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Original Contribution

Development of regional extracorporeal life support system: The importance of innovative simulation training☆

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ABSTRACT

Background: Despite advances in mechanical ventilation, severe acute respiratory distress syndrome (ARDS) is associated with high morbidity and mortality rates ranging from 30% to 60%. Extracorporeal Membrane Oxygenation (ECMO) can be used as a "bridge to recovery". ECMO is a complex network that provides oxygenation and ventilation and allows the lungs to rest and recover from respiratory failure, while minimizing iatrogenic ventilator-induced lung injury. In the critical care settings, ECMO is shown to improve survival rates and outcomes in patients with severe ARDS. The primary objective was to present an innovative approach for using high-fidelity medical simulation before setting ECMO program for reversible respiratory failure (RRF) in Poland's first unique regional program "ECMO for Greater Poland", covering a total population of 3.5 million inhabitants in the Greater Poland region (Wielkopolska).

Aim and methods: Because this organizational model is complex and expensive, we use advanced high-fidelity medical simulation to prepare for the real-life implementation. The algorithm was proposed for respiratory treatment by veno-venous (VV) Extracorporeal Membrane Oxygenation (ECMO). The scenario includes all critical stages: hospital identification (Regional Department of Intensive Care) - inclusion and exclusion criteria matching using an authorship protocol; ECMO team transport; therapy confirmation; veno-venous cannulation of mannequin's artificial vessels and implementation of perfusion therapy and transport with ECMO to another hospital in a provincial city (Clinical Department of Intensive Care), where the VV ECMO therapy was performed in the next 48 h, as training platform.

Results: The total time, by definition, means the time from the first contact with the mannequin to the cannulation of artificial vessels and starting VV perfusion on ECMO, did not exceed 3 h – including 75 min of transport (the total time of simulation with first call from provincial hospital to admission to the Clinical Intensive Care department was 5 h). The next 48 h for perfusion simulation "in situ" generated a specific learning platform for intensive care personnel. Shortly after this simulation, we performed, the first in the region: ECMO used for RRF treatment. The transport was successful and exceeded 120 km. During first year of Program duration we performed 6 successful ECMO transports (5 adult and 1 paediatric) with 60% of adult patient survival of ECMO therapies. Three patients in good condition were discharged to home. Two years old patient was successfully disconnected from ECMO and in stabile condition is treated in Paediatric Department.

Conclusions: We discovered the important role of medical simulation, not only as an examination for testing the medical professional's skills, but also as a mechanism for creating non-existent procedures. During debriefing, it was found that the previous simulation-based training allowed to build a successful procedural chain, to eliminate errors at the stage of identification, notification, transportation and providing ECMO perfusion therapy.

Abbreviations: RRF, reversible respiratory failure; ARDS, acute respiratory distress syndrome; ECMO, Extracorporeal Membrane Oxygenation.

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1. Introduction

Despite advances in mechanical ventilation, severe acute respiratory distress syndrome (ARDS) is associated with high morbidity and mortality rates ranging from 30% to 60%. ECMO oxygenation can be used as a "bridge to recovery" with good outcome [1-5]. ECMO is usually provided by specialized centers, but patients with reversible respiratory failure (RRF) are frequently taken care of at other centers. Transports only with conventional respirator therapy to an ECMO center can be hazardous, but without specialized "on ECMO" transport patients never reach dedicated intensive care units. For this reason, many ECMO centers have developed their own transport programs with mobile ECMO. After notification and including criteria matching, the mobile team with all necessary equipment to initiate ECMO is sent to the referring hospital, where the patient is cannulated and ECMO implemented. The patient is then transported on ECMO by road, helicopter, or fixed-wing aircraft depending on distance, weather conditions, etc. It should be noted that in the Greater Poland region before the launch of the program there was no dedicated perfusion center for the treatment of patients with RRF on ECMO and any paediatric or adult patient was transported on ECMO never before. The nearest center providing ECMO therapies is located 450 km from the capital city of Poznan.

Because this organizational model is complex and expensive, we used advanced high-fidelity medical simulation to prepare for the real-life implementation [6,7]. Clinically simulated scenarios are the best way to assess procedures that are rarely performed prior to real-life implementation [8-11].

