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MINIREVIEWS

Artificial intelligence in perioperative management of major gastrointestinal surgeries

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Abstract

Artificial intelligence (AI) demonstrated by machines is based on reinforcement learning and revolves around the usage of algorithms. The purpose of this review was to summarize concepts, the scope, applications, and limitations in major gastrointestinal surgery. This is a narrative review of the available literature on the key capabilities of AI to help anesthesiologists, surgeons, and other physicians to understand and critically evaluate ongoing and new AI applications in perioperative management. AI uses available databases called "big data" to formulate an algorithm. Analysis of other data based on these algorithms can help in early diagnosis, accurate risk assessment, intraoperative management, automated drug delivery, predicting anesthesia and surgical complications and postoperative outcomes and can thus lead to effective perioperative management as well as to reduce the cost of treatment. Perioperative physicians, anesthesiologists, and surgeons are well-positioned to help integrate AI into modern surgical practice. We all need to partner and collaborate with data scientists to collect and analyze data across all phases of perioperative care to provide clinical scenarios and context. Careful implementation and use of AI along with real-time human interpretation will revolutionize perioperative care, and is the way forward in future perioperative management of major surgery.

Key Words: Algorithms; Artificial intelligence; Big data; Data management; Machine learning; Perioperative care

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Core Tip: Artificial intelligence (AI) has revolutionized the way surgery and anesthesia are taught and practiced. Applications of AI in anesthesia are risk prediction, control of anesthesia by closed-loop anesthesia delivery systems, monitoring the depth of anesthesia, robotic intubation, monitoring cardiac output based on algorithms and ultrasound guidance. In surgery, AI focuses on generating evidence-based, real-time clinical decision support designed to optimize patient care and surgeon workflow. AI can be used to appropriately convey the results of prognosis and treatment algorithms to patients. Nevertheless, there is a lack of problem-solving by AI and a continuing dependence of human analysis.

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INTRODUCTION

Artificial Intelligence (AI) which means intelligence demonstrated by machines is based on reinforcement learning and revolves around the usage of algorithms. AI has already found an irreplaceable place in our lives with it use by smartphones, personal assistants like Alexa and many other applications. AI derives inspiration from the brain's complex neural network and uses artificial "neurons" that learn by comparing themselves to the desired output and "reinforce" connections that are useful, thus creating the basis of the artificial neural network approach. The healthcare field generates vast medical databases, also known as "big data" that include healthcare records, imaging, pathology, and surgical videos. Analysis of big data with the help of AI can help diagnose diseases early as well as predict outcomes better, which will eventually lead to effective and economical healthcare. Involvement of AI in perioperative management includes preoperative assessment with accurate risk predictions, intraoperative management includes intubating and operating robots, infusion devices, monitoring the depth of anesthesia (DOA), and early detection of anesthesia and surgical complications. The vast spectrum of AI and the ability of deep neural networks (DNN) to analyze intraoperative videos, the learning curve, and near misses may be reduced in minimally invasive surgery[1]. Postoperatively, AI has shown a role in reducing surgical site infections (SSI), intra-abdominal SSI after gastrointestinal (GI) surgeries[2,3], and identifying anastomotic leaks from electronic health records (EHRs)[4,5]. The applications of AI in the near future are expected to be significantly practice-changing, hence it becomes essential for surgeons and anesthesiologists to be updated with current applications and possible future uses.

BASICS OF AI IN A NUTSHELL

AI is a vast field in which machine learning (ML) forms a subfield (Figure 1). ML enables machines to learn from experience just as humans do. ML depends on the ability to perform tasks based on algorithms without actual programming and can be divided into supervised, unsupervised, and reinforcement learning[6]. Supervised learning enables the ML algorithm to achieve a predesigned outcome, unsupervised ML does not have prescribed output categories and can detect subtle patterns in large datasets that are imperceptible to human analysis. In supervised ML, datasets are divided into a training set and a test set to test the algorithm using the new dataset. Reinforcement learning is similar to conditioning and involves repeated trial and error situations that lead to a reward. DNN or deep learning involves multiple layers of the network that allow for the learning of more complex patterns (Figure 2). In DNN, to achieve the best association between the input and output layer, there are multiple intermediate hidden layers in that are fed data by their previous layers and thus influence the outcome. DNN can use EHR variables and accurately predict anastomotic leaks or mortality in postoperative patients[4,5]. Conventional neural

