Chapter 10

Education Curriculum on Extracorporeal Membrane Oxygenation: The Evolving Role of Simulation Training

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Abstract

Continuing education is essential for the success and safety of an extracorporeal membrane oxygenation (ECMO) programme. However, it is challenging due to the intrinsic characteristic of ECMO—a complex, high-risk, low-volume clinical activity which require teamwork, inter-professional communication, critical decision and rapid response especially in emergency. Thus, simulation is a rapidly evolving teaching methodology in ECMO education to address those training needs that cannot be entirely addressed by traditional teaching modalities. The development of a simulation programme requires commitment on resources for equipment, environment setup and training of personnel. Knowledge on ECMO management, education science and debriefing technique forms the cornerstone of successful ECMO simulation facilitators and hence the simulation programme. Currently, researches have already shown that ECMO simulation can improve individual and team performance despite that its impact on patient outcome is still unknown. In the future, the role of simulation will increase importantly in multicentre research, certifying specialists and credentialing if standardization of training curriculum can be achieved.

Keywords: extracorporeal membrane oxygenation, human learning, high-fidelity simulation, debriefing, credentialing

1. Introduction

Extracorporeal membrane oxygenation (ECMO) is well known to be a highly complex but low-volume clinical activity. Complications may arise at many stages of ECMO care—from cannulation to during the ECMO run, to weaning and decannulation. Most complications are low occurrence but potentially life-threatening events. As a result, continuing education is essential to ensure the success and safety of an ECMO programme. Due to the inherent characteristics of ECMO service provision, the implementation of such educational activities is not straightforward. Firstly, professionals who undergo training for ECMO are usually experienced health-care providers. The learning processes of experienced adults are more complex, requiring assimilation of newly acquired knowledge with past experiences and roles. In these instances, learning will be more effective when the teaching is learner-centred and the learner is actively engaged. Secondly, the low-volume nature of severe ECMO complications renders training by apprenticeship difficult. Thirdly, while most ECMO runs are uneventful, in situation when crises occur, ECMO care providers have to respond emergently and proficiently under a stressful environment and often in a team-based approach. Fourthly, the provision of ECMO care often requires critical decision-making across specialties and professions.

Traditional ECMO teaching modalities like reading, didactic lectures, water drills (referring to deliberate practice in a closed-loop ECMO circuit model, e.g. changing the oxygenator or using the hand crank) and practices in the animal laboratory (where a living animal is cannulated to simulate human responses) primarily focus on cognitive and technical skills, with little emphasis on behavioural skills like communication and leadership that are fundamental during training for ECMO. ECMO simulation has rapidly evolved as an effective learning methodology that supplements traditional teaching modalities. It creates a standardized, controlled, safe and repeatable environment that aims to mimic the realistic clinical environments, so that new skills can be learnt and practised without doing harm to patients and learners.

In this chapter, we discuss simulation training in ECMO from the perspectives of human learning theory, simulation programme setup (including scenario design, equipment and resources), debriefing, current evidence and future challenges.

2. Human learning models and simulation-based education

Simulation is often considered simply as an exercise where learners perform actions in an environment simulated to resemble reality, and facilitators are present to ensure its smooth running and to lead a discussion afterwards. As a relatively new method of teaching in medical education, there are often misunderstandings about simulation training and inadequate knowledge of its execution. High-quality simulation is backed by evidence-based educational theories and includes purposefully designed scenarios and well-trained facilitators.

Kolb's theory on experiential learning forms the foundation of simulation-based education. In his theory, learners enter the learning cycle through experiencing an event—either a real patient experience or simulated activities ('concrete experience'). Afterwards, through self-reflection or reflection assisted by facilitator ('reflection'), a new insight of the event is created ('abstract conceptualization'). Finally, this new insight is applied in a similar simulated or real-life event ('active experimentation') [1].

Neil Flemming's VARK model describes four modalities in an individual's preferred method of learning—Visual, Auditory, Reading and Kinesthetic [2]. Different individuals learn more

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effectively when they receive specific types of stimulation. Simulation, through active engagement with hands-on action, produces better training effect in kinesthetic learners.