This article describes an in-situ high-fidelity medical simulation scenario to prepare for the implementation of Extracorporeal Membrane Oxygenation (ECMO) for reversible respiratory failure (RRF). "ECMO for Greater Poland" is the nation's first regional program covering a total population of 3.5 million inhabitants of the Greater Poland region (Wielkopolska) and takes full advantage of the ECMO perfusion therapy opportunities. The main implementation areas are treatment of: severe reversible respiratory failure (RRF); patients with hypothermia; critical states resulting in heart failure i.e.: cardiac arrest; cardiogenic shock or acute intoxication and promotion of donor after circulatory death (DCD) strategy in selected organ donor cases, after unsuccessful life saving treatment, to achieve organ recovery [1]. One of the approved clinical indications is implementation of ECMO as a support in patients with RRF treatment [2-5]. Before the "ECMO for Greater Poland" program was started, patients with RRF did not reach and were not treated with ECMO support in this region.

2. Objective

The purpose of the presented research was to verify the RRF-ECMO procedure created for the "ECMO for Greater Poland" program. The simulation tested the communication and collaboration of several medical teams in prehospital and hospital settings. It also involved the use of specific equipment in the management of a patient with RRF (Table 1).

The specific objectives of the simulation were conducted to assess critical points, and compiled into the scenario checklist (Table 2) for the RRF-ECMO algorithm. The procedure of adult RRF treatment using extracorporeal perfusion has not been performed in the Greater Poland region. The secondary objective, based on the assessment of critical points and timeframe, was to develop an algorithm for RRF-ECMO procedure that would be used in the Program and test it on specialist emergency "ECMO" road transport teams – (Fig. 1).

3. Scenario CASE

The scenario occurred in 4 phases using the same type and number of personnel that is seen in a real clinical setting: 1 – Identification phase; 2 – ECMO Implantation phase; 3 – Transport to the destination phase; 4 – ICU phase.

Table 1
Team and equipment.

Equipment	
SimMan patient simulator (Laerdal Medical, Stavargen, Norway) with the ability of generating ECG rhythms, intubation, chest compression;	
Handmade femoral vascular loop filled under pressure with red liquids reproducing system of vessels and implanted in the groin and neck of mannequin, covered with subcutaneous tissue and artificial skin; loop is prepared from silicone tubing connected with the modified polyethylene; pressure was prepared in a pressure cuff established in a flexible container filled with red-dyed liquid and connected to the vascular loops through a three-way tap (hidden reservoir cuff into the abdominal cavity of the mannequin SimMan;	
ECMO: CARDIOHELP with heater-cooler (Maquet, Rastatt, Germany); emergency pump for manual	
transport respirator HAMILTON T1 (Hamilton Medical AG, Bonaduz, Sitzerland)	
Lifepak 15 monitor/defibrilator (Physio-Control, Redmond, USA), heart rhythm, saturation, venous and arterial pressure and temperature monitoring devices	
8 infusion pumps (Bbraun, Hessen, Germany)	
Set of oxygenator and drains system	
Surgical set for cannulation	
Teams	
Emergency medical team	2 persons (paramedics)
Regional ICU personnel	5 persons medical staff
Coordinator of the "ECMO for Greater Poland" Program in a centralized Dispatcher Medical Emergency Medical Station	1 person
Perfusion Mobile ECMO team	3 persons (heart surgeon, anesthesiologist, perfusionist)
Clinical ICU department personnel	6 persons
Instructors from the Medical Simulation Center, observers	9 persons
Photography and videography (registration of the procedure in real time)	3 photographers

ECG – electrocardiography; ECMO – extracorporeal membrane oxygenation; ICU – intensive care unit.

The simulated scenario presents a 34-year-old man admitted to the Regional ICU ward with emerging signs of respiratory failure. Three days earlier he presented with symptoms of pneumonia. He was mechanically ventilated for two days. His laboratory studies did not confirm the aetiology of AH1N1. The subject was non-responsive to conventional therapy and had increasing hypoxia, despite maximum treatment efforts, he was qualified for extracorporeal therapy – the RRF scenario run. The patient was started on veno-venous ECMO after successful criteria matching and protocol (taken from www.ecmo.pl) consent for qualifying the patient using guidelines for ECMO therapy in respiratory failure.

After verification of therapy compliance, the Mobile ECMO Team was activated. The "ECMO for Greater Poland" Program coordinator was informed to prepare special transport. Within 120 min, the Mobile ECMO Team arrived at the regional hospital. Upon final verification tests, the patient was cannulated via the Seldinger technique

Table 2
The procedure for case scenario checklist – specific objectives.

