

REVIEW ARTICLE

Eur J Med Transl Biosci. 2026;1(1):100–106 · Open Access · CC BY 4.0 · Selected from ICMTB, peer reviewed by members of the editorial board

ROLE OF ARTIFICIAL INTELLIGENCE IN MINIMALLY INVASIVE SURGERY: CLINICAL APPLICATIONS, SURGICAL OUTCOMES, AND ETHICAL CHALLENGES

Amela Gjana^{1*}

¹*Department of Medicine, Faculty of Technical Medical Sciences, Western Balkans University, 1001 Tirana, Albania*

**Corresponding author: E-mail: a.gjana24@wbu.edu.al*

Abstract

There has been an increasing use of artificial intelligence (AI) in contemporary medicine. Minimally invasive surgery (MIS) is commonly used because it is associated with reduced tissue damage, less postoperative pain, and a shorter recovery period. This review is intended to examine the present uses of AI in MIS with special attention to clinical uses of AI, surgical outcomes and ethical issues involved in its use. A narrative literature review with a structured search was conducted using PubMed, Scopus, and Web of Science, identifying studies published from 2020 to 2025. Systematic reviews and other evidence concerning the use of AI in MIS, robot-assisted surgery, computer vision, machine learning, surgical planning, and ethics were included in this review. From the available findings, there is sufficient evidence that AI technology can be used in preoperative planning, intraoperative navigation, identification and recognition of anatomical structures, and surgical decision-making. Computer vision helps in real-time identification and visualization of anatomical structures, whereas AI-based robots can help in improving surgical instrument control and dexterity during surgeries. Predictive analytics models can also be used in risk assessment and perioperative decision-making. There are also possibilities for enhancing surgical accuracy and minimizing errors. However, several limitations are still relevant in the area. AI has great potential to revolutionize MIS through increased accuracy, efficiency, and safety. However, for responsible use, AI technology must be subject to robust clinical trials, proper regulation, ethical guidelines, and continuous human supervision. Further research in clinical trials is necessary to prove the efficacy, safety, and applicability of AI.

Keywords: Artificial Intelligence, Minimally Invasive Surgery, Robotic Surgery, Computer Vision, Predictive Analytics, Surgical Outcomes.

1. Introduction

Technology has continually changed how surgery is performed. One of the most impactful innovations has been the transition from traditional open surgery to minimally invasive surgery (MIS). MIS uses smaller incisions and is generally associated with less tissue trauma, shorter recovery, and reduced postoperative morbidity compared with open approaches.

Artificial intelligence (AI) is another major technological development in medicine. AI includes computational methods that can learn from data, recognize complex patterns, support prediction, and assist decision-making. In surgery, machine learning, deep learning, and computer vision are increasingly being investigated for intraoperative guidance, surgical assessment, robotic assistance, and prediction of clinical outcomes [1–3].

Contemporary surgical procedures generate large amounts of data, including operative video, imaging, electronic health records, physiological measurements, and postoperative outcomes. AI can process these data and identify patterns that may be difficult to recognize manually [1,2].

In MIS, reported applications include real-time anatomical recognition, surgical workflow analysis, instrument tracking, robotic assistance, and predictive modeling. However, the clinical value of these technologies remains dependent on dataset quality, external validation, transparency, and appropriate human oversight [1,3,4]. Ethical concerns include privacy, algorithmic bias, explainability, accountability, and regulation [1,4].

The aim of this review is to summarize the current clinical applications of AI in MIS, examine reported technical and surgical outcomes, and discuss the main ethical and implementation challenges.

2. Materials and Methods

2.1. Research Design

The present study is a narrative literature review with a structured search. The main objective was to summarize the current use of AI in MIS and to synthesize evidence concerning clinical applications, technical performance, surgical outcomes, and ethical considerations. No formal systematic-review or meta-analytic framework was applied.

2.2. Database Search Strategy

A structured search for peer-reviewed articles was conducted in PubMed, Scopus, and Web of Science covering January 2020 through March 2025. The following keywords were used:

- “Artificial Intelligence”
- “Minimally Invasive Surgery”
- “Robotic Surgery”
- “Computer Vision”
- “Machine Learning”
- “Surgical Outcomes”
- “AI-Assisted Surgery”

Boolean operators AND/OR were also used. The 2026 article by Pescio et al. was used only as the source of the adapted figures illustrating AI application domains (Figure 1) and publication trends (Figure 2); it was not included as evidence in the 2020–2025 literature synthesis [5].

