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ORIGINAL RESEARCH

SimMan 3G Simulation-Based Instruction for the Extracorporeal Cardiopulmonary Resuscitation Transfer Procedure

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Objective: The purpose of this study is to determine if patient transfers involving extracorporeal cardiopulmonary resuscitation (ECPR) can be effectively taught using SimMan 3G training.

Methods: To evaluate the efficacy of the training, 48 medical professionals were randomly assigned to either a conventional teaching group or a SimMan 3G simulation teaching group, and they each underwent training in the ECPR transfer process and were then assessed on their theoretical knowledge, practical skills, and patient transfer time.

Results: The study recruited a total of 48 healthcare professionals, including 10 males and 38 females. The age distribution was as follows: 10 individuals aged 18–29 years, 24 individuals aged 30–44 years, and 39 individuals aged ≥45 years. All participants had an educational level of at least a bachelor's degree. There was a statistically significant difference in theoretical knowledge scores, operational skill scores, and patient transfer time between the pre- and post-training periods ($P < 0.05$). Following training, the conventional teaching group had a theoretical knowledge average score of 82.46±10.91, the highest score was 92, and the lowest score was 64, operational skill average score of 88.35±17.71, the highest score was 93, and the lowest score was 76, and patient transfer time of 97±10.68 seconds, while the SimMan 3G simulation teaching group had a theoretical knowledge average score of 88.78±13.55, the highest score was 96, and the lowest score was 78, operational skill average score of 95.32±20.15, the highest score was 98, and the lowest score was 85, and patient transfer time of 68.25±4.03 seconds.

Conclusion: The training effect of the ECPR transfer process can be greatly improved by using the SimMan3G simulation-based teaching, and this method can also play a role in clinical continuing education with significantly less time and effort invested.

Keywords: ECPR, simman 3G, simulation teaching, transfer process

Introduction

With the continuous improvement of emergency cardiopulmonary resuscitation (CPR) techniques, the return of spontaneous circulation (ROSC) rate for patients with cardiac arrest can reach 40–60% through timely and high-quality CPR. ROSC refers to the resumption of organized cardiac activity following cardiac arrest, allowing for the restoration of normal blood perfusion to the body's tissues. The signs of ROSC include the presence of spontaneous breathing, coughing, limb movement, and palpable pulses or measurable blood pressure. However, conventional cardiopulmonary resuscitation (CCPR) can only provide 30–40% of normal cerebral blood flow and is unable to supply adequate oxygenation and perfusion to the patient's body. As a result, the survival rate after discharge for patients receiving CCPR remains only 5%–19%.[1–4] In contrast, venous-arterial extracorporeal membrane oxygenation (V-A ECMO) technology can effectively maintain oxygen supply and oxygenation of vital organs such as the heart, brain, and lungs. Therefore, with the advancement of ECMO technology and equipment, as well as the development of biocompatible conduits, the combination of CCPR and ECMO in adult extracorporeal cardiopulmonary resuscitation (ECPR) has been gradually promoted in clinical practice.[5,6] ECPR provides a higher cerebral blood flow compared with CCPR,

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which may reduce cellular damage following hypoxia. ECPR can also be regarded as a "bridge" and a valuable option for the treatment of cardiac arrest. It should be initiated as soon as possible when CCPR is ineffective for cardiac arrest, in order to buy time for patients with cardiac arrest.

Extracorporeal cardiopulmonary resuscitation (ECPR) provides a higher cerebral blood flow compared with conventional cardiopulmonary resuscitation (CCPR), which may reduce cellular damage following hypoxia. ECPR can also be regarded as a "bridge" and a valuable option for the treatment of cardiac arrest. It should be initiated as soon as possible when CCPR is ineffective for cardiac arrest, in order to buy time for patients with cardiac arrest.

The implementation of ECPR typically requires specific equipment, techniques, and a multidisciplinary team with extensive experience. Not all hospitals have the capacity to conduct ECPR. This has given rise to the urgent need for ECPR transport. ECPR transport refers to the process of safely and effectively transferring critically ill cardiac arrest patients who are undergoing ECPR support (ie, ECMO has been established and is operational) from one location (such as a primary hospital or emergency scene without the capacity for sustained ECPR management or etiological treatment) to another medical institution with advanced life support capabilities and ultimate treatment goals (such as a cardiac catheterization laboratory, ECMO center, or ICU). This process is a crucial and highly challenging link in the ECPR treatment chain.

