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Short Review

From Virtual Patients to AI-Powered Training: The Evolution of Medical Simulation

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ABSTRACT

Simulation is a learning technique or tool that allows medical professionals to have dynamic training for diagnosing and treating clinical-surgical pathologies. It can also be employed on the patient as a distraction to reduce pain and anxiety using virtual reality. The objective of this research was to determine the usefulness of medical simulation and its current advances, for which a bibliographic search was carried out of 58 medical articles obtained from databases such as PubMed, ScienceDirect, Mendeley, Latindex, published in the last 5 years that included observational studies, randomized studies, systematic reviews and meta-analyses referring to the research topic. It is concluded that the advances of simulation in medicine and the vast majority of medical specialties recommend implementing this technique for teaching, diagnosis, and treatment. In addition, it can also be used through virtual reality, artificial intelligence, and mixed reality to reduce stress in patients, being an advance in development; however, it was found that there are areas where the help of expert evaluators is indispensable, in topics such as resuscitation and physical rehabilitation where simulation did not surpass conventional treatment.

Keywords: Patient simulation; Training Simulation; Faculties of Medicine; Coroner; Medical Specialties.

INTRODUCTION

Simulation is a learning technique or tool that allows medical professionals to provide dynamic training for diagnosing and treating clinical-surgical pathologies, aiming to perfect technical skills and competencies necessary for health care. [1, 2]

Simulation can be used in medical learning and the evolution of the patient with positive results, [3, 4] for example, when virtual reality is used on the patient as a distraction to reduce pain and anxiety. [5]

Simulation is developed in several high-tech fields such as artificial intelligence (AI), virtual reality, mixed reality (MR), intelligent robotics, cybersecurity, and virtualization, which can be applied in the medical field, [6, 7] improving clinical-surgical practices with a level of superiority compared to traditional education, [8] reducing the period of cognitive learning, skills or technical skills, enhancing the effectiveness of learning. [9]

Models with 3D printing are an innovation that allows the operator to generate safe practices, decreasing the risk of error and developing a better experience for the doctor. [10, 11,] and preparing him to treat a medical complication promptly. [12, 13]

Training for managing diseases such as stroke can be carried out through simulation around diagnostic imaging and in the application of surgical medical procedures, mainly [14-17] in neurosurgery, whose simulated skills are of great importance for their continuous practices. [18] However, simulation can be used at any level of medicine, contributing to improving the processes of teaching, learning, evaluation, safety of care, and quality control, [19, 20] providing students and health professionals with the opportunity to learn about new advances and procedures, favoring the search for various areas with deficiencies in competencies, providing powerful intervention tools, to improve skills that require more training such as intensive care, cardiology, anesthesiology, hospitalization, delivery rooms, operating room, emergency room among others. [21, 22]

In situations of medical emergencies such as stroke, status epilepticus, coma, or respiratory failure, simulation is used to avoid errors during the administration of medications, resuscitation, management, diagnosis of seizures, and diagnostic imaging. [23, 24]

Among the advantages are the possibility of doing repetitions during the practice as many times as necessary, using the mistake virtually to the last consequences without ethical and legal repercussions, and allowing you to learn from the error without causing harm. It makes up for the lack of clinical experience and the failures of team coordination. It will enable learning in different circumstances or environments, from the simplest to the most complex, from the most common to the least frequent, and to receive real-time feedback. [25, 26]

Augmented reality in simulation is a technology that allows the operator to explore and manipulate three-dimensional multimedia environments, natural or artificial, generated by a computer to improve the knowledge and skills of health professionals and thus reduce the complications of highly complex procedures. [27, 28]

OBJECTIVES: To determine the usefulness of medical simulation and its current advances.

METHODOLOGY

A structured review of articles was carried out with the research question: What is the usefulness of medical simulation and its current advances? Keywords and databases such as PubMed, ScienceDirect, Mendeley, Latindex, WOS, and Global Index Medicus, with articles published in the last 5 years, were used for the bibliographic search. Observational studies, randomized studies, systematic reviews, and meta-analyses referring to the research topic were chosen for the selection. A sub-analysis of the randomized clinical trials was carried out to improve the results of the available high-quality evidence that reported the P value with statistical significance in favor or against the medical simulation. Methodological quality was variable in the studies, some without conclusive results, heterogeneous populations, different techniques implemented, a comprehensive assessment enhanced with sub-analysis of randomized trials obtained from the search to suppress selection bias in the publication studies with reported positive and negative results, the heterogeneity observed in the medical simulation studies and the results obtained as well as the technological tools, diverse range of applications, environments and technologies affect the generalization of the results of the research, statistical heterogeneity was eliminated using the P value as the final variable.

