Standardized Assessment of Simulation Based ECMO Educational Courses: A Pilot Study

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Abstract

Background: The Extracorporeal Life Support Organization (ELSO) education taskforce (ELSOed) recently identified seven extracorporeal membrane oxygenation (ECMO) educational domains that would benefit from international collaborative efforts among which standardized assessments of ECMO courses was prioritized. We aimed to develop a standardized online assessment tool to evaluate the effectiveness of a comprehensive didactic and simulation-based ECMO course on participants’ gain in confidence, knowledge, and simulation-based skills.

Methods: We performed a prospective multicenter observational study of five US adult ECMO courses. Standardized online assessment forms were developed and administered before and after courses, covering demographics, self-assessment regarding ECMO management, and knowledge exam (15 simple-recall multiple choice questions), while psychomotor skill assessment was performed during the course (time to complete pre-specified critical actions during simulation scenarios). Self-assessment covered cognitive, behavioral, and technical aspects of ECMO care.

Results: Out of 211 participants, 107 completed both pre- and post-course forms (97 completed both pre and post-course knowledge forms). Physician-intensivists were the largest group (53%) and the majority practiced at academic hospitals (51%) and had less than 1-year of ECMO experience (50%). Post-course, participants reported significant increases in confidence across all domains (cognitive, technical, and behavioral; \( p<0.0001 \) CI: 1.2-1.5, \( p<0.0001 \) CI: 2.2-2.6, and \( p=0.002 \) CI: 1.7-2.1, respectively) as well as an increase in knowledge scores (\( p<0.001 \), CI: 1.4-2.5). These findings were consistent for all specialties and prior ECMO experience. There were also significant reductions in the times to critical actions in 3 of the 4 scored simulation scenarios.

Conclusions: We successfully developed and tested a comprehensive standardized ECMO course assessment tool, demonstrating participants’ self-reported benefit as well as improvement in both knowledge and psychomotor skill acquisition. Standardized course evaluation is feasible and potentially provides important information to improve ECMO courses. Future steps include national implementation, addition of questions targeting clinical decision making to further assess knowledge gain, and multi-language translation for implementation at international courses.

Background

Extracorporeal membrane oxygenation (ECMO) has become a mainstay therapy for life-threatening cardiopulmonary failure. Its use has increased significantly in the past 2 decades by almost 10-fold in adults and 4-fold in children \([1, 2]\). The 2009 influenza pandemic, as well as the current SARS-COV-2 (COVID-19) pandemic, have seen an exponential increase in ECMO use, primarily in adults \([3-8]\), with a growing number of centers reporting to the Extracorporeal Life Support Organization (ELSO) \([2]\).

With the exponential increase in ECMO use, there has been a parallel surge in ECMO educational programs worldwide reflecting recognition of the high cost, relatively low volume, intense resource
utilization, and high risk nature of ECMO support, mandating that clinicians be properly trained [9, 10]. Despite this growth, however, there is a lack of consensus on the curriculum and structure of these educational programs [11]. As such, ELSO created a dedicated taskforce, ELSOed, charged with defining international educational needs and identifying opportunities for standardization and international collaboration. An ELSOed position statement outlined educational priorities [12] to include standardizing an ECMO curriculum for delivery at ECMO courses, to standardize a process for ECMO course evaluation, and to outline mechanisms to evaluate the educational benefits of ECMO courses worldwide.

The Kirkpatrick evaluation model is a well-defined method for objectively measuring the effectiveness of training programs [13]. This model outlines the four level evaluation framework: reaction, learning, behavioral change, and organizational performance. Reaction evaluates the trainees’ perceptions about the program and the usefulness of the material to their work; learning gauges the participants’ developed expertise and knowledge and is ideally assessed prior to (“pre-test”) and following (“post-test”) training. Behavioral change and organizational performance assess the differences in participants’ behavior and impact on their work after completing the program, thereby requiring long-term follow-up.

