THE ROLE OF SIMULATION IN SURGICAL EDUCATION: CURRENT PRACTICES AND FUTURE DIRECTIONS

SIMULACIÓN Y EDUCACIÓN EN CIRUGÍA GENERAL: PRÁCTICAS ACTUALES Y DIRECCIONES FUTURAS

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Abstract

Introduction
Simulation-based education has become an essential component of modern surgical training. We aimed to evaluate the current state of simulation in surgical education and its impact on clinical outcomes, and potential future direction for enhancing its role in surgical training.

Methods
We utilized a comprehensive approach to examine the current role of simulation-based education in surgical training. A systematic search of relevant literature was conducted across major databases using a combination of keywords.

Results
Across multiple studies, simulation improved both the acquisition and retention of surgical skills. There was also a positive correlation with patient outcomes, e.g. reduction in operative times, enhancement of procedural accuracy, and decrease in intraoperative and postoperative complications. Specialty-specific applications of simulations improved technical skills and confidence, procedural speed, and overall performance in vascular, orthopedic and transplant surgery. We also found barriers to implementation and widespread adoption of simulation in surgical education that included high costs, resource limitations, lack of simulation validation to real world scenarios, and lack of complete curriculum development.

Conclusion
The integration of simulation into surgical education has proven to be a critical step in overcoming the challenges posed by modern surgical training and provides a structured, risk-free environment for trainees to develop both technical and non-technical skills, while also maintaining competency over time. Despite the benefits, there are still significant barriers to the widespread adoption of simulation in surgical training that must be addressed to fully realize the potential of simulation in improving surgical training and patient outcomes.

Resumen

Introducción
La educación basada en simulación se ha convertido en un componente esencial de la formación quirúrgica moderna. Nuestro objetivo fue evaluar el estado actual de la simulación en la educación quirúrgica, su impacto en los resultados clínicos y las posibles direcciones futuras para mejorar su papel en la formación quirúrgica.

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Métodos
Utilizamos un enfoque integral para examinar el papel actual de la educación basada en simulación en la formación quirúrgica. Se realizó una búsqueda sistemática de la literatura relevante en las principales bases de datos utilizando una combinación de palabras clave.

Resultados
En múltiples estudios, la simulación mejoró tanto la adquisición como la retención de habilidades quirúrgicas. También hubo una correlación positiva con los resultados de los pacientes, por ejemplo, reducción de los tiempos operatorios, mejora de la precisión de los procedimientos y disminución de las complicaciones intraoperatorias y postoperatorias. Las aplicaciones específicas de especialidad de las simulaciones mejoraron las habilidades técnicas y la confianza, la velocidad de los procedimientos y el rendimiento general en cirugía vascular, ortopédica y de trasplante. También encontramos barreras para la implementación y adopción generalizada de la simulación en la educación quirúrgica, que incluían altos costos, limitaciones de recursos, falta de validación de la simulación en escenarios del mundo real y falta de desarrollo completo del currículo.

Conclusión
La integración de la simulación en la educación quirúrgica ha demostrado ser un paso crítico para superar los desafíos que plantea la formación quirúrgica moderna y proporciona un entorno estructurado y sin riesgos para que los aprendices desarrollen tanto habilidades técnicas como no técnicas, al tiempo que mantienen la competencia a lo largo del tiempo. A pesar de los beneficios, todavía existen barreras significativas para la adopción generalizada de la simulación en la formación quirúrgica que deben abordarse para aprovechar al máximo el potencial de la simulación en la mejora de la formación quirúrgica y los resultados de los pacientes.

INTRODUCTION

Simulation-based education has become an essential component of modern surgical training, providing opportunities for skill development, refinement, and assessment in a risk-free environment. Over the past two decades, simulation has evolved from simple anatomical models to sophisticated virtual reality simulators. This transformation has significantly enhanced the learning process for surgical trainees, allowing them to practice complex procedures before stepping into the operating room.

