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EDITORIAL

ARTIFICIAL INTELLIGENCE IN SURGERY AND SURGICAL EDUCATION

Modern surgery has undergone an impressive evolution due to advancements in fundamental research, anesthesia, diagnostic tools, genetics, immunology, pharmacology, and especially artificial intelligence (AI). AI is defined as *"the study of computations that enable a machine to perceive, reason, and act."* In 1950, Alan Turing described intelligent behavior in computers as the ability to achieve human-level performance in cognitive tasks. Over the past 20 years, interest in AI in the medical field has significantly increased, leading to a true revolution and high expectations.

Modern medicine faces the challenge of acquiring, analyzing, and storing large amounts of information needed to solve complex clinical problems. The development of AI-based medical programs generally aims to formulate diagnoses, make therapeutic decisions, and predict outcomes. AI tools are designed to support the medical team in their daily tasks by processing data efficiently. This major progress has been made possible by the convergence of four key factors:

1. Large databases
2. Increased computing power
3. Deep learning algorithms, which have become the primary approach to creating intelligence at levels exceeding human capabilities, from image recognition to digital language processing
4. Significant investments

The cognitive revolution promised by AI has the potential to mitigate the shortage of doctors, particularly in fields like radiology and pathology, but it will not replace doctors in making therapeutic decisions.

Today, we can talk about **digital surgery (DS)**, which is shaping a global framework for surgical training, education, and planning. DS represents a milestone in computer-assisted surgery and the new era of automated surgery, robotic learning, and augmented environments. Digital surgery, which already exists (e.g., robotic surgery), leverages AI's power and connectivity as a crucial resource for the next generation of surgeons, particularly through machine learning on both regional and global scales.

As the **third revolution in surgery**, DS will help surgeons manage complex surgical environments, optimize team efficiency, and improve patient outcomes. It will enable healthcare teams to perform better, understand the needs of surgeons and surgical teams, and ultimately provide better patient care. Furthermore, DS will enhance hospital administration by offering a clear perspective on operating room activities, adjusting financial resources accordingly, and improving treatment efficiency while making surgical care more accessible worldwide.

By leveraging data, optimizing best practices, and refining surgical training, DS will ensure high-quality care, reduce outcome variability, and identify key factors that improve patient recovery. DS presents major opportunities, including enhanced surgical training through simulation, increased transparency in operating rooms, and the identification of factors influencing postoperative outcomes. It relies on robotic surgery, advanced instrumentation, improved visualization, connectivity, and data analysis. For DS to develop, it is essential to establish an infrastructure that seamlessly integrates robotics, AI, advanced surgical tools, and

educational programs to facilitate rapid innovation and surgical progress.

AI in Surgery: Enhancing, Not Replacing, the Human Element

AI is already integrated into all phases of surgery:

Preoperative phase: AI enhances preoperative planning by improving risk assessment and 3D modeling, allowing for better-informed decisions;

Intraoperative phase: AI aids in real-time image analysis and robotic assistance, increasing precision and minimizing complications;

Postoperative phase: AI predicts and detects complications early, personalizes recovery monitoring, and enables long-term patient follow-up.

With the rising number of surgical procedures, AI's role in surgery will continue to grow by improving precision, real-time diagnostics, customized surgical approaches, intraoperative navigation, risk prediction, and postoperative monitoring. AI has the potential to enhance patient outcomes, facilitate surgical education, and optimize surgical care.

AI supports surgeons in three main phases of their work:

1. **Preoperative planning**: AI can integrate population-level surgical data to determine patient-specific risks and expected outcomes, facilitating evidence-based treatment decisions. Deep learning techniques enable AI to recognize individual anatomical variations from medical images, helping surgeons anticipate intraoperative challenges. Sophisticated AI algorithms can process large imaging datasets to generate detailed 3D models of anatomical structures, offering interactive visualizations that enhance surgical field analysis.

2. **Intraoperative assistance**: AI-powered imaging techniques help surgeons identify anatomical structures with high precision and track instruments in real-time. AI systems assist in robotic surgeries by providing instant feedback and performing automated tasks. In colorectal cancer surgery, for instance, AI-powered tumor sensors ensure precise tumor resection, reducing positive surgical margins and improving oncological safety.

