonstrate an improvement in the student's confidence level for each item evaluated. When reviewing the student's confidence assessment from the two studies, similar percent differences were found between Pre-test and Post-test assessment for each item evaluated. However, it is important to note that there was some degree of variability due to the different clinicians enrolled in both studies. Proportions of procedural success of VA ECMO initiation and VAV ECMO transition were comparable to the initial live tissue training study. The inability to initiate ECMO or transition to VAV ECMO was due to fatal arterial lacerations. This same complication was observed in our previous study and can be reduced by further practicing cannulation skills to obtain better performance. Additionally, swine anatomy makes placement of the large ECMO cannulas more challenging than in humans for multiple reasons. First, the femoral artery and vessels of 70-90 kg swine are smaller than those of human adults. Second, the proximal femoral vessels are more tortuous and follow a less linear path as they transition to the iliac vessels. Third, large muscles overlying the femoral vessels of

swine results in significant resistance to placement of the large ECMO cannulas. The authors have noted vascular injury due to deviation of the cannulas path from the intended route despite use of the guide wire. Finally, swine hypercoagulability results in rapid intravascular thrombus formation if vessel puncture occurs without successful wire placement, making additional attempts to access the vessel significantly challenging. While not a hypothesis of this study or the preceding study, it is the opinion of the authors that obtaining central vascular access and placing cannulas in swine models is a greater challenge than doing so in human patients. Thus, the procedural success found in these studies may underestimate the effectiveness of procedural success on human patients.

All the serious adverse events in this study and the phase I study resulted from injuries caused during the cannulation process. ECMO programs should place emphasis on ensuring physicians cannulating ECMO patients have significant experience accessing the central vasculature. This is not to state that this procedure should be limited to vascular surgeons as previous research has demonstrated high rates of successful cannulation performed by non-surgical physicians with adequate experience.[17]

With the current study, we were also able to demonstrate that the use of a mannequin-based ECMO training produced similar increases in post-course confidence and ability to initiate and manage ECMO in a swine model, compared to our initial study utilizing a swine model for the training phase. This suggests that mannequin-based training may provide the necessary skills for participants to initiate, prime and troubleshoot this specialized technique before using it on a live model.

Given the surge of patients with cardiopulmonary failure, it is evident the need to implement this type of training on clinicians that are in the frontline of this pandemic so they have the necessary skills to successfully initiate these procedures, decrease delays prior to ECMO

initiation, and alleviate the already overwhelmed ECMO teams in hospitals and trauma centers.[18] The authors have initiated a subsequent study using an identical methods except for the addition of telemedicine support to aid the team during the ECMO circuit preparation, cannula placement, and troubleshooting of complications. If the addition of telemedicine is found to be effective, the expansion of ECMO training in combination with telemedicine support from ECMO centers may allow the expansion of ECMO capabilities to areas currently lacking this life-saving therapy.

Limitations

First, this study was conducted using an animal model which, is not completely representative of humans. However, the validation of the efficacy of the ECMO lectures and hands-on mannequin-based training on humans is impractical due to logistical and ethical concerns. The swine model, with similar anatomical and physiological characteristics, is a feasible alternative to assess the efficacy of this training model. Additionally, the authors consider ECMO cannula placement on swine more challenging than on humans for the aforementioned reasons. Second, the knowledge and confidence assessments used to validate the efficacy of the training were performed immediately after the training, so the duration of knowledge and skill retention is unknown. As with the development of other clinical knowledge and skills, the authors believe that repetition and refresher training will likely result in greater performance and skill sustainment. Additional practice of cannulation procedures could easily be incorporated into routine procedure labs and grand rounds sessions. Finally, the intent of this course is to train personnel to initiate ECMO, stabilize a critical patient and then admit or transfer the patient to an inpatient ECMO team. This curriculum does not provide training for the long-term management of patients on ECMO or on the weaning of ECMO therapy. Finally, our study in phases I and II was aimed at the emergency medicine and general surgery physicians whose respective residences require extensive

procedural training. Further studies may be needed to assess successful initiation and troubleshooting of the ECMO circuit and cannulation by internal medicine physicians and intensivists who might be in the position to utilize ECMO.

Conclusions

We developed and validated an abbreviated 1-day course of consisting of lectures and hands-on mannequin-based ECMO training for a physician and nurse or respiratory therapist teams. Students achieved a high rate of successful skill demonstration in a live-tissue model and had increased scores on post-course knowledge and confidence assessments.

