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

Ahmed S Said
Washington University in St Louis School of Medicine
Elaine Cooley
Extracorporeal Life Support Organization
Rodrigo Diaz
Clínica Las Condes.: Clinica Las Condes
Elizabeth A Moore
UI Heart and Vascular Center: The University of Iowa Hospitals and Clinics
Kiran Shekar
The Prince Charles Hospital, University of Queensland
Christopher Beaty
Nemours A.I. duPont Hospital for Children
Timothy M Maul
Nemours Children's Hospital
Ramanathan Kollengode (ram_ramanathan@nuhs.edu.sg)
National University Singapore Yong Loo Lin School of Medicine https://orcid.org/0000-0003-1822-9455
Bishoy Zakhary
Oregon Health and Science University

Research

Keywords: ECMO, ELSOed, education, adult, course assessment, simulation

Posted Date: May 6th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-480044/v1

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 Speciliast 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 (pe-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 Assesment

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**).

Psychmotor 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 typicaly 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 a other course evaluations [22, 23]. Despite the statistically significant knowledge gain in our participants, regardless of specialty or experience, 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 sceanarios. 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

ELSO	Extracoporeal 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.

Financial support: Ahmed S. Said acknowledges research support from the Children's Discovery Institute Faculty Development Award at Washington University in St. Louis. Kiran Shekar acknowledges research support from the Metro North Hospital and Health Service.

References

1. Bartlett RH: **Esperanza: The First Neonatal ECMO Patient**. *ASAIO J* 2017, **63**(6):832-843.
2. (ELSO) ELSO: **ECLS registry report, international summary**. In. Ann Arbor, MI: ELSO; 2020.
3. Australia, New Zealand Extracorporeal Membrane Oxygenation Influenza I, Davies A, Jones D, Bailey M, Beca J, Bellomo R, Blackwell N, Forrest P, Gattas D *et al*: **Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1) Acute Respiratory Distress Syndrome**. *JAMA* 2009, **302**(17):1888-1895.
4. Pham T, Combes A, Roze H, Chevret S, Mercat A, Roch A, Mourvillier B, Ara-Somohano C, Bastien O, Zogheib E *et al*: **Extracorporeal membrane oxygenation for pandemic influenza A(H1N1)-induced acute respiratory distress syndrome: a cohort study and propensity-matched analysis**. *Am J Respir Crit Care Med* 2013, **187**(3):276-285.
5. Peek GJ, Mugford M, Tiruvoipati R, Wilson A, Allen E, Thalanany MM, Hibbert CL, Truesdale A, Clemens F, Cooper N *et al*: **Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial**. *Lancet* 2009, **374**(9698):1351-1363.
6. Sauer CM, Yuh DD, Bonde P: **Extracorporeal membrane oxygenation use has increased by 433% in adults in the United States from 2006 to 2011**. *ASAIO J* 2015, **61**(1):31-36.
7. **EuroELSO survey on ECMO use in adult COVID-19 patients in Europe** [https://www.euroelso.net/covid-19/covid-19-survey/]
8. **COVID-19 Cases on ECMO in the ELSO Registry** [https://www.elso.org/Registry/FullCOVID19RegistryDashboard.aspx]
9. Alinier G, Hassan IF, Alsalemi A, Al Disi M, Ait Hssain A, Labib A, Alhomsi Y, Bensaali F, Amira A, Ibrahim AS: **Addressing the challenges of ECMO simulation**. *Perfusion* 2018, **33**(7):568-576.
10. Al Disi M, Alsalemi A, Alhomsi Y, Bensaali F, Amira A, Alinier G: **Extracorporeal membrane oxygenation simulation-based training: methods, drawbacks and a novel solution**. *Perfusion* 2019, **34**(3):183-194.
11. Muratore S, Beilman G, John R, Brunsvold M: **Extracorporeal membrane oxygenation credentialing: where do we stand?** *Am J Surg* 2015, **210**(4):655-660 e652.
12. Zakhary B, Shekar K, Diaz R, Badulak J, Johnston L, Roeleveld PP, Alinier G, Lai PCK, Ramanathan K, Moore E *et al*: **Position Paper on Global Extracorporeal Membrane Oxygenation Education and Educational Agenda for the Future: A Statement From the Extracorporeal Life Support Organization ELSOed Taskforce**. *Crit Care Med* 2020, **48**(3):406-414.

