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Full-Scale high-fidelity simulation compared to procedural simulation workshop for veno-arterial ECMO cannulation during refractory cardiac arrest: a randomized controlled trial

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Abstract

Background Veno-arterial extracorporeal membrane oxygenation (VA-ECMO) is a critical intervention for patients in refractory cardiac arrest. Rapid and high-quality cannulation is essential for timely ECMO initiation and improved patient outcomes. Therefore, optimizing educational strategies for VA-ECMO training is crucial to ensure skill acquisition and effectiveness in clinical practice. This study aimed to compare the effectiveness of full-scale high-fidelity simulation versus a procedural simulation workshop for VA-ECMO cannulation training in anesthesiology and critical care residents.

Methods We conducted a prospective, randomized, two-arm, single-center, open-label trial at the Nantes university hospital simulation center. Thirty anesthesiology and critical care residents were randomly assigned to either a high-fidelity simulation group or a procedural simulation workshop group. Prior to the intervention, all participants completed an e-learning module on VA-ECMO cannulation. The procedural simulation workshop group underwent a 3-hour session focusing on technical skills, with guided hands-on practice. The high-fidelity simulation group participated in a full-day session incorporating immersive high-fidelity scenarios of refractory cardiac arrest, hands-on VA-ECMO cannulation, training on ECMO console management, and transesophageal echocardiography simulation. The primary outcome was total cannulation time (seconds) on a mannequin in a simulated refractory cardiac arrest scenario, measured from sterile preparation to circuit connection. Secondary outcomes included a procedural quality score, developed using a Delphi consensus method and assessed by blinded evaluators, as well as skill-specific sub-item analyses.

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Results Median cannulation times were similar between the procedural simulation workshop group (908 s; IQR 817–1015) and the high-fidelity simulation group (836 s; IQR 801–1029; $p=0.71$). Overall procedural quality scores did not significantly differ between groups. However, exploratory sub-item analyses suggested that specific procedural skills might be differentially influenced by each training modality.

Conclusions High-fidelity simulation and procedural workshops yielded similar performance for VA-ECMO cannulation. Although each may enhance specific skills, neither proved superior. Further research should determine the optimal integration of these training modalities.

Keywords Simulation Training, Medical Education, Clinical Competence, Educational Measurement

Background

Cardiac arrest refractory to medical treatment is a frequent condition with very high morbidity and mortality [1]. When cardiopulmonary resuscitation (CPR) fails, the likelihood of survival rapidly declines as no-flow (the time without circulation) and low-flow (the time of reduced cardiac output during cardiopulmonary resuscitation CPR) intervals lengthen [2].

Extracorporeal membrane oxygenation (ECMO) has emerged as a promising intervention for refractory cardiac arrest, with earlier studies reporting improved survival rates compared to conventional CPR [3, 4] and it has been progressively integrated into international guidelines [5]. The duration of cannulation is critical because it directly prolongs the low-flow period, a key independent predictor of neurological recovery [6, 7]. Therefore, developing effective educational methods is essential for this technically demanding procedure, which is often performed under high-stress conditions requiring rapid decision-making.

Simulation-based learning has become central to medical education and procedural training, offering a safe environment for skill acquisition without risk to patients [8, 9]. High-fidelity simulations are widely used because they create realistic, immersive scenarios that closely resemble real medical emergencies [10, 11]. These simulations help trainees improve both technical and non-technical skills (communication, teamwork, and situational awareness) needed for high-risk procedures [12]. For example, using a high-fidelity mannequin during an advanced cardiovascular life support course improved junior residents' performance on key tasks required for transcutaneous cardiac pacing [13]. In contrast, procedural simulation workshops focus on specific technical tasks, such as vascular access, airway management, or ultrasound-guided procedures [14, 15]. Conducted in controlled and cost-effective settings, they offer structured, hands-on, and repetitive practice.

As the optimal training method for teaching ECMO cannulation to anesthesiology and intensive care residents remains uncertain, we designed a randomized controlled trial to determine whether high-fidelity simulation achieves better training outcomes than procedural

simulation workshops regarding the speed and efficiency of femoro-femoral veno-arterial ECMO cannula insertion.

