Artificial Intelligence and Hepatic Surgery

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Review Article

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ABSTRACT

Artificial Intelligence (AI) is rapidly transforming the field of surgery, particularly hepatic surgery, by enhancing diagnostic accuracy, clinical decision-making, and surgical outcomes across pre-operative, intra-operative, and post-operative phases. This editorial explores the integration of AI technologies, including machine learning, computer vision, and augmented reality, which empower surgeons with tools that improve precision and reduce complications. AI-driven platforms, such as the Artificial intelligence Radiomics Genomics Oncopathomics and Surgomics (AiRGOS) Project, demonstrate the potential of integrating multiomics data-including radiomics, genomics, and pathomics-to provide a comprehensive understanding of patient-specific disease profiles and inform individualized treatment plans. AI's role extends beyond the operating room, with virtual reality simulations and 3D printing enhancing surgical training and education, allowing for risk-free practice of complex procedures. AI also plays a pivotal role in post-operative care, where predictive models help anticipate complications and optimize patient management. Despite these advancements, the adoption of AI in surgery faces significant ethical and technological challenges, including data security, trust in AI-driven decision-making, and maintaining transparency in patient-provider interactions. Addressing these issues through multidisciplinary collaboration and continued technological refinement is essential to fully realize AI's potential in advancing the safety, efficacy, and personalization of surgical care.

Key Words: Artificial Intelligence; AI; surgery; AI surgery; surgomics.

Received: 20 September 2024, **Accepted:** 29 September 2024, **Published:** 4 October 2024

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ISSN: 1110-1121, October 2024, Vol. 43, No. 4: 1127–1130, © The Egyptian Journal of Surgery

INTRODUCTION

The past 80 years have witnessed the birth and evolution of Artificial Intelligence (AI) starting with the decoding of the Enigma Machine during World War II to the launch and expansion of generative AI platforms such as ChatGPT in the early 2020s. Currently, there are many definitions of AI in circulation and the US Congress formalized its definition by the National Artificial Intelligence Act of 2020 where "The term 'artificial intelligence' means a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments[1]." Concerning the surgical domain, the role of AI is under intense investigation especially as it pertains to surgeons utilizing robotic tools where 6 levels of autonomy (Level 0 none to Level 5 full) has been described[2].

According to a 2020 International Monetary Fund (IMF) publication, 60% of jobs in advanced economies, 40% in emerging markets, and 26% in low-income countries will be impacted by AI[3]. In the age of Artificial Intelligence (AI), many industries have redefined possibilities by incorporating AI technology into their industries and exploring the possibilities AI has to offer. The global healthcare vertical is especially well positioned to benefit from a wide array of AI empowered applications and platforms utilizing conversational computing, machine learning, and intelligent robotic process automation. The utilization of AI will be a major factor in advancing precision medicine, providing highly accurate diagnoses and interpretations of radiology and pathology digital media, multimodal omnichannel based speech to text, autonomous surgery, and in particular hepatic surgery[4].

Multiomics and the AiROGS Project

Multiomics refers to analysis of data from various "omics" fields of study, such as radiomics, genomics, oncopathomics, surgomics, metabolomics, proteomics and

DOI: 10.21608/EJSUR.2024.322403.1206

various others. By integrating data from these fields of study, clinicians will possess an enhanced comprehension of underlying mechanisms of disease[5]. Applications of multiomics in human diseases includes cancer, neurodegenerative disease, drug targets, aging and many others[6].

Concerning the surgical domain, a team of multidisciplined surgeons, data scientists, computer / electrical engineers, and software architects has been working on the Artificial intelligence, Radiomics, Genomics, Oncopathomics and Surgomics (AiRGOS) Project to explore how surgeons can integrate AI into clinical practice both in and out of the operating theater. The AiRGOS Project aims to understand how AI algorithms can be implemented into clinical care to help physicians provide precise, individualized treatment regimens for their patients[7]. For example, in the pre-operative stage, AI can be utilized as an effective patient specific nutritional status and optimization care plan monitoring tool by empowering human nutritionists with conversational computing applications utilizing simple text based chatbots to realistic human avatars personalized to a patient's preference. Radiomics affords the analysis of large radiologic images and data sets rather than the limited number of images that a human radiologist and process. Through deep learning, AI in radiomics is able to provide more precise and accurate diagnoses than traditional methods. Additionally, with the ability of predicting the natural development of benign or pre-malignant lesions, AI can help surgeons decide the proper treatment and bolster surgeon confidence in their clinical decisions[8]. Pathomics, similar to radiomics, analyzes all histopathologic images to create a tumor profile for each patient. Utilizing all available data from radiomics, pathomics, and genomics, the next step in integrating data and AI to support surgical outcomes is surgomics. Surgomics aims to provide a holistic view of a patient's cancer profile to aid surgeons in clinical decision making and developing an individualized treatment plan. Applying AI and its ability to utilize machine learning, the goal of surgomics is to help surgeons move beyond traditional analysis methods dependent on predefined hypotheses to using a much richer and broader patient data set tailored to a personalized and comprehensive patient treatment[9].