13. Kirkpatrick DLaK, J.D.: **Evaluating Training Programs**. San Francisco, CA 94104-2916: Berrett-Koehler publishers; 2009.
14. Maran NJ, Glavin RJ: **Low- to high-fidelity simulation - a continuum of medical education?** *Med Educ* 2003, **37 Suppl 1**:22-28.
15. K A, M A, F L: **Debriefing Techniques Utilized in Medical Simulation**. In. Treasure Island (FL): StatPearls Publishing; 2020.
16. Maddry JK, Paredes RM, Paciocco JA, Castaneda M, Araña AA, Perez CA, Reeves LK, Newberry RK, Bebarta VS, Kester N *et al*: **Development and Evaluation of An Abbreviated Extracorporeal Membrane Oxygenation (ECMO) Course for Nonsurgical Physicians and Nurses**. *AEM Education and Training* 2020, **00**:1-12.
17. Brum R, Rajani R, Gelandt E, Morgan L, Raguseelan N, Butt S, Nelmes D, Auzinger G, Broughton S: **Simulation training for extracorporeal membrane oxygenation**. *Ann Card Anaesth* 2015, **18**(2):185-190.
18. Burkhart HM, Riley JB, Lynch JJ, Suri RM, Greason KL, Joyce LD, Nuttall GA, Stulak J, Schaff HV, Dearani JA: **Simulation-based postcardiotomy extracorporeal membrane oxygenation crisis training for thoracic surgery residents**. *Ann Thorac Surg* 2013, **95**(3):901-906.
19. Chan SY, Figueroa M, Spentzas T, Powell A, Holloway R, Shah S: **Prospective assessment of novice learners in a simulation-based extracorporeal membrane oxygenation (ECMO) education program**. *Pediatr Cardiol* 2013, **34**(3):543-552.
20. Kim GW, Koh Y, Lim CM, Huh JW, Jung SH, Kim JB, Hong SB: **The effect of an improvement of experience and training in extracorporeal membrane oxygenation management on clinical outcomes**. *Korean J Intern Med* 2018, **33**(1):121-129.
21. Zakhary BM, Kam LM, Kaufman BS, Felner KJ: **The Utility of High-Fidelity Simulation for Training Critical Care Fellows in the Management of Extracorporeal Membrane Oxygenation Emergencies: A Randomized Controlled Trial**. *Crit Care Med* 2017, **45**(8):1367-1373.
22. Maddry JK, Paredes RM, Paciocco JA, Castaneda M, Araña AA, Perez CA, Reeves LK, Newberry RK, Bebarta VS, Kester N *et al*: **Development and Evaluation of An Abbreviated Extracorporeal Membrane Oxygenation (ECMO) Course for Nonsurgical Physicians and Nurses**. *AEM Education and Training* 2020(00):1-12.
23. Fouilloux V, Gran C, Guervilly C, Breaud J, El Louali F, Rostini P: **Impact of education and training course for ECMO patients based on high-fidelity simulation: a pilot study dedicated to ICU nurses**. *Perfusion* 2019, **34**(1):29-34.
24. Anderson JM, Murphy AA, Boyle KB, Yaeger KA, Halamek LP: **Simulating extracorporeal membrane oxygenation emergencies to improve human performance. Part II: assessment of technical and behavioral skills**. *Simul Healthc* 2006, **1**(4):228-232.
25. Anderson JM, Boyle KB, Murphy AA, Yaeger KA, LeFlore J, Halamek LP: **Simulating extracorporeal membrane oxygenation emergencies to improve human performance. Part I: methodologic and technologic innovations**. *Simul Healthc* 2006, **1**(4):220-227.