Simulation experiences can trigger learner emotions and it is known that a highly activated core affect can positively influence the uptake and retention of knowledge and skills. The Change Theory proposed by Lewin/Schein highlights the relationship between affect and learning. It theorized a three-stage model of change, namely unfreezing, transition and refreezing. 'Unfreezing' refers to the motivation to change by adding new force or removing existing concepts that are influencing behaviour. It unavoidably leads to emotional stress, largely a sense of dissatisfaction with oneself as a result of disconfirmation of the present condition. Moreover, it creates a survival anxiety as the pre-existing belief is rejected and a learning anxiety in which the previously learnt knowledge has to be unlearnt. 'Unfreezing' is followed by 'transition', a process of moving onto a new state, which requires reconstruction of one's thoughts, feelings and behaviours. 'Refreezing' is the final stage in which the newly acquired knowledge, concepts and behaviours are adopted and assimilated [3].

The principles underlying simulation scenario design, together with the debriefing process, are largely developed based on one of these educational theories. Simulation training aims to facilitate acquisition of knowledge and skills and to change one's perceptions and behaviour. The following sections further elaborate on scenario design and debriefing in ECMO simulation.

3. Scenario design in ECMO simulation

Scenario design is one of the key elements in simulation education. On designing a scenario, thorough understanding of the background, training needs and experience of learners is essential. In particular, meticulous attention must be paid to tailor the learning goals and objectives to the target learner. The goal of a scenario refers to the overall educational mission the learners are expected to achieve. Detailed objectives may be made up of cognitive, psychomotor, behavioural or affective component [4]. As an example, the goals and objectives for novice ECMO learners would be different from experienced ECMO learners in a scenario of ECMO blood pump failure. For the novice, the goal would be 'to switch to a standby machine in emergency setting', with objectives including 'recognize blood pump failure and its related physiological changes' (cognitive) and 'acquire the technical skill of using hand crank' (psychomotor). For the experienced learner, the goal may be more advanced, such as 'demonstration of teamwork in managing blood pump failure crisis', achieved through the objective of 'demonstrating effective communication and leadership skills' (behavioural), in addition to the cognitive and psychomotor skills. **Table 1** lists examples of common scenarios used in an Asia-Pacific ELSO Adult ECMO Training Course and **Table 2** illustrates the goals and objectives of some of these scenarios.

Some deviation of simulation scenarios from the real-world practice is acceptable. Especially for novice ECMO learners, they are expected to adopt the role of the ECMO specialist during simulation learning, regardless of their current position as senior consultants, junior doctors, nurses or perfusionists. This is to ensure competency in the various aspects of troubleshooting and response to ECMO emergencies after they undergo training. This training concept reflects the reality that

Scenario Topic	Examples
Routine ECMO circuit management	External compression on return tubing
	Heater failure with hypothermia
	Oxygenator failure
Emergencies in ECMO care	Blood pump failure
	Oxygen supply failure
	Circuit air embolism
Patient management	Venous insufficiency
	Recirculation
	Permissive hypoxaemia in VV ECMO
	Tension pneumothorax
	Ventricular fibrillation in VA ECMO
	Differential hypoxaemia in VA ECMO

Table 1. Examples of scenarios in adult ECMO simulation training (adopted from Asia-Pacific ELSO Adult ECMO Training Course, Queen Mary Hospital).

Scenarios	Goals and learning objectives
External compression on return tubing	Goal:
	Understand the change in circuit pressure related to preload and afterload conditions.
	Objectives:
	(C) Recognize high return pressure with drop in ECMO blood flow signifying post-pump obstruction.
	(P) Systematic circuit check.
Oxygenator failure	Goal:
	Diagnosis of oxygenator failure.
	Objectives:
	(C) Recognize features of oxygenator failure – elevated transmembrane pressure, decrease oxygenator function, clot in oxygenator, disseminated intravascular coagulopathy blood picture.
	(P) Circuit check for clot in oxygenator.
Blood pump failure	Goal:
	Management of blood pump failure.
	Objectives:
	(C) Recognize presentation of blood pump failure—loss of ECMO blood flow, change of patient's hemodynamic and physiological parameters.
	(P) Technique of using hand crank.
	(B) Communication to call for help for resuscitation and patient stabilization.