Methods

Study design

We conducted a prospective, open-label, single-center randomized trial with two parallel arms. The simulation program was developed in accordance with the guidelines of the French National Health Authority [16]. Ethical approval was granted by the local ethics committee (GNEDS, approval number 23-36-03-141), and all participants provided written informed consent. Participation in the study was entirely voluntary. Residents were explicitly informed that they could decline or withdraw at any time without any impact on their training or evaluation. The study enrolled medical residents specializing in anesthesia and critical care at a University Hospital. Participants were randomly assigned in a 1:1 ratio using computer-generated allocation to one of two groups: (i) a procedural simulation workshop or (ii) high-fidelity patient simulation training. We reported our results in accordance with the CONSORT guidelines [17].

Training programs

Training content and structure

Prior to attending their assigned training sessions, residents completed an e-learning course that covered all steps of the cannulation procedure, from surgical preparation to the initiation of extracorporeal circulation. The formation included a video developed by a surgeon-anesthesiologist team, which provided detailed instructions on the required equipment and technical aids, such as ultrasound-guided puncture, progressive dilation, and the use of arterial and venous cannulas.

Procedural simulation workshop

The procedural simulation workshop, led by a cardiac surgeon, took place in a designated room within the cardiothoracic intensive care unit. Residents were divided into three small groups to engage in hands-on learning following an apprenticeship-style approach. Over three hours, the session covered a detailed introduction to the

equipment, step-by-step guidance on ultrasound-guided puncture, wire handling, key maneuvers, and common pitfalls. Participants then practiced cannulation on a CREAPLAST™ Evolution III mannequin (CREAPLAST, Verton, France) with simulated arterial and venous flows, allowing real-time training with ultrasound-compatible vascular puncture. The training focused exclusively on technical skills, without covering ECMO patient management or refractory cardiac arrest algorithms.

Full Scale High-fidelity Simulation Training

The training was conducted at the Experimental Laboratory for Intensive Care Simulation (LE SiMU) at Nantes University. Participants were separated into two groups, each attending a full-day session. Each formation day included two scenarios of refractory cardiac arrest using a high-fidelity patient simulator (SimMan™ 3G, Laerdal, Norway) with dynamic physiological features like heart rate, consciousness, lung sounds, cyanosis, and seizures.

Each session started with a briefing on the materials and simulation environment, followed by scenario-based training, procedural workshops, and debriefing as previously described by our team [18]. The scenarios addressed refractory cardiac arrest management, ECMO initiation, and patient transfer. Details of the two scenarios of the “Full-Scale High-Fidelity Simulation Training” group are provided in Appendix 1.

Between scenarios, participants participate at three procedural stations:

1. Ultrasound-guided cannulation on the CREAPLAST™ mannequin.
2. Transesophageal echocardiography (TEE) training on the US Mentor simulator™ (Simbionix, Cleveland, Ohio, USA) for ECMO-related imaging.
3. ECMO console training on the portable CardioHelp system™ (Maquet, Rastatt, Germany), focusing on bubble detection and alarm management.

Evaluation of the cannulation procedure

Participants were evaluated during simulated refractory cardiac arrest scenarios, with ongoing cardiopulmonary resuscitation performed using a mechanical chest compression device (LUCAS™ system, Stryker, Lund, Sweden). All cannulation procedures were performed on the CREAPLAST™ mannequin (CREAPLAST, Verton, France). The ultrasound imaging was performed using a Philips™ system (Philips Healthcare, Eindhoven, Netherlands). Arterial and venous punctures were performed using Edwards Percutaneous Insertion Kits (Edwards Lifesciences, Irvine, California, USA) and Medtronic PC3 Opus dilators (Medtronic, Minneapolis, Minnesota, USA). Extracorporeal circulation was simulated using the portable CardioHelp console (Maquet,

Rastatt, Germany), ensuring a realistic replication of clinical practice. This setup provided a standardized simulation environment that closely replicated the conditions encountered during refractory cardiac arrest management.

Outcomes

Primary outcome

The primary outcome was the total time (in seconds) required to complete a full femoral-femoral cannulation during a simulated refractory cardiac arrest. This process included sterile preparation, ultrasound-guided puncture, progressive dilation, cannulation, and connection to the ECMO circuit.

