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UPDATE IN INTENSIVE CARE MEDICINE: CRITICAL PATIENT SAFETY

Patient safety, what does clinical simulation and teaching innovation contribute?

María Jesús Broch Porcar*, **Álvaro Castellanos-Ortega**

Servicio de Medicina Intensiva, Hospital Universitario y Politécnico La Fe, Valencia, Spain

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Abstract Clinical simulation in Intensive Care Medicine is a crucial tool to strengthen patient safety. It focuses on the complexity of the Intensive Care Unit, where challenging clinical situations require rapid decision making and the use of invasive techniques that can increase the risk of errors and compromise safety. Clinical simulation, by mimicking clinical contexts, is presented as essential for developing technical and non-technical skills and enhancing teamwork in a safe environment, without harm to the patient. *in situ* simulation is a valuable approach to practice in realistic environments and to address latent security threats. Other simulation methods as virtual reality and tele-simulation are gaining more and more acceptance. Herein, we provide current data on the clinical utility of clinical simulation related to improved safety in the practice of techniques and procedures, as well as improvements of teamwork performance and outcomes. Finally, we propose the needs for future research.

PALABRAS CLAVE
Seguridad;
Simulación clínica;
Simulación in situ;
Entrenamiento;
Trabajo en equipo

Seguridad del paciente, ¿qué aportan la simulación clínica y la innovación docente?

Resumen La simulación clínica en Medicina Intensiva es un método de gran utilidad para potenciar la seguridad del paciente. Permite enfocar sobre la complejidad de la asistencia en la Unidad de Cuidados Intensivos, donde se han de afrontar situaciones críticas que requieren decisiones rápidas y técnicas invasivas que pueden aumentar el riesgo de errores. La simulación, al reproducir contextos clínicos, resulta esencial para desarrollar habilidades técnicas y conductuales, y potenciar el trabajo en equipo en un ambiente seguro, sin daño para

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* Corresponding author.
E-mail address: ixuscorreu@gmail.com (M.J. Broch Porcar).

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paciente. La simulación *in situ* es un enfoque valioso para entrenar en entornos de trabajo reales y detectar amenazas latentes de seguridad. Nuevos métodos como la realidad virtual y la tele-simulación están ganando aceptación. Se presentan evidencias de la utilidad de la simulación clínica para mejorar la seguridad de técnicas y procedimientos, el rendimiento de los equipos y los resultados clínicos. Finalmente, se proponen líneas futuras de investigación.

Introduction

Patient safety is the cornerstone of health care and a priority objective of any clinical activity.[1] It has been over two decades since the publication of the well-known report T̈o Err is Human: Building a Safer Health System:̈.[2] Since then, there has been a growing interest in delving into the origins of medical errors. As a result, there is a push to teach technical, as well as non-technical or behavioral skills, an area of knowledge that has received little attention and plays an important role in patient safety, especially in emergency situations. The health care system should be seen as a technical-social system with complex processes and interactions where medical errors are often more a consequence of avoidable system failures than individual practices.[3] Providing quality care, based on the most current scientific evidence, ultimately depends on the competencies of professionals and the structure of the system in which they work. In this context, medical education plays an essential role in making sure that these competencies are acquired. The Intensive Care Unit (ICU) is a care environment where professionals face complex and changing clinical situations that require rapid decision-making and the performance of multiple tasks almost simultaneously, which can affect care and communication, increasing the risk of errors and compromising patient safety.[4] In this truly challenging environment, clinical simulation offers ethical benefits by providing professionals with a safe and controlled environment to acquire and train both technical and non-technical skills, and adds effectiveness by providing greater precision in training and competency evaluation. Simulation provides new methods for teaching error management and a culture of safety.[1,2] In 2007, David Gaba already pointed out that ''the use of simulation to improve safety will require the full integration of its applications into the structures and routine practices of health care''[5]; however, through clinical simulation, its use has not been widespread or systematized adequately to harness its full potential. This narrative review article describes the most widely used methods in clinical simulation and presents the most updated medical evidence on its utility for developing technical and non-technical skills, strengthening teamwork, promoting patient safety in the ICU, and improving clinical outcomes.

Clinical simulation

Clinical simulation is a technique that mimics clinical practice contexts for learning without risking patient safety.[6] Its practice has been associated with accelerated learning of techniques and improvement of individual performance, teamwork, and clinical outcomes.[7–14] For decades, medical education has followed the model: s̈ee one, do one, teach oneön real patients. Fortunately, this model is gradually being replaced by clinical simulation, where health care professionals can train, make mistakes without risking patient safety, learn from those errors, and improve their skills, resulting in safer and more effective care in real situations. Simulation is constantly evolving, drawing from various disciplines such as learning theories, didactics, cognitive psychology, technology, and patient safety.[15,16] It is based on Kolb's theory, which argues that although experience is crucial for learning and professional development, without rigorous reflection on our actions, performance cannot change.[17] A practical simulation session consists of several stages: 1) briefing, aimed at guiding participants by explaining the methodology, key learning points, and the advantages and limitations of simulation and simulators, which is an important step to reinforce the participants' psychological safety[18,19]; 2) action, where the learner or team faces simulated clinical situations designed beforehand to achieve specific learning objectives; 3) debriefing, which involves analyzing observed performance to promote learning through reflection, helping participants identify gaps in knowledge, attitudes, and emotional reactions that could contribute to poor performance.[20,21] This dialogue-based reflection technique provides deeper and more lasting learning. Although there are different debriefing strategies, there is no evidence that one is superior to the other.[22,23] Within debriefing itself, there are several phases, starting by inviting participants to express their emotions to release the tension generated during the action in the simulated scenario,[24] to focus on the next phase, that of learning *per se*. There are different conversational styles that each instructor can adapt to their personality. The most popular one is the ''good judgment'' debriefing,[20] which explores with curiosity to understand the mental model on which participants' decisions are based and propose constructive solutions for learning.[25,26] In the final phase, closure or

