Acute Medicine & Surgery 2017; **4**: 79–88 doi: 10.1002/ams2.236

Original Article

Long-term efficacy of an extracorporeal membrane oxygenation simulation with a novel, low-cost vascular model "Endo-Circuit"

Tomoyuki Endo, Yutaka Kagaya, Yutaro Arata, and Hiroyuki Imai

Comprehensive Education Center for Community Medicine of Tohoku University School of Medicine, Sendai, Japan

Aims: This study investigated the long-term efficacy of a half-day extracorporeal membrane oxygenation simulation and low-cost vascular model for practitioner knowledge, skills, and attitudes in clinical settings and also assessed the usefulness of the vascular model.

Methods: We included participants who attended a half-day extracorporeal membrane oxygenation simulation focused on the veno-arterial method between April 2013 and January 2016 at Tohoku University Simulation Center (Sendai, Japan). A survey questionnaire form was sent to each participant in March 2016. Ninety-six survey respondents engaged in real extracorporeal membrane oxygenation practice after the simulation were eligible for this study, and their answers were analyzed for differences between doctors and nurses. The survey asked questions regarding occupation, workplace, course date, years of experience, extracorporeal membrane oxygenation practice before simulation, problems and fears before the simulation, usefulness of reference materials, long-term efficacy of the simulation for practice, usefulness of the vascular model, and intensive care data review.

Results: Among all eligible answers, every average self-reported score (ranging from 0 to 10) of the long-term efficacy for extracorporeal membrane oxygenation practice was above 4. Nurses reported experiencing fears more frequently than doctors before the simulation. The usefulness of an original low-cost vascular model was evaluated at a median score of 7.

Conclusion: A half-day extracorporeal membrane oxygenation simulation with an original low-cost vascular model had long-term positive efficacy for knowledge, skills, and attitudes of practitioners who engaged in real practice after the simulation, and the practitioners considered the model to be useful for them.

Key words: Cannulation, cardiopulmonary resuscitation, extracorporeal membrane oxygenation, simulation, vascular model

INTRODUCTION

EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO) is a definitive resuscitative procedure for life-threatening cardiopulmonary collapse such as cardiogenic shock, massive pulmonary embolism, and refractory ventricular tachyarrhythmia.[1–4] When used for cardiopulmonary resuscitation, ECMO is known as extracorporeal cardiopulmonary resuscitation (ECPR).

In 2015, the International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations recognized ECPR as an advanced alternative for refractory cardiac arrest.[5]

Although ECMO has been widely implemented in many hospitals in Japan in this decade, there has been no comprehensive simulation training for ECMO that includes real cannulation procedures and intensive care unit (ICU) management. There had previously been very few opportunities to learn about the general guidelines of the Extracorporeal Life Support Organization (ELSO) through simulation in Japan. Although the number of high-volume simulation centers is increasing in Japan, ECMO simulation remains rare.

In order to improve the success rate of on-site resuscitative ECMO, simulation training should be widely provided for resuscitation providers.[6–9] In particular, the cannulation procedure is uncommon and difficult to perform safely. Avoiding subsequent complications is key to the success of ECMO. In general, commercially available vascular models for simulation training are expensive and their use is limited

Corresponding: *Tomoyuki Endo, MD, PhD, Division of Emergency and Disaster Medicine, Tohoku Medical and Pharmaceutical University, 1-12-1, Fukumuro, Sendai, Miyagi, 983-8512, Japan. E-mail: entomo@med.tohoku.ac.jp*
Received 13 Jun, 2016; accepted 17 Jul, 2016; online publication 23 Aug, 2016

to high-volume simulation centers. Therefore, a low-cost vascular model is needed.

In addition to cannulation procedures, ECMO practitioners responsible for ECPR should be able to carry out ECMO management combined with targeted temperature management for post-cardiac arrest patients. Such interventions require multidisciplinary cooperation and special knowledge and skills. The ECMO practitioners should have comprehensive abilities to assess and manage post-cardiac arrest patients on ECMO under targeted temperature management in order to improve patients' neurological outcomes.[4,10,11]

We hypothesized that ECMO simulation including the cannulation procedure, combined with our novel low-cost vascular model and review of ICU management of a successfully resuscitated patient by ECPR from out-of-hospital refractory ventricular fibrillation, would have long-term efficacy for practitioner knowledge, skills, and attitudes in clinical settings.