3. **Postoperative monitoring**: AI continues to assist patients beyond the operating room by enabling personalized and proactive post-surgical care. Intelligent algorithms track vital parameters, analyze data from various sources, and detect early signs of complications, allowing timely intervention. Wearable devices provide real-time recovery data, enabling healthcare teams to tailor rehabilitation plans and schedule follow-ups based on prognostic data.

From an **ethical** perspective, AI systems must undergo continuous monitoring to ensure patient safety and data privacy. Surgeons play a crucial role in decision-making with AI, requiring adequate training. As AI systems take on critical roles in healthcare-ranging from diagnostics to treatment recommendations and surgical tool control-it is vital to ensure that AI-driven decisions align with ethical standards and individual patient needs. While AI-assisted clinical decision support systems can provide precise recommendations, there is a risk of over-reliance on AI, which may lead to potential harm if AI recommendations are followed without considering patient-specific factors. Additionally, there is a concern that patient trust may erode if AI is perceived as the sole decision-maker.

AI and Surgical Education

The **benefits of AI in medical education** are numerous. AI-powered tools, such as ChatGPT, help doctors quickly and accurately respond to patient inquiries, offer personalized medical advice, and streamline administrative processes, improving patient

care efficiency. While some believe AI could replace doctors in the near future, this remains an illusion and an undesirable outcome.

One of AI's most crucial roles is in **surgical training**. The training process for surgical residents has evolved from the Halsted model (1890) of *"see one, do one, teach one"* to structured training programs.

The Rasmussen model (three-phase learning process) has proven effective:

1. **Skill-based behavior** – learning fundamental surgical gestures, understanding surgical instruments, aseptic techniques, and anatomical landmarks.

2. **Rule-based behavior** – mastering operative sequences, performing surgical procedures, and understanding surgical indications.

3. **Knowledge-based behavior** – acquiring the ability to handle critical situations, intraoperative complications, and complex surgical decisions.

The goal of surgical training is to develop professional competencies, assess theoretical knowledge, and enhance practical skills. The AI revolution is set to transform surgical education by introducing personalized, simulation-based learning experiences that redefine skill acquisition and refinement.

In **Romania**, the first **MIST-VR simulator** was introduced in Iași before 2000, significantly improving the surgical education. Today, "Grigore T. Popa" University of Medicine and Pharmacy of Iași hosts the most advanced simulation center in Romania, further enhancing surgical training. AI algorithms can assess trainees' strengths and weaknesses, tailoring training to their specific needs. AI's impact on surgical education extends beyond practice, as AI tools accelerate training by providing personalized learning experiences and objective skill assessments.

AI enhances simulation-based training by offering real-time feedback, objective evaluation tools, and tele-mentoring opportunities. AI algorithms can predict a trainee's performance and skill development, optimize training programs, facilitate communication, update curricula, and generate interactive content. Surgeons must understand AI's strengths and limitations, especially when transitioning from simulations to real-life surgeries. Future surgical training programs will incorporate AI-related knowledge and skills, requiring **multidisciplinary collaboration** among specialists to develop and implement AI in surgery.

The Ethical and Humanistic Perspective

Over **25 years of innovation**, AI models have matched human performance in certain aspects of patient care. However, this evolution has also raised challenges, including ethical dilemmas, data security concerns, and the need for appropriate regulations. Strategies for the **safe and effective integration of AI in surgery** include establishing robust safety protocols, conducting prospective clinical trials, training surgeons as AI end-users, and fostering interdisciplinary collaboration.

To **fully harness AI's potential**, continuous research, innovation, and collaboration are necessary to address technical, ethical, and organizational challenges. Aligning technological advances with patient-centered ethics and medical values will allow AI to elevate the standard of surgical care and improve outcomes worldwide. Addressing ethical, legal, and practical complexities-such as bias mitigation, patient privacy protection, AI system validation, and efficient integration into surgical practice and education-is crucial.

As some question whether **Hippocrates' Oath** remains relevant today, it is clear that this ethical code is more important than ever. Despite high-tech advancements and globalization, **the most vital aspect of sur-**

gery remains humanism and empathy-qualities no AI can replicate. If we lose this **divine gift of healing through human connection, we lose everything**, as François Rabelais once said: *"Science without conscience is the ruin of the soul."*

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