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Figure 1. Flow chart of study procedures.

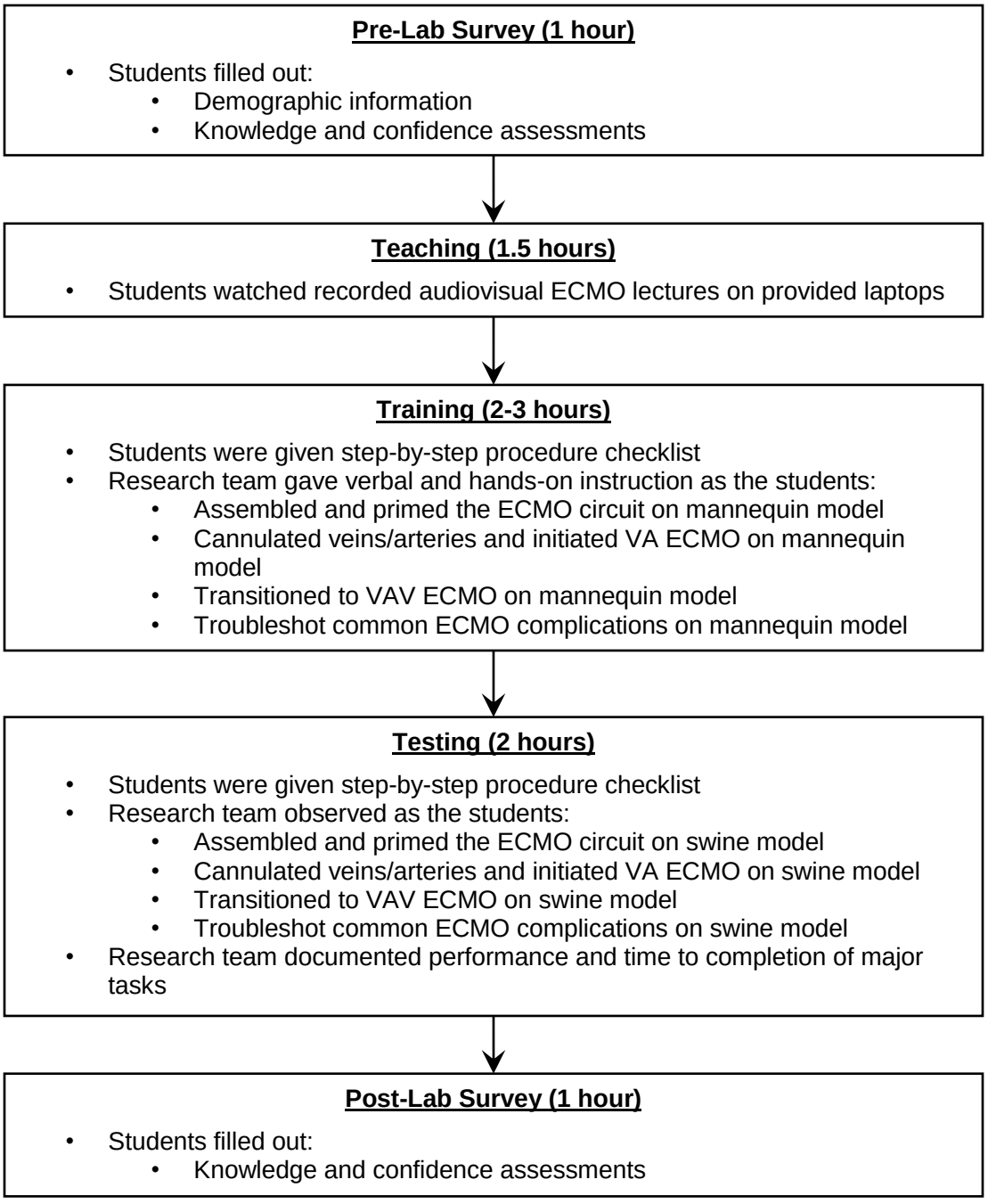

Table 1. Student characteristics

Variable	Total Sample (n=34)	Physicians (n=17)	RNs (n=14) and RTs (n=3)
Time in position			
<1 years	3 (9%)	1 (6%)	2 (12%)
1-5 years	23 (68%)	12 (71%)	11 (65%)
6-10 years	6 (18%)	3 (18%)	3 (18%)
>10 years	2 (6%)	1 (6%)	1 (6%)
Department			
ED	21 (62%)	16 (94%)	5 (29%)
ICU	10 (29%)	0 (0%)	10 (59%)
Research	1 (3%)	0 (0%)	1 (6%)
Respiratory Therapy	1 (3%)	0 (0%)	1 (6%)
Surgery	1 (3%)	1 (6%)	0 (0%)
Time in department			
<1 years	5 (15%)	1 (6%)	4 (24%)
1-5 years	23 (68%)	12 (71%)	11 (65%)
6-10 years	4 (12%)	3 (18%)	1 (6%)
>10 years	2 (6%)	1 (6%)	1 (6%)
Work experience caring for ECMO patient(s)			
0 hrs	15 (44%)	5 (29%)	10 (59%)
1-10 hrs	16 (47%)	10 (59%)	6 (35%)
11-35 hrs	1 (3%)	1 (6%)	0 (0%)
>36	2 (6%)	1 (6%)	1 (6%)
Formal ECMO training	0 (0%)	0 (0%)	0 (0%)
Other training			
Advanced trauma life support (mannequin lab)	15 (44%)	14 (82%)	1 (6%)
Advanced trauma life support (animal lab)	11 (32%)	11 (65%)	0 (0%)
Pediatric advanced life support	26 (76%)	17 (100%)	9 (53%)
Neonatal resuscitation program	12 (35%)	9 (53%)	3 (18%)
Emergency war surgery course	1 (3%)	1 (6%)	0 (0%)
Swine procedure lab or research	5 (15%)	5 (29%)	0 (0%)

Values given are number (column percentage).

ECMO = extracorporeal membrane oxygenation; ED = emergency department; ICU = intensive care unit.

Table 2. Team Characteristics and Results of ECMO Simulation