The goal of the present study was to develop a standardized online course assessment tool, based on the Kirkpatrick evaluation model, to assess the educational benefits of ECMO courses utilizing self-assessment, knowledge assessment, and psychomotor skill evaluation forms in a simulation setting.

**Methods**

*Study design*

We performed a prospective assessment of US-based adult ECMO courses, ELSO-run or ELSO-endorsed, using online forms. The study was reviewed by the institutional review board at Washington University in St. Louis and was granted waiver of consent.

ELSO and ELSO-endorsed ECMO courses have a standard structure for 25 hours over 3.5 days with 14.5 hours of simulation. Participants are provided with a copy of the ELSO Red Book and Speciﬁast Training manual on arrival. Didactics consist of structured lectures covering ECMO basics, circuit components, physiology, cannulation, complications, and literature review as well as interactive case studies provided by physicians, nurses, and perfusionists with ECMO expertise. Simulation makes up over 50% of course duration and is immersive with 2-3 instructors per 6 participants. Scenarios are high-fidelity incorporating an ECMO circuit connected to a mannequin via a simulated dual site cannulation [14]. In addition to realistic circuit variables, this setup incorporates patient vital signs, ventilator settings, laboratory test results, and radiologic images. Simulation scenarios are followed by structured debriefing sessions according to the “Three-Phase Debriefing Technique” [15].

*Study Subjects*
All course participants were eligible for this study and received individual links to pre- and post-course assessment forms hosted on the Google Forms platform. Completed form data was centrally collected, de-identified, and analyzed.

**Assessment Forms**

Pre- and post-course forms were developed by representatives from the ELSOed Course workgroup (AS, EC, RK, and BZ), following the first 2 levels of the Kirkpatrick evaluation model: reaction and learning. Course administrators were blinded to the form results. Pre-course forms included: 1) participant demographics, 2) participant self-assessment regarding ECMO management, and 3) knowledge assessment. Post-course form included: 1) participant self-assessment regarding ECMO management, 2) knowledge assessment, and 3) skills assessment during the course. The self-assessment forms covered cognitive, technical, and behavioral aspects of ECMO management. Assessment categories were defined to cover the basic knowledge and management skills identified as learning objectives for the courses. All questions were scored on a 5-point Likert scale (from “least confident” to “most confident”) ([Supplementary digital content 1](#)). Knowledge assessment forms were composed of 15 multiple choice, simple recall questions on ECMO physiology, management, and circuit setup. There were no repeat questions between pre- and post-knowledge assessments.

Four ECMO emergency simulation scenarios were repeated during the courses – initially as a standalone simulation, and then on the final day of the course as part of a mega-simulation where several scenarios were presented back to back as part of a clinical scenario. For each of these scenarios, actions critical to successful resolution of the scenario were identified for timing. As the multidisciplinary teams participated in these scenarios, times to each of these critical actions were recorded. The scenarios included: breach of circuit, recirculation on veno-venous (VV) ECMO, ventricular tachycardia (VT) on VV ECMO with conversion to veno-arterial (VA) ECMO, and air entrainment into the ECMO circuit.

**Statistical Analysis**

Statistical analysis was conducted in R (R Core Team, 2020) and figures were produced using the package ggplot2 (H. Wickham. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016). Categorical variables are presented as n (%) and quantitative variables are presented as median and interquartile range, unless otherwise stated. Wilcoxon signed rank sum test was used to compare pre- and post-course results. Pre- and post-course intergroup analyses were performed using Kruskal-Wallis one-way ANOVA tests. These subgroup analyses were solely explorative. A p-value of <0.05 was considered significant. Cohen's d was used to assess effect size based on differences between means with $d$ of 0.2 representing small, 0.5 medium, and 0.8 large effect sizes.