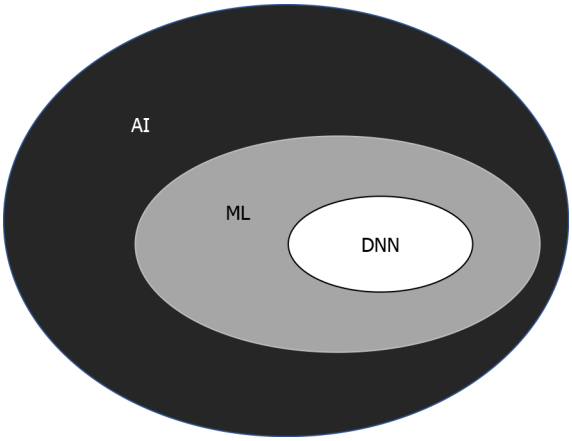

Figure 1 Machine learning is a subfield of artificial intelligence; deep neural networks in turn form a subfield of machine learning. AI: Artificial intelligence; DNN: Deep neural networks; ML: Machine learning.

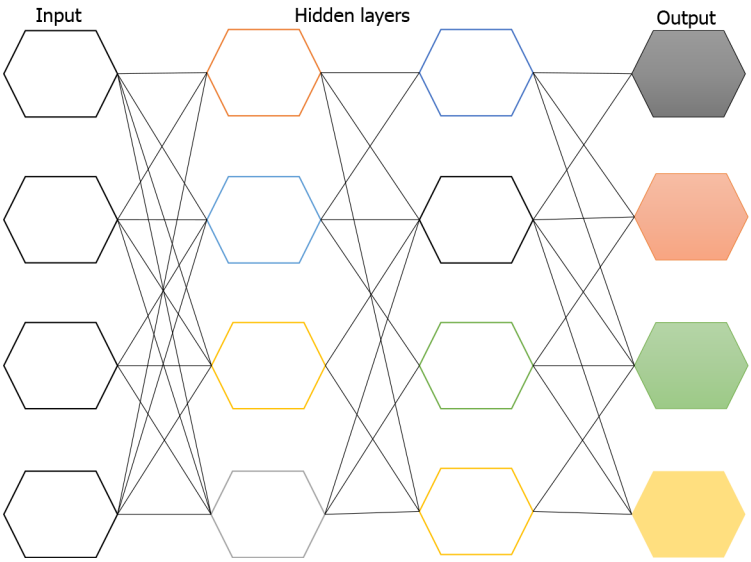

Figure 2 Deep neural networks have multiple intermediate layers that are hidden between the input and output layers.

networks, recurrent neural networks, and residual neural networks are currently commonly used architectures in deep learning. Techniques used by AI include computer vision (CV) and natural language processing (NLP). CV allows AI to identify objects through the processing of patterns and images; NLP allows machines to analyze human language beyond their machine language or code. CV and NLP have diverse applications in surgery and anesthesia.

PREOPERATIVE MANAGEMENT AND PLANNING

Preoperative planning of GI surgeries includes the combined use of pathological diagnosis, endoscopy, and imaging to identify patients at risk of complications, for early detection, and for timely treatment. Digital pathology with the transfer of slide images is in practice to report them remotely and can help obtain second opinions by remote centers with pathological dilemmas. Due to the sheer volume of specimen and ability to focus the microscope in an area of the field, even expert pathologists are bound to miss areas of interest. AI helps to analyze the whole field as well as to detect subtle changes[7,8]. AI algorithms can identify celiac disease[9], *Helicobacter pylori*[10], grade liver fibrosis[11], classify colonic polyps[12], grade dysplasia[13], predict 5-year overall survival in colorectal cancer from pathology[14], and predict microsatellite instability[15]. The drawbacks include large data storage and the need for an efficient network, computer, and equipment. ML learns from the data feed and because of