During ECPR, maintaining the continuous and normal operation of the machine is a basic condition to ensure patient treatment and sustain life. However, because the patients treated with ECPR are critically ill and prone to complications, and there are risks such as catheter dislodgement and abnormal machine operation during transport, the coordinated transport of ECPR patients is not simply a matter of patient movement. It is a high-risk, high-tech, and highly team-dependent mobile intensive care life support task. Its success or failure directly affects the patient's ultimate chance of survival. Establishing a safe and efficient ECPR transport system is one of the core pillars for the operation of a regional ECPR treatment network.[7]

In some regions of our country, regional ECPR treatment centers have been established. However, due to factors such as incomplete medical infrastructure, ethical limitations, and high costs, the development of ECPR technology remains at a bottleneck. Establishing a robust tiered referral system, regularly conducting specialized high-fidelity simulation training and certification for ECPR and transport, and continuously performing quality control and process optimization are key to the healthy and sustainable development of ECPR technology in our country.[8,9] The "2024 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care"[10] (hereinafter referred to as the "Guidelines") emphasize the importance of incorporating team collaboration and leadership skills training into the "Advanced Life Support Course" and specifically recommend the use of high-fidelity simulation mannequins for such training, especially in handling complex clinical scenarios like ECPR transport, which are high-risk, low-frequency but require a high level of proficiency. High-fidelity simulation training can safely reproduce the stress and complexity of real environments, allowing team members to repeatedly practice key skills, communication and coordination, decision-making, and management of unexpected events without risking real patients.

The SimMan 3G simulation mannequin is a medical robot imported from Norway. It stands at approximately 1.8 meters tall with a visage that suggests a 30-year-old individual and is capable of blinking. One can sense its respiration when close to its head and feel its pulse upon a gentle touch at the wrist. The mannequin is entirely enveloped in silicone skin, and pressing on its chest allows for the sensation of rhythmic breathing and heartbeats. It boasts an automatic drug recognition system that identifies medications and dosages, eliciting appropriate pharmacological responses from the mannequin. The eyes of the mannequin can blink at varying speeds, with pupils that automatically adjust to light in either a synchronized or desynchronized manner. Its degree of realism is considered leading on a global scale. Unlike traditional training mannequins, it can provide reactions during training exercises.

Our hospital has established an ECPR team, but the overall training outcomes have been less than satisfactory, particularly in simulating real-world transfer stress and complex scenarios. In line with the spirit of the 2024 AHA "Guidelines",[10] we propose utilizing the high-fidelity SimMan 3G simulation mannequin to conduct specialized simulation drills for the entire ECPR patient transport process (including in-hospital preparation, handover, loading, transfer via different modes of transportation, monitoring and management of unexpected events during transit, unloading upon arrival, and handover). This approach will be compared with traditional teaching methods (such as theoretical lectures, skills station practice, and low-fidelity simulation).

The core objective is to systematically cultivate and assess the team members' superior skills required for ECPR transport (such as ECMO system management, life support, and cannula safety), critical thinking, emergency decision-making abilities, team communication and leadership, as well as their comprehensive capabilities in handling various unexpected situations during transport (such as equipment failure, patient deterioration, and cannula issues). This will ensure the professionalism, coordination, and safety of the ECPR transport process to the greatest extent.[11] This study aims to explore a better training model, provide practical evidence for improving ECPR transport capabilities in our country, and ultimately promote the overall progress of ECPR treatment technology.

Data and Methods

Study Population

The study participants were doctors and nurses who worked in the emergency room at a grade A tertiary hospital in Nantong City from April to June of 2022.

Participants met the following criteria: (1) health care workers with at least five years of experience in the emergency department, ICU, or Emergency Intensive Care Unit (EICU); (2) workers in the emergency department and the ICU who had passed the medical licensing examination; (3) nurses who had obtained the nurse qualification certificate, and nurses working in the emergency room who had passed the emergency induction exam; and (4) voluntary participation in this study.