METHODS

Study design

THIS STUDY INVESTIGATED the effects of our half-day ECMO simulation on participant knowledge, skills, and attitudes, and also assessed the usefulness of our novel, low-cost vascular model "Endo-Circuit" that allows for cannulation and ECMO run.

The study included participants of our ECMO simulation between April 2013 and January 2016. We held 43 courses during this period. A total of 346 practitioners participated in this simulation. A survey questionnaire form was sent by mail or email to each participant during March 2016.

In order to elucidate the real effects on participants' ECMO practices, we chose only survey respondents who had actually engaged in ECMO practice after the simulation.

This simulation was one of the simulation programs supported by the Comprehensive Education Center for Community Medicine of Tohoku University School of Medicine (Sendai, Japan). This simulation was free of charge and announced on the internet and social network services. Participants applied to attend this seminar by email. Participant medical occupation was limited to physicians, nurses, and perfusionists who would have opportunities to engage in resuscitative ECMO in emergency departments, catheter laboratory rooms, or ICUs.

Extracorporeal membrane oxygenation simulation course

Our half-day (3-h) ECMO simulation was held in the Simulation Center for Medical Skills Training and Research at Tohoku University. This simulation was focused on veno-arterial ECMO. The Laerdal SimMan3G high fidelity simulator (Laerdal Medical, Stavanger, Norway) was used. A single instructor who had been dedicated to ECMO and ECPR practice for more than 5 years and simulation-based education as part of the emergency cardiovascular care program for more than 10 years taught every simulation. The agenda was not changed during the ECMO simulation study period. The core reference material for this simulation included web-accessible ELSO general guidelines.[12] Pre-simulation learning with these guidelines was recommended.

Novel, low-cost vascular model, "Endo-Circuit"

We developed a novel, low-cost vascular model for this simulation. The design of the vascular model is shown in Figure 1. All parts were commercially available. The internal diameter of both polyvinyl chloride tubes and plastic joints was 12 mm, which permitted insertion of cannulas up to 25 Fr. A semitransparent silicon tube with a wall thickness of 2 mm was used for puncture sites. The feeling of resistance while dilating and cannulating was similar to that of the real physical structure from the skin surface to vessels and there was almost no water leakage around the cannulation site during the actual ECMO runs. One circuit costs less than $100. In order to prevent the simulator from getting wet from leaked water, a thin transparent sheet was placed on the simulator first, and the vascular model was placed on top of the sheet.

Extracorporeal membrane oxygenation device and cannulas

Our simulation center was equipped with an old, non-clinically used ECMO machine only for training before starting this simulation. The ECMO machine was a CAPIOX (Terumo Corp., Tokyo, Japan). This is the most commonly used machine in Japan and most ECMO practitioners are familiar with it. We also used a Terumo ECMO circuit and its cannulas for this training.

Agenda

The simulation agenda was as follows:

1. Introduction to the ECMO machine (20 min)
2. Priming of the ECMO circuit (15 min)
3. Preparing cannulas (15 min)
4. Placing cannulas into the vascular model (20 min)
5. Connection of cannulas to the ECMO circuit and initiation of ECMO (15 min)

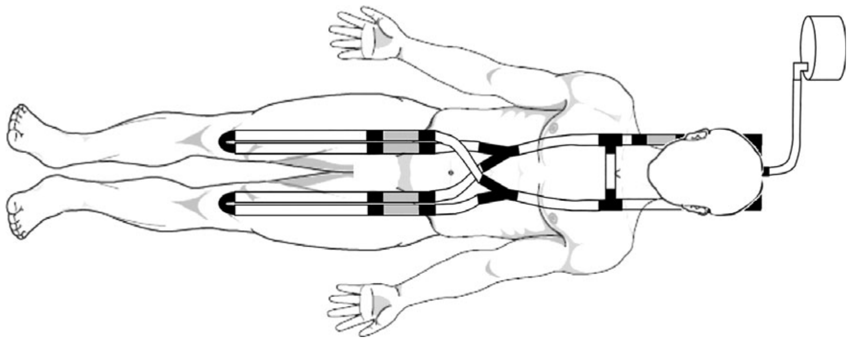

Fig. 1. Novel low-cost vascular model "Endo-Circuit". The model consisted of a water tank, polyvinyl chloride tubes (transparent parts), silicon tubes (gray parts), and joints (black parts). The internal diameter of the tubes was 12 mm. Silicon tubes with a wall thickness of 2 mm were interposed for each puncture site. Positive pressure in the circuit was generated by gravity.