**Results**
Between March 2019 and February 2020, 211 participants in 5 ELSO and ELSO-endorsed courses participated in the study. Of these, 107 (51%) completed both pre- and post-course assessment forms with 97 participants (91%) completing the pre- and post-course knowledge assessment forms (Figure 1). The median duration between pre-course form completion to course start day was 2.61 days IQR [1.05, 5.7] with 1.05 days [0.2, 4.95] between the course end day and post-course form completion. Physician intensivists made up over half of participants (53%), followed by nurses (11%), with the majority working in academic hospitals (51%). The majority of respondents had more than 5 years of clinical experience (62%) though half had less than 1 year of ECMO experience (50%). Table 1 displays the participant demographics and ECMO practices provided at the participants’ home institutions.

**Self-Assessment**

Participants reported improved self-confidence with management of patients on ECMO. This improvement was consistent across the 3 domains: cognitive (pre-course: mean ± SD: 3.16 ± 0.88, post-course: 4.5 ± 0.43, p<0.001, CI 1.2 to 1.5), technical (pre-course: mean ± SD: 1.7 ± 0.85, post-course: 4 ± 0.76, p<0.001, CI 2.2 to 2.6), and behavioral (pre-course: mean ± SD: 2.4 ± 1.1, post-course: 4.2 ± 0.78, p<0.001, CI 1.7 to 2.1) (Figure 2). On subgroup analysis, significant improvement in self-assessment scores persisted across specialties and experience level (Supplementary digital content 2).

**Knowledge Assessment**

There was a significant improvement in knowledge assessment scores (10 [9, 12] vs 12 [11, 13], pre- vs post-course, p<0.001, CI 0.8 to 1.9). There were no significant differences in either the pre- or post-course test scores among participants’ specialty, age group, or clinical experience. There were significant improvements in the post-course scores across specialties and experience level. On Cohen's d calculation, there was a moderate effect size (³0.5) in all subgroup analyses with larger effect sizes (³0.7) in non-intensivists, non-physicians, and participants with less than 1 year of ECMO experience (Figure 3, Supplementary digital content 3).

**Psychomotor Skill Assessment**

Times to critical actions were recorded during breach of circuit, recirculation on VV ECMO, VT on VV ECMO with conversion to VA ECMO, and air entrainment into the ECMO circuit scenarios (Supplementary digital content 4). For the breach of circuit scenario, there were significant decreases in all times to critical actions: recognition of pathology, clamping the ECMO circuit, and resumption of ECMO support (Pre vs post-course mean±SD: 88±152 vs 39±56 seconds, p=0.05; 310± 228 vs 171±215 seconds, p=0.02; 393±238 vs 246±214 seconds, p = 0.008 respectively). There were similar results in both the recirculation scenario tasks: recognition of pathology, decreasing blood flow, and cannula imaging (Pre vs post-course mean±SD: 264±167 vs 107±91 seconds, p <0.001; 440±181 vs 202±146 seconds, p=0.04; 314±192 vs 160±109 seconds, p<0.001 respectively); and the VT on VV ECMO tasks: initiate CPR, call for VA ECMO, and convert to VA ECMO (Pre vs post-course mean±SD: 82±151 vs 24±49 seconds, p=0.002; 278±150 vs 101±62 seconds, p<0.001; 563±59 vs 467±134 seconds, p=0.05, respectively). For the air entrainment
scenario, there was a significant decrease in time to task completion for the recognition of pathology (Pre vs post-course mean±SD: 38±75 vs 9±9 seconds, p 0.02) but there were no significant differences in clamping the ECMO circuit, de-airing the circuit, or resumption of ECMO support (Pre vs post-course mean±SD: 74±90 vs 56±64 seconds, p=0.4, 98±121 vs 132±189 seconds, p=0.6, 470±178 vs 341±163 seconds, p=0.07, respectively) (Supplementary digital content 4).

Table 2 displays the pre and post-course times to critical actions in addition to the post-course change for all the recorded tasks.