Participants who met any of the following exclusion criteria were not allowed to take part in the training: (1) Individuals who were unable to participate due to medical reasons, such as sudden physical discomfort or illness; and (2) Participants who withdraw from the training program due to family or personal factors.

Study Methods

Study Design

This study constitutes a randomized controlled trial. The population was selected through cluster sampling. Emergency physicians and nurses who met the inclusion criteria were randomly divided into an experimental group and a control group using the method of random number tables. The control group underwent ECPR transport training with traditional simulation mannequins, whereas the experimental group was trained in transport drills using the SimMan 3G simulated patient.

Simulated Teaching Protocol

This study was grounded in the "Guidelines for the Transport of Adult and Pediatric Patients on Extracorporeal Membrane Oxygenation (ECMO) Support"[10] to devise a training program for the transport of ECPR patients, detailed as follows: ① Training duration: 6 hours of theoretical instruction plus 3 hours of practical training; ② Theoretical instruction: Delivered through lectures for centralized teaching of participants, covering topics such as: fundamental ECMO theory, timing for initiating ECPR, configuration and management of ECMO parameters, strategies for addressing ECMO alarms, and the transport of ECMO patients, encompassing a spectrum from basic theory to clinical response; ③Practical training: Utilizing the "Push-Pause-Walk" (PPW) teaching method outlined in the 2024 AHA "Guidelines",[10] participants engaged in hands-on training for cardiopulmonary resuscitation, the operation of cardiac compression devices, and the handling of ECMO machinery. ④ Simulation exercises: In accordance with standards from both domestic and international guidelines, ECPR transport scenarios were established to mimic real patient cases, employing team collaboration for simulation drills in ECPR decision-making and the transport process. The control group employed conventional simulation mannequins, whereas the experimental group leveraged SimMan 3G simulation technology. Scenario settings encompassed patient baseline conditions, various catheter placements, administration of intravenous medications, and simulated transport complications (such as: catheter detachment, ECMO machine alerts, equipment power failures). Both groups underwent training once monthly over a period of 12 sessions. Throughout the training period, participants were assessed on three occasions: a preliminary assessment before training, an interim assessment at the 6-month mark, and a final assessment upon completion of the training.

Assessment Criteria

Throughout the training phase, participants in both the experimental and control groups will undergo three assessments that encompass both "theoretical and practical" components. The theoretical examination will be administered concurrently to all participants, whereas the practical assessment will be conducted through live case simulations. Grading will be based on the evaluative criteria outlined in the "Guidelines for the Transport of Adult and Pediatric Patients on Extracorporeal Membrane Oxygenation (ECMO) Support",[12] focusing on the preparation time and bed transfer time for ECPR patient transport as indicators of transport quality. However, based on current research and standards from both domestic and international guidelines,[12,13] there is a lack of specific quantitative data regarding the precise durations for preparation, bed transfer, and handover times in the transport of ECPR patients.

Statistical Methods

SPSS23.0 was used for statistical analysis, statistical inference was conducted using two-sided tests, with a significance level set at $P < 0.05$. Descriptive statistics for the participants' demographic characteristics are presented as counts (n) and proportions (%). Data regarding the preparation time, bed transfer time and theoretical examination scores for ECPR patient transport were analyzed as continuous variables and are expressed as mean ± standard deviation ($\bar{x} \pm s$). The independent-samples *t*-test was used to compare the assessment results between the two groups. Paired t-tests were employed to compare the pre- and post-training assessment results within each group.

Results

General Information

According to the inclusion and exclusion criteria, 48 participants were selected, including 10 males and 38 females, all of whom worked in the emergency department of a tertiary care general hospital in Nantong City. According to age segmentation, 10 were 18–29 years old, 24 were 30–44 years old, and 39 were ≥ 45 years old; according to education segmentation: 8 had an educational qualification lower than a bachelor's degree, 28 had completed graduate studies, and 5 had completed postgraduate and above; according to professional title, there were 8 residents, 6 attending physicians, 2 associate chief physicians, 15 nurses, 14 nurse practitioners, and 3 supervising nurse practitioners, as detailed in Tables 1 and 2, there was no significant difference in demographic characteristics between the two groups. Both, the experimental group and the control group had 8 doctors and 16 nurses each out of the total 48 participants.