synthesis, the teacher needs to make sure that students have achieved the learning objectives of the simulation exercise.[25] Medical education through simulation requires instructors who are not only trained in the subject they want to teach but also knowledgeable in clinical simulation and conflict resolution. Instructors must be empathetic, create emotionally safe environments, have active listening skills, and argumentative capacity to lead debriefing sessions constructively.[27] Effective feedback provided by the instructor will eventually change performance, shape skills and knowledge, and contribute to creating the participant's professional identity, being the most decisive element in learning. Although high-technology simulation better recreates reality, it is not essential to achieve relevant objectives. The first simulator used in health care was recorded back in 1960,[28] and since then, its development has been constant and significant. Currently, there are very realistic simulators designed to train technical skills, such as partial task trainers, and clinical skills such as full-scale simulators (manikins) that can be of low, medium, or high fidelity, the latter with realistic physiological responses.[29] Standardized patients (actors) are also available. The choice of simulator will depend on the learning objectives. Currently, clinical simulation is used to learn new techniques, put knowledge into practice, acquire individual and teamwork behavioral skills, identify gaps in the performance of ICU professionals and during specialized training, as well as a formative and summative assessment method to demonstrate the maintenance of professional competencies.[29–32] In fact, the American Commission for some specialties such as Internal Medicine and Anesthesiology incorporates simulation into their recertification programs.[33,34]

Simulation can be conducted in different environments, with the most well-known being the Simulation Center, designed to reproduce a variety of clinical scenarios, including an ICU. In the last decade, the use of in-situ simulation has expanded, which is conducted in a real clinical environment with professionals who are working at that time. Virtual reality (VR) simulation has also been developed,[35–38] which can be defined as a three-dimensional simulated space generated by a computer to replicate real or imaginary world environments and interactions for various purposes. It allows the user to ''interact'' and ''immerse'' themselves in a virtual environment, apparently real, using electronic devices such as virtual reality glasses, handheld controllers, or gloves with motion tracking sensors. VR seeks to provide a sense of presence and action in a digital environment and has some theoretical advantages compared to simulation with manikins and actors: lower cost, more accessible, and adaptable to training needs, activities can be repeated as many times as desired, training can be conducted at any time convenient for the user, and volunteers, consumables, or large facilities are not required. In contrast, simulation with manikins and standardized patients provides a more authentic experience as it takes place in a real environment, with real interaction in the practice of techniques and equipment management. Manikins allow a complete medical team to train in complex scenarios of effective communication, quick decision-making, and coordination among different professionals. Group learning and direct feedback provided by expert instructors are a great advantage. The choice between these technologies will depend on the specific training objectives and the skills that need to be developed. The combination of both technologies can offer a comprehensive and effective approach to medical education. Finally, since the pandemic, tele-simulation has also been promoted,[39] with a concept very similar to telemedicine. All modalities have advantages and disadvantages, but they share their usefulness and complementarity.

Training technical skills through clinical simulation

In the field of intensive care medicine, mastering specialized techniques and procedures is of paramount importance. These practices can be associated with potentially life-threatening adverse events. When patient safety is a concern, the traditional approach of ''see one, do one, teach one'' is not the most suitable one, as it may entail risks due to inexperience or malfunctioning equipment. Acquiring technical skills through simulation offers a safe alternative, facilitating reflective, repeated, and planned practice of activities of increasing complexity, all guided with specific feedback.[34] This approach helps reduce the learning curve and improves the competence of intensive care physicians and nurses. Training technical skills with partial task simulators is an effective strategy evidenced in numerous studies. A systematic review that included 162 studies concluded that simulation was more effective than bedside learning in 12 invasive procedures, including endotracheal intubation and central venous catheterization.[7] Another meta-analysis found that simulation outperformed other teaching methods in the acquisition of technical skills in critical care.[8] The effectiveness of learning through simulation has been highlighted in different studies on the following common techniques in the ICU:

- **Mechanical ventilation (MV):** Clinical simulation has emerged as a highly effective form of learning compared to traditional methods, especially at a multiprofessional level.[40–42] It allows handling various conditions with a real mechanical ventilator and observing the immediate consequences of actions, offering immediate personalized feedback.[43] Training through clinical simulation in this area can also improve clinical outcomes, as demonstrated by the decrease in ventilator-associated pneumonia after training specific protocols.[44] The use of virtual reality simulators[41] and tele-simulation has increased recently to train ventilator management in institutions lacking experts in this field.[45] In conclusion, simulation positively impacts MV practice by creating a controlled and safe environment where professionals can familiarize themselves with equipment, gain confidence in decision-making in complex situations, provide varied and realistic scenarios, optimize interaction with the ventilator, identify areas for improvement, and plan professional development activities.
- **Vascular access:** Simulation has proven to be effective in learning central venous catheter placement, offering higher success rates than traditional methods.[46,47] Additionally, it has shown a significant reduction in adverse events,[9] an increase in confidence compared to conventional methods, and better skills transfer to the actual

clinical practice.[48] It has also contributed to improving compliance with insertion protocols[48] and reducing the incidence density of catheter-related bloodstream infection.[10]