Team ID	Time in position, years		Department		Time in department, years		Work experience with ECMO patients, hours		Primed ECMO circuit?	Time to prime circuit, minutes	Initiated VA ECMO?	Trans. to VAV ECMO?	Time to ECMO initiation, minutes	Total lab time, minutes	Notes
	PHYS	RN/RT	PHYS	RN/RT	PHYS	RN/RT	PHYS	RN/RT							
1	1.5 (A)	5 (RN)	ED	ED	5.5	5	1-10	1-10	Yes	27	No	No	78	105	Fatal arterial laceration
2	3 (R)	2 (RN)	ED	Res	3	2	0	1-10	Yes	31	Yes	Yes	41	122	
3	3 (A)	10 (RN)	ED	ICU	3	7	1-10	0	Yes	31	Yes	Yes	101	189	
4	4 (A)	4 (RN)	ED	ED	4	4	1-10	0	Yes	41	Yes	Yes	57	178	
5	2 (R)	7 (RN)	ED	ICU	2	5	1-10	0	Yes	26	Yes	Yes	83	183	
6	8 (A)	3 (RN)	ED	ICU	1.5	2	0	>36	Yes	25	Yes	Yes	57	157	
7	2 (A)	20 (RN)	ED	ICU	7	20	11-35	1-10	Yes	25	Yes	Yes	52	124	
8	3 (R)	2 (RN)	ED	ICU	3	1	0	0	Yes	26	Yes	Yes	48	125	
9	3 (R)	3 (RN)	ED	ICU	3	0.75	1-10	0	Yes	21	Yes	Yes	49	129	
10	3 (R)	4 (RN)	ED	ED	3	3	1-10	1-10	Yes	20	Yes	Yes	68	140	
11	16 (A)	0.5 (RT)	ED	ICU	16	0.25	0	0	Yes	29	Yes	No	62	153	Fatal arterial laceration, unable to convert to VAV
12	0.5 (A)	0.75 (RT)	ED	RT	0.5	0.75	1-10	1-10	Yes	24	Yes	Yes	52	125	
13	2.5 (R)	6 (RT)	ED	ICU	2.5	3	>36	1-10	Yes	26	Yes	Yes	92	160	
14	3 (R)	1 (RN)	Surg	ICU	3	4	1-10	0	Yes	22	Yes	Yes	73	146	
15	7 (A)	1 (RN)	ED	ICU	10	1	0	0	Yes	24	Yes	Yes	58	135	
16	9 (A)	5 (RN)	ED	ED	3	0.5	1-10	1-10	Yes	33	Yes	Yes	72	193	
17	5 (A)	4 (RN)	ED	ED	5	1	0	0	Yes	27	Yes	Yes	71	160	

PHYS = physician; RN = registered nurse; RT = respiratory therapist; A = attending; R = resident; ED = emergency department; Res = research; ICU = intensive care unit; Surg = surgery; VA = venoarterial; VV = venovenous; VAV = veno-arterial-venous.