Comparison of Scores Before and After Training Between the Two Groups

As shown in Table 3, after training on the SimMan 3G simulator, the experimental group's test scores were significantly higher than those of the control group ($P< 0.05$).

Table 1 Demographic Data of the SimMan 3G Simulated Patient Transfer Training Participants (n = 48)

Item:	Number of Cases: (n)	Composition Ratio: (%)
Gender		
Male	10	20.83
Female	38	79.17
Age		
18~29 years	30	62.50
30~44 years	16	33.33
≥ 45 years	2	4.17

(*Continued*)

Table 1 (Continued).

Item:	Number of Cases: (n)	Composition Ratio: (%)
Education		
Below bachelor's degree	8	16.67
Bachelor's degree	28	58.33
Postgraduate degree	12	25.00
Professional title		
Resident	8	16.67
Attending physician	6	12.5
Associate chief physician	2	4.17
Nurse	15	31.25
Nurse practitioner	14	29.16
Nurse-in-charge	3	6.25

Table 2 Comparison of General Demographic Data Between Two Groups

Groups	n	Gender		Age	Education Background			Professional Title		
		Male	Female		Below Bachelor	Bachelor	Above Bachelor	Junior	Middle	Senior
Experimental group	24	5	19	29.17±5.85	3	15	6	18	5	1
Control group	24	5	19	29.29±6.15	5	13	6	19	4	1
Statistical value				*t*=0.072	*F*=0.959			*F*=0.339		
p				0.949	0.333			0.563		

Notes: The p-value represents the comparison of demographic data between the experimental group and the control group. After comparison, all values are greater than 0.05.

Table 3 Comparison of Scores Before and After Training Between the Two Groups ($\bar{x} \pm s$)

	Number of Participants	Theoretical Test Scores		Clinical Skill Scores	
		Before Training	After Training	Before Training	After Training
Control group	24	80.03±12.81	82.46±10.91	87.23±18.48	88.35±17.71
Experimental group	24	81.62±11.74	88.78±13.55	88.91±17.10	95.32±20.15
P		>0.05	<0.05	>0.05	<0.05

Comparison of the Time Spent in Each Stage of Transfer Before and After Training Between Both Groups

Prior to the intervention, no significant differences were observed in the time expenditure at various stages between the two groups ($P > 0.05$). Post-training, the experimental group exhibited a marked reduction in the time spent at each stage when compared to the control group, with these differences reaching statistical significance ($P < 0.05$), as delineated in Table 4. Subsequent to the training, a reduction in time expenditure across all stages was noted for both groups relative to their pre-training measurements. Utilizing a paired-sample *t*-test for intra-group comparisons, it was observed that, with the exception of the control group's "preparation time (s)" which showed a non-significant reduction ($P > 0.05$), all other stages revealed significant differences ($P < 0.05$), as further elaborated in Table 5.

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Table 4 Comparison of Time Spent in Each Stage Before and After the Intervention ($\bar{x} \pm s$)

	n	Before the Intervention			After the Intervention		
		Preparation Time (s)	Bed Change Time (s)	Handover Time (s)	Preparation Time (s)	Bed Change Time (s)	Handover Time (s)
Control Group	24	94.25±19.64	91.00±3.16	147.75±23.29	71.50±15.09	76.75±11.59	97.00±10.68
Experimental Group	24	92.00±13.93	93.00±5.10	148.25±16.74	53.00±5.10	43.50±3.42	68.25±4.03
t		−0.19	0.67	0.04	−2.32	0.67	0.04
P		0.86	0.53	0.97	0.09	0.00	0.00

Table 5 Comparison of Time Spent in Each Stage Before and After Intervention ($\bar{x} \pm s$)