2.3. Inclusion Criteria for Studies

Selected studies fulfilled the following criteria:

- Peer-reviewed journal articles and other relevant scholarly sources.
- Articles written in English.
- Concerned with AI use in minimally invasive surgery.
- Presented clinical outcomes, technical performance, ethical considerations, or issues regarding the application of AI techniques.
- Included systematic reviews, randomized controlled trials, cohort studies, observational studies, and expert opinions.

Articles that were not concerned with surgical procedures or lacked sufficient methodological detail were excluded.

2.4. Data Synthesis

Data were analyzed and classified according to four themes:

- AI-based computer vision technology.
- Robotic surgical devices.
- Predictive analysis and surgical decision-making.
- Legal, regulatory, and ethical issues.

2.5. Ethical Approval

The study did not require ethical approval because it involved analysis of previously published literature and did not involve human or animal experimentation.

3. Results

3.1. Computer Vision With AI Support

Computer vision is one of the most developed applications of AI in MIS (Figure 1). It uses operative video to identify anatomical structures, instruments, tissue planes, and procedural events and can provide information to support intraoperative decision-making [2,3].

A specific example is the study by Mascagni et al., which developed a deep-learning model to segment hepatocystic anatomy and assess the critical view of safety during laparoscopic cholecystectomy [6]. The study used 2,854 images from 201 laparoscopic cholecystectomy videos, with 402 images additionally segmented. Mean intersection-over-union for anatomical segmentation was 66.6%, while the model achieved a mean average precision of 71.9% and a balanced accuracy of 71.4% for assessment of the critical-view criteria [6]. These results demonstrate measurable technical performance, but they were obtained from still images and do not by themselves establish improved patient outcomes.

A broader systematic review by Gumbs et al. identified computer-vision approaches for anatomical recognition, instrument tracking, workflow analysis, and increasingly autonomous surgical actions, while also emphasizing limitations related to data quality, validation, and the need to keep clinicians in the loop [3,7].

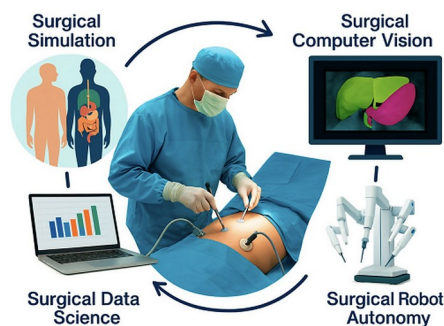


Figure 1. Overview of AI applications in MIS. Reproduced from Pescio et al. (2026), *Journal of Personalized Medicine*, 16(2), 71. Licensed under CC BY 4.0.

3.2. Surgical Robots With AI Support

AI-assisted robotic surgery is being investigated for intraoperative visualization, tissue recognition, instrument delineation, haptic feedback, workflow recognition, surgical skills assessment, and partial automation [1,8,9].

In a narrative review of recent robotic-surgery applications, Knudsen et al. described several quantitative examples. An instrument-delineation model for robot-assisted kidney transplantation achieved a Dice score of 97.10%, while an endoscopic instrument and tooltip detection approach reported sensitivities of 93.02% and 87.05%, respectively [1]. The same review described haptic feedback that reduced median maximum force during a robotic task from 6.43 N to 3.57 N ($P < 0.001$), as well as AI-guided automation of selected suturing tasks [1].

These findings support the potential of AI to improve technical assistance and provide objective intraoperative feedback. Nevertheless, the reviewed applications range from assistance to highly task-specific automation, and they should not be interpreted as evidence that current robotic systems can independently perform complete surgical procedures [1,7,8].

3.3. Predictive Analytics and Surgical Planning

Machine-learning models can combine clinical, demographic, imaging, and procedural data to estimate perioperative risk, surgical difficulty, and postoperative outcomes [1]. Potential applications include prediction of complications, hospitalization duration, postoperative recovery, and risk stratification.

For example, Knudsen et al. described a deep-learning model using automated performance metrics and clinical data to predict continence after robot-assisted radical prostatectomy; the reported model achieved a concordance index (C-index) of 0.60, and automated performance metrics ranked above clinicopathological features in that analysis [1]. This illustrates the potential of combining surgical performance data with patient data, while also showing that predictive performance remains limited and requires external clinical validation before routine use.

3.4. Effect on Surgical Results

The reviewed literature demonstrates improvements in technical measures and intraoperative assistance, including anatomical visualization, segmentation, instrument detection, workflow recognition, and selected measures of robotic task performance [1–3,6].