baseline inter-individual variability amongst pathologists, there is a grey zone regarding a 100% precision. Endoscopists have embraced AI and currently used it increase detection of polyps as well as to differentiate hyperplastic from adenomatous polyps based on endoscopic images[16,17]. However, most of the additional polyps detected by trained DNN are sub-centimetric adenomas[17]. It can also be used to differentiate malignant *vs* nonmalignant tissue, identify the depth of invasion, and margins of endoscopic resection[18,19]. An important feat achieved through AI is the evaluation of huge numbers of endoscopic images obtained by wireless capsule endoscopy[20] as well as an integrated ultrasound system in the capsule for evaluation as described by Sonopill[21]. Owing to the problem of organ deformation in the abdomen, integration of AI in imaging of GI pathologies has not been as fast as in breast or lung diseases. However, for a complex solid organ like the liver AI has expanded the scope of complex surgeries by three-dimensional (3D) visualization, virtual simulation surgery[22-24] and navigation-assisted surgery (see below). With that technology, it is possible to assess patients with large tumors initially considered inoperable[25]. The ability of 3D imaging to assess biliary anatomy and the liver remnant helps to predict the optimal surgical path to avoid residual tissue in complex hepatolithiasis[26-28]. 3D imaging has helped to better understand pancreatic vascular anatomy and determine the resectability of tumors[29-31]. Photoacoustic imaging combines optical imaging with high resolution ultrasound and large penetration depth. This has shown promise in Crohn's disease to assess intestinal hemoglobin levels and differentiate between active and inactive disease to avoid unnecessary invasive procedures[32].

The other aspect of perioperative planning is decision making and risk assessment. The surgical decision is not made only by the surgeon, a shared-decision includes patient involvement in the management, increases patient satisfaction, compliance and allows the patient to cope up with any unfortunate complications[33]. IBM Watson Oncology was built to help oncologists to keep up to date with current evidence and guide decision making. Despite the associated hype, it has not been able to deliver well for GI cancers[34,35]. Unfortunately, the available risk assessment models like major adverse cardiac events, the Revised Cardiac Risk Index, and Gupta Perioperative Risk for Myocardial Infarction or Cardiac Arrest underestimate the risk involved[36-38]. The American Society of Anesthesiologists (ASA) classification, which is used widely is also not devoid of subjective assessment errors[39]. AI and ML platforms that are fed data from vast databases of patients outcomes can identify and accurately predict risk based on the variables available EHRs. The MySurgeryRisk platform uses EHR data of 285 variables and has been shown to predict perioperative risk with better accuracy than clinical judgement[5]. It utilizes the big data from EHRs and obviates manual input of variables to give accurate mortality prediction. ML has been shown to accurately predict mortality, sepsis, and acute kidney injury using intraoperative data[40-43]. The Predictive OpTimization Trees in Emergency Surgery Risk (POTTER) calculator is an ML platform based on the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database to calculate perioperative risk and mortality[44]. POTTER is accurate, user-friendly and can be integrated with EHR data to identify and prevent risks like SSI, sepsis, pneumonia, urinary tract infection, cardiac complications, and prolonged intensive care unit (ICU) stay in postoperative patients. Similarly, for the prevention of anesthesia-related complications, ML algorithms can interpret data from previous surgery that includes both patient risk factors and postoperative outcomes to recommend the anesthetic drugs to be used[45].

INTRAOPERATIVE MANAGEMENT

AI has led to several advancements for the induction and maintenance of anesthesia in the current era. Intubation robots like the Kepler intubation system, which uses a video laryngoscope and a robotic arm to place the endotracheal tube, has shown a 91% success rate[46]. Monitoring DOA requires the assessment of a multitude of parameters and is a complex task to be converted in real-time to an ML algorithm. AI utilizes the bispectral index (BIS), which is derived from electroencephalogram data, to maintain tight feedback and control of DOA[47]. McSleepy automated intravenous infusion machines use the BIS along with vital signs to maintain DOA by administering propofol, narcotics, and muscle relaxants[48]. The maintenance of DOA is a critical balance between infusion and assessment of parameters and under-dosing or excessive DOA may be caused by equipment imbalance, therefore automated

anesthesia is still in its infancy and not ready to be adopted in general practice. Closed-loop anesthesia delivery systems which are another automated delivery system based on BIS have been shown to be effective and efficient[49].