6. Assessment and intervention after ECMO initiation (10 min)
7. Demonstration of in-hospital transfer of patients on ECMO (10 min)
8. Comprehensive review of whole ECMO days in ICU (60 min)
9. Weaning and decannulation of ECMO (15 min)

Cannulation procedure

We focused on the percutaneous Seldinger technique. As the vascular model was not designed for ultrasound-guided puncture, participants did not experience this technique.

Intensive care data review

In order for participants to understand the whole process of veno-arterial ECMO from initiation to weaning, we provided the interactive retrospective data review of a patient who had been successfully resuscitated with good neurological outcome by ECPR.

This retrospective review of ICU management for 7 whole days on ECMO was carried out with sequential data sheets and physiological parameters displayed on the simulator's monitor. To allow participants to simultaneously observe ICU data and physiological parameters, two monitors were placed side-by-side. Representative daily physiological parameters, including heat rate, blood pressure, pulse oximetry, respiratory rate, wave-form end-tidal carbon dioxide, and core temperature were preprogrammed in the operating computer of the simulator.

Each sheet contained a comprehensive dataset, which included ECMO settings, ventilator setting, drugs and doses, echocardiographic values and movies if available, chest radiographs, arterial blood gas analysis, complete blood count, coagulation, blood chemistry, fluid balance over 24 h, and body weight. While reviewing ICU

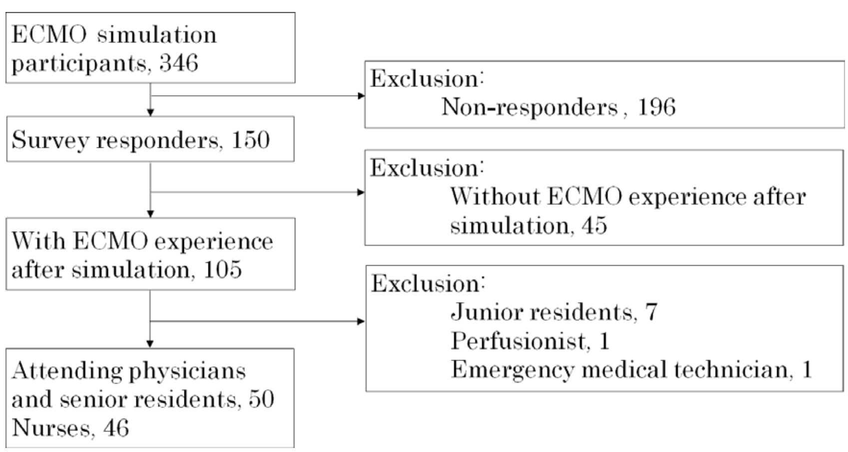

Fig. 2. Study flowchart of extracorporeal membrane oxygenation (ECMO) simulation with a novel, low-cost vascular model.

management, the instructor avoided a one-sided lecture and tried to interact with participants. Several specific physiological parameters, laboratory results, and adverse events were discussed among participants based on ELSO general guidelines.

As the modeled patient had gone through myocardial stunning for several days and had experienced bleeding complications during his ECMO run, participants focused on the assessment of cardiac function and management of bleeding complications.

Remote survey questionnaire after simulation

The remote survey asked questions on the following subjects: occupation, workplace, date of course, years of career experience, ECMO practice before simulation, problems and fears about ECMO before simulation, usefulness of the reference materials, remote effects of simulation on their practice, cannulation procedures, usefulness of the vascular model, usefulness of the ICU data review, and free comments. Their answers were based on self-evaluation, and were not objective. Some questions required evaluation on a scale from 0 to 10. The general sense of this scale was as follows: 0, nothing; 1–3, small; 4–6, moderate; 7–9, great; and 10, extreme. The Survey Questionnaire form is shown in the Appendix.

Data analysis

Statistical analysis was carried out using JMP version 12.2.0 (SAS Institute Inc., Cary, NC, USA). Comparisons between doctors and nurses were undertaken using the χ^2-test or Student's t-test as required, with significance at $P < 0.05$.

Institutional review board

This study was approved by the Institutional Review Board of Tohoku University School of Medicine. Written answers were collected anonymously and analyzed by an unlinkable anonymization. We regarded those answers as consent for this study.