Scenarios	Goals and learning objectives
Oxygen supply failure	Goal:
	Understand the importance of complete circuit check in ECMO emergency.
	Objectives:
	(C) Recognize patient desaturation, loss of color difference in ECMO limbs.
	(P) Systematic circuit check and potential sites of oxygenation supply disconnection.
Circuit air entrainment	Goal:
	Diagnose and manage circuit air entrainment.
	Objectives:
	(C) Recognize presentation of circuit air entrainment—abnormal noise from ECMO circuit, decrease ECMO blood flow with corresponding change in patient's hemodynamic and physiological parameters.
	(C) Recognize potential source of air entrainment—negative pressure side.
	(P) Complete circuit check to identify source of air and stop further entrainment. Technical skill for circuit de-airing or technical skill to change to new circuit.
	(B) Teamwork and communication skills during circuit de-airing, changing ECMO circuit, and patient resuscitation.
Venous insufficiency	Goal:
	Understand the cause of venous insufficiency and its management.
	Objectives:
	(C) Recognize presentation of venous insufficiency—drainage limb chattering, more negative venous pressure, decrease ECMO blood flow.
	(C) Recognize the cause of venous insufficiency—hypovolaemia, excessive pump speed, inappropriate drainage catheter position; and their respective management.
Recirculation	Goal:
	Understand the physiology of recirculation and its management.
	Objectives:
	(C) Recognize the presentation of recirculation—desaturation without problems in ECMO blood flow and oxygen supply, loss of color differential in drainage and return limb, elevated SvO2.
	(C) Recognize the causes of recirculation—close proximity of drainage and return cannula, excessive pump speed.

Table 2. Examples of goals and learning objectives of common ECMO simulation scenarios (C = cognitive, P = psychomotor, B = behavioural) (adopted from Asia-Pacific ELSO Adult ECMO Training Course, Queen Mary Hospital).

many ECMO centres nowadays adopt a mixed ECMO care model, with the ECMO team consisting of physicians, nurses, perfusionists and respiratory therapists [5, 6]. The other advantage of including mixed roles in simulation is the possibility of modifying the focus of training as the team matures, to aspects such as leadership, communication and teamwork during emergencies.

Furthermore, simulation scenarios can be adjusted according to the characteristics of the respective ECMO team and health-care institution. The scenario design for institutions using a bedside nurse ECMO care model will be different from that using a perfusionist care model.

By fine-tuning the expected roles of participants, flexibility in meeting the training needs of individual centres can be met, although possibly at the expense of lack of standardization and generalizability across centres.

4. Setup of a high-fidelity and immersive simulation

High-fidelity simulation usually involves full-body manikins set up in environments made to simulate real-life situations. The presentation of changing patient physiology data and machine or physiological parameter alarms is used to mimic realistic health-care settings and elicits desired responses from learners. This is in contrast to water drills, considered low-fidelity simulation, which runs in the form of deliberate practice in a static and alarm-free environment. High-fidelity simulation is an immersive experience for the participant and offers the opportunity to introduce knowledge through challenging and reflecting upon learners' individual responses. It is also a useful tool to introduce concepts related to team-based care.

4.1. Simulation environment

A variety of clinical environments involving ECMO care may be simulated, for example, ICU, operating theatre and emergency room. In institutions without dedicated simulation facilities, one can consider setting up the simulation model in an unoccupied cubicle in the ICU or the emergency room to achieve contextual reality.

Typical equipment for veno-venous ECMO simulation will include an intubated manikin (e.g. megacode Kelly) attached to a mechanical ventilator. Arterial lines, drug infusion devices and Foley catheters may be added as necessary. Essential physiological parameters, for example, arterial blood pressure, pulse rate, ECG rhythm, SpO2 and central venous pressure should be clearly displayed (**Figure 1**), and these should be controlled remotely by a compatible computer programme (e.g. Laerdal SimMan).