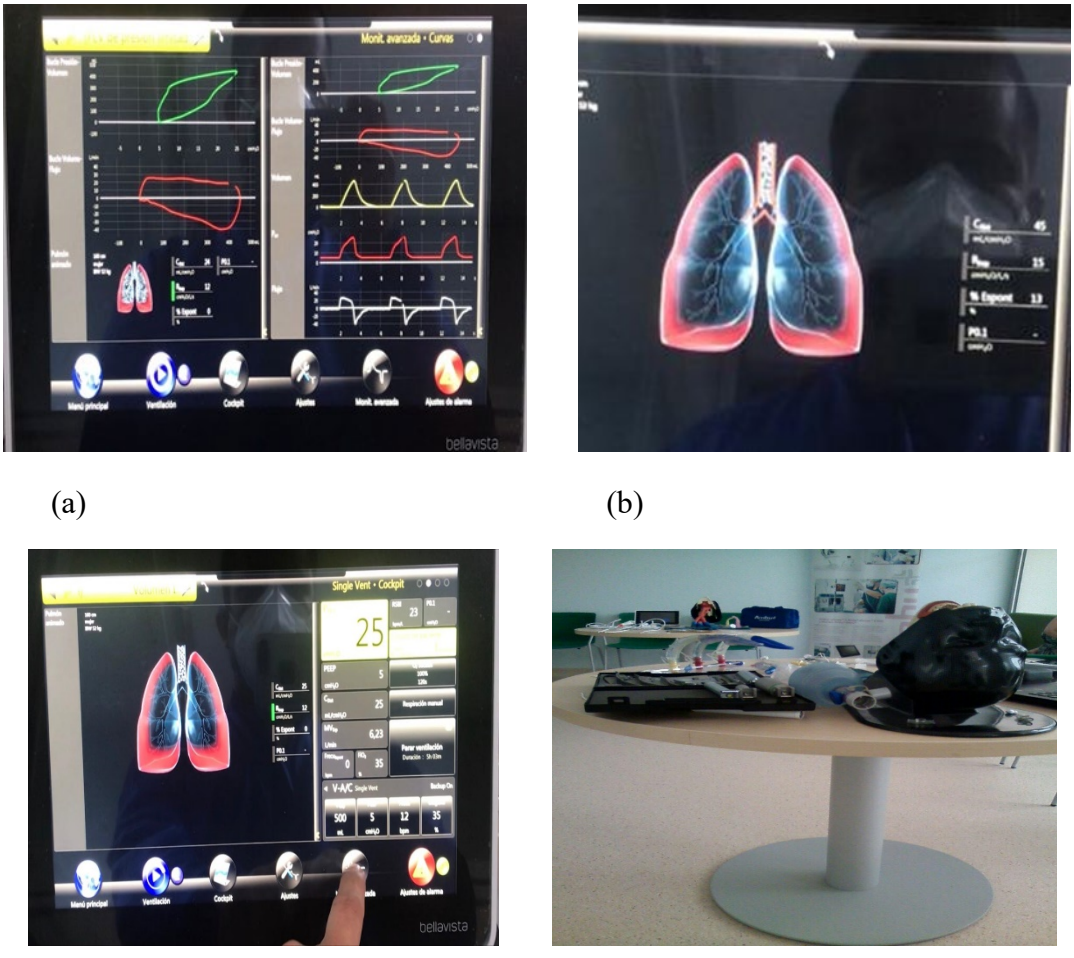
RESULTS

The results of Tables 1 and 2 demonstrate the usefulness of simulation in procedures such as out-of-hospital cardiopulmonary resuscitation, otoscopy, endotracheal intubation of adults and neonates, [29-31] cricothyrotomy,

training courses such as ACLS, and for clinical examinations presented a statistically significant benefit. Traditional methods such as expert mentoring or physical rehabilitation simulation need human presence.