RESULTS

THE 346 PRACTITIONERS who participated in the simulation included 83 attending physicians, 36 senior residents, 49 junior residents, 162 nurses, 12 perfusionists, 3 emergency medical technicians, and 1 dental doctor. Of these, 150 (43%) responded by mail or e-mail. Of those respondents, we excluded those with no ECMO experience after their simulation. Moreover, we excluded 7 junior residents, 1 perfusionist, and 1 emergency medical technician in order to assess the remote changes in the most relevant and responsible ECMO practitioners in clinical settings. Finally, 96 respondents were eligible for this study (Fig. 2).

Responses from 96 eligible survey respondents, including 50 doctors who were both attending physicians and senior residents and 46 nurses, were analyzed. The average years of clinical experience of the doctors and nurses were 8 and 10 years, respectively. The average period from simulation to this survey was 18.6 months (range, 2–34 months).

The characteristics of the eligible survey respondents are shown in Table 1. Most of the doctors and nurses worked in

Table 1. Characteristics of survey respondents who engaged in real extracorporeal membrane oxygenation (ECMO) after training with simulation

Characteristics	*n* (%)
Occupation (*n* = 96)	
Attending physician and senior resident	50 (52)
Nurse	46 (48)
Workplace of attending physician and senior resident (*n* = 50)	
Emergency department and/or ICU	37 (74)
Anesthesiology	2 (4)
Cardiology	2 (4)
Internal medicine	2 (4)
Cardiothoracic surgery	1 (2)
Surgery	1 (2)
Unknown	5 (10)
Workplace of nurses (*n* = 46)	
Emergency department and/or ICU	43 (93)
Unknown	3 (7)
Experience with ECMO before the simulation, Yes (*n* = 96)	
Priming	18 (19)
Cannulation	24 (25)
Assistance for cannulation	39 (41)
ICU care	81 (84)
Circuit exchange	33 (34)
In-hospital transfer	64 (67)
Experience with ECMO after the simulation, Yes (*n* = 96)	
Priming	15 (16)
Cannulation	33 (34)
Assistance for cannulation	35 (36)
ICU care	83 (86)
Circuit exchange	27 (28)
In-hospital transfer	58 (60)

ICU, intensive care unit.

emergency departments and/or ICUs. According to their retrospective estimations, the respondents had problems and fears to some degree about ECMO before simulation, especially among nurses (Table 2).

Among all answers from eligible participants, the average score for long-term efficacy for every practice was more than 4 (Table 3). Doctors' ratings of priming (skills, attitude), puncture/cannulation/connection (knowledge, skills, and attitude) and ECMO initiation/pump flow setting (skills, attitude) were significantly higher than nurses' ratings.

The ICU data review showed a score of more than 6 on average for every subject (Table 4). Doctors' ratings of understanding of echocardiography and weaning process were significantly higher than nurses' ratings.

The usefulness of our original low-cost vascular model was rated at a median score of 7 in every subject (Table 5).

DISCUSSION

OUR STUDY IS unique in terms of evaluating the long-term efficacy of ECMO simulation. The results showed that even experienced ECMO practitioners had problems and fears regarding ECMO before simulation, especially nurses. Among all eligible participants, the average long-term efficacy score for every practice was above 4 (scale, 0–10). Even though this scaling was based on self-evaluations, our ECMO simulation was considered to have moderate positive long-term efficacy for the knowledge, skills, and attitudes of these participants.

With regard to differences in long-term efficacy between doctors and nurses, doctors tended to be confident with priming, puncture/cannulation/connection, and ECMO initiation/pump flow setting than were nurses. As doctors would usually be responsible for these practices, they might be more aware of them after the simulation.