4.2. Manikin modification and incorporation of an ECMO circuit

A commonly used method in ECMO simulation is to connect the access and return cannulae of the ECMO circuit to a volume reservoir hidden inside the manikin (**Figure 2**, left upper panel). Access ports on the volume reservoir are mandatory (**Figure 2**, left lower panel) to allow manipulation of volume and hence pressure status within the ECMO circuit in different simulation scenarios. For example, access insufficiency is simulated by withdrawal of fluid from the reservoir, causing collapse of the reservoir, a decreased ECMO flow, and a negative access pressure. Circuit air entrainment may be simulated by the controlled introduction of air into the circuit. Additional modification may be required for the display of pressure changes, depending on the ECMO machine used—the Medos Deltastream and Maquet Cardiohelp systems display the operating pressures directly on the screen of the ECMO consoles, whereas older ECMO systems like the Maquet Rotaflow require connection of pressure transducers to different parts of the ECMO circuit (**Figure 2**, right panel). Lansdowne et al.

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Figure 1. Basic setup of a high-fidelity ECMO simulation environment. A confederate (dressed in blue scrubs) participated in this scenario (adopted from Asia-Pacific Adult ECMO Course, Queen Mary Hospital).

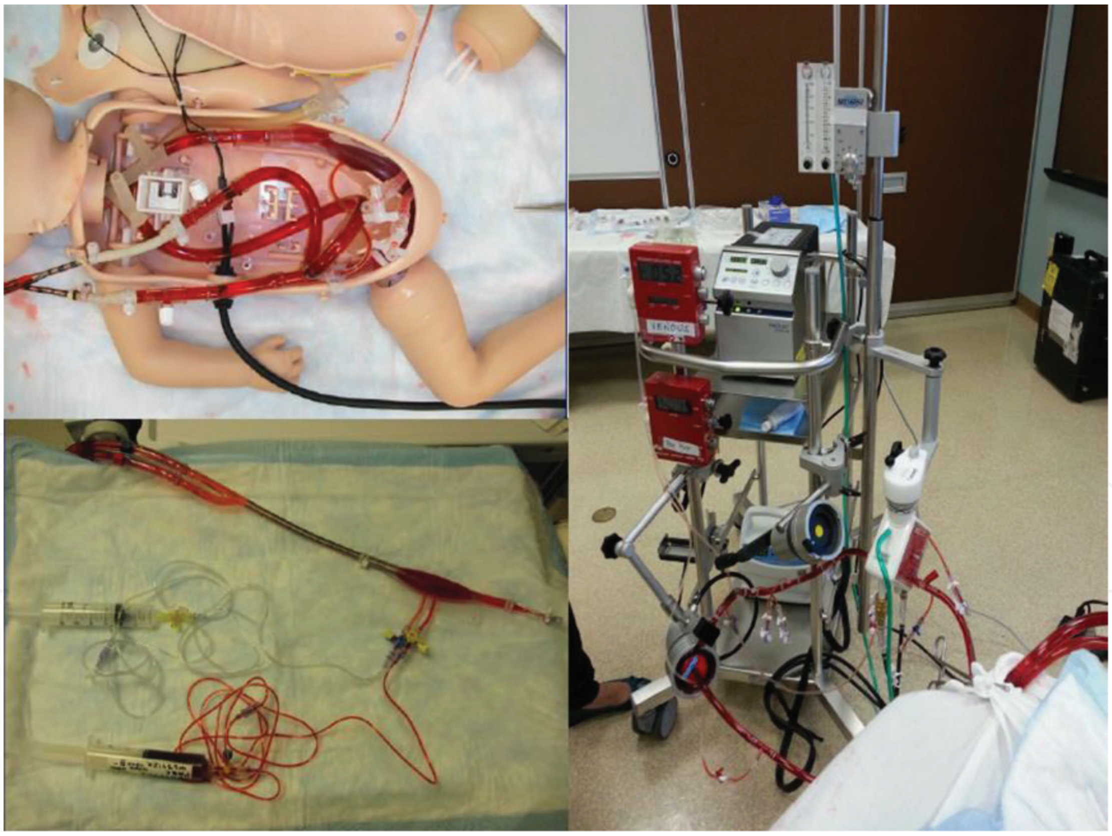

Figure 2. Left upper and lower panels—hidden volume reservoir and tubings inside a pediatric manikin; and the setup of a volume reservoir (photos courtesy of Dr. Mark Ogino). Right panel—ECMO circuit setup with additional pressure transducers (in red) for circuit pressure display.

described a model that incorporates a modified manikin, an ECMO circuit and the hydraulic module of the Orpheus Perfusion Simulator to produce a realistic simulation [7].