Discussion

This study presents the first implementation of a structured assessment tool for simulation-based ECMO courses evaluating changes in participants’ self-reported confidence in managing patients on ECMO in addition to assessments of their knowledge gain and change in psychomotor skills. We present the preliminary results from five US-based courses. Our findings show (1) improved participants’ self-confidence in managing ECMO patients across all specialties and experience level; (2) improved knowledge, and (3) significant reductions in times to complete critical actions during simulated ECMO emergency scenarios.

To objectively assess the educational benefits of ECMO courses, we followed the commonly accepted Kirkpatrick model of training course evaluation by prospectively evaluating course participants both before and after the courses. We selected levels one and two of the Kirkpatrick model, as they are the short-term levels. Our study population was heterogenous with a variety of disciplines and specialties as well as varied clinical and ECMO experience. This is of pragmatic value representing the typically multidisciplinary team involved in managing ECMO patients.

Our study showed the ability of the assessment tool in identifying significant improvement in participants’ self-confidence with ECMO management. These findings are consistent with previously reported improvements in self-confidence in participants of one-day simulation-based ECMO courses for intensive care physicians, nurses, thoracic surgery residents, and ECMO specialists [16] [17] [18]. Others have reported improvement in confidence levels for a group of ECMO-novice practitioners following simulation training [19]. In addition to including a significantly larger cohort at 5 different courses nationwide, our results complement these studies by demonstrating improvement across specialties and clinical or ECMO experience. Additionally, the comprehensive tool presented in this study assesses improvements across the 3 categories: cognitive, technical, and behavioral. Such a comprehensive assessment is of special importance in ECMO education where the multidisciplinary team’s confidence in both technical and non-technical aspects is essential to effectively provide this life-saving therapy [20].

We also found improvement in knowledge assessment scores across specialties and experience levels. These findings are consistent with other studies showing significant knowledge gain in ECMO-naive critical care fellows following simulation-based training [21]. Similar knowledge gain following one-day and two-day high-fidelity ECMO simulation courses has also been shown with other course evaluations [22, 23]. Despite the statistically significant knowledge gain in our participants, regardless of
There was a noticeably narrow range for both pre and post-course scores. We supplemented the evaluation with further effect size analysis that demonstrated at least a moderate post-course knowledge gain in all groups. There was a more significant effect in participants with less ECMO clinical decision-making experience, including non-physicians, non-intensivists, and those with less clinical and ECMO experience.

For the simulation assessments, there was a significant decrease in the time to critical action completion in all tasks for 3 of the 4 evaluated scenarios. These findings are consistent with previous reports [21]. Zakahry et al. found that simulation-based training improved time to completion of critical actions for novice ECMO practitioners. More importantly, these results persisted on long-term follow up [21]. Similarly, it has also been shown that there was a decrease in the number of technical errors following simulation, even though reduction in reaction time did not reach statistical significance [24], while Burkhat et al. reported a significant improvement in time to critical action following simulation training [18].

Previous studies of ECMO courses have been limited with the majority focusing on the feasibility and benefit of high-fidelity simulation [18, 21, 25-28]. A recent publication highlighted an abbreviated ECMO course for non-surgical clinicians [22] and reported an improvement in participants’ knowledge and confidence following the 1-day ECMO course. Their study was limited to participants with no previous ECMO experience and focused on the initiation of ECMO with no training on the subsequent management of patients or on weaning of ECMO support. The nature of the knowledge tests and the confidence assessments were not clearly delineated in the study. The current study developed and utilized a tool for assessing the impact of ECMO courses with participants of multidisciplinary representation and of varying experiences in addition to providing a structured assessment of post-course knowledge, confidence, and skill gain.

**Strengths and limitations**

This study has several strengths. First, it provides a comprehensive structured evaluation for simulation based ECMO courses. Second, the study reflects the applicability of the assessment model across a large multidisciplinary cohort that represents the different specialties involved in caring for patients on ECMO. Finally, we outline a comprehensive approach to assess the short-term educational benefits of simulation-based ECMO courses that can be applied on both national and international levels.