Teaching with simulation	Usefulness	Results
Resuscitation of patients with out-of-hospital cardiac arrest	Training of paramedical equipment	Paramedics will perform better in teamwork.
Otoscopy simulation	Otoscopy simulation is an effective training method	32.0% higher scores in the simulation group
Neonatal endotracheal intubation	The simulation obtained higher success rates.	Simulation in neonatal endotracheal intubation had a positive impact.

Table 1. Medical Utilities of Simulation Practice. Research on simulation for medical training shows examples of how otoscopy, resuscitation, or intubation is performed. [29-31]



(a) (b)

(c) (d)

Figure 1. Types of simulators used in medical training. In panels a and b, you can see the animated lung that simulates the entry of air employing a mechanical ventilator, measures the values, and simulates a lung; this allows you to have an approximate vision of the entry and exit of air from the lungs, the simulation in mechanical ventilation is part of the training in critical medicine. Panel c operator interface and machine simulating a person's breathing on a mechanical ventilator, panel d training equipment for challenging airway simulation.

Usefulness of Medical Simulation	Intervention	Comparison	Results
Training in cricothyrotomy	Auto video feedback is a method that uses simulation	Expert-assisted video feedback	Time to procedure was lowest in the expert-assisted group compared to self-feedback alone ($p < 0.05$).
Simulated Pediatric Resuscitation	App designed to help with pediatric medication preparation	Conventional methods of preparing medicines without assistance	The application reduces medication errors and administration time ($P < 0.001$).
Prehospital pediatric cardiopulmonary resuscitation	Preparation of 4 intravenous emergency drugs	Conventional methods	Positive changes in stress response were observed in participants who used the application ($P < 0.001$)
Cases of otolaryngology enhanced with mixed reality	Enhanced case-based remote learning with mixed reality	Conventional teaching	There were no significant differences in the overall objective measures of participation.
Simulation of 4 ACLS scenarios in resuscitation of patients with out-of-hospital cardiac arrest	Simulation with resuscitation equipment	Decision-making without simulation	ACLS in a simulated environment is superior ($p = 0.0001$)
Trauma Simulation	Advanced modular mannequin	Peripheral simulators	First responders and surgeons rated their experience as high ($p < 0.001$) except for anesthesiology ($p = 0.014$).
Simulation in the training of pediatric residents on the score of neonatal withdrawal syndrome	Simulation of a standard training video of the Neonatal Abstinence Scoring System	Expert control evaluators received traditional video instruction.	Similar results between the simulation-trained residents versus expert evaluators.
Artificial Intelligence vs. Medical Control by Humans in Virtual Reality Simulation for Sepsis Team Training	Sepsis team with an AI-powered doctor group nursing students	Medical students using virtual reality simulation	Significant improvement in knowledge about sepsis care was observed from baseline in the AI-driven group ($P<.001$)
Desktop Virtual Reality and Face-to-Face Simulation on Stress Responses and Performance Outcomes of a Simulation Training	Desktop Virtual Reality with Simulated Patient	Face-to-face simulation with simulated patient	No significant differences were found

Table 2. Comparative studies on the usefulness of medical simulation.

Table 2 describes types of teaching with simulation, such as virtual reality, artificial intelligence, and mixed reality, compared to traditional methods. [32-40]

The results show that simulation is part of current medicine both in continuing medical education, diagnosis, treatment, after-hospital care, and patient education in pathologies in which simulation recreates complex scenarios; more research is needed on artificial intelligence, mixed reality or virtual reality and its application in certain areas where classical teaching is still necessary. The simulation of the quality of patient care demonstrated greater patient satisfaction and subsequent care in the intensive care unit. [41]

In-hospital cardiopulmonary resuscitation simulation improves resuscitation performance in pediatric intensive care; training aspects included chest compressions, intra-arrest hemodynamics, and mechanics of cardiopulmonary resuscitation. [42]

Artificial intelligence (AI)-assisted on-screen simulations compared to breast self-examination simulations had a higher score ($p < 0.05$) for breast self-examination compared to AI training in participants with breast cancer, [43] showed that simulation with hybrid training of longer duration improves participants' skills in breast self-examination. [44]