Secondary outcome

The secondary outcome was a “procedural quality score” (range 0 to 17) developed through a rigorous Delphi method [19] in collaboration with the cardiac surgery and anesthesiology teams. Initially, structured interviews were conducted with five cardiac surgeons and five anesthesiologists to identify relevant criteria for assessing procedural quality, including technical, organizational, and clinical aspects. A preliminary list of items was then subjected to two Delphi validation rounds. During each round, the experts reviewed the proposed criteria, provided feedback, and rated the relevance, clarity, and importance of each item. Discrepancies were resolved through iterative discussion until consensus was reached, resulting in a final score that comprehensively reflects key dimensions of procedural quality. The grid was designed to comprehensively assess both technical and non-technical aspects of VA-ECMO implantation in case of refractory cardiac arrest (Appendix 2), covering essential steps such as aseptic preparation, cannulation, and communication.

Briefly, aseptic preparation included proper gowning and draping to maintain sterility. The cannulation procedure involved ultrasound-guided vascular puncture, the use of progressively larger dilators, precise wire management using the “fixed-point” technique, and the correct connection of the cannulas to the ECMO machine. Non-technical elements included effective communication about the procedure’s progress, clear and timely requests for equipment, and secure fixation of cannulas at the end of the procedure.

To ensure objective evaluation, an independent assessor, blinded to the randomization group and not involved in the students’ training, reviewed video recordings of the procedures. This approach ensured an unbiased assessment through the application of standardized evaluation criteria.

Statistical analysis

We analyzed previous cannulation times on mannequins performed by cardiac surgery residents at our simulation center, reporting a mean time of 540 ± 60 s. We hypothesized a 70-second improvement in the high-fidelity simulation group (470 s) compared to the procedural simulation workshop group (540 s). To detect this difference with 90% power and a 5% significance level, a sample size of 32 participants (16 per group) was required. Continuous data were summarized as medians with 25th and 75th percentiles or means $\pm$ standard deviations (SD). We employed the Mann-Whitney U test to analyze the primary outcome (cannulation time) and to compare total scores between groups, as it is appropriate for small sample sizes and non-normally distributed data. For secondary outcomes, we used Fisher's exact test to compare validation rates for each item, given its suitability for categorical data with small frequencies or zero counts. A p -value < 0.05 was considered statistically significant for all analyses, which were conducted using R version 4.4.2 (2024-10-31) software.

Results

Study population

We randomized thirty anesthesiology and intensive care residents into two equal groups: 15 attended a procedural simulation workshop, while 15 participated in high-fidelity simulation training (Table 1 for participant

characteristics). The median age was 27 years (IQR: 24–32), with 40% of participants being female. Clinical experience levels varied, with a median of six semesters in their specialty (IQR: 4–8), and residents in the high-fidelity group had significantly more experience ($p = 0.03$).

Most participants had limited prior exposure to ECMO, although over 40% had managed more than four veno-arterial (VA)-ECMO patients, and 50% had managed more than four veno-venous (VV)-ECMO patients. Experience with refractory cardiac arrest cases also varied: half of the participants had managed maximum 1 case, and only a minority had handled more than four. All participants had previously attended a high-fidelity simulation session unrelated to extracorporeal cardiac arrest, and 23.3% had received theoretical ECMO training before the study.

Primary outcome

The median cannulation time across all participants was 897 s (IQR 797–1025). The procedural simulation workshop group showed a median cannulation time of 908 s (IQR 817–1015), compared to 836 s (IQR 801–1029) in the high-fidelity simulation group. This difference was not statistically significant ($p = 0.71$) (Table 2).

Secondary outcomes

The total procedural quality score did not significantly differ between groups, with a median of 12.0/17 (IQR