4.3. Limitations

A major limitation in ECMO simulation is the cost of medical devices and ECMO consumables. The abovementioned simulation models all require a functioning ECMO machine and a complete ECMO circuit, including the oxygenator, that are subject to wear and tear. The availability of equipment and the costs of replacement are real economical concerns, especially for newly developed centres. The advent of 3-D printing technologies may hold promise for the construct of economical oxygenators [8].

Other limitations arise from the technological parts of the simulation. For instance, it is difficult to simulate the difference in colour of oxygenated and deoxygenated blood, which is important in scenarios related to recirculation and oxygen supply failure. Other technical difficulties include simulating blood clots in the oxygenator and access line chattering. Ongoing research to overcome these challenges is underway, such as the use of thermochromic fluid to simulate colour changes of the circuit blood [8].

5. Special role of the facilitator in ECMO simulation and the debriefing process

The important role of facilitators in simulation education cannot be underscored. Firstly, facilitators should have a thorough understanding of ECMO physiology, patient physiology and their interaction. This forms the prerequisite for facilitators to react swiftly and accurately in real time according to the actions of learners, by manipulating the ECMO flow and pressure (through volume manipulation of the reservoir) and the physiological parameters (through the computer software). For example, when learners increase the ECMO pump speed excessively, the facilitator should make a series of changes to the circuit and patient parameters, which includes withdrawing volume from the reservoir to create a state of venous insufficiency, dropping the SpO2 and SvO2, creating mild tachycardia, and so on. More importantly, during the simulation exercise, facilitators have to denote key actions and behaviours that will be valuable for discussion in the subsequent debriefing session. As a result of the many roles and actions required of facilitators in ECMO simulation, most scenarios require the presence of at least two facilitators.

The other role of the facilitator is the debriefer. Debriefing, the reflective process in Kolb's learning theory provides an opportunity for learners to reflect upon their performance, resolve lingering questions and reinforce learning objectives. It is the most crucial part of simulation learning and was described as the 'heart and soul' of the simulation experience. The aim of debriefing is to constructively review 'what has happened' and 'why it happened' in the simulated event. In the 'frame-action-result' model described by Rudolph, learners have their own 'frames'—their assumption, knowledge and feelings that drive their 'actions', which in turn end up with different 'results' [9]. While actions and results are easily observable, frames are often invisible. A successful debriefer needs to act as a 'cognitive detector', to uncover the 'frame of mind' of the learners and to help them gain better insight of their own frames, so that behavioural change may follow.

The detailed techniques to achieve an effective debriefing are out of the scope of this chapter. Nonetheless, it is worthwhile to mention some of the main principles. As a rule of thumb, confidentiality with regard to learners' performance should be strictly complied, so that they feel safe to express themselves, especially after difficult, stressful, or poorly performed scenarios.

Mutual respect and trust among learners and debriefers are essential to encourage free communication. Debriefers should positively acknowledge the contribution and motivation of the learners. Even when faced with an apparently 'poor' performance, debriefers should remain curious and explore the reasons behind the behaviour [10]. The 'advocacy-inquiry' conversation technique has been described to facilitate this process.

Simulation educators have developed frameworks to facilitate the debriefing process. Scholars from the Center for Medical Simulation at Harvard Medical School advocate a three-step model (reaction, understanding and summary), while those from the Winter Institute for Simulation Education and Research (WISER) of University of Pittsburgh use the 'gather, analyze, and summarize' (GAS) debriefing tool. Debriefers should familiarize themselves with different tools and adopt a systematic approach during debriefing.