In a study conducted in China on primiparous women who were given education with simulation of childbirth compared to regular prenatal care, they found that sham-based childbirth reduced fear of childbirth. [45] also observed that virtual reality simulation for visualizing green spaces reduces the physiological stress of pregnant women during labor. [46]

In surgery, combined training of both techniques, consisting of a mixture of traditional and simulation training, obtained better results ($p < 0.0001$). [47] In robotic surgery, simulation with virtual reality is helpful in training subspecialty robotic techniques. [48]

In patients operated on knee arthroplasty, simulation was performed with physiotherapy, with a higher percentage of falls, 19.4%, compared to classic physiotherapy, 14.6%. The simulation did not have good results; it could not overcome conventional methods. [49]

The simulation centers in university centers, which are included in the study program, give great importance to training in health sciences, [50, 51] which suggests an integration of simulation in specialized health training, mainly in laparoscopic surgery, simulating with non-biological material, providing good results in appendectomy and cholecystectomy. [52]

A systematic review observed that simulation provides the future professional with a look at what professional life means, gives him a physical representation of the complexity of certain vital situations, and offers the opportunity to refine medical techniques. [53, 54]

The relationship between stress-producing factors such as the external environment can be annulled by virtual reality techniques that act on the psychological state and suppress the stressor of error in medical practice, improving performance and making it an essential tool in medicine. [55, 56]

Simulation has been implemented in several countries for difficult situations, for example, in emergencies and disasters, managing to improve four domains of risk management that fail: 1) adequate personnel, 2) adequate material, 3) spaces, and 4) prepared warning systems. [57]

In a study conducted on patients during the preoperative period, simulation safely and effectively reduced anxiety. [58]

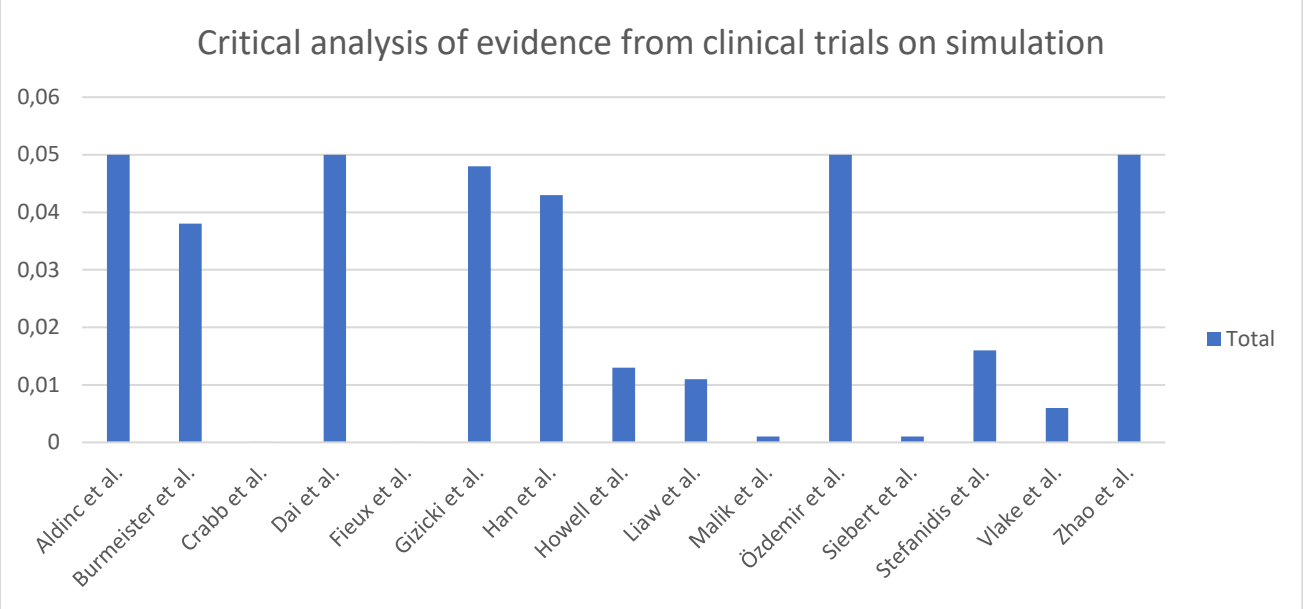


Figure 2. Randomized studies on medical simulation. Studies of high methodological quality that investigated medical simulation and its practical applications