AI in the Pre-, Intra-, and Post-Operative Phases

Apart from its diagnostic capabilities, AI technology utilized outside of the intra-operative phase, defined as 'AI in surgery,' can be transformative in education and training. Virtual reality (VR) training has proven to enhance trainee efficiency and error reduction when compared to traditional training methods. VR simulations provide a cost-effective and risk-free platform for surgeons to practice complex techniques and gain confidence before operating on real patients. Moreover, AI can be a powerful educational tool through 3D printing technologies. In endovascular aneurysm repairs, 3D printed models have allowed surgeons to simulate procedures pre-operatively. 3D models can also be used to help explain pathology and surgical risks to patients, clearing any confusion and concerns for patients[10]. In addition to the role of AI in education and training, considerable research has been undertaken and continues to evolve concerning the role of hyperspectral imaging combined with machine learning that provides considerable insights into tissue segmentation for image guided surgical interventions on organs such as the liver[11]. Transplant surgery is also benefiting from the utilization of AI. An interesting study has demonstrated that the use of AI to analyze hepatic steatosis prior to transplantation of the liver has the potential to decrease enter-observer variability and assessment biases[12]

Concerning the intra-operative phase, there has been concerted efforts over the past 25 years to provide surgeons with as much digital information as possible during an operative procedure to decrease complication rates and improve technical proficiency. This has been referred to as the digital operating room where it not only strives to integrate data and workflows, but also record and distribute digital content[13]. Unlike traditional surgery where a surgeon has direct physical contact with a patient, teleroboic surgery must utilize haptic sensors and a combination of electrical and mechanical devices for enabling the surgeon's hand to experience the tactile experience of the robotics arm[14]. Interestingly, during the late 1990s, the use of tactical audio to enhance a surgeon's accuracy in guiding an instrument though space to a tissue target (tactical audio) met with early technical success but was too early for clinical commercialization[15].

The role and benefits of robots in surgery continues to expand. For example, minimally invasive tele-manipulator robotic surgery offers significant advantages when compared to traditional surgery. These benefits include 3D visualization, improved ergonomics, the ability to control a third arm, and up to seven degrees of articulation. 'AI Surgery' is defined as the use of AI technology - specifically machine learning, deep learning, and computer vision - during an operation that ultimately offers surgeons short- or long-term benefits. Augmented reality (AR) is another example that is already in use. AR systems work by superimposing images onto structures in real time, and they help guide surgeons gain better visualization of their surgical field[16].

AI via computer vision and machine learning is empowering surgeons with enhanced key anatomic region and object identification along with the ability to categorize risk involved in tissue manipulation[17]. The importance of recording all operative procedures is currently under review and there is consensus that not only is this essential for building out highly accurate computer vision based anatomical identifications, but provides a wealth of data for other relevant clinical investigations such as the analysis of the vast corpus of recorded operative procedures such as laparoscopic cholecystectomies provides machines with the ability to continuously improve their tissue identification and related risk algorithms resulting in a lower incidence of surgical biliary complications[18].

Fortunately for patients, the utilization of AI within the post-operative phase, traditionally while a patient is at home, is yielding dividends via the reduction of unnecessary costs and most importantly, decreases in patient suffering. For example, machine learning machine learning (ML) models have demonstrated accuracies ranging from 63% to 89% for predicting postoperative complications after hepatopancreaticobiliary (HPB) surgery. The promising and ever improving predictive modeling and performances afforded by ML illuminates the potential to surpass a surgeon's non-AI enhanced assessment and complication predictions. Ideally, ML models could be helpful in guiding prophylactic measures and enhanced patient monitoring based on the predicted complications. This could prevent delayed hospital discharge for patients with severe postoperative[15]. Complications. The utilization of deep learning models has been reported to be helpful for predicting postoperative complications and survival outcomes by examining preoperative medical images. Microvascular invasion of hepatocellular carcinoma (HCC) is an indicator of an aggressive tumor, tumor recurrence, and poor survival after surgery. Deep learning-based AI using preoperative CT can predict microvascular invasion and survival outcomes[19].

CONCLUSION

The global utilization of AI within the healthcare vertical continues to increase and expand, especially within the domain of surgery. Surgeons uniquely engage in patient care within the pre-operative, intra-operative, and post-operative phases where a wide range of AI abilities including but not limited to ML are proving their worthiness in not only decreasing costs but improving clinical outcome while reducing complications. In addition, the expansion of surgical robotics within the global community, much of it fueled by AI utilization, is going to result in a wider range of cost-effective products.

Despite the increased utilization of AI within healthcare in general and surgery in particular, there remains considerable ethical and technological challenges to overcome. Patients have traditionally engaged in face-to-face patient – provider interactions. They have been exposed to and in many instances comfortable with non-face to face interactions afforded via a telemedicine-based application where acceptance has been accelerated due to the COVID-19 Pandemic. Patients are exposed to robotic surgery, especially during surgery of the prostate. However, there is a trust and assumption that the surgeon is performing the procedure. As AI takes a greater role in many aspects of healthcare delivery, especially relevant within surgery, it will become more difficult for patients to fully be aware of which services are being delivered by their human provider and by the AI. These and other related ethical challenges will need to be addressed by a wider audience of stakeholders including but not limited to patients, providers, industry representatives, academics, and many others.

Fortunately, technological advances have empowered the rise and expansion of AI within all verticals, not only healthcare. Despite these advances, technical challenges remain to achieve ubiquitous high speed wireless connectivity, reliable and redundant power supplies, data security vulnerabilities to threat actors, more accurate generative AI models, and many others The next generation of surgeons will benefit from gaining considerable expertise in the use of AI and the technology stack that supports it. It is important for surgeons to be engaged in the decision making of healthcare systems concerning equipment and technologies that will impact their ability to deliver care and most importantly, impact their patients. This will be particularly true in hepatic surgery, due to its inherent risk and complexity.

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