Heading forward, efforts are underway to enhance the quality of debriefing by developing assessment tools. In The Debriefing Assessment for Simulation in Healthcare (DASH), the following aspects are considered the key elements of a good debriefer:

1. establishes an engaging learning environment;
2. maintains an engaging learning environment;
3. structures debriefing in an organized way;
4. provokes engaging discussions;
5. identifies and explores performance gaps; and
6. assists trainee achieve or sustain good future performance.

6. Current evidence and status of ECMO simulation

In a recent survey from the United States, lectures (99%), water drills (99%) and bedside training (99%) remain the chief training modalities for new ECMO specialists. Forty-six per cent of ECMO centres had an ECMO simulation programme. ECMO centres with access to a simulation centre, those with higher case numbers and pediatric cardiothoracic ICU are more likely to have an ECMO simulation programme [11].

Simulation-based ECMO education is a growing research area with increasing evidence to support its effectiveness. Earlier publications were mainly descriptive and focused on the setup and content of simulation courses and the evaluation of the learner [12, 13]. Some studies reported an improvement in confidence and performance after ECMO simulation training. Su et al. reported a faster deployment time to ECPR initiation after simulation training [14], and Allan et al. reported a decrease in cannulation time for ECPR in pediatric cardiac surgery trainees [15].

Recently, Zakhary et al. published the first randomized controlled trial comparing the performance after conventional water-drill training and simulation training. In this study, the simulation training group had a higher scenario score and a shorter time to critical action in certain scenarios. More importantly, this superior performance was sustained over 1 year [16]. However, it must be noted that despite the ongoing research and implementation of simulation training, there is yet evidence of association with better patient outcomes.

7. Challenge and future directions

Percutaneous cannulation for ECMO is increasingly performed by intensivists, cardiologists and emergency physicians. Despite infrequent occurrences, complications of cannulation may be associated with significant morbidity and mortality [17]. Existing simulation models mainly focus on ECMO circuit management, with less emphasis on percutaneous cannulation, and there are yet publications related to percutaneous cannulation model. Collaborative international endeavours targeted to improve cannulation safety are in progress. We have developed a simulation model for fluoroscopic-assisted dual-lumen cannulation (https://www.youtube.com/watch?v=dr02RAMRk1A) and two-cannula cannulation in veno-venous ECMO.

Despite the increasing use of simulation in many ECMO education programmes, the role of simulation remains unclear in currently available guidelines and international recommendations. The latest Extracorporeal Life Support Organization (ELSO) guideline on ECMO specialist training published in 2010 only included didactic lectures, water drills, animal laboratory sessions and bedside training as the main training modalities. Moreover, it only targeted 'ECMO specialists' (i.e. nurses, respiratory therapists, perfusionists and medical professions providing care under the guidance of ECMO physicians) and not ECMO physicians.

In a United States survey published in 2015, simulation has been adopted as part of the institutional ECMO credentialing programme for ECMO physicians in 73% of the centres, highlighting its increasing importance [18]. The EuroELSO guidelines for training and continuing education of ECMO physicians published in 2017 have incorporated high-fidelity simulation training as an alternative training modality to supplement bedside clinical hours. More importantly, its significance in teamwork and communication skills training has been acknowledged [19]. It is expected that the role of simulation will be further expanded in future versions of the ELSO guideline.

As mentioned earlier, ECMO training curriculum and thus simulation programmes are institutional specific and may be modified according to the characteristics and training needs of the institution. As a result, significant variances exist among different institutions, imposing difficulties in standardization and validation of the assessment tools. Currently, there are no validated assessment tools to assess the learning efficacy of common and essential ECMO scenarios. Joint efforts are ongoing among international ECMO educators to develop

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a standardized curriculum. Only through the implementation of a uniform ECMO simulation programme can multi-centred studies be carried out to provide a better understanding of the best approach in ECMO education.

8. Conclusion

ECMO is a low-volume but highly complex technology. The management of ECMO patients often requires an integration of cognitive, psychomotor and behavioural skills that can be addressed by simulation training. As a result, simulation is increasingly acknowledged as one of the essential learning tools in ECMO education. Further researches in simulation technology, medical science pedagogy and clinical trials are warranted to delineate its impact on patient outcomes.

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