Table 2. Problems and fears about extracorporeal membrane oxygenation (ECMO) before the simulation, reported by course participants

	All (n = 96)	Doctors (n = 50)	Nurses (n = 46)	P-value
Problems				
Usage of device	42 (44)	25 (50)	17 (37)	0.190
Priming	39 (41)	22 (44)	17 (37)	0.480
Cannulation	28 (29)	17 (34)	11 (24)	0.270
ECMO initiation/pump flow setting	40 (42)	25 (50)	15 (33)	0.080
Evaluation of hemodynamic variables	38 (40)	20 (40)	18 (39)	0.930
Evaluation of cardiac function	36 (38)	19 (38)	17 (37)	0.910
Anticoagulation management	23 (24)	16 (32)	7 (15)	0.041
In-hospital transfer	17 (18)	7 (14)	10 (22)	0.320
Circuit exchange	29 (30)	16 (32)	13 (28)	0.690
Hemorrhagic complication	30 (31)	18 (36)	12 (26)	0.290
Ischemic complication	29 (30)	17 (34)	12 (26)	0.390
Weaning	33 (34)	19 (38)	14 (30)	0.430
Fears				
Usage of device	64 (67)	31 (62)	33 (72)	0.310
Priming	65 (68)	31 (62)	34 (74)	0.210
Cannulation	46 (48)	22 (44)	24 (52)	0.420
ECMO initiation/pump flow setting	45 (47)	19 (38)	26 (57)	0.070
Evaluation of hemodynamic variables	43 (45)	11 (22)	32 (70)	<0.001
Evaluation of cardiac function	35 (37)	10 (20)	25 (54)	<0.001
Anticoagulation management	29 (30)	6 (12)	23 (50)	<0.001
In-hospital transfer	51 (53)	18 (46)	33 (72)	<0.001
Circuit exchange	61 (64)	24 (48)	37 (80)	0.001
Hemorrhagic complication	53 (55)	19 (38)	34 (74)	<0.001
Ischemic complication	50 (52)	20 (40)	30 (65)	0.001
Weaning	51 (53)	20 (40)	31 (67)	0.007

Data are given as number (%).

Table 3. Long-time efficacy of simulation training in extracorporeal membrane oxygenation (ECMO) in terms of knowledge, skills, and attitude

	All, mean ± SD	Doctors, mean ± SD	Nurses, mean ± SD	*P*-value
Usage of device				
Knowledge	5.5 ± 2.2	5.6 ± 2.4	5.4 ± 2.0	0.730
Skills	5.3 ± 2.4	5.6 ± 2.6	5.0 ± 2.1	0.210
Attitude	5.1 ± 2.3	5.5 ± 2.4	4.8 ± 2.2	0.120
Priming				
Knowledge	5.2 ± 2.5	5.6 ± 2.5	4.7 ± 2.4	0.065
Skills	4.6 ± 2.6	5.5 ± 2.5	3.6 ± 2.4	<0.001
Attitude	4.4 ± 2.7	5.4 ± 2.4	3.3 ± 2.6	<0.001
Puncture/cannulation/connection				
Knowledge	5.1 ± 2.8	5.9 ± 2.9	4.2 ± 2.5	0.003
Skills	4.3 ± 3.1	5.6 ± 3.0	2.9 ± 2.6	<0.001
Attitude	4.2 ± 3.1	5.4 ± 3.0	2.8 ± 2.5	<0.001
ECMO initiation/pump flow setting				
Knowledge	5.1 ± 2.6	5.5 ± 2.9	4.7 ± 2.3	0.150
Skills	4.7 ± 2.8	5.4 ± 2.9	3.9 ± 2.5	0.006
Attitude	4.5 ± 2.8	5.3 ± 2.8	3.8 ± 2.6	0.009
Understanding of hemodynamic variables				
Knowledge	5.7 ± 2.2	5.9 ± 2.5	5.5 ± 1.8	0.400
Skills	5.5 ± 2.3	5.9 ± 2.5	5.1 ± 2.1	0.093
Attitude	5.3 ± 2.3	5.6 ± 2.6	5.0 ± 2.1	0.200
Understanding of cardiac function				
Knowledge	5.4 ± 2.1	5.5 ± 2.5	5.3 ± 1.7	0.710
Skills	5.1 ± 2.3	5.3 ± 2.6	4.9 ± 2.0	0.400
Attitude	5.0 ± 2.2	5.1 ± 2.4	4.8 ± 2.0	0.400
Anticoagulation management				
Knowledge	5.1 ± 2.4	4.8 ± 2.8	5.3 ± 1.8	0.270
Skills	4.8 ± 2.4	4.6 ± 2.7	5.0 ± 2.0	0.420
Attitude	4.7 ± 2.4	4.5 ± 2.7	4.9 ± 2.1	0.480
In-hospital transfer				
Knowledge	5.0 ± 2.4	4.9 ± 2.6	5.1 ± 2.3	0.610
Skills	4.7 ± 2.4	4.9 ± 2.6	4.5 ± 2.2	0.500
Attitude	4.6 ± 2.5	4.9 ± 2.6	4.3 ± 2.3	0.240
Circuit exchange				
Knowledge	4.8 ± 2.4	4.7 ± 2.7	4.8 ± 2.1	0.830
Skills	4.3 ± 2.6	4.6 ± 2.8	4.0 ± 2.3	0.340
Attitude	4.2 ± 2.7	4.4 ± 2.9	3.9 ± 2.4	0.310
Hemorrhagic complications				
Knowledge	5.4 ± 2.2	5.3 ± 2.6	5.6 ± 1.8	0.450
Skills	5.1 ± 2.4	5.2 ± 2.6	5.1 ± 2.1	0.840
Attitude	5.0 ± 2.5	5.1 ± 2.7	4.8 ± 2.3	0.590
Ischemic complications				
Knowledge	5.5 ± 2.2	5.2 ± 2.6	5.8 ± 1.7	0.170
Skills	5.1 ± 2.4	4.9 ± 2.7	5.2 ± 2.0	0.510
Attitude	4.9 ± 2.4	4.8 ± 2.6	5.0 ± 2.1	0.800
Weaning/decannulation				
Knowledge	5.6 ± 2.4	5.7 ± 2.8	5.4 ± 2.1	0.580
Skills	5.2 ± 2.4	5.4 ± 2.7	5.1 ± 2.1	0.600
Attitude	5.1 ± 2.5	5.3 ± 2.7	4.8 ± 2.3	0.360