Table 1 Characteristics of Participants

	All (N=30)	Procedural simulation workshop (N=15)	Full-scale high-fidelity simulation (N=15)	P-value
Age, Years, Median [IQR]	26.5 [26.0–27.75]	26.0 [26.0–27.0]	27.0 [26.0–28.0]	0.15
Female, n (%)	12 (40)	7 (46.7)	5 (33.3)	0.46
Interval between training and evaluation, days, median (IQR)	7 [7–11]	11 [8–12]	7 [7–7]	< 0.01
Resident experience, semesters, median [IQR]	6 [4–8]	4 [4–6]	8 [6–8]	0.03
Number of ecmo cannula placement				0.80
0–1	12 (40)	6 (40)	6 (40)	
2–3	12 (40)	5 (33.3)	7 (46.7)	
> 4	6 (20)	4 (26.7)	2 (13.3)	
Number of va-ecmo patients managed, n(%)				0.18
0–1	9 (30)	7 (46.7)	2 (13.3)	
2–3	8 (26.7)	3 (20)	5 (33.3)	
> 4	13 (43.3)	5 (33.3)	8 (53.3)	
Number of vv-ecmo patients managed, n (%)				0.20
0–1	7 (23.3)	4 (26.7)	3 (20)	
2–3	8 (26.7)	6 (40)	2 (13.3)	
> 4	15 (50)	5 (33.3)	10 (66.7)	
Number of refractory cardiac arrest patients managed, n (%)				0.20
0–1	15 (50)	9 (60)	6 (40)	
2–3	10 (33.3)	4 (26.7)	6 (40)	
> 4	5 (16.7)	2 (13.3)	3 (20)	
Participation in others high-fidelity simulation session	30 (100)	15 (100)	15 (100)	> 0.99
Previous theroretical ecmo formation, n (%)	7 (23.3)	3 (20)	4 (26.7)	0.67

VV-ECMO veno-venous extra corporal membrane oxygenation, VA-ECMO veno-arterial extra corporal membrane oxygenation

Table 2 Primary and secondary outcomes

	All (N=30)	Procedural simulation workshop (N=15)	Full-scale high-fidelity simulation (N=15)	P-value
Primary outcome				
Timing for total va-ecmo cannulation (seconds), mediane (IQR)	897 (797–1025)	908 (817–1015)	836 (801–1029)	0.71
Secondary outcome (procedural quality score)				
Dressing /1	30 (100)	15 (100)	15 (100)	> 0.99
Installation & Preparation /5, Median (IQR)	3.0 (3.0–3.0)	3.0 (2.0–3.0)	3.0 (3.0–3.0)	0.1
Surgical draping (2 SCARPAS), <i>n</i> (%)	18 (60)	5 (33.3)	13 (86.7)	0.01
Clear request for equipment, <i>n</i> (%)	8 (26.7)	5 (33.3)	3 (20)	0.68
Sterile protection for linear probe, <i>n</i> (%)	30 (100)	15 (100)	15 (100)	> 0.99
Ultrasound-guided identification of veins and arteries, <i>n</i> (%)	30 (100)	15 (100)	15 (100)	> 0.99
Lubrication of introducers and guides, <i>n</i> (%)	1 (3.3)	0 (0)	1 (6.7)	> 0.99
Catheterisation /7, Median (IQR)	5.0 (4.25–6.0)	6.0 (5.5–6.0)	5.0 (4.0–5.0)	0.006
Safe handling of sharp objects, <i>n</i> (%)	13 (43.3)	5 (33.3)	8 (53.3)	0.46
Scalpel opening, <i>n</i> (%)	30 (100)	15 (100)	15 (100)	> 0.99
Dilatator of increasing sizes, <i>n</i> (%)	29 (96.7)	14 (93.3)	15 (100)	0.99
Fixed point, <i>n</i> (%)	30 (100)	15 (100)	15 (100)	> 0.99
Guide handling, <i>n</i> (%)	24 (80)	10 (66.7)	14 (93.3)	0.17
Advanced communication, <i>n</i> (%)	16 (53.3)	14 (93.3)	2 (13.3)	< 0.001
Connection /4, Median (IQR)	3.0 (3.0, 3.75)	3.0 (3.0, 3.5)	3.0 (3.0, 3.5)	> 0.99
Respect for circuit connection sites, <i>n</i> (%)	29 (96.7)	14 (93.3)	15 (100)	0.99
Connection and priming procedure, <i>n</i> (%)	30 (100)	15 (100)	15 (100)	> 0.99
Bubble-free control, <i>n</i> (%)	28 (93.3)	13 (86.7)	30 (100)	0.48
Cannula fixation, <i>n</i> (%)	8 (26.7)	4 (26.7)	4 (26.7)	> 0.99
Total /17, Median (IQR)	12.0 (12.0–13.0)	13.0 (12.0–13.0)	12.0 (11.5–12.5)	0.15