Case scenario checklist – for RRF-ECMO procedure		
1	The identification protocol for ECMO therapy verification	Y/N
2	Reaction time of the emergency medical ECMO Program coordinator	Time
3	In-hospital respiratory optimalization	Y/N
4	The mobile ECMO team stand-by and transport transfer	Time
5	Vessels cannulation, the priming preparation and filling the ECMO	Y/N
6	The time to ECMO cannulation	Time
7	ECMO start - keeping perfusion in real-time	Y/N
8	Preparation for transport, efficacy of sources of supply of electricity and oxygen in ambulance confirmation	Y/N
9	Patient with implanted ECMO ambulance long road transport – 80 km – "for himself"	Time
10	RRF-ECMO procedure "in situ simulation"	Time

ECMO – extracorporeal membrane oxygenation; RRF – reversible respiratory failure.

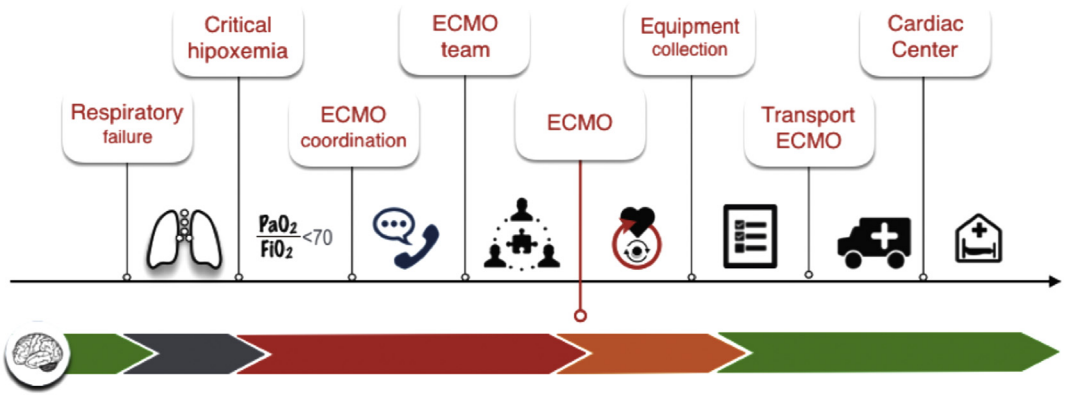

Fig. 1. RRF-ECMO straight line architecture.

percutaneously. Firstly, safe access was obtained to the jugular vein and next the femoral vein under ultrasound guidance. The jugular vein was cannulated with 19 F (Medtronic) cannula and the femoral vein was cannula using 23 F (Medtronic) cannula. After the venting drains from the ECMO console are set, the ECMO perfusion therapy was initiated in the following 20 min at a flow rate of 2.0 L/m^2/min. The flow of gas was set at 1 L/min at FiO^2 of 100%. After another 20 min, the patient on ECMO was connected to a heater exchange system and was prepared for transport. The total road transport lasted 75 min and the patient was transferred to the Clinical Department of Intensive Care for further treatment – Fig. 2. High-fidelity "in situ" simulation scenario was terminated after 48 h – Table 3.

Fig. 2. Documentation: mannequin preparation; percutaneous cannulation and starting ECMO; preparation for transportation; transportation; therapy in the department of intensive care.

Table 3
Scenario action time.

Scenario time	Action
00:00:00	Respiratory optimalization; identification protocol
00:30:00	ECMO program coordination; EMS and Mobile ECMO team activation
01:00:00	Mobile ECMO team transport START
02:00:00	Mobile ECMO team arrives
02:40:00	Therapy confirmation; vessel cannulation; ECMO priming
02:50:00	ECMO START
03:10:00	Preparation for transport; equipment collection
03:30:00	Ambulans transportation START
04:45:00	Ambulans STOP
05:00:00	Clinical Department of Intensive Care admission
05:10:00	Simulation scenario ICU START
48:00:00	Simulation scenario ICU STOP

Phase 1 – identification in regional intensive care department.
Phase 2 - ECMO implantation.
Phase 3 - transport to the destination department.
Phase 4 – ICU.
EMS – emergency medical service; ECMO – extracorporeal membrane oxygenation; ICU – intensive care unit.

4. Description

We present groundwork for a procedure for reversible respiratory failure treatment where ventilation is supported by ECMO. The system, we developed as an adaptation to SimMan 3G, using silicone tubing to form a loop to mimic blood vessels. The tubing was filled with pressurized red-dyed liquid and was embedded into the groin and neck of a mannequin and covered with artificial skin. The real time scenario included all crucial steps: hospital identification (Regional Department of Intensive Care) - inclusion and exclusion criteria matching using authorship protocol; ECMO team transport (80 km); therapy confirmation; percutaneous veno-venous cannulation of the mannequin's artificial vessels; implementation of perfusion therapy and transport (80 km) with ECMO and therapy monitoring (according to Extracorpreal Life Support Organization – ELSO Guidelines) to another hospital in a provincial city (Clinical Department of Intensive Care), where the VV ECMO therapy was performed in the next 48 h – Fig. 2. All activities were video recorded for debriefing, discussion and evaluation.