Table 3. Proportion of Students Rating Themselves as "Competent" or Better on the Confidence Assessment

Question	Pretest	Posttest	Percent difference/increase (95% CI)
1. Determining which patients would benefit from ECMO initiation	2 (6%)	16 (47%)	41% (24%-59%)
2. Initiation of IV anticoagulation	19 (56%)	25 (74%)	18% (0%-36%)
3. Placement of percutaneous cannula using Seldinger technique.	12 (35%)	19 (56%)	21% (2%-39%)
4. Preparing cannulas for connection to ECMO circuit.	0 (0%)	22 (65%)	65% (48%-82%)
5. Connecting patient to ECMO circuit.	0 (0%)	22 (65%)	65% (48%-82%)
6. Securing cannulas.	5 (15%)	21 (62%)	47% (29%-65%)
7. Achieving respiratory and hemodynamic goals.	9 (26%)	18 (53%)	27% (9%-44%)
8. Maintaining ECMO during patient transport.	1 (3%)	16 (47%)	44% (27%-62%)
9. Trouble shooting and managing issues with circuit/equipment.	0 (0%)	15 (44%)	44% (27%-62%)
10. Initiation of ECMO in a critical patient (impending death) in a deployed setting.	0 (0%)	15 (44%)	44% (27%-62%)

Values given are number (percentage out of n = 34). Differences are statistically significant if the 95% confidence interval does not include or cross zero.
On the assessment, "competent" is defined as "able to mostly recognize and complete the skillset or problem using my own judgment and able to achieve most tasks without additional input."
ECMO = extracorporeal membrane oxygenation.

Table 4. Results of Troubleshooting Complications

Complication	Teams Successful	Time to Troubleshoot Complications*
Venous air	14 (82%)	5:32 [4:24-6:39]
Arterial air	15 (88%)	5:06 [4:08-5:05]
Loss of circuit integrity	16 (94%)	5:01 [4:01-6:01]
Loss of power	15 (88%)	3:11 [2:43-3:40]
Chatter	16 (94%)	2:04 [1:34-2:32]

Values given are n (percentage out of n = 17) or median time in minutes:seconds [interquartile range].
*The single team that was unsuccessful in initiating VA ECMO was excluded from the time analysis. Teams who were unsuccessful in troubleshooting the complication were also excluded from the respective time analysis.