Apart from induction and maintenance, automated regional anesthetic blockade has been performed by the da Vinci® system, and the Magellan robot has been used to place peripheral nerve blocks[50,51]. Intraoperative intelligence can help to predict return of consciousness after general anesthesia, and neural networks can predict post-induction hypotension as well as the rate of recovery from neuromuscular blockade [47]. Hatib *et al*[52] have utilized arterial waveforms to formulate a model that was able to predict hypotension 15 min before its occurrence using waveform analysis. In an unblinded randomized clinical trial (HYPE trial), the use of a ML-derived early warning system compared resulted in less intraoperative hypotension with standard care[53]. Neural networks can assist in the identification of vertebral level and epidural landmarks for postoperative pain from ultrasound images[47]. In supra major abdominal surgeries like cytoreductive surgeries or hyperthermic intraperitoneal chemotherapy, it is recommended to use cardiac output monitoring. Currently, noninvasive arterial pressure-based cardiac output monitoring is used in a majority of cases[54]. A noise-robust bioimpedance approach for cardiac output monitoring using a regression support vector machine and DNN is the most accurate and robust method for monitoring cardiac output, but it has not been used in surgical patients[55].

Today's operation theater (OR) utilizes a multitude of anesthesia and surgical machines that provide a regular status report and adequate assistance. The heterogeneous sensors in the OR are known as "context-aware assistance" and help in the smooth functioning of the surgical procedures[56]. ML and data annotation can be used to identify the phases of surgery and apply them to identify any deviation or delay in surgical steps[57]. Surgical navigation technology or computer-assisted abdominal surgery use preoperative or intraoperative imaging to track surgical instruments and help to describe hidden surgical anatomy. These have been described in case reports in laparoscopic adrenalectomy[58], splenectomy[59], pancreaticoduodenectomy[60], and esophagectomy[61]. However, integrating this entire system in current practice is difficult because of the effort required in the setup and the problem of organ deformation in the abdomen. Liver surgery, with its complex biliary and vascular anatomy, makes a perfect match for the use of navigation-assisted procedures[62-65]. Prediction of the resectability of peritoneal carcinomatosis often requires a laparotomy to assess the burden of disease. ML like the random forest model have been shown to predict resectability with an accuracy of 97.82% in peritoneal carcinomatosis[66] and could help prevent unnecessary laparotomies and to improve the efficiency of the OR.

The da Vinci Surgical System® (Intuitive Surgical, Sunnyvale, CA, United States) is the most commonly used robotic platform and is used for a majority of pelvic surgeries, where it has shown superior postoperative outcomes[67]. Robotic surgery gives surgeons full control with robotic arms, but there is an increase in operative time and cost. A standalone robotic camera can reduce costs and has been evaluated for pancreatic procedures[68] and for laparoscopic cholecystectomy[69]. In laparoscopic cholecystectomy, there was an increase in operating time, which was possibly caused by a lack of real autonomy or reinforced learning and needs to be controlled by the surgeon either verbally or by manual interaction. The human-machine interface can be controlled by gaze gesture recognition or recognition of the surgeon's head movement to control the laparoscope or endoscope remotely[70-72]. As an alternative to automated anesthesia and robotic surgery, Jacob *et al*[73,74], designed Gestonurse, a robotic scrub nurse with a sensor that understands nonverbal hand gestures, can help to deliver surgical instruments to surgeons. The Smart tissue anastomosis robot is used for minimally invasive suturing and it has been shown in experimental models to have better accuracy and consistency than human surgeons[75,76]. Minimally invasive laparoscopic surgery is a continuously evolving process for surgeons, requires skill and has a learning curve. With AI it is possible to identify the real-time automatic surgical phase for real-time workflow recognition and teaching[77]. A DNN approach has shown an accuracy of 91.9% for the identification of surgical phases in 71 patients with laparoscopic sigmoidectomy[77]. With the help of AI and DNN, it will be possible to predict the occurrence of intrasurgical events and to avoid near-miss events in laparoscopic surgery[1].