12.0–13.0) across all participants (Table 2). The procedural simulation workshop group achieved a median score of 13.0/17 (IQR 12.0–13.0), compared to 12.0/17 (IQR 11.5–12.5) in the high-fidelity simulation group ($p=0.15$). Despite the lack of a difference in total scores, specific domains showed notable variations: in the « Installation & Preparation » domain, the high-fidelity simulation group demonstrated significantly better performance on surgical draping of the two scarpas, with 86.7% of participants achieving success compared to only 33.3% in the procedural simulation workshop group ($p=0.01$). Other sub-items in this domain, including clear request for equipment, sterile protection for the linear probe, ultrasound-guided identification, and lubrication of introducers, showed no significant differences between groups ($p>0.99$). The “catheterization” domain revealed a median score of 6.0/7 (IQR 5.5–6.0) for the procedural simulation workshop group, which was significantly higher than the 5.0/7 (IQR 4.0–5.0) observed in the high-fidelity simulation group ($p=0.006$). This improvement was primarily attributed to better performance in advanced communication, where 93.3% of participants in the procedural simulation workshop group succeeded, compared to 13.3% in the high-fidelity simulation group ($p<0.001$). Other sub-items, including safe handling of sharp objects, scalpel opening, dilators of increasing

sizes, fixed point, and guide handling, did not show significant differences ($p>0.99$).

Discussion

Our randomized trial evaluating two training methods for femoro-femoral VA-ECMO cannulation found no significant difference in the median cannulation times between full scale high-fidelity simulation and the procedural simulation workshop. Similarly, there were no differences in the procedural quality score, which was developed using a Delphi process in collaboration with the cardiac surgery and anesthesiology teams. Some variations were noted in certain procedural sub-items, but these were exploratory findings and should be considered as hypothesis-generating.

Given the complexity of ECMO cannulation in refractory cardiac arrest and the critical need for precise and rapid intervention to minimize the low-flow period, effective training for healthcare professionals is essential. A recent systematic review and meta-analysis showed that learners using high-fidelity simulation demonstrated better knowledge and skill performance in advanced life support compared to those using low-fidelity simulation or traditional training [20]. Expert centers have already integrated simulation-based training into their units. The ARREST team showed that early ECMO-facilitated resuscitation for patients with out-hospital

cardiac arrest and refractory ventricular fibrillation significantly improved survival to hospital discharge compared to standard advanced cardiovascular life support treatment [21]. The training program included 16 h of lectures and didactic discussions, complemented by 12 h of simulation, which contributed to a 100% cannulation success rate [22]. However, these extensive multidisciplinary training protocols are not directly comparable to our study, which focused on individual procedural performance and did not evaluate team dynamics or ECPR activation workflows. The brief duration of both training interventions in our trial may have contributed to the absence of differences between groups. More comprehensive or repeated training may be needed to develop technical and non-technical competencies. Simulation programs have also been evaluated in pediatric population; a 2016 Italian study showed a significant improvement in cannulation times and in the management of common emergencies associated with pediatric ECMO following a high-fidelity simulation protocol [23]. This protocol consisted of 16 h of lectures, 16 h of high-fidelity simulation, and 32 h of bedside supervision, with repeated simulations every three months, specifically designed for novice practitioners. In 2010, the Italian health authorities established ECMOnet, a network of ICUs to prepare for treating severe influenza patients with veno-venous ECMO. Simulation technology effectively trained ICU physicians, improving their skills and contributing to positive survival outcomes, making it a valuable alternative to traditional animal-based ECMO training [24]. Only two controlled trials showed that high-fidelity simulation offered moderate benefits in retaining ALS skills three months after training but it did not significantly enhance long-term retention of resuscitation knowledge [25, 26]. In our study, neither of the two training methods demonstrated a clear benefit in ECMO cannula insertion. Some skills were better in the high-fidelity simulation group, while others were superior in the procedural simulation workshop group. This aligns with the French health simulation guidelines, which advocate for procedural simulation over full-scale simulation when teaching just technical skills [16]. Reduced task complexity has been shown to enhance performance and decrease cognitive load during skill acquisition and retention, as demonstrated in lumbar puncture training [27]. Interestingly, while high-fidelity simulation in medical training does not always lead to better performance compared to low-fidelity simulation, depending on the skill being learned, it has been associated with increased overconfidence in students in some situations [28]. In our study on the optimal training method for ECMO cannulation in refractory cardiac arrest, the analysis of specific skills acquired through each approach suggests that a combined training model (starting with a procedural

simulation workshop and progressing to high-fidelity simulation) may be more effective in enhancing overall competency. Based on our results, we also reviewed and revised both curricula, notably strengthening the section on “surgical draping of the scarpa,” which participants had identified as insufficiently covered during the procedural workshop.