Table 5. ABGs and Vitals for Swine at Baseline, ECMO Initiation, and End of Lab

Variable	Baseline	ECMO initiation	End of Lab
ABGs			
pH	7.47 (7.45-7.50)	7.49 (7.44-7.53)	7.27 (7.19-7.36)
pH*	7.47 (7.45-7.49)	7.49 (7.44-7.53)	7.28 (7.19-7.36)
pCO2	40.05 (37.54-42.55)	35.59 (31.26-39.91)	49.58 (42.04-57.11)
pCO2*	40.38 (37.34-43.42)	35.98 (31.64-40.31)	48.89 (41.12-56.66)
pO2	194.2 (172.6-215.9)	222.5 (160.6-284.4)	163.9 (94.54-233.3)
pO2*	195.2 (174.3-216.0)	224.0 (162.9-285.2)	161.7 (93.64-229.8)
cK+	3.68 (3.42-3.95)	3.93 (3.69-4.17)	4.14 (3.52-4.77)
cNa+	141.2 (140.5-141.8)	140.3 (139.3-141.2)	142.3 (140.8-143.7)
cCa2+	1.22 (1.18-1.26)	1.21 (1.16-1.26)	1.20 (1.14-1.25)
cCl–	99.54 (86.35-112.7)	107.6 (105.7-109.4)	110.8 (108.1-113.5)
cGLu	68.59 (58.48-78.70)	87.75 (76.93-98.57)	97.31 (68.65-126.0)
cLac	1.43 (1.16-1.70)	2.28 (1.73-2.84)	5.36 (3.71-7.02)
p50e	24.72 (24.12-25.32)	24.24 (23.03-25.45)	30.83 (27.86-33.80)
cBase(Ecf)c	5.34 (3.68-7.00)	2.98 (1.53-4.44)	-12.6 (-33.2-7.99)
cHCO3-(P,st)e	29.35 (27.88-30.82)	27.59 (26.27-28.91)	20.78 (17.72-23.83)
tHb	9.60 (9.06-10.14)	9.18 (8.55-9.81)	10.69 (9.89-11.49)
O2Hb	96.51 (96.07-96.95)	95.99 (95.20-96.77)	93.11 (91.09-95.14)
COHb	0.57 (0.28-0.87)	0.71 (0.28-1.15)	0.43 (0.08-0.78)
MetHb	1.09 (0.84-1.34)	1.07 (0.76-1.37)	0.98 (0.70-1.26)
Vitals			
HR	91.59 (81.71-101.5)	111.4 (97.93-124.8)	142.1 (123.3-160.9)
SBP	87.41 (75.77-99.05)	98.76 (83.65-113.9)	92.00 (78.03-106.0)
DBP	59.94 (54.04-65.84)	76.88 (63.07-90.69)	48.94 (43.29-54.60)
SPO2	98.18 (97.19-99.16)	96.76 (95.03-98.50)	95.25 (93.53-96.97)
Temp	37.28 (36.96-37.61)	37.23 (36.75-37.71)	36.66 (36.25-37.08)
RR	10.59 (9.11-12.07)	10.29 (9.19-11.40)	9.94 (9.02-10.86)
ECO2	44.59 (43.17-46.01)	37.06 (31.83-42.28)	40.65 (33.83-47.47)
Pven	-	-35.2 (-42.4--28.1)	-79.1 (-202-43.54)
Part	-	156.7 (148.4-165.0)	142.8 (114.2-171.5)
Pint	-	164.2 (151.9-176.6)	150.4 (116.7-184.2)
RPM	-	2543 (2467-2620)	3396 (3078-3714)
LPM	-	1.74 (1.60-1.88)	3.17 (2.45-3.89)

Values given are mean (95% CI).

ABG = arterial blood gases; DBP = diastolic blood pressure; ECO2 = carbon dioxide; HR = heart rate; LPM = liters per minute; Part = pressure after oxygenator; PCO2 = partial pressure of carbon dioxide; Pint = pressure before oxygenator; Pven = negative pressure in venous line; RPM = revolutions per minute; RR = respiratory rate; SBP = systolic blood pressure; SPO2 = pulse oximetry.

*Values are temperature-adjusted.

Table 6. Comparison of outcomes between live-tissue study and current study

Variable	Live-tissue study (n=17)	Current study (n=17)	Difference (95% CI)
Primary outcomes			
Prime and prepare ECMO circuit	17 (100%)	17 (100%)	0%
Time to prime circuit, minutes	31:26 (28:10-34:42)	27:01 (24:23-29:38)	4:26 (0:26 to 8:26)*
Initiate VA ECMO	15 (88%)	16 (94%)	-6% (-30% to 19%)
Time to initiate VA ECMO, minutes	59:11 (44:31-73:52)	65:34 (57:07-74:01)	-6:23 (-21:51 to 9:05)
Convert to VAV ECMO	14 (82%)	15 (88%)	-6% (-34% to 22%)
Time to convert to VAV ECMO, minutes	20:59 (16:49-25:09)	17:51 (13:45-21:58)	3:08 (-2:54 to 9:09)
Total lab time, minutes	145:24 (132:00-158:54)	148:30 (135:00-161:54)	3:03 (-21:14 to 15:09)
Assessments			
Confidence assessment			
Pre-test	17.3 (13.5-21.0)	17.5 (12.5-22.5)	-0.2 (-6.4 to 5.9)
Post-test	57.6 (51.3-63.9)	52.6 (45.6-59.7)	5.0 (-4.3 to 14.2)
Change from pre-test to post-test	40.3 (35.6-45.0)	35.1 (29.1-41.2)	5.2 (-2.4 to 12.7)
Knowledge assessment			
Pre-test	64.7 (60.8-68.6)	65.3 (60.3-70.3)	-0.6 (-6.8 to 5.6)
Post-test	85.9 (82.8-88.9)	89.6 (86.0-93.1)	-3.7 (-8.3 to 0.9)
Change from pre-test to post-test	21.2 (16.5-25.8)	24.3 (18.6-29.9)	-3.1 (-10.3 to 4.1)
Troubleshooting			
Venous air	15 (88%)	14 (82%)	6% (-22% to 34%)
Time to troubleshoot venous air, minutes	4:30 (2:34-5:44)	5:32 (4:24-6:39)	-0:57 (-2:24 to 0:31)
Arterial air	15 (88%)	15 (88%)	0%
Time to troubleshoot arterial air, minutes	4:19 (3:23-5:52)	5:06 (4:08-5:05)	0:12 (-2:15 to 2:39)
Loss of circuit integrity	15 (88%)	16 (94%)	-6% (-30% to 19%)
Time to troubleshoot loss of integrity, minutes	5:00 (2:47-5:46)	5:01 (4:01-6:01)	-0:20 (-1:59 to 1:18)
Loss of power	15 (88%)	15 (88%)	0%
Time to troubleshoot loss of power, minutes	3:26 (2:42-3:43)	3:11 (2:43-3:40)	-0:14 (-1:06 to 0:38)
Chatter	15 (88%)	16 (94%)	-6% (-30% to 19%)
Time to troubleshoot chatter, minutes	1:08 (1:03-2:49)	2:04 (1:34-2:32)	9:46 (-5:08 to 24:40)