The need for simulation-based training arises from increasing demands on surgical education, which include restricted working hours, reduced patient exposure, and the complexity of modern surgical procedures[1]. Traditional apprenticeship models, while effective, are no longer sufficient to meet these challenges. Studies have consistently shown that simulation improves not only technical proficiency but also the retention of skills, thereby preventing the decay of skills that often occurs in low-exposure environments[2]. Simulation-based education has also demonstrated a positive impact on patient safety by allowing trainees to gain confidence and precision in their techniques before performing on actual patients[1,3].
Despite these advancements, gaps still exist in integrating simulation into routine surgical curricula. Resources, curriculum design, and the long-term benefits of simulation require further research and development[4]. This manuscript aims to evaluate the current state of simulation in surgical education, the methods employed in its implementation, and its impact on clinical outcomes, while also exploring the barriers to widespread adoption and potential future direction for enhancing its role in surgical training.

METHODS

This review utilizes a comprehensive approach to examine the current role of simulation-based education in surgical training. A systematic search of relevant literature was conducted across major databases, including PubMed, Google Scholar, and MEDLINE, using a combination of keywords such as "surgical simulation", "surgical education", "surgical skills", "transplant surgery simulation", and "technical skills training". The search was restricted to articles published in the last 15 years to ensure the inclusion of the most recent and relevant findings in the field.

Inclusion criteria for this review consisted of original research articles, meta-analyses, and systematic reviews that specifically evaluated the impact of simulation-based

education on the development of technical and non-technical skills in surgical trainees. Studies examining the effects of different simulation modalities, such as virtual reality, haptic feedback systems, and physical models were included. Articles that discussed the transfer of skills from simulation to clinical practice, patient outcomes, and the barriers to integrating simulation into surgical curricula were also selected. Studies not focused on surgical education or simulation-based interventions were excluded.

A thematic analysis was conducted to categorize studies based on their focus areas, including the type of simulation used, surgical specialty, and clinical outcomes. The findings were synthesized to identify common themes related to the effectiveness of simulation, its implementation challenges, and future directions for improving its adoption in surgical education. Data was also extracted on resource allocation, curriculum development, and trainee performance metrics where applicable.

RESULTS

The literature review identified several key findings regarding the effectiveness and challenges of simulation-based education in surgical training. Across multiple studies, simulation was shown to significantly enhance both technical and non-technical skills in surgical trainees, which translated into improved clinical performance and patient outcomes.

1. Skills Acquisition and Retention

A number of studies confirm the role of simulation in both the acquisition and retention of surgical skills. Higgins et al.[2] found that simulation significantly reduces the decay of procedural skills, a major issue in low clinical exposure environments. Siu et al.[5] further highlighted that robotic surgery simulation allows trainees to gain proficiency in complex procedures before performing on actual patients. Additionally, Agha and Fowler[6] reviewed the overall role of simulation in maintaining technical skill levels and improving readiness for real-world surgical environments, concluding that simulation improves trainee learning and has the potential to meet the needs of the surgical profession.

2. Impact on Patient Outcomes

Simulation not only enhances trainee performance, but also shows a positive correlation with patient outcomes. One meta-analysis demonstrated that simulation training reduces operative times and enhances procedural accuracy, contributing to improved patient outcomes[1]. Other studies found that skills acquired on simulators have consistently been shown to transfer to the operating room and have the potential to improve patient outcomes[2,3]. Further, a randomized control trial by Zendeas et al.[7] evaluated resident performance during a totally extraperitoneal (TEP) inguinal hernia repair with a simulation-based curriculum vs standard practice and found decreased operative times, improved operative scores, and decreased intraoperative and postoperative complications for the simulation trained group.

3. Specialty-Specific Applications

Simulation is increasingly being applied across surgical specialties. In vascular surgery, Pantoja et al.[8], found that simulation-based training in open aneurysm repair helped trainees build both technical skills and confidence. Beaudoin et al.[9], demonstrated that simulation-based training, particularly in arthroscopic surgery, improved procedural speed, camera path accuracy, and overall performance in untrained participants. Transplant surgery has also benefited from specialized simulation models. For example, high-fidelity, tissue-based porcine models have been used to teach cardiac transplantation, including the complex steps of organ procurement, anastomosis, and implantation under cardiopulmonary bypass[10]. Further, similar models have been incorporated in solid organ transplantation training, where residents practiced multi-organ procurement and kidney transplantation with significant improvements in their technical skills[11].