The total time, by definition, means the time from the first contact with the mannequin to the cannulation of artificial vessels and starting VV perfusion on ECMO, did not exceed 3 h – including 75 min of transport (the total time of simulation with first call from provincial hospital to admission to the Clinical Intensive Care department was 5 h). The 48 h for perfusion simulation "in situ" generated a specific learning platform for intensive care personnel. ECMO team training "in situ" simulation scenarios have been created and preliminarily examined by all intensive care department staff – 10 intensivist and 24 nurses – Table 4. The primary objectives of the scenarios included:

- Ability to diagnose problems during ECMO treatment using clinical signs, echocardiography or ultrasound examinations, gasometry and other necessary blood exam interpretations,
- Ability to communicate with other members of the ECMO team
- Describe successive changes in clinical parameters and accompanying changes in vital signs of the patient and ECMO,
- Ability to protect the patient without compromising their safety during the procedure.

5. Discussion

5.1. Guidelines

Bromar and Freckner reports in their publication analysis of ECMO transportation more than 1400 patient transports on ECMO in the world [12]. However only two deaths during transport have occurred but a number of other procedural complications without effect on patient outcome are described. In fact the survival of patients transported on ECMO is similar to that of non-transported ECMO patients. Their conclusion is that long-, short-distance interhospital transports on ECMO can be performed safely. The necessary conditions are: experienced staff in intensive care, ECMO cannulation, ECMO treatment and intensive care transport [13-15].

Extracorporeal Life Support Organization (ELSO, Ann Arbor, MI, USA, www.elso.org) is a worldwide patronage organization of more than 400 centers units providing ECMO. The main mission of ELSO is to collect registry of ECMO treatments and provide guidelines associated with ECMO treatment, also for ECMO transport [16]. The ELSO recommendation to improve outcomes in ECMO therapies is to consolidate ECMO treatment to high-volume centers. The ELSO Registry [17-22] showed that minimum ECMO therapies for good outcomes is 6 per year, but providing more than 30 annual adult ECMO had a significantly lower ECMO mortality. Therefore, the position of therapy in centralized dedicated centers is strongly promoted, rather than diversifying therapies in smaller centers [17,22]. The centralized model with the use of specialized ECMO transport has been developed in many centers around the world [17,18,22-24]. There are no special published data of ECMO transports numbers a mobile ECMO team should perform. The majority of publications reports small numbers of ECMO transport groups. Only eight centers reported a number of transports exceeding 50, including 4 above 100 - three in the US and 1 in Sweden (with more than 700) [12].

The "Hub-and-Spoke" model was introduced by Combes et al. [25]. A high reference center with a large number of hospitalizations should be a model that integrates the regional hospitals applying only conventional therapeutic methods and those that can initiate ECMO therapies. Patient who requires ECMO therapy can be transferred to a large volume unit by a mobile ECMO team. To offer ECMO services with patient's safety, including economy and effectiveness the well prepared ECMO transport organizations are required [20]. The Polish Guidelines issued by the National Intensive Care Consultant and VV ECMO therapy Team recommended instruction for the mobile ECMO teams assessment, notification and ECMO implementation before transfer that patient to the high-volume ECMO center [26]. It should be noted that international experts suggest transport of unstable refractory respiratory patient is safer on ECMO than conventionally ventilated. [5,27]. Brechot et al. in a retrospective single-center study proved the safety of ECMO-supported transport. The principal message of this study was that implementation of VV ECMO by a mobile ECMO retrieval team did not impact negatively on the prognosis of patient with RRF when compared with on site ECMO implantation [28].

In definition the primary ECMO transport consists of three parts: (1) transport to the referring hospital with mobile ECMO team and equipment, (2) procedures at the referring hospital (final assessment of the patient, cannulation, stabilization, etc.), and (3) transport back to dedicated ECMO center [12,16].

Procedures starts with a phone call from the referring hospital, and a decision is made to launch the mobile ECMO team. It is important to minimize the time to organizing preparation but when transporting the patient on ECMO patient safety is the overriding priority. Therefore the ECMO team must be summoned, necessary equipment packed, and transport vehicle be organized. In the ELSO guidelines, ground transport is recommended for distances up to 400 km (250–300 miles) and helicopter transport for distances up to 650 km (300–400 miles). Fixed-wing aircraft can transport any distance [16].