POSTOPERATIVE MANAGEMENT

A smooth postoperative recovery for all patients is the goal. NLP allows ML algorithms to understand EHR data and to utilize it to predict outcomes[5,78]. ML algorithms have been shown to accurately predict superficial SSI, organ space SSI, sepsis, and bleeding requiring transfusion after liver, pancreatic, or colorectal surgery[79]. Statistically, it has shown to outperform the ASA and ACS-Surgical Risk Calculator. One of the most undesirable complications after major GI surgeries is an anastomotic leak. Various clinical signs and biochemical and radiological investigations are used to assess leaks. The use of NLP data from EHRs can predict anastomotic leaking after colorectal or bariatric surgery[5,80]. AI has been shown to predict the risk of postoperative pancreatic fistula (POPF) after pancreaticoduodenectomy by using prediction platform algorithms. A patient's predicted POPF risk could guide clinical management and prevent or mitigate untoward outcomes[81]. ML has been used in the postoperative period or in ICUs in patients with sepsis to predict urine output and fluid status after fluid administration and to help avoid fluid overload and oliguria[82].

As has been recently published, an ML algorithm performed by the DASH Analytics High-Definition Care Platform can use EHR data predict the risk of SSI and suggest ways to reduce the risk in real-time during the closure. The platform reduced SSIs by 74% in 3 years at the University of Iowa Hospitals and Clinics[83]. AI research has also focused on minimizing postoperative pain and maximizing patient comfort. Postoperative pain after abdominal surgeries was studied in a randomized controlled trial (RCT) involving 50 patients using the Nociception Level (NOL) index, a multiparameter AI-driven index designed to monitor nociception during surgery. That study found no differences in perioperative opioid (fentanyl and morphine) consumption, but there was a 1.6-point improvement in postoperative pain scores in the NOL-guided group[84] (Figure 3).

EDUCATION AND TRAINING

AI can help in the training of anesthesiologists by recreating realistic case scenarios not encountered in routine training, which makes them more prepared for possible situations in the OR. Virtual reality (VR) uses computer technology to simulate the real environment. Minimally invasive surgeries or liver surgeries that require a high level of skill or expertise, are performed better by surgeons who have been trained by VR[85,86]. Currently, there is no robust objective assessment tool to assess competency in advanced laparoscopic colorectal surgery. Observational clinical human reliability analysis and assessment of errors in laparoscopic videos may potentially be useful for specialist recertification and revalidation[87,88].

ROLE IN THE CORONAVIRUS DISEASE 2019 PANDEMIC

The coronavirus disease 2019 (COVID-19) pandemic has changed lives worldwide and has affected healthcare delivery to a great extent. Elective major surgeries were put on hold because of the sudden need of beds and the risk of postoperative infection with the virus, which could lead to adverse outcomes[89]. Healthcare workers were at high risk for infection along with the elderly and individuals with comorbidities. As of July 2020, more than 1800 healthcare workers from 64 countries had died of COVID-19[90]. Intubation generates aerosols that increase the risk of infection, and the use of intubation robots might reduce exposure of healthcare workers. The da Vinci® system, the most widely used surgical robot can reduce exposure allowing minimal contact with the patient. Robotic surgeries require fewer OR personnel than open surgeries, require less intrabdominal pressure than laparoscopic surgery, which reduces aerosol generation[91,92]. Robotic procedures are moving towards contactless surgeries with the help of magnetic navigation systems, which require an external magnet placed on the patient's body[93]. Delaying elective surgery has resulted in a patient backlog. Clearing the backlog requires the efficient use of OR time and resources. An ML algorithm with a custom Python script has been shown to optimize the efficiency of operating room booking times that resulted in a reduction in nursing overtime of 21%, which was equivalent to saving of half a million dollars[94]. Robots can be used to perform surgery on weekends and after hours under supervision that will help to clear the surgical backlog and mitigate surgeon fatigue[95]. Training programs have also