- **Other invasive procedures:** Airway management is crucial in critically ill patients, often needing to be performed in emergency situations with limited physiological reserve, making prior skill acquisition indispensable. A meta-analysis including 76 studies and 5226 participants concluded that simulation in airway management surpasses non-simulation-based training in terms of satisfaction, skill acquisition, and patient outcomes.[11] Simulation has also been shown to be effective in acquiring and maintaining skills related to other procedures such as fiberoptic bronchoscopy, thoracentesis, pleural drainage, pericardiocentesis, cricothyroidotomy, tracheostomy, lumbar puncture, and paracentesis, among others. Additionally, it allows familiarity with aseptic techniques, understanding the necessary equipment, mastering the appropriate technique, and learning maneuvers to avoid adverse events.[11,49–51]
- **Management of advanced medical devices and life support:** Safe management of devices such as pacemakers, defibrillators, extracorporeal membrane oxygenation (ECMO), dialysis, ultrasound, infusion pumps, and vital signs monitors is essential in critical patient care. A randomized trial involving 44 intensive care specialists with no previous experience in ECMO showed that the group trained with high-fidelity simulation acquired more knowledge and required less time for critical action compared to the group that learned based on experience.[52] Some programs developed for nursing have achieved similar results.[53] At the European Congress on Extracorporeal Life Support (EuroELSO, London 2022), 43 simulation-based training sessions were conducted on V—V ECMO, A–V ECMO, mechanical circulatory support, Impella, renal replacement therapy on ECMO, cannulation during out-of-hospital ECPR, and problem-solving. We should mention that 88% of the 400 participants stated that the training received would change their routine clinical practice.[54]

The use of point-of-care ultrasound (POCUS) to perform rapid assessments of organs and systems has become a highly valuable skill in ICUs. Clinical simulation offers the opportunity to practice and acquire skills in obtaining and interpreting images and performing ultrasound-guided invasive techniques to reduce adverse events.[55]

Monitors and devices used in ICUs have numerous alarms. Improving knowledge and proper use of them should be a priority objective in patient safety programs. Many alarm-related incidents are attributed to fatigue due to the large number of false alarms. However, although fatigue can certainly contribute, a study involving 30 ICU nurses who performed 40 common tasks related to proper monitoring and safe alarm management in a simulated environment revealed that only 5% of all tasks were successfully completed by all nurses. This study found poor interaction between the nurse and the monitor. In this context, training in monitor use and knowledge of critical monitoring functions through simulation improves nurses' response to alarms.[56]

Table 1 Key points of CRM model (Crisis Resource Management).

1. Know the environment
2. Anticipate, plan
3. Call for help early
4. Leadership
5. Task distribution
6. Mobilize all available resources
7. Effective communication
8. Use all available information
9. Avoid fixation errors
10. Cross-check
11. Cognitive aids
12. Continuously reassess
13. Good teamwork. Coordination
14. Maintain attention
15. Dynamically prioritize

Rall M, Gaba DM: Human Performance and Patient Safety, in Miller 6th edition 2005.

Training non-technical skills and teamwork through clinical simulation

According to reports from the Joint Commission,[57] approximately 68% of clinical adverse events are due to human factors. These factors include, among others, awareness of the severity of the situation, lack of communication and coordination within teams, errors in decision-making and conflict resolution, as well as failures in planning. These elements are part of non-technical or behavioral skills, which are fundamental for effective teamwork.[58] Their absence represents a vulnerability point in the quality and safety of any health care organization. Currently, there are different programs designed to acquire knowledge and skills to improve team performance.[59,60] Among the methods for training teamwork, the most used ones are CRM (Crisis Resource Management),[61,62] and TeamSTEPPS (Team Strategies and Tools to Enhance Performance and Patient Safety).[63]

Studies conducted in the field of Intensive Care Medicine using clinical simulation have reported improvements in behavioral skills such as overall teamwork, leadership, clinical management, knowledge, communication, and safety climate.[12,64–67]

CRM aims to use all available resources in a coordinated manner to optimize patient treatment safety and the final outcomes. These resources include, in addition to equipment, all individuals involved in the process, with their skills, attitudes, and limitations. It is about maximizing the use of all available sources of information and training health care professionals to detect potential adverse events before they occur, intervene effectively when they appear, and mitigate their consequences. The principles commonly addressed in CRM (Table 1) can be summarized as knowledge of the working environment, awareness of the severity of the situation, anticipation and planning, leadership, communication, resource utilization, workload distribution, prioritization, and reassessment.[62] Although there is a shortage of tools to quantify their actual effects on patient safety,[68] this training has been shown to improve cognitive and interpersonal behaviors of professionals in