Values are count (column percentage) or mean (95% confidence interval).

*Comparisons are significant if the 95% confidence interval of the difference does not include or cross 0.

Supplementary Table: Procedural checklists

Procedure Validation: ECMO Initiation, Transport & Trouble Shooting

Team ID #:_____Reviewer:_____ Date: _____

		YES	NO	COMMENTS
1.	START ECMO (complete training slides and paperwork)			
2.	Draw ABG (label lab start or initial)			
3.	Gather supplies: (CardioHelp device, extension tubing x3, posicaps x3, Luer lock syringe 60ml, Toomey Syringe, Marquet HLS ECMO kit, 2x 1 Liter Bags of PlasmaLyte, (**LR used for lab**), sterile gloves, mask, Heparin, 3/8 Y connector, 3/8 tubing, 1 Liter bottle of NaCl, 10ml syringe, sterile scissors, several sterile clamps)			
4.	Ensure the blue handle is raised on the CardioHelp			
5.	Don mask and gloves			
6.	Open Marquet ECMO kit, saving top label with lot number			
7.	Open extension tubing (3) and posicaps (3), and drop into Circuit box			
8.	Don sterile gloves			
9.	Attach posicaps to end of extension tubing **AND** place on the oxygenator (red box)			
10.	Connect red box (oxygenator) to the CardioHelp, (de-airing cap should remain off)			
11.	Connect black integrated sensor **AND** lower the blue handle			
12.	Place sterile clamshell pack onto the silver handle			
13.	Clamp the flow/bubble sensor onto the red return line (between two white tape marks). Arrow should point **towards** the patient			
14.	Remove priming bag, ensure all stopcocks are clamped and closed tight			
15.	Hang priming bag and spread apart on IV pole			
16.	Infuse 1 ½ liters of LR into priming bag			
17.	Connect priming bag to tubing lines, ALL clamps should remain clamped			
18.	Turn on CardioHelp, press and hold the power button			

19.	Place alarm in global override, press **S** button and global override button, which also has a **S** on it (when activated button will turn red)			
20.	Zero each alarm. Press Pven, then the 0 button, the check mark, the green check; Press Part, then the 0 button, the check mark, the green check			
21.	Open the clamps on the priming bag and allow the circuit to fill			
22.	Turn the RPM to 3000 for two minutes then 4000 RPM for 1 minute. If pumping sounds can be heard, repeat this step until no sounds are heard. Reduce RPM to 1500***. If you get cavitation or continue to get air bubbles, check the venous line at the priming bag outlet, it may be twisted.***			
23.	De-air all the pigtails by pulling back with a syringe			
24.	Close de-airing port with the yellow protective cap			
25.	Connect oxygen tubing to your D cylinder or wall to 2L			
26.	Infuse Heparin into ECMO circuit (1000 units)			
27.	Reduce RPM to 0			
28.	Zero flow probe by placing clamps on both sides of the flow probe, press the V button on top left (flow symbol), press 0, green check, check. Remove clamps			
29.	Press yellow button down on the bottom right, press bubble sensor button, press reset then the green check			
30.	Deactivate global override			
31.	Remove the gray venous probe from the blue handle and connect it to the venous side clip on the circuit			
32.	Reactivate global override			
33.	Connect priming bag lines together **AND** then connect table tray lines together, (Red to Blue, Red to Blue) **ALL** plastic clamps should remain clamped tight			
34.	Set Alarm limits Pven (-100/-150) linked for intervention Part (400/500) linked for intervention Pint (400/500) not linked for intervention			
35.	**ECMO Circuit fully primed, record vitals**			
36.	***(pt start values should be temp 37.5-40C, PCO2 38-42 have A-line in place, foley in place)***			