SD, standard deviation.

Table 4. Usefulness of intensive care unit daily data review during simulation training in extracorporeal membrane oxygenation

	All, mean ± SD	Doctors, mean ± SD	Nurses, mean ± SD	*P*-value
Understanding of echocardiography	6.1 ± 2.6	6.8 ± 2.2	5.5 ± 2.7	0.012
Understanding of arterial blood gas analysis	6.4 ± 2.3	6.7 ± 2.2	6.1 ± 2.3	0.180
Understanding of laboratory data	6.5 ± 2.2	6.8 ± 2.3	6.2 ± 2.1	0.200
Understanding of fluid balance	6.4 ± 2.3	6.5 ± 2.4	6.3 ± 2.1	0.590
Understanding of vasoactive agents	6.3 ± 2.4	6.4 ± 2.5	6.2 ± 2.2	0.540
Understanding of weaning process	6.5 ± 2.4	7.0 ± 2.4	5.9 ± 2.4	0.022
Understanding of blood transfusion protocol	6.5 ± 2.2	6.7 ± 2.3	6.2 ± 2.2	0.260
Understanding of management for hemorrhagic complication	6.5 ± 2.1	6.6 ± 2.2	6.4 ± 2.1	0.580

SD, standard deviation.

Table 5. Usefulness of the low-cost vascular model in simulation training in extracorporeal membrane oxygenation (ECMO)

	Median (IQR)
Procedure of puncture/guide wire insertion/cannulation	7 (6–10)
Understanding of hemodynamics during ECMO	7 (6–9)
Understanding of negative pressure on the venous drainage side	7 (5–9)

IQR, interquartile range.

Interestingly, the ICU data review had average scores above 6 (scale, 0–10) for every subject. Participants could learn about the complex relationships among many variables shown simultaneously on two monitors. One monitor showed a comprehensive dataset and treatment for a single day, while the other showed representative physiological parameters such as heat rate, pulse oximetry, waveform capnography, arterial pressure, pulmonary arterial pressure, and core temperature. This teaching method might be beneficial and made it easy for participants to understand the entire process of a single ECMO run. In addition, the modeled patient had typical myocardial stunning and hemorrhagic complications, that helped the participants to learn about these topics.

From a procedural point of view, the vascular model we developed for cannulation training seemed to be very useful. This model has several advantages. Learners are able to: (i) apply on any adult full-body simulator, (ii) change punctured parts very easily, (iii) experience backflow while performing puncture and cannulation due to positive pressure in the circuit generated by gravity, (iv) watch the whole process of wiring and cannula insertion though transparent polyvinyl chloride tubes, (v) experience connecting cannulas to the ECMO circuit, (vi) actually run ECMO. Despite its low fidelity in terms of anatomical structure, participants evaluated the usefulness of this model at a relatively high score (median score of 7). In order to disseminate this kind of simulation, this vascular model could be an effective tool for instructors in charge of ECMO simulation.