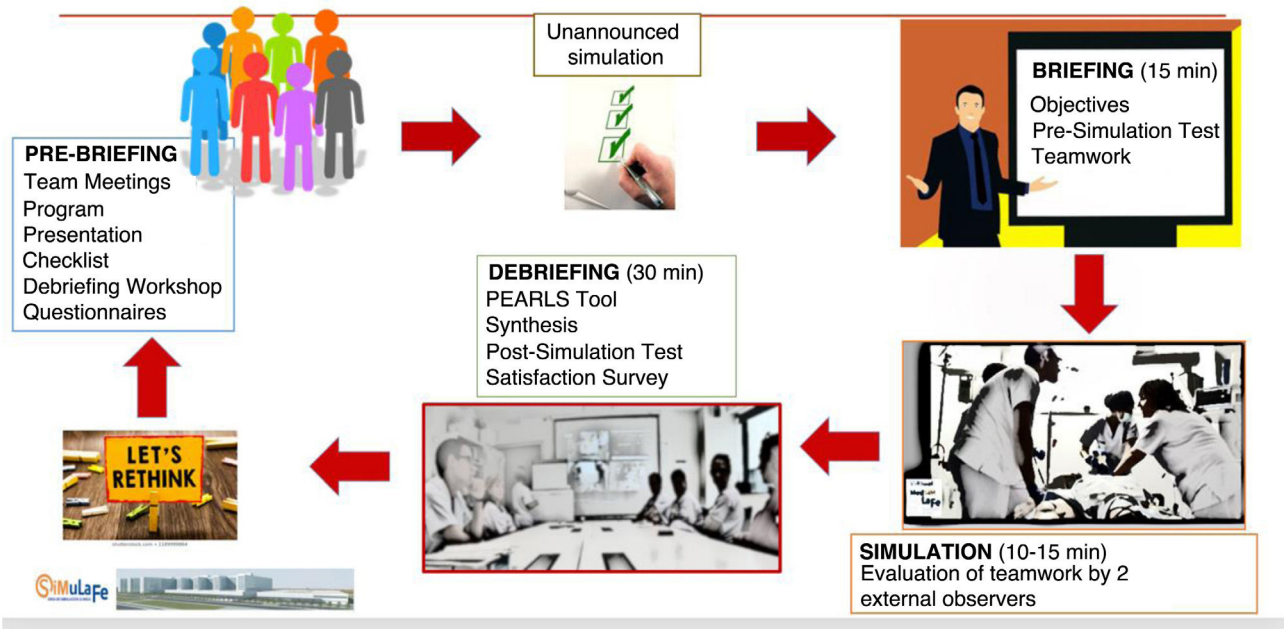

Figure 1 On-site Simulation Program at La Fe Hospital ICU in Valencia.

simulated environments[69] and team performance in the actual workplace.[12]

Studies conducted in critical care units have shown that the TeamSTEPPS model improves professionals' perception of teamwork and communication,[70] attitudes, and performance.[71] These training models have the potential to teach how to detect thinking and decision-making errors that can contribute to diagnostic delays, incorrect treatments, or an inability to recognize clinical changes that anticipate the occurrence of adverse events. Critical thinking and information sharing are essential to prevent these dangers. Murray et al. demonstrated a significant improvement in decision-making after training this skill in 8 simulated scenarios.[72] There are also specific simulation-based tools to improve team critical thinking and error management.[73,74] Repeated practice in a simulated environment increases the health professionals' confidence in making critical decisions and performing complex procedures. This confidence translates into more accurate, safe, and effective care in real practice. A study conducted on severely traumatized patients demonstrated an improvement in teamwork and the effectiveness of real-time care, reducing the time elapsed from patient arrival at the hospital to orotracheal intubation, CT scan, and surgical intervention.[75] Simulation is also useful for training professionals in the activation and application of emergency response protocols such as cardiac arrest, stroke code, sepsis code, rapid response teams, management of COVID-19 patients, ECMO-CPR code, etc., as it allows practicing roles and protocols in realistic scenarios.

On-site simulation

On-site simulation refers to conducting clinical simulation sessions in the actual workplace environment. This activity aims to replicate the conditions and challenges of the everyday clinical environment more accurately. It can simulate anything from emergency situations to routine procedures, allowing medical and nursing staff to practice clinical skills, make decisions, and work as a team in an environment closely resembling reality. This approach not only helps to refine specific skills and promote teamwork among different ICU professionals but also stands out for its unique ability to identify latent safety threats (LSTs) that may go unnoticed. Besides training, it is a valuable tool for evaluating professionals' effectiveness and the Department organization to address problems, prevent medication errors, assess systems and equipment, and improve communication. Ultimately, on-site simulation emerges as an essential pillar for raising patient safety standards, facilitating a smooth transition between training and real clinical practice.[76] On-site simulation has been associated with a perceived increase in confidence, improvements in patient care safety, error reduction, and positive changes in attitudes and behaviors.[77] A relevant aspect of on-site simulation is the rate of LSTs identified in different scenarios. In a study focused on in-situ management of cardiac arrests, 106 LSTs were identified in 74 conducted simulations, 4 of which were imminent safety threats.[78] During the COVID-19 pandemic, some hospitals tested workflows and care locations through on-site simulations, allowing them to identify and address numerous LSTs related to airway management and other safety issues, leading to changes in equipment and protocols.[79] Many of the identified LSTs were linked to communication, medication, and equipment issues. Implementing an on-site simulation program requires the Service's commitment as it requires time and involvement of a certain number of team members. Ideally, it should be integrated into the usual clinical schedule, requiring prior planning.[76] Some centers, after conducting pilot programs, have expanded their use

to other services and units, suggesting that on-site simulation is sustainable and economically viable.[80] However, the potential value of on-site simulation may be compromised when performed in a real and active clinical environment, with possible limitations including difficulty in maintaining a safe and confidential learning environment, engaging staff in simulation scenarios, the potential to generate safety problems (e.g., dirty equipment returned to patient use), and lack of time for planning and execution.[76]

Before implementing a program of this nature, specific needs of each ICU must be identified, highlighting critical areas where on-site simulation can make the greatest difference in patient safety. It is recommended to start with simple scenarios and gradually increase their complexity, including risky situations and specific ICU-threatening events. It is essential to involve the entire team in the process, provide constructive feedback after each session to analyze performance, identify areas for improvement, propose solutions and also highlight practices that were conducted safely (Fig. 1).