37.	**CANNULATION (gather supplies)**			
38.	Place wire in right femoral vein using Seldinger technique.			
39.	Place wire in left femoral vein using Seldinger technique.			
40.	Place wire in left femoral artery using Seldinger technique.			
41.	Confirm placement of wires with Fluoroscopy			
42.	Draw baseline lab, (ABG) **AND** Record vital signs			
43.	Prior to placing dilators, administer IV anticoagulation to the patient (not the circuit). **The dose is 5000 Units of heparin in humans, 10,000 Units in pigs.**			
44.	Perform serial dilations of the right femoral vein up to the (**20F** in pig).			
45.	Place the (**21F** in pig) into the right femoral vein			
46.	Securely suture the line into place.			
47.	Perform serial dilations of the left femoral artery up to **14Fr**			
48.	Place catheter **15F** into the left femoral artery			
49.	Securely suture the line into place.			
50.	Bring the ECMO lines out of the clamshell packaging onto the field, keeping them sterile. There are two lines, the blue line is the venous (pre-pump) line while the red is the arterial (post-pump) line. There is a spot on each of the two lines (a sticker with clamp marks) where it indicates to clamp here; clamp those two lines at those spots, **AND** cut line approx. 3-4 inches above clamp			
51.	Remove the introducer from the venous line (21 Fr) and allow some blood to flow ensuring no clots have formed, then place metal clamp			
52.	Have your Toomey syringe ready and fill with an ample supply of NaCl for connection of the circuit lines to cannula lines. As the NaCl is poured with the Toomey syringe it will be creating a steady stream while connecting lines so that air bubbles will not be present when connection of the lines is made.			
53.	Connect the ECMO Venous line (blue line) to the 21 Fr venous cannula ensuring no air gets into the line, with method described previously			

54.	Remove the introducer from the arterial cannula (15 Fr) and allow some blood to flow ensuring no clots have formed, then place metal clamp			
55.	Connect the ECMO Arterial line (red line) to the 15 Fr cannula ensuring NO air gets into the line using Toomey syringe and NaCL (This is VA ECMO Configuration)			
56.	Look for air bubbles in lines thoroughly			
57.	Remove clamps from patient (cannula) side, then circuit side			
58.	Place patient on ECMO			
59.	Increase RPMs to 2500-3000			
60.	Deactivate Global Override			
61.	An arterial oxyhemoglobin saturation of > 75 percent for VV ECMO	-----	-----	
	A venous oxyhemoglobin saturation 20 to 25 percent lower than the arterial saturation, measured on the venous line	-----	-----	
	Adequate tissue perfusion, as determined by the arterial blood pressure, venous oxygen saturation and blood lactate level	-----	-----	
62.	Once the initial respiratory and hemodynamic goals were achieved, the blood flow was maintained. Frequent assessment and adjustments were facilitated by continuous venous oximetry			
63.	Record vitals **AND** Draw lab (ABG) (label VA ECMO)			
PROBLEMS/participant go on break				
64.	****LOSS OF CIRCUIT INTEGRITY (hole in tubing)**** Recognizes leak in tubing			
65.	Cross clamps properly & discontinues ECMO therapy to patient			
66.	Implements emergency vent settings **(verbalizes)**			
67.	Removes damaged portion of tubing and connects remaining ends with proper connector			
68.	Unclamps and resumes ECMO flow			
69.	Record vitals, monitor trends (circuit and patient)			
70.	Consider Drawing lab (ABG- label post loss of integrity)			
71.	****VENOUS AIR****			