Critical analysis of the evidence from all studies analyzed demonstrates statistical benefits in medical practice, e.g., learning, resuscitation training, examination, case analysis, feedback from learning, error reduction, and stress reduction, in various medical areas such as surgery, pediatrics, internal medicine, ophthalmology, emergency medicine, etc. no studies reported benefits or effects on mortality despite improving all the surgical skills of the participants, no data on reduction of operative complications were found. In addition, simulation technologies, such as artificial intelligence, mixed reality, or robotic technology, are still under development, and their impact on improving the quality of care is still unknown. More high-quality studies are needed with the real benefit of simulation; no benefits have been reported in reducing mortality since simulation does not replace usual medical training with actual practices. The ethical implications of medical simulation, patient safety, and data privacy could provide insight into the future of medical simulation, highlighting technologies such as artificial intelligence, virtual reality, and mixed reality and their potential to revolutionize healthcare education and training.

DISCUSSION

The analysis of high-quality evidence demonstrates that simulation provides significant benefits across various medical disciplines. As shown in Tables 1 and 2, simulation proves helpful in resuscitation, otoscopy, intubation, and cricothyrotomy, offering a statistically significant advantage over traditional methods like expert tutoring, which often require human presence. Simulation is becoming increasingly integral to modern medicine, aiding in continuing education, diagnosis, treatment, post-hospital care, and patient education by recreating complex scenarios.

Specifically, simulation has been shown to reduce anxiety [3] and enhance learning in various contexts, including neurological examinations [7], anatomy education [9], and endoscopic discectomy. Furthermore, it facilitates skill acquisition in direct ophthalmoscopy and otoscopy, leading to fewer attempts and shorter intubation times in neonatal simulations. Notably, a mobile application for simulated pediatric cardiopulmonary resuscitation training significantly decreased errors.

Advanced simulation technologies, such as mixed reality for case practice and systems for clinical decision visualization, have shown promise in advanced cardiac life support by reducing medication delivery times. Artificial intelligence has also demonstrated the potential to improve sepsis team training and enhance patient satisfaction and post-ICU care. Moreover, virtual reality interventions have been beneficial for critically ill COVID-19 patients and have been shown to reduce cesarean section rates in obstetrics [45].

While the evidence largely favors simulation, it's crucial to acknowledge certain limitations. Notably, the reviewed studies did not demonstrate a direct impact on mortality or operative complications. This highlights the need for further high-quality research to explore the full potential of simulation, particularly in areas where it has not yet reached statistical significance. Additionally, the ongoing development of simulation technologies, such as AI, mixed reality, and robotics, necessitates continued investigation into their impact on healthcare quality. Ethical considerations surrounding patient safety and data privacy must also be addressed as these technologies evolve.

CONCLUSIONS

Currently, advances in simulation in medicine and most medical specialties recommend implementing this technique for teaching, diagnosis, and treatment. It can also be used through virtual reality, artificial intelligence, and mixed reality to reduce stress in patients, being an advance in development; however, it was found that there are areas where the help of expert evaluators is indispensable, in topics such as resuscitation and physical rehabilitation where simulation did not surpass conventional treatment.

The review provides a comprehensive and critical overview of medical simulation in the digital age, contributing to the advancement of this rapidly evolving field, to effectively integrate medical simulation into practice, the economic costs of medical simulation, benefits of different simulation modalities and its impact on the allocation of healthcare resources is hindered by the little evidence to reduce mortality, complications, hospital times, reducing sepsis, which are the significant remains of these emerging technologies in medicine, factors such as infrastructure, training and the integration of new research plans need to be improved.

Constant feedback leads to improved technical skills and increased confidence, teaching surgical skills over time and participation in real-world scenarios, with the disadvantages of insufficient preparation time or surgical risks predominating, described by different researchers. In this situation, with scientific and technical development, the benefits of using simulators are that they minimize risks and offer safety to professionals. The simulator allows for unlimited and constant repetition, improving technical skills and increasing confidence even for the patient.

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