		Preparation Time (s)	t	P	Bed Change Time (s)	t	P	Handover Time (s)	t	P
Experimental group	Before intervention	92.00±13.93			93.00±5.10			148.25±16.74		
	After intervention	53.00±5.10			43.50±3.42			68.25±4.03		
	D-value	39.00±9.90	7.88	0.00	49.50±5.45	18.18	0.00	80.25±13.49	11.86	0.00
Control group	Before intervention	94.25±19.64			91.00±3.16			147.75±23.29		
	After intervention	71.50±15.09			76.75±11.59			76.75±11.59		
	D-value	22.75±15.97	2.85	0.07	14.25±8.73	3.26	0.047	50.75±16.32	6.22	0.01

Discussion

SimMan 3G Simulation Teaching in Enhancing Mastery of ECPR-Related Theoretical Knowledge Among Healthcare Providers

The novel clinical education model—medical simulation teaching—makes use of cutting-edge technological models and clinical simulation scenarios that integrate traditional steps of teaching, learning, and real-world practical experience. The ability of medical professionals to teach and the quality of their teaching methods can be improved through the use of the SimMan 3G simulator, which allows for the design and development of clinical cases of varying difficulties in accordance with different teaching objectives.[14] In this study, we utilized the SimMan 3G simulator in tandem with medical simulation teaching to develop ECPR transfer case materials and prepare the transfer team for simulation-based instruction. Final theoretical assessment scores in the experimental group showed a statistically significant difference between pre- and post-teaching, while there was no such difference in the control group, which had been taught using the traditional approach. This demonstrated that the ECPR patient transport team benefited more with respect to theoretical knowledge from the SimMan 3G simulation teaching than from traditional methods of instruction. Studies have shown that the shorter the initiation time of the ECPR team, the better the prognosis for patients.[15] As a critical component of resuscitation, improving the theoretical knowledge of healthcare providers is an essential means of enhancing the effectiveness of ECPR teams. Qualitative research by Eddison J and Millerchip O[16] has identified that insufficient understanding of ECPR among rescue teams is one of the main barriers to its implementation. Even in medical institutions with established ECPR teams, the relevant theoretical knowledge of healthcare personnel remains inadequate. This finding is consistent with the results of our study. Our research demonstrates that simulation-based teaching using SimMan 3G can significantly improve the mastery of ECPR-related theoretical knowledge among healthcare providers, thereby facilitating the development of an efficient ECPR team.

SimMan 3G Simulation Teaching to Improve the Skill Level of the ECPR Team

Although ECPR has greatly increased the survival rate of critically ill patients, the technique is challenging to operate and requires a large medical and nursing staff to be effective.[17,18] In the study by Eddison J and Millerchip O,[16] it was found that a certain degree of simulation training can enhance team collaboration skills. Through effective teaching and training, they achieved effective collaboration among team members, which is similar to the results of our study. The importance of training was further corroborated by the study of Pan et al,[19] which showed that targeted training can significantly improve the mastery of core ECPR skills among healthcare providers. Based on medical simulation teaching and using the high-fidelity SimMan 3G simulator, our study conducted the most realistic ECPR transport simulation training, highly replicating clinical scenarios. This allowed trainees to purposefully engage in operations within the context, with the realistic scenarios enabling them to experience the tension of real clinical situations, thereby better exercising their clinical judgment, professional operational skills, and team collaboration abilities.[20] Our study results indicate that ECPR simulation teaching using the SimMan 3G simulator has a significant effect on improving the overall operational skills of the transport team. Importantly, compared with traditional training models (such as theoretical lectures and single-skill practice), this high-fidelity simulation teaching is more effective in enhancing the team's comprehensive emergency response capabilities, operational proficiency, and coordination levels. This highlights the important value of high-fidelity simulation teaching in the training of complex and high-risk emergency techniques like ECPR, and it is worthy of promotion and application in clinical practice. In the study by Kruit et al,[21] the use of animals (pigs) as substitutes for simulators also demonstrated the importance of simulation training.