Conclusions

Clinical simulation emerges as a highly effective method for acquiring professional competencies in the field of Intensive Care Medicine, with a direct impact on patient safety. In the on-site modality, precise recreation of scenarios in the real workplace environment provides valuable resources to the entire ICU team to address the complexity of different Intensive Care Medicine scenarios. Training in technical and non-technical skills and teamwork empowers intensivists and nurses to make informed decisions, communicate effectively, and collaborate in critical situations where little information is available, and quick and accurate decisions are required. The combination of various simulation environments such as virtual reality and telemedicine expands training options, ensuring comprehensive preparation and higher quality and safer patient care. Finally, although research in this field has some limitations such as lack of standardization of training techniques and outcome measurement methods, the available evidence strongly recommends the integration of clinical simulation into the safety system of Intensive Care Medicine services, in specialist training programs in Intensive Care Medicine, professional recertification programs, and also as training in the clinical practice of teams. The most immediate objectives in this field are to assess the long-term sustainability of these programs and quantify the real impact on clinical outcomes.

Conflicts of interest

None declared.

References

1. Rocco C, Garrido A. Seguridad del Paciente y Cultura de Seguridad. Rev Med Clin Condes. 2017;28:785–95, http://dx.doi.org/10.1016/j.rmclc.2017.08.006.
2. Kohn LT, Corrigan JM, Donaldson MS. To err is human. Building a safer heath system. Washington, DC: National Academy Press; 1999.
3. Martín MC, Ruíz J. Acontecimientos adversos en medicina intensiva. Gestionando el riesgo. Med Intensiva. 2006;30:284–92, http://dx.doi.org/10.1016/s0210-5691(06)74526-0.
4. Khairat S, Whitt S, Craven CK, Pak Y, Shyu CR, Gong Y. Investigating the impact of intensive care unit interruptions on patient safety events and electronic health records use: an observational study. J Patient Saf. 2021;17:e321–6, http://dx.doi.org/10.1097/PTS.0000000000000603.
5. Gaba DM. The future vision of simulation in healthcare. Simul Healthc. 2007;2:126–35, http://dx.doi.org/10.1097/01.SIH.0000258411.38212.32.
6. Green M, Tariq R, Green P. Improving patient safety through simulation training in anesthesiology: where are we? Anesthesiol Res Pract. 2016;2016:4237523, http://dx.doi.org/10.1155/2016/4237523.
7. Huang GC, McSparron JI, Balk EM, Richards JB, Smith CC, Whelan JS, et al. Procedural instruction in invasive bedside procedures: a systematic review and meta-analysis of effective teaching approaches. BMJ Qual Saf. 2016;25:281–94, http://dx.doi.org/10.1136/bmjqs-2014-003518.
8. Beal MD, Kinnear J, Anderson CR, Martin TD, Wamboldt R, Hooper L. The effectiveness of medical simulation in teaching medical students critical care medicine: a systematic review and meta-analysis. Simul Healthc. 2017;12:104–16, http://dx.doi.org/10.1097/SIH.0000000000000189.
9. Barsuk JH, McGaghie WC, Cohen ER, O'Leary KJ, Wayne DB. Simulation-based mastery learning reduces complications during central venous catheter insertion in a medical intensive care unit. Crit Care Med. 2009;37:2697–701, http://dx.doi.org/10.1097/CCM.0b013e3181a57bc1.
10. Barsuk JH, Cohen ER, Potts S, Demo H, Gupta S, Feinglass J, et al. Dissemination of a simulation-based mastery learning intervention reduces central line-associated bloodstream infections. BMJ Qual Saf. 2014;23:749–56, http://dx.doi.org/10.1136/bmjqs-2013-002665.
11. Kennedy CC, Cannon EK, Warner DO, Cook DA. Advanced airway management simulation training in medical education: a systematic review and meta-analysis. Crit Care Med. 2014;42:169–78, http://dx.doi.org/10.1097/CCM.0b013e31829a721f.
12. Hughes AM, Gregory ME, Joseph DL, Sonesh SC, Marlow SL, Lacerenza CN, et al. Saving lives: a meta-analysis of team training in healthcare. J Appl Psychol. 2016;101:1266–304, http://dx.doi.org/10.1037/apl0000120.
13. Neily J, Mills PD, Young-Xu Y, Carney BT, West P, Berger DH, et al. Association between implementation of a medical team training program and surgical mortality. JAMA. 2010;304:1693–700, http://dx.doi.org/10.1001/jama.2010.1506.
14. Brazil V, Purdy EI, Bajaj K. Connecting simulation and quality improvement: how can healthcare simulation really improve patient care? BMJ Qual Saf. 2019;28:862–5, http://dx.doi.org/10.1136/bmjqs-2019-009767.
15. Díaz-Guio DA, Del Moral I, Maestre JM. Do we want intensivists to be competent or excellent? Clinical simulation-based mastery learning. Acta Colomb Cuid Intensivo. 2015;15:187–95, http://dx.doi.org/10.1016/j.acci.2015.05.001.
16. Rojo E, Maestre JM, Díaz-Mendi AR, Ansorena L, Del Moral I. Innovation in healthcare processes and patient safety using clinical simulation. Rev Calid Asist. 2016;31:267–78, http://dx.doi.org/10.1016/j.cali.2015.12.008.
17. Kolb DA. Experiential learning: Experience as the source of learning and development. Englewood Cliffs, NJ: Prentice-Hall; 1984.