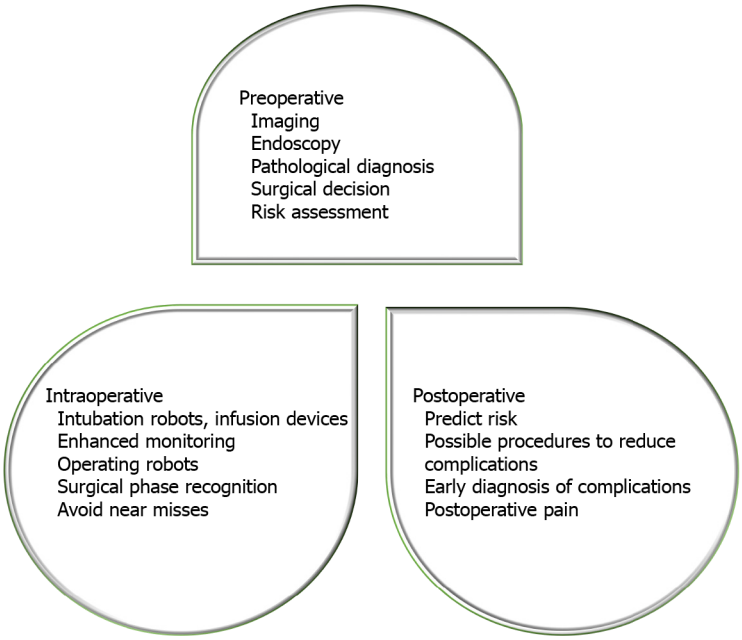

Figure 3 Comprehensive view of areas that reflect the benefits of artificial intelligence in management of major gastrointestinal surgery.

been transformed by the pandemic is the surgical. Conversion of hospitals to dedicated COVID-19 centers, halting of non-urgent surgeries, and reallocation of space to ICU services have drastically hampered the training of surgery residents[96]. VR can allow residents to engage in minimally invasive surgeries amongst others rather than experiencing a complete void in surgical training[85,86]. AI can help to resolve and provide alternative solutions to a few of the problems resulting from the pandemic.

LIMITATIONS

AI should not be looked upon as the answer to all problems. AI can help identify subtle differences in large datasets, but there are certain instances where traditional methods perform better. AI is as good as the data that is used to generate the answers. The results will depend on the questions asked, the variables labelled, and the datasets that are available. Any glitches in those components will result in an incorrect algorithm. Also, the generalizability of the algorithm is dependent on the data that is used to generate it. If the algorithm has been derived from data extracted from an Asian population, then it cannot be generalized and used to predict accurate answers for white Americans. Similarly, there unknown confounders might be present. For example, in one study, an algorithm was more likely to classify a skin lesion as malignant if an image had a ruler in it[97]. The practice of evidence-based medicine has been built upon strictly regulated RCTs. To adopt AI as standard, it will need to undergo vigorous RCTs to confirm their performance in a blinded fashion. Lack of transparency because of multiple layers in a neural network becomes problematic and may not be considered trustworthy or accepted in healthcare because wrong results can lead to devastating consequences[98].

LEGAL IMPLICATIONS

Ethicos is a Greek word meaning a way of conduct accepted in society. *Moralis* is a Latin word that denotes judgement of the appropriateness of a given action. Most of the time, ethics and morality are used interchangeably. The ethical and legal implications of AI are heavily debated. It has already been explained that if the algorithm is flawed, AI will generate inaccurate results. Those errors are different from ones that occurring because of network loss or computer malfunction. AI was initially used only to augment clinical decision making but with its current development and autonomy, flaws in the device that harm patients, resulting in medical negligence, require that

responsibility needs to be predetermined. The allocation of responsibility was traditionally to the surgeon, but with the self-learning capability of AI, it may not be possible for the surgeon to override certain procedures. Legal implications have still not reached a consensus regarding allocation. O'Sullivan *et al*[99] have classified the responsibility of AI and autonomous robotic surgery as (1) accountability; (2) liability; and (3) culpability. Accountability means the capacity of a system to explain its actions, liability is subject to action by the legal system, and culpability relates to punishment. Accountability can be determined by recording the actions, but the issues of liability and culpability require a consensus to adapt to the scenario of AI and robotics.

CONCLUSION

AI is emerging as a powerful tool in healthcare, with the ultimate aim of achieving better patient outcomes. However, we have not yet achieved that goal. Many aspects need to be refined or addressed, beginning with algorithm development and extending to legal and ethical issues. Future advances could definitely allow patients entering the clinic to be given accurate perioperative risks related to both anesthesia and surgery derived from previous surgical experience and patient histories. Intraoperatively along with automated anesthesia and robotic surgery, AI could help predict events like hypotension or delay in surgical steps or to avoid near misses. AI could identify the risk of postoperative complications like sepsis or renal failure as well as anastomotic leak to plan for early intervention. The use of AI in the OR is not intended to replace the surgeon or the anesthesiologist but to expand human capacity and capability through enhanced vision, dexterity, and complementary machine intelligence for improved surgical safety and outcomes.

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