	Recognizes air issue (may hear bubbles running through oxygenator) will not be an audible alarm			
72.	Verbalizes air is pre-bladder/oxygenator (no need to cross clamp)			
73.	Removes air from bladder by removing yellow cap and pulling back from extension tubing			
74.	Assesses patient and cannula's in attempt to identify leak source/s			
75.	Assesses bubble detector to ensure functionality by clamping, and RESETTING			
76.	Resumes flow			
77.	Consider collecting ABG (label Venous air)			
78.	****CHATTER**** Turn dial on Pump to lower RPMs			
79.	Look for cannula malposition and kinking			
80.	Consider Volume Repletion **(verbalizes)**			
81.	Look for Hemorrhage sources			
82.	Consider collecting lab to recheck H&H, monitor trends in vitals, and ECMO circuit			
83.	****ELECTRICAL FAILURE**** Ensures pump is plugged in red outlet			
84.	Verbalizes existence of battery backup & emergency power backup			
85.	Begins hand cranking at proper RPM (whichever RPM you were at when power was lost)			
86.	Hand cranking initiated			
87.	Hand cranks until power restored (5minutes) ****Power restored****			
88.	Resumes ECMO therapy with Cardiohelp			
89.	Consider Collecting lab (ABG- label post power loss)			
90.	****ARTERIAL AIR**** Recognizes air bubble			
91.	Recognizes NO flow			
92.	Clamps lines at patient and circuit			
93.	Implements emergency vent settings			
94.	Checks oxygenator			
95.	Checks all connections			
96.	Removes air			
97.	Removes clamps			
98.	Resumes ECMO therapy			
99.	Take patient off emergency vent settings			
100.	Record vitals **AND** Collect lab (ABG) (Label Post Air)			
Transport Patient				

101.	Move to transport stretcher Ensure lines do not get pulled			
102.	Transport Patient			
103.	Move patient to bed Ensure lines do not get pulled			
104.	Complications: ☐ N/A			
Convert to VAV ECMO				
105.	Perform serial dilations of the left femoral vein up to 18Fr.			
106.	Place the 19Fr catheter into the left femoral vein to the same depth (based on cm markers on the line)			
107.	Securely suture in place			
108.	Remove the introducer from the line (19 Fr) and allow some blood to flow ensuring no clots have formed, then place metal clamp			
109.	Get your 3/8 extra tubing and cut a piece approximately 18inches, get y connector			
110.	Connect cut tubing to 19Fr cannula (CLAMP should still remain in place			
111.	Fill cut tubing with NaCl **AND** place metal clamp approx. 2-3 inches from the end			
112.	Connect Y connector to end of cut tubing			
113.	Turn RPMs down to Zero on CardioHelp			
114.	Clamp all lines (Circuit side and patient side)			
115.	Approximately 18 inches down from 15Fr cannula insertion--- Place a metal clamp			
116.	As you Apply pressure on tubing (15Fr) approx. 1 inch away from where you just placed metal clamp, place another metal clamp approx. another 3-4 inches away (Pressure applied in between two clamps placed)			
117.	Cut in between the two clamps			
118.	Connect remaining portions of Y connector to this time using NaCl and your Toomey syringe (Essentially connecting 19Fr line to 15Fr line)			
119.	Apply metal flow regulators to {Arterial sides (venous and arterial) ECMO tubing in order to regulate ECMO outflow between arterial and venous line}			
120.	LOOK FOR AIR in Tubing THOROUGHLY			
121.	Unclamp patient lines, **THEN** unclamp circuit			

122.	TURN RPMs up to 2500-3000 or higher dependent on patient needs			
THIS IS VAV ECMO				
123.	Adequate tissue perfusion, as determined by the arterial blood pressure, venous oxygen saturation and blood lactate level	-----	-----	
124.	Connected patient to the ECMO circuit increased blood flow until respiratory and hemodynamic parameters are satisfactory.	-----	-----	
125.	Once the initial respiratory and hemodynamic goals were achieved, the blood flow was maintained. Frequent assessment and adjustments were facilitated by continuous venous oximetry			
126.	Record vitals **AND** Draw lab (ABG) (Label VAV)			
127.	Draw ABG (label END OF LAB)			
128.	**COMPLETE LAB (complete AAR/ paperwork)**			

Disclaimer: The views expressed are those of the authors and do not reflect the official views or policy of the Department of Defense or its' Components. This study was conducted under a protocol reviewed and approved by the USAF 59th Medical Wing IACUC and in accordance with the approved protocol.