Despite the transportation type ECMO team must be self-sufficient with respect to all ECMO specific supplies (manual power ECMO supply, spare emergency ECMO circuit., connectors, extra pump head and oxygenator, and spare tubing in suitable sizes according to the weight of the patient). Devices for assessment of blood gases, anticoagulation monitoring, i.e., ACT machine and additional surgical equipment includes sterile surgical instruments, surgical disposables like sutures, etc., surgical dressing, and head lamps for cannulation should be brought by the transport team – dedicated equipment is usually not available at the referring hospital. The electrical cautery device and bedside ultrasound (line and echocardiography) devices for percutaneous cannulation are generally available at the referring hospital. All equipment should be stored in prepacked sealed and signed bags. In ELSO guidelines it is recommended to prepare check lists for necessary equipment to ECMO procedure and all equipment and supplies necessary during conventional transports of intensive care patients: transport ventilator, monitoring device, infusion pumps, and pharmaceuticals [16,17] There should be no compromise on the patient and ECMO team safety.

There are many different composition of ECMO transport teams depends on different competences, duties, traditions and example of how a transport team can be composed is given in the ELSO guidelines. In most centers, the ECMO machine is primed by a perfusionist like in ours, but in other centers this may be accomplished by a physician or a nurse after special education course. Depend of centers, the cannulation can be performed opened by a surgeon or percutaneously by intensivist [19,20,23,24] Our dedicated mobile ECMO team consist of: two critical paramedics, perfusionist, cardiac surgeon and intensivist with all responsibilities to evaluate the patient and ECMO indication, to cannulate the patient, to prime the ECMO circuit, to initiate ECMO treatment, to manage the critical ill patient on ECMO, including the ECMO circuit, ventilator, medications, and anticoagulation. They are well prepared to handle common or any unforeseen problems and complications.

Transports on ECMO conducted by experienced staff are generally safe but high-risk or *Immediate-threat-of-life* situations will occur. The necessary immediate intervention should be taken within seconds demanding highly trained personnel. In publications regarding adverse events or complications during ECMO transports the incidence of any kind occurred in 30.8% of the transports [12]. In 6.2%, more than one complication was reported [12,19]. Most common were event related to the patient (28.2%), of which loss of tidal volume accounted for 11.5%. Second most common were circulatory problems, including bleeding (5.6%) [12,19]. Equipment-related problems can occur in 5–8%. Others unforeseen but reported problems were hypothermia, intravenous lines froze, traffic accidents. In another publications authors reported the lack of knowledge and adaptation by the ambulance service that exposed both patient and transport team to risk in 4% of the transports and observed in 2%, an *Immediate-threat-of-life* situation [12,20].

Safe ECMO transport is only the beginning, long-lasting and demanding therapy. It enforces an interdisciplinary approach at every stage of care for a critically ill patient. That existing ELSO recommendations regarding conducting VV ECMO therapy are a signpost, however, in each center it is necessary to develop individualized therapy protocols for severe respiratory failure treatment. The ECMO system does not cure, it is a temporary respiratory prosthesis, it gives the time necessary to cure the underlying disease. However, perfusion therapy is very demanding, it forces the creation of a dedicated and trained team that allows responsible and safe therapies [8-10].

5.2. Program results

The program's intention – with medical simulation – is to create algorithms and improve the coordination of Medical Rescue Teams in the "ECMO rescue chain". The team is prepared for this procedure – Fig. 2. Previous simulation-based training allowed to build a successful procedural chain, which will be useful in eliminating errors at various stages in identification, notification, transportation and ECMO perfusion. The first scenario tested in the region included a patient (mannequin) with implanted ECMO console, which had to be transported via road ambulance between two cities. During transportation all critical parameters were under control including: ECG, heart rate, capillary oxygen saturation, body temperature, venous and arterial pressure. This allowed us to control the deployment of qualified medical personnel, know what equipment was needed in the ambulance, as well as confirm the efficacy of electrical sources and oxygen therapy that was needed for the complicated procedure – Table 1. In addition with creating Mobile ECMO Team we tested all responsibilities that are needed for the mission. It included capability to verify the patient and ECMO indication, to perform cannulation, to prime the ECMO circuit and to initiate ECMO treatment.