Our study has several strengths. First, we used the same equipment (cannulas, ECMO circuit, and machine) as that employed by our ECMO Retrieval Team, ensuring consistency and relevance to real-world clinical practice. Second, we utilized surrogate outcomes that are well correlated with patient-centered outcomes, such as neurological recovery. These measures, including cannulation time and procedural quality scores, serve as early indicators of procedural success and provide valuable insights into their potential impact on long-term patient outcomes.

Our study has limitations. First, the cannulation times were longer than estimated times reported for cardiac surgery residents in simulated settings. This was likely due to the evaluation scenario, integrating the comprehensive management of refractory cardiac arrest, for example using a LUCAS-type mechanical chest compression device, which closely replicated real-life conditions. Nonetheless, these times are comparable to those observed in major randomized studies, such as the INCEPTION trial, which reported a median cannulation time of 20 min [29]. A second limitation of our study is the absence of follow-up to assess long-term knowledge retention after the intervention. While some studies have demonstrated that high-fidelity simulation enhances initial knowledge acquisition and skill performance compared to traditional training methods, this improvement appears to have limited impact on long-term retention [30, 31]. Moreover, as non-technical skills such as communication, teamwork, and situational awareness are critical in ECMO initiation and as challenging as the technical steps themselves, future studies should evaluate training strategies that also target these competencies. Third, we included 30 residents instead of the 32 initially planned, but this slight reduction is unlikely to have influenced the study's findings. Moreover, the single-center design, conducted among residents from the same institution, may limit generalizability to other training environments. Our study did not assess long-term retention or the transfer of skills to real clinical performance, and randomization was not stratified by prior ECMO exposure, which may explain the pre-training differences observed between groups. Fourth, all sub-item analyses were exploratory and were not adjusted for multiple comparisons; they should therefore be interpreted with caution and considered hypothesis-generating only. Although the high-fidelity group had more experienced

residents, the lack of performance differences suggests no superiority of either training modality. Finally, the study's limited statistical power can be attributed to the substantial discrepancy between the estimated and actual cannulation times.

Conclusion

In our randomized controlled trial, high-fidelity simulation and procedural workshops yielded similar performance outcomes for training in femoro-femoral VA-ECMO cannulation during refractory cardiac arrest. Although each approach may enhance certain specific skills, the evidence does not support the superiority of either method. Further research should determine how best to combine or sequence these modalities and assess their long-term impact on clinical performance and patient outcomes.

Abbreviations

ALS	Advanced Life Support
CPR	Cardiopulmonary Resuscitation
ECMO	Extracorporeal Membrane Oxygenation
GNEDS	Groupe Nantais d'Éthique et de Déontologie en Santé
IQR	Interquartile Range
LE SiMU	Laboratoire Expérimental de Simulation en Médecine d'Urgence
SD	Standard Deviation
TEE	Transesophageal Echocardiography
VA	ECMO–Veno–Arterial Extracorporeal Membrane Oxygenation
VV	ECMO–Veno–Venous Extracorporeal Membrane Oxygenation

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12909-026-09618-5>.

Supplementary Material 1.

Supplementary Material 2.

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Study registration

Our study was not prospectively registered in a clinical trial registry. Our institution does not permit retrospective registration once participant enrollment has begun, which precluded registration after study initiation. However, the complete study protocol — including predefined primary and secondary outcomes, sample size calculation, statistical analysis plan, consent forms, and participant information sheets — was prepared and submitted to the ethics committee (Groupe Nantais d'Éthique dans le Domaine de la Santé, GNEDS) in January 2023, prior to the start of the study. A favorable opinion was issued on 14 March 2023 (opinion no. 23-36-03-141), and participant enrollment began in April 2023, in strict accordance with the approved protocol. To ensure full transparency and to demonstrate that the trial was entirely designed a priori, all study-related documents — including the complete protocol (in both English and French), all documents submitted to the ethics committee, and the ethics committee approval are available from the corresponding author.

