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Artificial Intelligence Surgery

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Artificial intelligence in gastrointestinal surgical oncology: from prediction models to clinical decision support

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MAIN TEXT

Few areas of surgery are as data-rich and decision-heavy as gastrointestinal surgical oncology. The multidisciplinary team, comprising surgeons, radiologists, and oncologists, evaluates the computed tomography (CT) and Magnetic Resonance Imaging (MRI) findings together with endoscopic and histopathological data to determine whether there is an indication for surgical resection or for neoadjuvant or adjuvant chemotherapy and/or radiotherapy. Within this framework, the surgeon selects the operative approach, determines the timing and the extent of resection, identifies planes and vascular control, assesses tissue perfusion, and then assumes responsibility for the consequences of an anastomosis. Some of these decisions are supported by strong evidence, while others still depend on experience, pattern recognition, and memory at the end of a demanding operation. Anastomotic leakage after colorectal resection remains common and consequential, and cognitive bias has been recognized as part of surgical error more broadly[1,2].

This is the practical reason artificial intelligence (AI) could help the surgeon. It is not because surgeons need another fashionable technology, but because many of our hardest decisions are probabilistic, visual, and time-sensitive[3]. The most useful way to think about AI in surgery, and specifically in surgical oncology, is not as a robot surgeon, but as an additional tool of measurement along the perioperative pathway. Before surgery, it may turn images and clinical data into a more explicit risk map; during surgery, it may help identify anatomy, planes, and perfusion; after surgery, it may learn from outcomes, prognosis, and refine care. This framework is not new, but it is becoming realistic because surgical data science is beginning to connect imaging, video, operative events, and registry outcomes[4,5].

Preoperative applications are already closest to routine clinical reasoning. In gastric cancer, CT-based radiomics and deep-learning models have been used to estimate nodal burden before surgery[6]. In colorectal and rectal cancer, AI has been applied to

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lymph-node staging and to the prediction of pathological complete response after neoadjuvant treatment[7,8]. Rather than replacing the multidisciplinary team, these tools are designed to support surgical oncologists and multidisciplinary decision-making by refining oncological and surgical risk stratification, reducing diagnostic uncertainty, and enabling more informed treatment planning and patient counseling. Along the same continuum of decision-support technologies, three-dimensional reconstructions and digital twins extend the role of AI from diagnostic assessment to surgical planning. Although the term digital twin may sound futuristic, its surgical purpose is straightforward: to provide a more accurate understanding of the patient's anatomy before the first trocar is placed, thereby facilitating safer and more individualized operative strategies[9].

The operating room is where interest has accelerated. Computer vision systems can now recognize structures that gastrointestinal surgeons actively try not to injure: ureters, autonomic nerves, pelvic nerves during colorectal resection, and the loose connective tissue planes used in gastrectomy[10-12]. Other tools have been trained to alert the team to occult peritoneal or intra-abdominal metastases during gastric cancer surgery[13]. These examples are important because they move AI away from static prediction and into the actual work of surgical oncology. The promise is not that the algorithm "knows" more than the surgeon. It is that it may maintain attention to a narrow visual task continuously, without fatigue, and provide a second check at moments of risk.

Perfusion assessment is a good example of this concept[14]. Indocyanine green (ICG) fluorescence has become familiar in clinical practice; however, its interpretation is still based primarily on the surgeon's visual assessment, making it inherently subjective, semi-quantitative, and lacking standardized objective criteria. Machine-learning approaches that analyze the kinetics of fluorescence can make perfusion assessment more reproducible, and real-time AI interpretation of ICG has now been reported in colorectal operating rooms[15,16]. At the same time, randomized trials remind us to be cautious: the routine use of ICG fluorescence has not consistently been shown to reduce the risk of anastomotic leakage. Rather than providing a universal benefit, its greatest value appears to lie in supporting intraoperative decision-making in equivocal situations, particularly during left-sided colorectal resections, where assessment of bowel perfusion may influence the level of transection and the construction of a well-perfused anastomosis[17,18]. This is where AI may actually offer added value in real-time surgery. By converting fluorescence imaging into objective, quantitative perfusion assessment, AI has the potential to reduce subjective interpretation and support intraoperative decision-making, particularly in equivocal situations where the risk of perfusion misjudgment may influence the occurrence of anastomotic leakage.