During the simulation we were able to identify very basic problems, for example difficulties in power and oxygen supply during transport longer than 50 km. In addition, we verified the list of equipment necessary for the mobile ECMO team and we realized how limited was the working space in the ambulance. In addition, the experience gained during the simulations and the first 5 transports in the standard ambulances enabled us to re-design and equipped the most modern ambulance to provide optimal transport on ECMO-supported patients. Moreover, owing to successful implementation of "ECMO for Greater Poland" Program, it was possible to raise funds for the another ambulance dedicated for ECMO transport (the first ECMO ambulance in Poland). The last challenging ECMO transport of 2-year-old child was successfully due to experience gained in both simulation training and real-life emergency transports as well as extraordinary-equipped ECMO ambulance.

Finally it was important to create workflow to manage the critical ill patient on ECMO, including the ECMO circuit, ventilator, medications, and anticoagulation, and to handle common or any unforeseen problems and complications. Continued in the next two days, "in-situ" simulation in the intensive care department was a live training platform for all treatment levels personnel to familiarize themselves with the device and therapy, which has never been run before. During those days four simulation scenarios sessions were performed and tested to train and discuss the principles of conducting therapy, how to determine therapeutic and nursing tasks, including the method of monitoring the cannulation sites, the operation of the device, critical moments, traps and threats of ECMO therapy.

"In situ" simulation gives the opportunity for repetitive structured training for a whole team of people working together in characteristic "own" workplace conditions. In addition, using properly conducting educational activities, it allows to abandon expensive courses at foreign centers offering ECMO training.

The history of the use of medical simulation as a training tool dates back to the 50s of the last century, especially in the field of rescue techniques in critical states. Simulation for extracorporeal therapy as a tool allowing for organized and comprehensive training for ECMO therapy was first described by Anderson in 2006 [29]. Throughout the last ten years, the simulation techniques have been improved from low to high fidelity models to mimic human responses in a very realistic way.

It was also a powerful tool in times of crisis. In 2009, in the face of a new H1N1 pandemic, WHO recommended training courses based on medical simulation techniques as those that could bring the best

Table 4
"In-situ" simulation scenarios for educational purposes.