Authors' contributions

Marwan Bouras: Writing original draft, Investigation, Methodology, Data curation, Formal analysis, Validation- Thomas Senage: Writing - review & editing, Validation, Methodology, Formal analysis, Data curation- Emma Meulé: Writing - review & editing, Validation, Methodology, Formal analysis, Data curation- Charles-Henri David: Writing - review & editing, Investigation-

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Data availability

The datasets used and/or analyzed in the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the ethical guidelines of the French National Health Authority. Ethical approval was obtained from the local ethics committee (GNEDS, approval number 23-36-03-141). All participants provided written informed consent before enrollment in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Empana JP, Lerner I, Valentin E, Folke F, Böttiger B, Gislason G, et al. Incidence of Sudden Cardiac Death in the European Union. *J Am Coll Cardiol* mai. 2022;79(18):1818–27.
2. Goto Y, Funada A, Goto Y. Relationship Between the Duration of Cardiopulmonary Resuscitation and Favorable Neurological Outcomes After Out-of-Hospital Cardiac Arrest: A Prospective, Nationwide, Population-Based Cohort Study. *J Am Heart Assoc*. 2016;5(3):e002819.
3. Chen YS, Lin JW, Yu HY, Ko WJ, Jerng JS, Chang WT, et al. Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis. *Lancet Lond Engl*. 2008;372(9638):554–61.
4. Avalli L, Maggioni E, Formica F, Redaelli G, Migliari M, Scanziani M, et al. Favourable survival of in-hospital compared to out-of-hospital refractory