4. Barriers to Implementation

Despite its benefits, several studies identified significant barriers to the widespread adoption of simulation in surgical education. High costs and resource limitations were frequently cited. Zevin et al.[4], emphasized the need for standardized curricula to ensure consistent outcomes, while Agha and Fowler[6], noted the importance of validating simulation models to replicate real-world scenarios effectively. Rangarajan et al.[12], pointed out that while virtual haptics show promise, more research is needed to fully integrate it into training programs. These barriers highlight that coordinated efforts in resource allocation and curriculum development are necessary for broader adoption.

DISCUSSION

The integration of simulation into surgical education has proven to be a critical step in overcoming the challenges posed by modern surgical training, such as limited operative exposure and the increasing complexity of procedures. Across specialties, simulation provides a structured, risk-free environment for trainees to develop both technical and non-technical skills, while also maintaining competency over time.

One of the greatest strengths of simulation-based education is its ability to provide immediate, structured feedback during practice, allowing trainees to continuously refine their skills. Unlike traditional learning environments, simulation offers the opportunity to practice complex

surgical procedures repeatedly in a controlled setting, with real-time feedback from instructors or the system itself. This continuous feedback loop improves technical precision, decision-making, and confidence, leading to higher competency when transitioning to live surgeries. Furthermore, these skills can be learned and maintained even when clinical exposure is limited. This is particularly critical in environments where opportunities for hands-on surgical practice are restricted, such as the COVID-19 pandemic.

However, despite the benefits, there are still significant barriers to the widespread adoption of simulation in surgical training. Issues such as the high cost of high-fidelity simulators, lack of standardized curricula, and the need for validation of models continue to hinder its broader integration. Addressing these challenges will be critical to fully realizing the potential of simulation in improving surgical training and patient outcomes.

Looking forward, the future of simulation in surgical education is promising. Emerging technologies such as virtual reality and patient-specific simulations are likely to play an increasingly prominent role. For simulation to reach its full potential, a collaborative effort is needed to ensure greater access to resources, validation of models, and development of standardized curricula that can be applied across institutions.

Table 1: List of studies in surgical simulation and education organized by them

Theme	Article	Author	Year
Skills Acquisition and Retention			
	Agha RA et al The role and validity of surgical simulation. International surgery.	Agha	2015
	Higgins et al. Development and decay of procedural skills in surgery: A systematic review of the effectiveness of simulation-based medical education interventions. Surgeon.	Higgins	2021
	Siu et al. Robotic surgery: Human learning, simulation and training on surgical education. Front Surg.	Siu	2022
Impact on Patient Outcomes			
	Stefanidis et al Association for Surgical Education Simulation Committee. Simulation in surgery: what's needed next? Ann Surg.	Stefanidis	2015
	Meling et al. The impact of surgical simulation on patient outcomes: a systematic review and meta-analysis. Neurosurg Rev.	Meling	2021
	Higgins et al. Development and decay of procedural skills in surgery: A systematic review of the effectiveness of simulation-based medical education interventions. Surgeon.	Higgins	2021
Speciality-Specific Applications			
	Golriz et al Pig as an animal model for liver surgery and transplantation. Hepatobiliary Pancreat Dis Int.	Golriz	2020
	Pantoja et al Trainee Experience in Simulation-Based Education of Open Vascular Surgery. Ann Vasc Surg.	Pantoja	2021
	Beaudoin et al. Module-Based Arthroscopic Knee Simulator Training Improves Technical Skills in Naive Learners: A Randomized Trial. Arthrosc Sports Med Rehabil	Beaudoin	2021
	Gladden A, Westbrook E, Charco R, Kumar G, Solga S. Use of tissue-based porcine models for open and laparoscopic vascular surgery training: A multicenter experience.	Gladden	2021
Barriers to Implementation			
	Zevin et al. A consensus-based framework for design, validation, and implementation of simulation-based training curricula in surgery. J Am Coll Surg.	Zevin	2012
	Agha RA et al The role and validity of surgical simulation. International surgery.	Agha	2015
	Systematic review of virtual haptics in surgical simulation: a valid educational tool?. J Surg Educ.	Rangarajan	2020

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