18. Rudolph JW, Raemer DB, Simon R. Establishing a safe container for learning in simulation: the role of presimulation briefing. Simul Healthc. 2014;9:339–49, http://dx.doi.org/10.1097/SIH.0000000000000047.
19. Kolbe M, Eppich W, Rudolph J, Meguerdichian M, Catena H, Cripps A, et al. Managing psychological safety in debriefings: a dynamic balancing act. BMJ Simul Technol Enhan Learn. 2020;6:164–71, http://dx.doi.org/10.1136/bmjstel-2019-000470.
20. Rudolph JW, Simon R, Rivard P, Dufresne RL, Raemer DB. Debriefing with good judgment: combining rigorous feedback with genuine inquiry. Anesthesiol Clin. 2007;25:361–76, http://dx.doi.org/10.1016/j.anclin.2007.03.007.
21. Rudolph J, Raemer D, Shapiro J. We know what they did wrong, but not why: the case for' frame-based' feedback. Clin Teach. 2013;10:186–9, http://dx.doi.org/10.1111/j.1743-498X.2012.00636.x.
22. Rivière E, Jaffrelot M, Jouquan J, Chiniara G. Debriefing for the transfer of learning. Acad Med [Internet]. 2019;94:796–803, http://dx.doi.org/10.1097/ACM.0000000000002612.
23. Sawyer T, Eppich W, Brett-Fleegler M, Grant V, Cheng A. More than one way to debrief: a critical review of healthcare simulation debriefing methods. Simul Healthc. 2016;11:209–17, http://dx.doi.org/10.1097/SIH.0000000000000148.
24. LeBlanc VR, McConnell MM, Monteiro SD. Predictable chaos: a review of the effects of emotions on attention, memory and decision making. Adv Heal Sci Educ. 2014;20:265–82, http://dx.doi.org/10.1007/s10459-014-9516-6.
25. Rudolph JW, Simon R, Raemer DB, Eppich WJ. Debriefing as formative assessment: closing performance gaps in medical education. Acad Emerg Med. 2008;15:1010–6, http://dx.doi.org/10.1111/j.1553-2712.2008.00248.x.
26. Medina MS, Castleberry AN, Persky AM. Strategies for improving learner metacognition in health professional education. Am J Pharm Educ. 2017;81:78, http://dx.doi.org/10.5688/ajpe81478.
27. Oriot D, Alinier G. Pocket book for simulation debriefing in healthcare. Springer International Publishing; 2018.
28. Grenvik A, Schaefer J. From Resusci-Anne to Sim-Man: the evolution of simulators in medicine. Crit Care Med. 2004;32 2 suppl:S56–7, http://dx.doi.org/10.1097/00003246-200402001-00010.
29. Seam N, Lee AJ, Vennero M, Emlet L. Simulation training in ICU. Chest. 2019;156:1223–33, http://dx.doi.org/10.1016/j.chest.2019.07.011.
30. Nair SS, Kaufman B. Simulation-based training in response to the COVID-19 Pandemic. Simul Health. 2020;15:447–8, http://dx.doi.org/10.1097/SIH.0000000000000513.
31. Castellanos-Ortega Á, Broch MJ, Palacios-Castañeda D, Gómez-Tello V, Valdivia M, Vicent C, et al. Competency assessment of residents of Intensive Care Medicine through a simulation-based objective structured clinical evaluation (OSCE). A multicenter observational study. Med Intensiva (Engl Ed). 2022;46:491–500, http://dx.doi.org/10.1016/j.medine.2022.01.001.
32. Castellanos-Ortega A, Broch MJ, Barrios M, Fuentes-Dura MC, Sancerni-Beitia MD, Vicent C, et al. Acceptance and validity of the methods used to implement a competency based medical education programme in an Intensive Care Department of a teaching referral center. Med Intensiva (Engl Ed). 2021;45:411–20, http://dx.doi.org/10.1016/j.medine.2019.12.011.
33. Ross BK, Metzner J. Simulation for maintenance of certification. Surg Clin N Am. 2015;95:893–905, http://dx.doi.org/10.1016/j.suc.2015.04.010.
34. Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. Acad Med. 2015;90:1471–86, http://dx.doi.org/10.1097/ACM.0000000000000939.
35. Bruno RR, Wolff G, Wernly B, Masyuk M, Piayda K, Leaver S, et al. Virtual and augmented reality in critical care medicine: the patient's, clinician's, and researcher's perspective. Crit Care. 2020;26:326, http://dx.doi.org/10.1186/s13054-022-04202-x.
36. Bracq MS, Michinov E, Jannin P. Virtual reality simulation in nontechnical skills training for healthcare professionals: a systematic review. Simul Healthc. 2019;14:188–94, http://dx.doi.org/10.1097/SIH.0000000000000347.
37. Abbas JR, Chu MMH, Jeyarajah C, Isba R, Payton A, McGrath B, et al. Virtual reality in simulation-based emergency skills training: a systematic review with a narrative synthesis. Resusc Plus. 2023;16:100484, http://dx.doi.org/10.1016/j.resplu.2023.100484.
38. Wolff G, Bruno RR, Reiter M, Kantzow B, Kelm M, Jung C. Virtual reality device training for extracorporeal membrane oxygenation. Crit Care. 2020;24:390, http://dx.doi.org/10.1186/s13054-020-03095-y.
39. Yasser NBM, Tan AJQ, Harder N, Ashokka B, Chua WL, Liaw SY. Telesimulation in healthcare education: a scoping review. Nurse Educ Today. 2023;126:105805, http://dx.doi.org/10.1016/j.nedt.2023.105805.
40. Schroedl CJ, Frogameni A, Barsuk JH, Cohen ER, Sivarajan L, Wayne DB. Impact of Simulation-based Mastery Learning on Resident skill managing mechanical ventilators. ATS Sch. 2020;2:34–48, http://dx.doi.org/10.34197/ats-scholar.2020-0023OC.
41. Lee H, Han JW. Development and evaluation of a virtual reality mechanical ventilation education program for nursing students. BMC Med Educ. 2022;22:775, http://dx.doi.org/10.1186/s12909-022-03834-5.
42. Havaldar AA, Krishna B, Sampath S, Paramasivam SK. Simulation Training in Hemodynamic Monitoring and Mechanical Ventilation: an assessment of physician's performance. Indian J Crit Care Med. 2020;24:423–8, http://dx.doi.org/10.5005/jp-journals-10071-23458.
43. Yee J, Bennerr A, Hammong J, Malone B, Fuenning C, George R, et al. Mechanical ventilation boot camp curriculum. J Vis Exp. 2018;12:57303, http://dx.doi.org/10.3791/57303.
44. Michelángelo H, Angriman F, Pizarro R, Bauque S, Kecskes C, Staneloni I, et al. Implementarion of an experiential learning strategy to reduce the risk of ventilator-associated pneumonia in critically ill adult patients. J Intensive Care Soc. 2022;21:320–6, http://dx.doi.org/10.1177/1751143719887285.
45. Ciullo A, Yee J, Frey JA, Gothard MD, Benner A, Hammond J, et al. Telepresent mechanical ventilation training versus traditional instruction: a simulation-based pilot study. BMJ Simul Technol Enhanc Learn. 2018;5:8–14, http://dx.doi.org/10.1136/bmjstel-2017-000254.
46. Madenci AL, Solis CV, de Moya MA. Central venous access by trainees: a systematic review and meta-analysis of the use of simulation to improve success rate on patients. Simul Healthc. 2014;9:7–14, http://dx.doi.org/10.1097/SIH.0b013e3182a3df26.
47. Evans LV, Dodge KL, Shah TD, Kaplan LJ, Siegel MD, Moore CL, et al. Simulation training in central venous catheter insertion: improved performance in clinical practice. Acad Med. 2010;85:1462–9, http://dx.doi.org/10.1097/ACM.0b013e3181eac9a3.
48. Peltan ID, Shiga T, Gordon JA, Currier PF. Simulation improves procedural protocol adherence during central venous catheter placement: a randomized controlled trial. Simul Healthc. 2015;10:270–6, http://dx.doi.org/10.1097/SIH.0000000000000096.