Scenario	Education objectives
Accidental cable outage	• Ability to recognize the outage and/or damage of the cable connecting the driver to the ECMO console • The team detects disconnection the extended driver cable from the console when the patient is protected by a respirator, ambu ventilator or ALS if necessary. Blood flow is restored to the ECMO console via the emergency drive. The driver cable is properly inserted into the console, the pump is reset and the pump flow, ventilator and ECMO settings return to their initial values.
Accidental hypothermia	• Ability to diagnose hypothermia symptoms during V-V ECMO treatment • The team disconnects the heater from the oxygenator, activates the water heater circuit and heats the water in the tank to 31 degrees Celsius. Afterwards they must reconnect to the oxygenator. The heater is gradually turned on and the patient's vital parameters gradually stabilize and return to their initial values
Circuit aeration	• Ability to diagnose ECMO circuit aeration • The vent system circuit, e.g. as follows: pump is stopped, the liners are closed, the patient's canals to the lure locked, the sterile shunt is connected to the cannula and the sensor is suspended and the shroud is recirculated until the air is completely removed from the system. The patient is turned over and the patient's vital parameters, ventilator settings and ECMO return to their initial values. Ventilation of the system must take place within 10 min.
Accidental circuit disconnection	• Ability to emergency diagnose ECMO circuit disconnection • The team diagnoses the circuit disconnection, stops the circuit and clamps the cannulas to stop bleeding. The patient is protected by a respirator or ambu ventilation or ALS if necessary. The cannulas are reconnected, vent circuit and system restarted. Bleeding should be recognized urgently and the system restart must take place within 3–5 min.
System clotting	• Ability to recognize symptoms of clot formation in the circuit • The team diagnoses the circuit clotting, stops the circuit and clamps the cannulas, until then the patient is protected by a respirator, ambu ventilation or ALS if necessary. The oxygenator should be replaced in the ECMO system, refilled and reconnected. The system restart must take place within 15 min.
Bleeding	• Ability to diagnose emergency bleeding • The team diagnoses bleeding, stops the circuit and clamps the cannulas to stop bleeding, until then the patient is protected by respirator, ambu ventilation or ALS if necessary. The cannula's are repositioned and reconnected. The vent circuit and system is restarted. Bleeding should be recognized urgently and the system restart must take place within a maximum of 3–5 min.
Line obstruction	• Ability to recognize symptoms of venous line obstruction • The team closes the venous line, the autopilot is switched off, the patient is protected by chest compressions and ambu ventilation, the staff recognizes that the cause of the pump stopping was venous line obstruction. The operator confirms that there are no additional pump issues and the pump is restarted, cardiopulmonary resuscitation is stopped and the patient's vital parameters, ventilator settings and ECMO system return to initial values. If the staff performs all of the aforementioned steps but does not turn off the autopilot which leads to circuit aeration, the team must vent the system within 10 min to ensure that the scenario is successful.
Accidental detachment of cannula	• Ability to emergently diagnose accidental cannula detachment • The team diagnoses the detachment of a cannula, stops the circuit and clamps the cannulas to stop bleeding, until then the patient is protected by ventilator or ambu ventilation or ALS if necessary. The cannula's are repositioned, the vent circuit and system is restarted. Bleeding should be recognized urgently within 3–5 min, and the system restart must take place within a maximum 15–20 min.
No power supply - manual power supply	• Ability to recognize the lack of power supply and change to manual power supply • The team detects the power supply problem, and immediately protect the patient via a respirator, ambu ventilation or ALS if necessary and restores blood flow to the ECMO via the emergency drive. Backup of the console is initiated. The pump is reset and the pump flow and patient life, ventilator and ECMO console settings return to their initial values.
Planned decannulation and system recirculation	• Ability to prepare for planned decannulation with system recirculation • The team prepares for decannulation, stop the circuit and clamp the cannulas, until then the patient is observed and the lines are disconnected from the patient and reconnected via a proper connector without aeration. The system is then restarted. The system restart must take place within 10 min.
SIG alarm	• Ability to recognize the "SIG" alarm with appropriate intervention • The team closes the venous line and the patient is protected by chest compressions administered by one member of the team and ambu ventilation. The team recognizes that the cause of the pump stopping was due to the cream under the flow sensor drying out. The management includes stoping the pump slowly, clamping the inflow and outflow lines to pump head. Applying silicone creame, and reinserting the head and close clip. Unclamping the lines and slowly restarting flow. The system restart must take place within 5 min
Emergency ECMO cannulation	• Ability for fast arteriovenous artery cannulation of a patient with peripheral femoral access - during resuscitation using a device for chest compressions • The team quickly prepares the ECMO system and starts VA ECMO during a resuscitation operation in a patient with cardiac arrest undergoing chest compression in hospital conditions
Hemofiltration connection	• Ability to connect the hemofiltration system via drains to the ECMO system • Team prepare the hemofiltration machine and connect the in and out line with appropriate connectors to ECMO machine and patient
Nurse care protocol	• Protocol for safe manipulation of the patient to provide care i.e. wash the patient, blood probe collection, tracheal suction • All manipulations should be performed with care and attention to the ECMO system
Rehabilitation protocol	• Protocol for safe rehabilitation of ECMO patient i.e. prone position, passive exercises with patient under sedation, active exercises with conscious patient with ECMO • All manipulations should be performed with care and attention to the ECMO system

ECMO – extracorporeal membrane oxygenation; VV – veno-venous; ALS – advanced life support.

tangible clinical results [29-32]. High fidelity simulation ECMO training could offer promising outcomes but have rarely been studied. [33,34].

Unfortunately, the majority of published reports did not answer to the question if the use of simulators improved outcomes and/or decreased the number of serious adverse events.

Zakhary et al. demonstrated that simulation-based ECMO training was effective and superior to traditional water-drill-based one. This study is the first randomized controlled trial evaluating the application of simulation in ECMO education with objective, measurable, clinically relevant and long-term outcomes. Authors present the benefits of a practical experience in improving ECMO skills and significant reduction in delay to undertake critical actions for emergency circuit management [35].

Currently, the additional studies are needed to determine if simulation training will reduce complication rate and eventually improve clinical outcomes in patients receiving ECMO therapy [36].

Our limited experience does not allow us to assess the impact of medical simulation on the improvement of clinical results. Be aware of our limited experience, the medical simulation had been applied before the first VV ECMO procedures in our region. Thus we had treated it as professional preparation for the first real-life ECMO application. Moreover, we discovered its important role not only as a skill tester but also as valuable tool for creation of the non-existing procedures. The role of medical simulation becomes effective when applied to clinical situations.