SimMan 3G Simulation Teaching to Enhance the Overall Collaboration of the ECPR Team

During the transfer process, the probability of critically ill patients dying are extremely high. Medical equipment, conduits, drugs, and other aspects involved in the in-hospital transfer of ECMO patients are more complex and variable to operate in clinical practice; once an adverse event occurs, it can be life-threatening.[22] The high-fidelity SimMan 3G simulation system creates a highly realistic and controllable training environment for extracorporeal cardiopulmonary resuscitation (ECPR), significantly enhancing the overall collaborative efficacy of multidisciplinary teams. This system accurately replicates complex patient pathophysiological states and dynamic responses to interventions such as medications, defibrillation, mechanical compressions, and ECMO cannulation. It forces team members to integrate information rapidly and make joint decisions under high-pressure, time-sensitive, and ambiguous information conditions, thereby honing their situational awareness and stress-resistant collaboration skills.

The SimMan 3G simulation teaching method, through predefined ECPR process components (such as establishing vascular access, priming circuits, and managing complications), allows team members to deepen their understanding of their core responsibilities through repeated practice. They also master the key skills of dynamic task coordination (such as seamless rotation of compressions, synchronized cannulation, and resolution of resource conflicts). This approach facilitates the transition from individual skill proficiency to team synergy, effectively reducing transfer times. Compared with traditional teaching methods, the results are much more significant. Similarly, Kang et al[23] used the "5P transfer system" to enhance the transfer capability of the extracorporeal membrane pulmonary oxygenation team for patients with acute and critical illnesses, proving that the "5P transfer system" can enhance the safety and feasibility of ECMO patient transfer. Through repeated simulation training, the overall coordination of the ECPR team is enhanced, and core elements of collaboration such as communication, role synergy, emergency decision-making, and shared mental models are systematically strengthened. This forges a highly coordinated life-rescue chain to tackle the challenge of cardiac arrest. In the study by Sams et al,[7] it is also emphasized that only well-trained professional teams can ensure the safety of on-site operations.

Future research could focus on integrating the "5P transfer system" with high-fidelity simulation training to construct a dual-track training model of "standardized processes - dynamic stress response." Specifically, modular simulation training units (such as team management of membrane lung plasma leakage during transport) could be embedded in the planning phase of the 5P system. By repeatedly exposing the team to controllable crisis scenarios, their collaborative resilience can be enhanced. This refers to the team's ability to quickly reconfigure the collaborative chain and maintain core functions when encountering sudden disturbances, thereby providing a more robust safety barrier for ultra-high-risk transfer scenarios like ECPR.

Currently, SimMan 3G simulation teaching is an important method for the training of medical and nursing staff as it can significantly reduce transfer time and improve the success rate of resuscitation. In the field of emergency medicine and anesthesia, SimMan 3G simulation-based trainings have become increasingly popular,[24,25] as well as instruction in the techniques of cardiopulmonary resuscitation, advanced life support, and airway management.[20,26–28] This approach has distinct advantages with respect to learning new things, being prepared for emergencies, working collaboratively, and feeling more confident.[29,30] However, the initial investment cost is high, and many primary hospitals have not equipped themselves with the requisite equipment, which hinders the promotion of SimMan 3G simulation-based training for ECPR transfer training.

Conclusion

The results of this study revealed that by incorporating the SimMan 3G simulator into the ECPR transfer rehearsal, the clinical treatment scenario can be reproduced, which not only helps to improve first aid skills, communication and collaboration among team members, and problem-solving and decision-making skills, but also addresses the issue of a lack of clinical cases, the high difficulty factor, and the lack of practice opportunities for medical and nursing staff. However, this study did not conduct a multicenter investigation, and the relatively small sample size imposes certain limitations. Nevertheless, the medical simulation teaching technology employed in this study, combined with the high-fidelity SimMan 3G simulator, represents a relatively novel teaching approach. In future research, the incorporation of AI technology could be considered to maximize the potential of simulation teaching. Additionally, multicenter studies should be conducted. Through repeated simulation training, the "time window" for ECPR patient transport could be shortened, thereby improving the quality of resuscitation.

Data Sharing Statement

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

This study was conducted with approval from the Ethics Committee of The Second Affiliated Hospital of Nantong University. This study was conducted in accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

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Disclosure

The authors declare that they have no competing interests in this work.

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