- cardiac arrest patients treated with extracorporeal membrane oxygenation: An Italian tertiary care centre experience. *Resusc. mai.* 2012;83(5):579–83.
5. Wyckoff MH, Singletary EM, Soar J, Olasveengen TM, Greif R, Liley HG, International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. 2021 : Summary From the Basic Life Support; Advanced Life Support; Neonatal Life Support; Education, Implementation, and Teams; First Aid Task Forces; and the COVID-19 Working Group. *Resuscitation.* 2021;169:229–311.
 6. Otani T, Sawano H, Natsukawa T, Nakashima T, Oku H, Gon C, et al. Low-flow time is associated with a favorable neurological outcome in out-of-hospital cardiac arrest patients resuscitated with extracorporeal cardiopulmonary resuscitation. *J Crit Care.* 2018;48:15–20.
 7. Matsuyama T, Irisawa T, Yamada T, Hayakawa K, Yoshiya K, Noguchi K et al. Impact of Low-Flow Duration on Favorable Neurological Outcomes of Extracorporeal Cardiopulmonary Resuscitation After Out-of-Hospital Cardiac Arrest: A Multicenter Prospective Study. *Circulation.* 2020;141(12):1031–3.
 8. Park CS, Rochlen LR, Yaghmour E, Higgins N, Bauchat JR, Wojciechowski KG, et al. Acquisition of Critical Intraoperative Event Management Skills in Novice Anesthesiology Residents by Using High-fidelity Simulation-based Training. *Anesthesiology.* 2010;112(1):202–11.
 9. Steadman RH, Coates WC, Huang YM, Matevosian R, Larmon BR, McCullough L, et al. Simulation-based training is superior to problem-based learning for the acquisition of critical assessment and management skills*. *Crit Care Med.* 2006;34(1):151–7.
 10. Lewis R, Strachan A, Smith MM. Is High Fidelity Simulation the Most Effective Method for the Development of Non-Technical Skills in Nursing? A Review of the Current Evidence. *Open Nurs J.* 2012;6:82–9.
 11. Rodgers DL, Securo S, Pauley RD. The Effect of High-Fidelity Simulation on Educational Outcomes in an Advanced Cardiovascular Life Support Course. *Simul Healthc J Soc Simul Healthc.* 2009;4(4):200–6.
 12. McFetrich J. A structured literature review on the use of high fidelity patient simulators for teaching in emergency medicine. *Emerg Med J.* 2006;23(7):509–11.
 13. Ranger C, Paradis MR, Morris J, Perron R, Drolet P, Cournoyer A, et al. Transcutaneous cardiac pacing competency among junior residents undergoing an ACLS course: impact of a modified high fidelity manikin. *Adv Simul.* 2018;3(1):24.
 14. Sanchez Novas D, Domenech G, Belitzky NG, Errecart MM, Terrasa SA, Garcia Fornari G. Simulation-based training for early procedural skills acquisition in new anesthesia trainees: a prospective observational study. *Adv Simul.* 2020;5(1):19.
 15. Augustine EM, Kahana M. Effect of Procedure Simulation Workshops on Resident Procedural Confidence and Competence. *J Grad Med Educ.* 2012;4(4):479–85.
 16. HAS. Haute Autorité de Santé Good Practice Recommendations for Simulation Training. 2024. https://www.has-sante.fr/portail/upload/docs/application/pdf/2013-01/guide_bonnes_pratiques_simulation_sante_guide.pdf.
 17. Hopewell S, Chan AW, Collins GS, Hróbjartsson A, Moher D, Schulz KF et al. CONSORT 2025 Statement: Updated Guideline for Reporting Randomized Trials. *JAMA.* 2025;333(22):1998.
 18. Lejus-Bourdeau C, Grillot N, Dupont S, Robert-Edan V, Bazin O, Viquesnel S, et al. Randomised comparison of Enk™ and Manujet™ for emergency tracheal oxygenation with a high-fidelity full-scale simulation. *Anaesth Crit Care Pain Med.* 2020;39(6):807–12.
 19. Dalkey N, Helmer O. An Experimental Application of the DELPHI Method to the Use of Experts. *Manag Sci.* 1963;9(3):458–67.
 20. Zeng Q, Wang K, Liu W, xin, Zeng J, zhi, Li X lan, Zhang Q et al. feng, sept. Efficacy of high-fidelity simulation in advanced life support training: a systematic review and meta-analysis of randomized controlled trials. *BMC Med Educ.* 2023;23(1):664.
 21. Yannopoulos D, Bartos J, Raveendran G, Walser E, Connett J, Murray TA, et al. Advanced reperfusion strategies for patients with out-of-hospital cardiac arrest and refractory ventricular fibrillation (ARREST): a phase 2, single centre, open-label, randomised controlled trial. *Lancet Lond Engl.* 2020;396(10265):1807–16.
 22. Bartos JA, Frascione RJ, Conterato M, Wesley K, Lick C, Sipprell K et al. The Minnesota mobile extracorporeal cardiopulmonary resuscitation consortium for treatment of out-of-hospital refractory ventricular fibrillation: Program description, performance, and outcomes. *EClinicalMedicine.* 2020;29–30:100632.
 23. Di Nardo M, David P, Stoppa F, Lorusso R, Raponi M, Amodeo A, et al. The introduction of a high-fidelity simulation program for training pediatric critical care personnel reduces the times to manage extracorporeal membrane oxygenation emergencies and improves teamwork. *J Thorac Dis.* 2018;10(6):3409–17.
 24. Brazzi L, Lissoni A, Panigada M, Bottino N, Patroniti N, Pappalardo F, et al. Simulation-Based Training of Extracorporeal Membrane Oxygenation During H1N1 Influenza Pandemic: The Italian Experience. *Simul Healthc J Soc Simul Healthc.* 2012;7(1):32–4.
 25. Settles J, Jeffries PR, Smith TM, Meyers JS. Advanced cardiac life support instruction: do we know tomorrow what we know today? *J Contin Educ Nurs.* 2011;42(6):271–9.
 26. Aqel AA, Ahmad MM. High-fidelity simulation effects on CPR knowledge, skills, acquisition, and retention in nursing students. *Worldviews Evid Based Nurs.* 2014;11(6):394–400.
 27. Haji FA, Cheung JJH, Woods N, Regehr G, de Ribaupierre S, Dubrowski A. Thrive or overload? The effect of task complexity on novices' simulation-based learning. *Med Educ.* 2016;50(9):955–68.
 28. Massoth C, Röder H, Ohlenburg H, Hessler M, Zarbock A, Pöpping DM, et al. High-fidelity is not superior to low-fidelity simulation but leads to overconfidence in medical students. *BMC Med Educ.* 2019;19(1):29.
 29. Bol ME, Suverein MM, Lorusso R, Delnoij TSR, Brandon Bravo Bruinsma GJ, Otterspoor L, et al. Early initiation of extracorporeal life support in refractory out-of-hospital cardiac arrest: Design and rationale of the INCEPTION trial. *Am Heart J.* 2019;210:58–68.
 30. Zinsmaster J, Vliem S. The Influence of High-Fidelity Simulation on Knowledge Gain and Retention. *Nurs Educ Perspect.* 2016;37(5):289–90.
 31. Lo BM, Devine AS, Evans DP, Byars DV, Lamm OY, Lee RJ, et al. Comparison of traditional versus high-fidelity simulation in the retention of ACLS knowledge. *Resusc.* 2011;82(11):1440–3.

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