26. Brazzi L, Lissoni A, Panigada M, Bottino N, Patroniti N, Pappalardo F, Gattinoni L: **Simulation-based training of extracorporeal membrane oxygenation during H1N1 influenza pandemic: the Italian experience**. *Simul Healthc* 2012, **7**(1):32-34.
27. Burton KS, Pendergrass TL, Byczkowski TL, Taylor RG, Moyer MR, Falcone RA, Geis GL: **Impact of simulation-based extracorporeal membrane oxygenation training in the simulation laboratory and clinical environment**. *Simul Healthc* 2011, **6**(5):284-291.
28. Fehr JJ, Shepard M, McBride ME, Mehegan M, Reddy K, Murray DJ, Boulet JR: **Simulation-Based Assessment of ECMO Clinical Specialists**. *Simul Healthc* 2016, **11**(3):194-199.

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)

	Both VV & VA	90 (84)
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 Median [IQR]	Post-course time Median [IQR]	Delta time Median [IQR]	p value
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

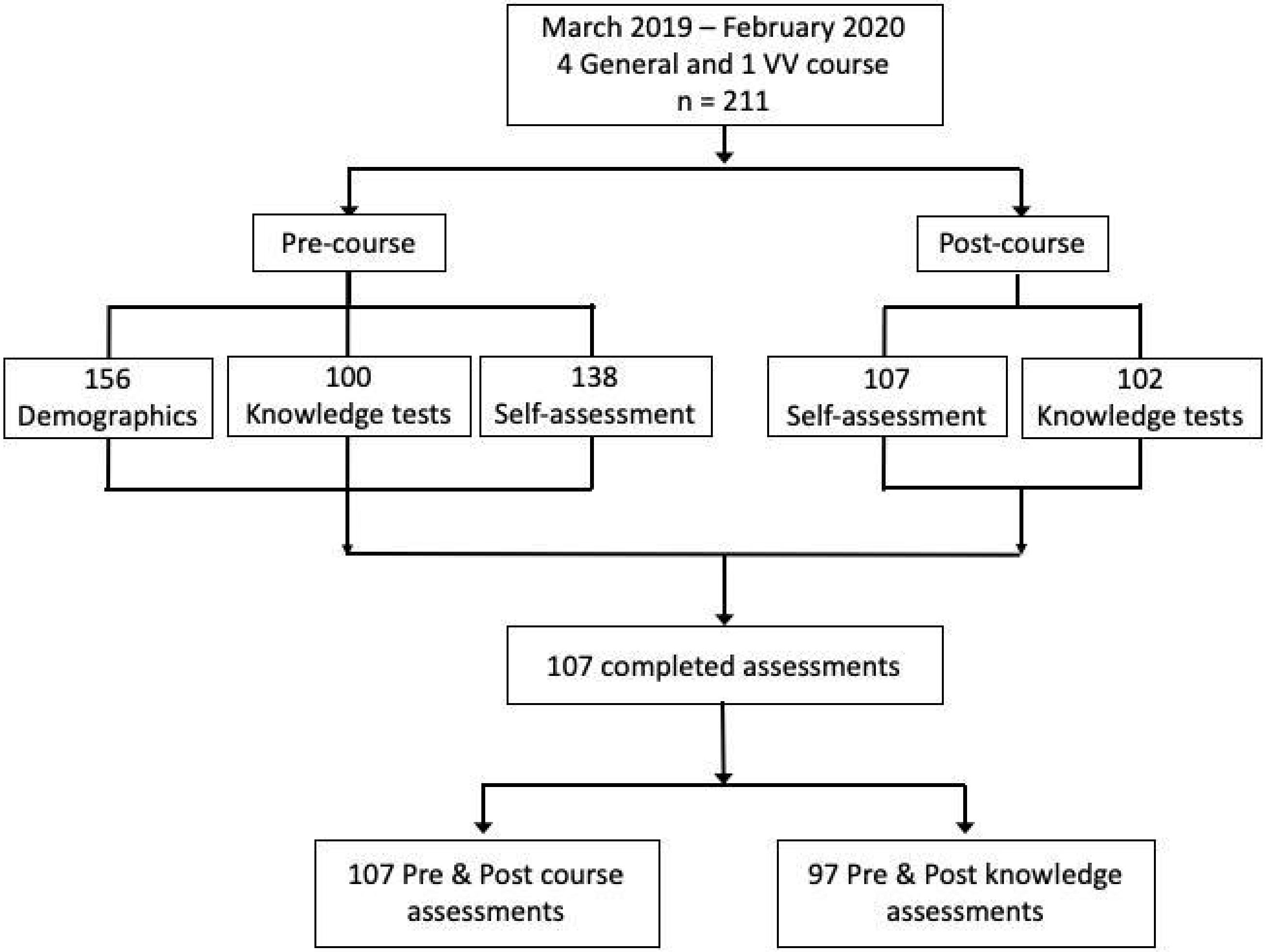

Figure 1

Participant enrollment diagram

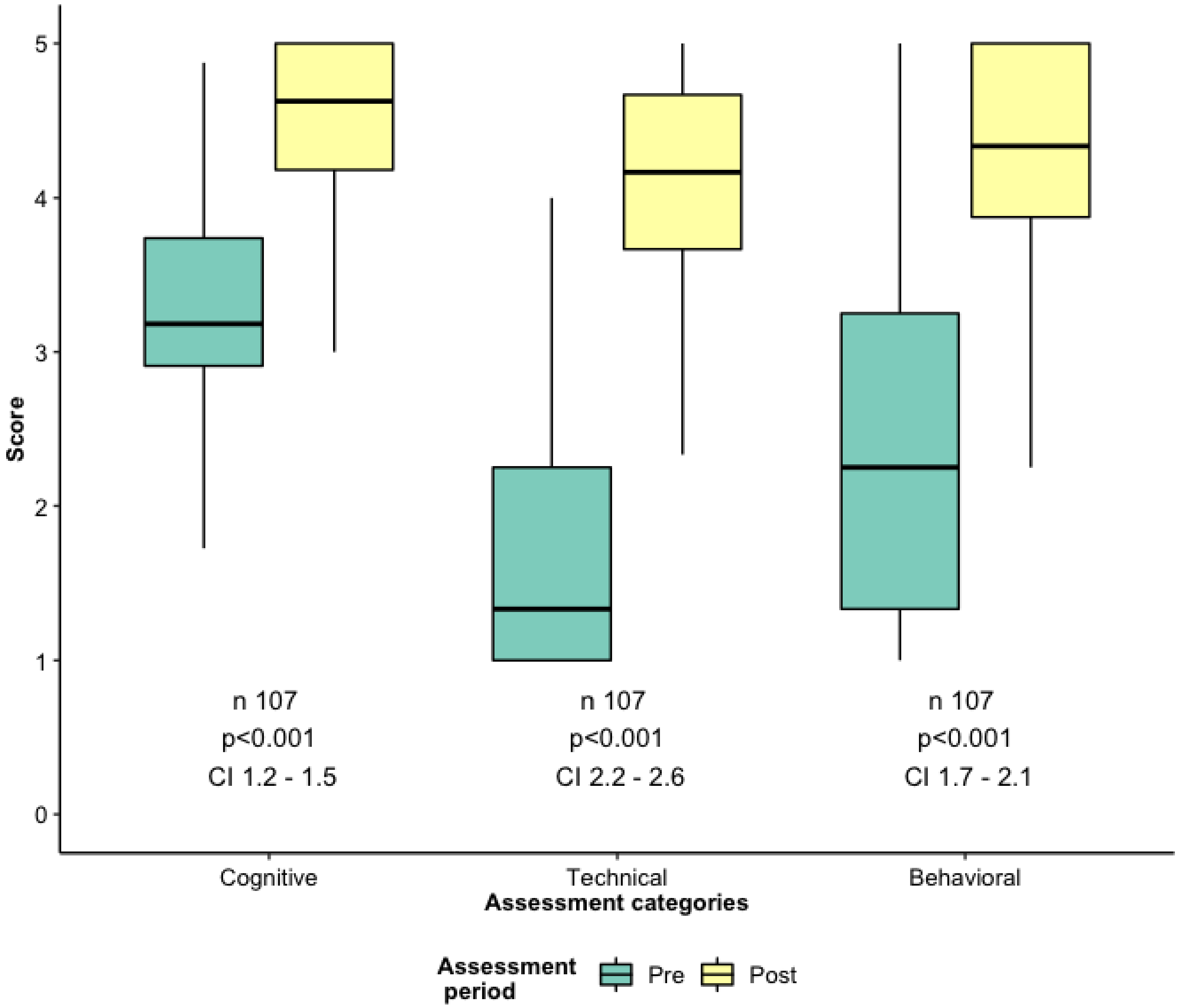

Figure 2

Pre and Post-course self-assessment results

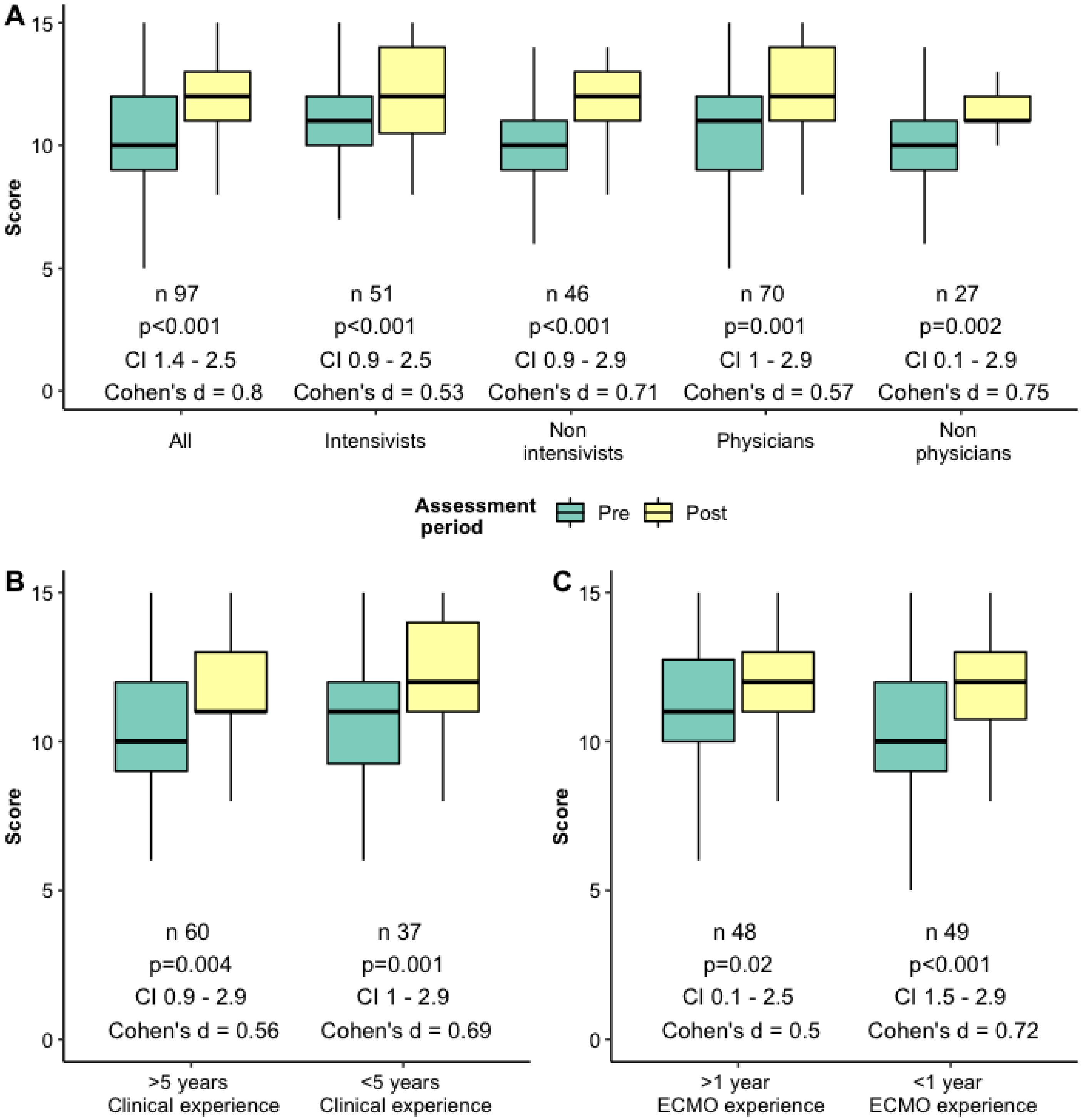

Figure 3

Pre and post-course knowledge assessment tests

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarydigitalcontent.pdf