Although this simulation is a short, half-day program, it could lead to positive changes in the knowledge, skills, and attitudes of ECMO practitioners in various subjects. Regarding the moderate to high rates of reported problems and fears before the simulation, this kind of learning opportunity might need urgent implementation. This compact simulation could be provided to anyone wanting to learn about ECMO.

Limitations

This study has several limitations. The survey respondents represented 43% of all participants. Thus, this survey consisted of answers from only motivated practitioners and does not necessarily reflect the perspectives of all participants. The survey was based on the participants' subjective evaluations. Thus, the assessment does not reflect true improvement in their knowledge and skills. Objective evaluations with comparison are necessary in order to assess their true competency. The time periods between simulation and this survey ranged from 2 months to 3 years. Experience during this period may cause biases in the respondents' answers to the survey questions. As the puncture site was not designed for an ultrasound-guided procedure, the participants could not practice these procedures with the vascular model. Instead, they were required to develop these skills in real clinical settings.

CONCLUSION

A HALF-DAY ECMO simulation including a cannulation procedure with a low-cost vascular model and complete review of the ICU management of a successfully resuscitated patient had positive long-term efficacy for the knowledge, skills, and attitudes of ECMO practitioners who engaged in ECMO practice after simulation.

CONFLICT OF INTEREST

NONE.

ACKNOWLEDGEMENTS

WE GRATEFULLY THANK the Simulation Center for Medical Skills Training and Research for their assistance in hosting the simulation program. This study was supported by the Comprehensive Education Center for Community Medicine of Tohoku University School of Medicine, Japan.

REFERENCES

1 Mebazaa A, Tolppanen H, Mueller C *et al.* Acute heart failure and cardiogenic shock: a multidisciplinary practical guidance. Intensive Care Med. 2016; 42: 147–63.
2 Yusuff HO, Zochios V, Vuylsteke A. Extracorporeal membrane oxygenation in acute massive pulmonary embolism: a systematic review. Perfusion. 2015; 30: 611–6.
3 Stub D, Bernard S, Pellegrino V *et al.* Refractory cardiac arrest treated with mechanical CPR, hypothermia, ECMO and early reperfusion (the CHEER trial). Resuscitation. 2015; 86: 88–94.
4 Sakamoto T, Morimura N, Nagao K *et al.* Extracorporeal cardiopulmonary resuscitation versus conventional cardiopulmonary resuscitation in adults with out-of-hospital cardiac arrest: a prospective observational study. Resuscitation. 2014; 85: 762–8.
5 Callaway CW, Soar J, Aibiki M *et al.* Part 4: advanced life support: 2015 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2015; 132: S84–145.
6 Brum R, Rajani R, Gelandt E *et al.* Simulation training for extracorporeal membrane oxygenation. Ann. Card. Anaesth. 2015; 18: 185–90.
7 Allan CK, Pigula F, Bacha EA *et al.* An extracorporeal membrane oxygenation cannulation curriculum featuring a novel integrated skills trainer leads to improved performance among pediatric cardiac surgery trainees. Simul. Healthc. 2013; 8: 221–8.
8 Brazzi L, Lissoni A, Panigada M *et al.* Simulation-based training of extracorporeal membrane oxygenation during H1N1 influenza pandemic: the Italian experience. Simul. Healthc. 2012; 7: 32–4.
9 Burton KS, Pendergrass TL, Byczkowski TL *et al.* Impact of simulation-based extracorporeal membrane oxygenation training in the simulation laboratory and clinical environment. Simul. Healthc. 2011; 6: 284–91.
10 Nagao K, Kikushima K, Watanabe K *et al.* Early induction of hypothermia during cardiac arrest improves neurological outcomes in patients with out-of-hospital cardiac arrest who undergo emergency cardiopulmonary bypass and percutaneous coronary intervention. Circ. J. 2010; 74: 77–85.
11 Nagao K, Hayashi N, Kanmatsuse K *et al.* Cardiopulmonary cerebral resuscitation using emergency cardiopulmonary bypass, coronary reperfusion therapy and mild hypothermia in patients with cardiac arrest outside the hospital. J. Am. Coll. Cardiol. 2000; 36: 776–83.
12 Extracorporeal Life Support Organization [homepage on the internet]. General Guidelines for all ECLS Cases Version 1.3. [cited November 2013]. Available from: http://www.elso.org/resources/Guidelines.aspx.