The current study should be interpreted within the context of certain limitations. First, only 50% of participants completed all the pre- and post-course forms. This is likely due to the fact that completion was voluntary. Our results, in addition to the constructive feedback collected on these forms, provide an incentive for course organizers to include assessment form completion as a mandatory part of the course in the future. Second, the study was limited to US-based courses. We are currently translating the assessment forms to allow for implementation at international courses. Third, as mentioned above, the knowledge questions were limited to rapid recall questions, which likely limits our ability to detect significant differences in knowledge acquisition and critical application; the incorporation of multi-step
logic questions may allow for a more in-depth evaluation of participants’ knowledge gain. Furthermore, evaluation on Kirkpatrick levels 1-2 has limited ability to extrapolate findings to real-life performance and patient outcome improvements. Additionally, it is important to acknowledge the limitation of self-confidence as a surrogate for competence, as extensively studied in medical education. This highlights the need for long-term follow up of participants to evaluate the impact of the ECMO course on their daily work practices and while allowing for assessment of levels three and four of the Kirkpatrick model.

**Conclusions**

This study demonstrates the successful development of a comprehensive ECMO course assessment tool. Implementation of this new tool demonstrated improvement in participants’ self-confidence with management of ECMO patients in addition to improvement in both knowledge acquisition and time to critical action in simulated scenarios. Future directions include national and international implementation and evaluation of long-term effects of ECMO courses on participants’ work practice.

**List Of Abbreviations**

| Abbreviation | Description                                          |
|--------------|------------------------------------------------------|
| ELSO         | Extracorporeal Life Support Organization             |
| ECMO         | Extracorporeal membrane oxygenation                  |
| VV           | Veno-venous                                          |
| VT           | Ventricular tachycardia                              |
| IQR          | Interquartile range                                  |
| CPR          | Cardiopulmonary resuscitation                        |
| VA           | Veno-arterial                                        |

**Declarations**

**Ethical Approval and Consent to participate** – Obtained

**Consent for publication** - NA

**Availability of supporting data** - available

**Competing interests** - The authors have no conflict of interest to disclose

**Author contributions** - AS, EC, RK and BZ developed the course assessment tool. EC collected the assessment tool data. CB, TM and BZ collected the simulation data. AS performed the statistical analysis and developed the study design. AS, EC, RK and BZ wrote the manuscript and are guarantors of the paper, taking responsibility for the work as a whole from the inception to published article. RD, EM and KS
critically reviewed the manuscript. All authors discussed the results and provided the final manuscript review.

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Tables

Table 1: Participant demographics
| Parameter            | n (%)              |
|----------------------|--------------------|
| Gender               | Male 62 (58)       |
|                      | Female 45 (42)     |
| Age group            | 21-30 years 5 (4.7)|
|                      | 31-40 years 57 (53)|
|                      | 41-50 years 29 (27)|
|                      | 51-60 years 9 (8.4)|
|                      | >60 years 7 (6.5)  |
| Specialty            | Physician - Intensivist 57 (53) |
|                      | Physician - Anesthesiologist 6 (5.6) |
|                      | Physician - Pulmonologist 6 (5.6) |
|                      | Physician - Cardiac Surgeon 2 (1.9) |
|                      | Physician - Cardiologist 2 (1.9) |
|                      | Physician - Trainee 2 (1.9) |
|                      | Physician - Transplant surgeon 3 (2.8) |
|                      | Nurse 12 (11)      |
|                      | Nurse Practitioner 10 (9.3) |
|                      | Respiratory therapist 5 (4.7) |
|                      | Other 2 (1.9)      |
| Hospital setting     | Community Hospital 46 (43) |
| Government Hospital | 4 (3.7) |
|---------------------|---------|
| Academic Hospital   | 55 (51) |
| Other               | 2 (1.9) |
| **Age group managed** |  |
| Pediatric           | 5 (4.7) |
| Neonatal            | 2 (1.9) |
| Adult               | 96 (90) |
| Pediatric & Adult   | 4 (3.7) |
| **Years in practice** |  |
| <5 years            | 41 (38) |
| >5 years            | 66 (62) |
| **ECMO experience** |  |
| <1 year             | 54 (50) |
| >1 year             | 53 (50) |
| **ECMO duration at local hospital** |  |
| <6 months           | 2 (1.9) |
| 1-2 years           | 18 (17) |
| 2-5 years           | 41 (38) |
| > 5 years           | 32 (30) |
| Do not have ECMO and are not planning to | 1 (0.9) |
| Do not have ECMO but are planning to | 13 (12) |
| **ECMO modes at local hospital** |  |
| None                | 8 (7.5) |
| VV                  | 8 (7.5) |
| VA                  | 1 (0.9) |
| ECMO capability at local hospital | No ability to cannulate or refer for ECMO | 4 (3.7) |
|----------------------------------|------------------------------------------|--------|
|                                 | Can cannulate patients onto ECMO but then refer to outside institutions | 9 (8.4) |
|                                 | Can cannulate and care for ECMO patients | 94 (88) |