49. Zante B, Schefold J. Simulation training for emergency skills: effects on ICU fellows' performance and supervision levels. BMC Med Educ. 2020;498, http://dx.doi.org/10.1186/s12909-020-02419-4.
50. Vitale KM, Barsuk JH, Cohen ER, Wayne DB, Hansen RN, Williams LM, et al. Simulation-based mastery learning improves critical care skills of advanced practice providers. ATS Sch. 2023;4:48–60, http://dx.doi.org/10.34197/ats-scholar.2022-0065OC.
51. Kennedy CC, Maldonado F, Cook DA. Simulation-based bronchoscopy training: systematic review and meta-analysis. Chest. 2013;144:183–92, http://dx.doi.org/10.1378/chest.12-1786.
52. Gannon WD, Stokes JW, Pugh ME, Bacchetta M, Benson C, Casey JD, et al. Simulation versus interactive mobile learning for teaching extracorporeal membrane oxygenation to Clinicians: a randomized trial. Crit Care Med. 2022;50:e415–25, http://dx.doi.org/10.1164/rccm.202110-2399LE.
53. Fouilloux V, Gran C, Guervilly C, Breaud J, Louali FE, Rostini P. Impact of education and training course for ECMO patients based on hight-fidelity simulation: a pilot study dedicated to ICU nurses. Perfusion. 2019;34:29–34, http://dx.doi.org/10.1177/0267659118789824.
54. Cvetkovic M, Antonini MV, Rosenberg A, Meadows CI, Dabrowski M, Puslecki M, et al. ''Bridging the GAP'' international ECLS training and simulation - evaluation of the 10th educational corner on EuroELSO congress 2022 in London, United Kingdom. Perfusion. 2023;38 1_suppl:3–12, http://dx.doi.org/10.1177/02676591231157273.
55. Shin KX, Ha YR, Lee SJ, Ahn JH. Review of simulation model for education of point-of-care ultrasound using easy-to-make tools. World J Clin Cases. 2020;8:4286–302, http://dx.doi.org/10.12998/wjcc.v8.i19.4286.
56. Sowan AK, Staggers N, Berndt A, Austin T, Reed CC, Malshe A, et al. Improving the safety, effectiveness, and efficiency of clinical alarm systems: simulation-based usability testing of physiologic monitors. JMIR Nurs. 2021;4:e20584, http://dx.doi.org/10.2196/20584.
57. The Joint Commission. National patient safety goals effective January 1, 2014: Hospital accreditatio program. Available from: http://www.jointcommission.org/assets/1/6/HAP_NPSG_Chapter_2014.pdf.
58. Patient Safety Network. Teamwork training. [Accessed 8 December 2023]. Available from: https://psnet.ahrq.gov/primer/teamwork-training.
59. Salas E, Diaz-Granados D, Klein C, Burke CS, Stagl KC, Goodwin GF, et al. Does team training improve team performance? A meta-analysis. Hum Factors. 2008;50:903–33, http://dx.doi.org/10.1518/001872008X375009.
60. Buljac-samardzic M, Doekhie KD, Van Wijngaarden JDH. Interventions to improve team effectiveness within health care: a systematic review of the past decade. Hum Resour Health. 2020;18:2, http://dx.doi.org/10.1186/s12960-019-0411-3.
61. Gaba DM. Crisis resource management and teamwork training in anaesthesia. Br J Anaesth. 2010;105:3–6, http://dx.doi.org/10.1093/bja/aeq124.
62. Lei C, Palm K. Crisis resource management training in medical simulation. [Updated 2023 Jul 24]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023. Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK551708/
63. Agency for Healthcare Research and Quality. Team STEPPS. [Accessed 8 December 2023]. Available from: https://www.ahrq.gov/teamstepps-program/index.html.
64. George KL, Quatrara B. Interprofessional simulations promote knowledge retention and enhance perceptions of teamwork skills in a surgical-trauma-burn intensive care-unit setting. Dimens Crit Care Nurs. 2018;37:144–55, http://dx.doi.org/10.1097/DCC.0000000000000301.
65. Pascual JL, Holena DN, Vella MA, Palmieri J, Sicoutris C, Selvan B, et al. Short simulation training improves objective skills in established advanced practitioners managing emergencies on the ward and surgical intensive care unit. J Trauma. 2011;71:330–8, http://dx.doi.org/10.1097/TA.0b013e31821f4721.