Postoperatively, prediction is easier to build but harder to make useful. Many models can estimate leakage, pulmonary complications, or survival; fewer change what the team does in real-world practice. For this reason, the AID-SURG experience is worth attention. AID-SURG is an AI-driven clinical decision support system developed from a large multicenter surgical registry to generate individualized perioperative risk predictions and guide tailored perioperative management. Rather than simply identifying high-risk patients, the model was integrated into clinical workflows to support personalized interventions for patients undergoing colorectal cancer surgery. Its implementation was associated with fewer major postoperative complications and lower healthcare costs[19]. Whether this result generalizes remains to be seen, but it changes the standard by which we should judge the field. A model should not be celebrated only because its area under the curve looks respectable. It should be judged by whether it changes care, safely and measurably.

Despite the rapid growth of the field, the current literature is still characterized by important methodological limitations that hinder widespread clinical adoption. Most studies are retrospective, single-center, and based on relatively small or highly selected cohorts, making them vulnerable to selection and spectrum bias. External validation remains the exception rather than the rule, and model performance frequently declines when algorithms are tested in institutions, patient populations, or clinical workflows different from those in which they were developed[20]. Furthermore, large registry analyses have shown that machine learning models do not consistently outperform well-calibrated conventional statistical models, suggesting that increasing algorithmic complexity alone does not necessarily translate into greater clinical utility[21]. Similar concerns apply to AI applications in surgical video analysis, where impressive performance metrics are often derived from limited, highly curated datasets and should therefore be considered proof-of-concept rather than evidence of real-world effectiveness[22]. These limitations largely explain why the clinical impact of AI in colorectal surgical oncology remains modest despite encouraging technical advances. High predictive accuracy alone is not sufficient if a model is not robust, reproducible, interpretable, and capable of supporting decisions across different healthcare settings. In surgical oncology, premature implementation of inadequately validated algorithms may create a false sense of confidence, potentially influencing critical decisions such as the extent of resection, the level of vascular ligation, the need for a diverting stoma, the indication for organ preservation, or postoperative surveillance strategies. For this reason, the challenge is no longer to develop models with higher accuracy, but to generate trustworthy, externally validated, and clinically integrated decision-support systems that demonstrably improve patient outcomes.

Finally, there is also a governance problem that surgeons should not leave to engineers alone. Decision-support tools in surgery are likely to fall within high-risk regulatory categories, and currently cleared surgical systems remain at low levels of autonomy[23,24]. Liability, bias, explainability, and automation bias are not abstract ethical topics when the screen is influencing a stapler firing or a decision to abandon resection. Surgeons therefore need to be involved early in dataset design, endpoint selection, and prospective testing. Multicenter validation, transparent reporting, robust video annotation, and trials with clinical endpoints should become requirements rather than aspirations.

In our view, the most sensible future for AI in gastrointestinal surgical oncology is deliberately unspectacular. It will not be a machine replacing judgment. It will be a set of tools that measures what we currently estimate, documents what we currently remember, and warns us when our attention is stretched. The surgeon should remain responsible for the decision, but responsibility is not the same as working unaided. If AI can help us plan more honestly, dissect more safely, and respond earlier to postoperative risk, it will have earned a place in the specialty. The task now is to prove that benefit in patients, not only in datasets.

DECLARATIONS

Authors' contributions

Conception, drafting, critical revision, and final approval of the manuscript: Celotto F, Bao QR, Spolverato G
All authors agree to be accountable for all aspects of the work.

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Not applicable.

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