APPENDIX

Remote post-simulation survey questionnaire regarding training in extracorporeal membrane oxygenation (ECMO)

Survey questionnaire of ECMO simulation	
1. Your occupation	
2. Your working place or department	
3. Date of your participation in this simulation	
4. Please let us know your years of career experience at the time that you participated in this simulation	
5. Please let us know your experience with ECMO before you participated in this simulation	
Priming	Yes/No
Cannulation	Yes/No
Assistance with cannulation	Yes/No
ICU care	Yes/No
Circuit exchange	Yes/No
In-hospital transfer	Yes/No
6. Please let us know your problems and fears regarding ECMO before your participation in the simulation	
Device usage	Problems/Fears
Priming	Problems/Fears
Cannulation	Problems/Fears
ECMO initiation/pump flow setting	Problems/Fears
Evaluation of hemodynamic variables	Problems/Fears
Evaluation of cardiac function	Problems/Fears
In-hospital transfer	Problems/Fears
Circuit exchange	Problems/Fears
Hemorrhagic complications	Problems/Fears
Ischemic complications	Problems/Fears
Anticoagulation management	Problems/Fears
Weaning	Problems/Fears
7. Please let us know your latest status about ECMO practice	
Experienced ECMO run	Yes/No
Experienced cannulation	Yes/No
Experienced cannulation assistance	Yes/No
Experienced ICU care	Yes/No
Experienced in-hospital transfer	Yes/No
Experienced circuit exchange	Yes/No
8. Have you ever used any materials that were used in simulation?	
ELSO general guidelines	
Written tips related to ECMO care	
Images related to ECMO care	
Information about ECMO from Japanese Circulation Society guidelines	
ICU daily data review	
9. If you have used any of the former materials, please rate their usefulness, from 0 to 10	
10. In a real clinical setting, has this simulation had any effects on your knowledge, skills, and attitude? Please rate on a scale from 0 to 10, respectively. If you have had no ECMO experience after the simulation, please estimate the expected change on your next ECMO practice	
Usage of device	Knowledge/Skills/Attitude
Priming	Knowledge/Skills/Attitude
Puncture/cannulation/connection	Knowledge/Skills/Attitude
ECMO initiation/setting pump flow	Knowledge/Skills/Attitude
Understanding of hemodynamic variables	Knowledge/Skills/Attitude
Understanding of cardiac function	Knowledge/Skills/Attitude
Anticoagulation management	Knowledge/Skills/Attitude

Appendix. (Continued)

Survey questionnaire of ECMO simulation	
In-hospital transfer	Knowledge/Skills/Attitude
Circuit exchange	Knowledge/Skills/Attitude
Hemorrhagic complication	Knowledge/Skills/Attitude
Ischemic complication	Knowledge/Skills/Attitude
Weaning/decannulation	Knowledge/Skills/Attitude
11. Please rate your practice of ECMO cannulation before and after simulation (only experienced provider)	
Puncture procedure before simulation	Blind puncture without ultrasound Puncture after making landmark with ultrasound Real-time ultrasound-guided puncture
Puncture procedure after simulation	Blind puncture without ultrasound Puncture after making landmark with ultrasound Real-time ultrasound-guided puncture
Guidewire confirmation before simulation	Without any image With fluoroscope Check inferior vena cava and aorta with ultrasound
Guidewire confirmation after simulation	Without any image With fluoroscope Check inferior vena cava and aorta with ultrasound
12. Please evaluate the usefulness of the low-cost vascular model used in the simulation, from 0 to 10	
Understanding of procedures about puncture, guidewire handling, and cannulation	
Understanding of hemodynamics during ECMO run	
Understanding of negative pressure on the venous drainage side	
13. Please evaluate the usefulness of the ICU data review sheets used in this simulation, from 0 to 10	
Understanding of echocardiography	
Understanding of arterial blood gas analysis	
Understanding of laboratory data	
Understanding of fluid balance	
Understanding of vasoactive agents	
Understanding of weaning process	
Understanding of blood transfusion protocol	
Understanding of management for hemorrhagic complication	
14. Any other comments	

ELSO, Extracorporeal Life Support Organization; ICU, intensive care unit.