66. Frengley RW, Weller JM, Torrie J, Dzendrowskyj P, Yee B, Paul AM, et al. The effect of a simulation-based training intervention on the performance of established critical care unit teams. Crit Care Med. 2011;39:2605–11, http://dx.doi.org/10.1097/CCM.0b013e3182282a98.
67. Sandahl C, Gustafsson H, Wallin CJ, Meurling L, Øvretveit J, Brommels M, et al. Simulation team training for improved teamwork in an intensive care unit. Int J Health Care Qual Assur. 2013;26:174–88, http://dx.doi.org/10.1108/09526861311297361.
68. Meneer J. Why crisis resource management and evidence-based medicine make uncomfortable bedfellows. Emerg Med Australas. 2012;24:581–2, http://dx.doi.org/10.1111/j.1742-6723.2012.01566.x.
69. Ballangrud R, Hall-Lord M, Persenius M, Hedelin B. Intensive care nurses' perceptions of simulation-based team training for building patient safety in intensive care: a descriptive qualitative study. Intensive Crit Care Nurs. 2014;30:179–87, http://dx.doi.org/10.1016/j.iccn.2014.03.002.
70. Gaston T, Short N, Ralyea C, Casterline G. Promoting patient safety: results of a Team-STEPPSR initiative. J Nurs Adm. 2016;46:201–7, http://dx.doi.org/10.1097/NNA.0000000000000333.
71. Rice Y, DeLetter M, Fryman L, Parrish E, Velotta C, Talley C. Implementation, and evaluation of a team simulation training program. J trauma Nurs. 2016;23:298–303, http://dx.doi.org/10.1097/JTN.0000000000000236.
72. Murray DJ, Boyle WA, Beyatte MB, Knittel JG, Kerby PW, Woodhouse J, et al. Decision-making skills improve critical care training: using simulation to measure progress. J Crit Care. 2018;47:133–8, http://dx.doi.org/10.1016/j.jcrc.2018.06.021.
73. Browne AM, Deutsch ES, Corwin K, Davis DH, Teets JM, Apkon M. An IDEA: safety training to improve critical thinking by individuals and teams. Am J Med Qual. 2019;34:569–76, http://dx.doi.org/10.1177/1062860618820687.
74. Macrae C. Imitating incidents: how simulation can improve safety investigation and learning from adverse events. Simul Healthc. 2018;3:227–32, http://dx.doi.org/10.1097/SIH.0000000000000315.
75. Capella J, Smith S, Philp A, Putnam T, Gilbert C, Fry W, et al. Teamwork training improves the clinical care of trauma patients. J Surg Educ. 2010;67:439–43, http://dx.doi.org/10.1016/j.jsurg.2010.06.006.
76. Bajaj K, Minors A, Walker K, Meguerdichian M, Patterson M. No-Go considerations for situ simulation safety. Simul Heathc. 2018;13:221–4, http://dx.doi.org/10.1097/SIH.0000000000000301.
77. Wu WT, Wu YL, Hou SM, Kang CM, Huang CH, Huang YL, et al. Examining the effects of an interprofessional crew resource management training intervention on perceptions of patient safety. J Interprof Care. 2016;30:536–8, http://dx.doi.org/10.1080/13561820.2016.1181612.
78. Bentley SK, Meshel A, Boehm L, Dilos B, McIndoe M, Carroll-Bennett R, et al. Hospital-wide-cardiac arrest in situ simulation to identify and mitigate latent safety threats. Adv Simul (Lond). 2022;7:15, http://dx.doi.org/10.1186/s41077-022-00209-0.

79. Jafri FN, Yang CJ, Kumar A, Torres RE, Ahmed ST, Seneviratne N, et al. In situ simulations as a tool to longitudinally identify and track latent safety threats in a structured quality improvement initiative for SARS-CoV-2 airway management: a single-center study. Simul Healthc. 2023;18:16–23, http://dx.doi.org/10.1097/SIH.0000000000000633.

80. Moffatt-Bruce SD, Hefner JL, Mekhjian H, McAlearney JS, Latimer T, Ellison C, et al. What is the return on investment for implementation of a crew resource management program at an academic medical center? Am J Med Qual. 2017;32:5–11, http://dx.doi.org/10.1177/1062860619873226.