ECMO = extracorporeal membrane oxygenation, VV = veno-venous, VA = veno-arterial

**Table 2: Time to critical actions in simulation scenarios in seconds**
| Critical action                  | Pre-course time | Post-course time | Delta time | p value |
|---------------------------------|-----------------|------------------|------------|---------|
|                                 | Median [IQR]    | Median [IQR]     | Median [IQR] |         |
| **Breach of circuit**           |                 |                  |            |         |
| Recognize pathology            | 42 [9, 79]      | 14 [3, 52]       | 0 [-59, 5] | 0.05    |
| Clamp ECMO circuit              | 260 [110, 493]  | 111 [42, 206]    | -15 [-302, 12] | 0.02    |
| Resume ECMO                     | 287 [199, 600]  | 172 [109, 310]   | -80 [-328, 35] | 0.008   |
| **Recirculation on VV ECMO**    |                 |                  |            |         |
| Recognize pathology            | 202 [139, 360]  | 92.5 [45, 156]   | -80 [-289, 0] | <0.001  |
| Decrease ECMO flow              | 496 [274, 600]  | 169 [118, 254]   | 0 [-220, 121] | 0.04    |
| Cannula imaging                 | 290 [154, 491]  | 146 [82, 194]    | -114 [-299, 16] | <0.001  |
| **VT on VV ECMO**               |                 |                  |            |         |
| Initiate CPR                    | 30 [15, 68]     | 10 [7, 16]       | -16 [-56, 0] | 0.04    |
| Call for VA ECMO                | 240 [178, 382]  | 85 [54, 133]     | -140 [-229, 0] | <0.001  |
| Convert to VA ECMO              | 600 [527, 600]  | 467 [367, 600]   | 0 [0, 422] | 0.05    |
| **Air entrainment**            |                 |                  |            |         |
| Recognize pathology            | 12 [5, 30]      | 5 [3, 12]        | -2 [-17, 2] | 0.02    |
| Clamp ECMO circuit              | 30 [18, 103]    | 27.5 [15, 86]    | 0 [-48, 23] | 0.4     |
| Vent ECMO circuit               | 49 [30, 152]    | 39 [26, 176]     | 0 [-30, 34] | 0.6     |
| Resume ECMO                     | 541 [256, 600]  | 298 [204, 502]   | 0 [-158, 168] | 0.07    |

IQR = interquartile range, ECMO = extracorporeal membrane oxygenation, VT = ventricular tachycardia, VV = veno-venous, CPR = cardiopulmonary resuscitation, VA = veno-arterial

Paired t test

Figures
Figure 1

Participant enrollment diagram
Figure 2

Pre and Post-course self-assessment results
Figure 3

Pre and post-course knowledge assessment tests

Supplementary Files

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- Supplementarydigitalcontent.pdf