5.3. Clinical results

The success of our first simulated RRF-ECMO procedure in the region is reassuring. Shortly after RRF simulation scenario, we performed, the first in the region: ECMO used for acute respiratory distress syndrome (ARDS) treatment. The transport was successful and exceeded 120 km – Table 5. The indication was exacerbation of bronchial asthma with pneumonia. The patient was treated with success on VV ECMO support for 14 days, and after 3 next days because of acute respiratory failure exacerbation the VV ECMO protocol was implemented second time. It was explanted 7 days later with success. Unfortunately patient died 3 days later because of cerebral stroke with intracranial bleeding. The next young woman was admitted with AH1N1 influenza in critical state. She was after lung transplantation 6 years ago. Because of immunosuppression, the influenza treatment was ineffective. After 6 days VV ECMO support she died resolving multiorgan dysfunction. Few months later we have been treated using RRF-Algorithm another 3 patients. Two of them with obesity (160 kg and 140 kg) and with respiratory failure were transferred from another hospital (10 km and 40 km) with implanted ECMO system. After 2 weeks the ECMO system were successfully explanted, and patients after another 3 weeks of hospitalization were discharged to home in good condition. Our last patient was the young man with pneumonia (Legionella pneumonia) transferred on ECMO from regional hospital (50 km). He was on ECMO support 17 days and after 2 another weeks he was discharged to home. Every patient treated with VV ECMO in our material needed artificial support of kidney dysfunction during hospital stay – hemodialysis. The patient survival of VV ECMO support rate was 60%. They were discharge from the hospital in good condition and normal activity. Our last 6 transport was the most demanding. We received a report from another hospital, 200 km away, reporting a 2-year-old child from a semi-pregnant infant pregnancy. Due to post-operative complications, he had an exacerbation of acute respiratory failure. Mobile ECMO Team preparations, ECMO implantation and transport took a total of 11 h and were successful. After 7 days of support, the ECMO was successfully explanted. The patient in stable condition is still hospitalized in Paediatric Department.

The success of applying this algorithm in the Clinic, aids in establishing future programs in Intensive Care Units. The algorithm can bridge the gap for Intensive Care Centers cooperating with Mobile ECMO Teams.

5.4. Limitations

It should be clearly stated that simulation training gives safety and responsibility in therapy. All our transports, preceded by this simulated one, ran smoothly without critical moments for patients, equipments or logistic problems. In addition, a simulation training in situ in a dedicated department allowed the patient to overcome the fear and abilities of the staff before conducting the therapy. What is more important, many of these people retrospectively confirm that without action in simulated steamers, they would not dare to conduct ECMO therapy. The only limitation of the high fidelity medical simulation as a creation tool seems to be only imagination and a lack of personnel for additional workload.

6. Conclusions

ECMO is a complex network that provides oxygenation and ventilation and allows the lungs to rest and recover from respiratory failure while minimizing iatrogenic ventilator-induced lung injury. In critical care settings, ECMO is proven to improve survival rates and outcomes in patients with severe ARDS.

We created an algorithm of RRF procedure treatment and implemented it in reality for the first time in Poland. The algorithm was implemented as part of a standard routine procedure in the Department of Intensive Care in Poznan, Poland. The algorithm is dedicated for intensive care centers cooperating with perfusion Mobile ECMO Teams and can be recommended as a reference center for all centers in Poland.

The most important are clinical results, which in the course of growing experience should be only better. Undoubtedly our biggest success is algorithms creation and implementation in life. Our results of RRF treatment are also promising. The 60% survival of adult patients and saved life of paediatric patient with RRF is a very good result especially for the newly established VV ECMO therapeutic center. Moreover, we discovered the important role of medical simulation, not only as a skill tester, but also as a mechanism for creating non-existing procedures. The role of medical simulation becomes effective when applied to clinical situations.

Table 5
Therapy indications, support type and time, results.

No	Patient	Age (years)	ECMO type	Cannulation	On ECMO transportation distance (km)	Indication	Support time (days)	Result
1	F	56	VV VV	Percutaneous	120	RRF, COPD	14 4	Died Cerebral stroke
2	F	19	VV	Percutaneous	10	RRF, bridge to reLTX	6	Died MODS
3	M	52	VV	Percutaneous	10	RRF	16	Discharged
4	M	59	VV	Percutaneous	40	RRF	17	Discharged
5	M	28	VV	Percutaneous	50	RRF	20	Discharged
6	M	2	VV	Percutaneous	200	RRF	7	ECMO explanted Hospitalized

ECMO – extracorporeal membrane oxygenation; VV – veno-venous; COPD – chronic obstructive pulmonary disease; MODS – multi organ dysfunction syndrome; RRF – reversible respiratory failure; reLTX – lungs retransplantation.

Summary of author contribution

MP, **ML**, **MD**, **MZ**, **SS**, **MLa**, – concept, simulation scenario preparation.

ML, **MP**, **MLa**, **AP**, **MZ** – real time therapy implementation.

BP, **LS**, **MJ** – critical revision of article.

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