However, the available evidence should be interpreted carefully. Technical accuracy or improved performance on a surgical task does not necessarily translate into lower complication rates, shorter hospitalization, or improved long-term patient outcomes. The evidence base therefore supports the potential of AI-assisted MIS rather than a universal conclusion that AI already improves clinical outcomes across procedures [1,3,6].

Prospective clinical studies comparing AI-assisted and conventional care are needed to determine whether improvements in technical performance lead to meaningful patient benefits.

3.5. Current Limitations

Several limitations may prevent successful implementation. Data quality and integrity strongly influence algorithm performance, and algorithms trained on non-representative datasets may reproduce or amplify bias [1,4]. Model performance may also decrease when systems are applied to institutions, patient populations, procedures, or imaging environments that differ from the original development setting [1,3].

Other important barriers include limited external validation, lack of transparency of some deep-learning systems, privacy risks associated with surgical video and patient data, and uncertainty about accountability when AI contributes to an adverse event [1,4].

4. Discussion

AI is increasingly being incorporated into minimally invasive and robotic surgery, but the current evidence is best understood as a combination of validated technical demonstrations, early clinical applications, and developing research rather than proof of widespread autonomous surgery [1–3].

Computer vision is among the most clinically relevant applications. Operative video can be analyzed to identify anatomy, instruments, surgical phases, and safety-related events [2,3]. The study by Mascagni et al. provides a concrete example: its deep-learning system assessed the critical view of safety in laparoscopic cholecystectomy with a balanced accuracy of 71.4% [6]. Such systems could eventually support intraoperative safety, but their performance and generalizability must be established in broader and prospective clinical settings.

In robotic surgery, AI can augment the surgeon through image enhancement, tissue and instrument recognition, performance assessment, haptic feedback, and task-specific automation [1,8,9]. The evidence reviewed by Knudsen et al. includes high technical performance for some instrument-detection tasks and measurable reductions in force with haptic feedback [1]. These findings support the concept of AI as an assistive technology rather than a replacement for the surgeon.

Predictive analytics may also support individualized risk assessment and surgical planning. However, prediction models must be externally validated and assessed for calibration, generalizability, and clinical usefulness before they can be relied upon for high-stakes decisions [1].

Ethical issues remain central. AI systems may require large volumes of operative video, imaging, and patient data, creating privacy and data-governance concerns [1,4,10]. The limited interpretability of some deep-learning systems can also make it difficult for clinicians to understand why a recommendation was produced. Accountability is another unresolved issue because responsibility for an adverse event may involve the surgeon, healthcare institution, software developer, or device manufacturer [1,4,10].

Future development should therefore prioritize representative datasets, external validation, transparent reporting, human-in-the-loop systems, appropriate regulation, and prospective evaluation of patient-centered outcomes. AI should be introduced as a tool that augments surgical expertise while preserving meaningful human oversight [1,3,4].

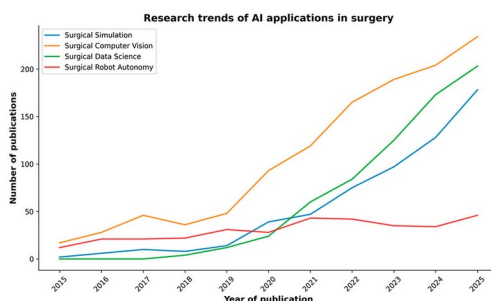


Figure 2. Publication trends in four domains of surgical AI, 2015–2025. Reproduced from Pescio et al. (2026), *Artificial Intelligence in Minimally Invasive and Robotic Gastrointestinal Surgery: Major Applications and Recent Advances*, *Journal of Personalized Medicine*, 16(2), 71. Licensed under CC BY 4.0.

5. Conclusions

Artificial intelligence has substantial potential to support minimally invasive surgery through computer vision, robotic assistance, predictive analytics, and surgical decision support [1–3,6,8,10]. Current studies demonstrate measurable improvements in selected technical tasks, such as anatomical segmentation, instrument detection, and intraoperative assistance. However, these technical findings should not be equated with proven improvements in overall patient outcomes.

Important challenges include data quality, algorithmic bias, limited generalizability, privacy, lack of transparency, accountability, and regulatory requirements [1,3,4]. Future research should prioritize prospective clinical validation and patient-centered outcomes. AI is most appropriately developed as an intelligent assistant that augments, rather than replaces, the surgeon.

Acknowledgements: The author thanks Western Balkans University for providing the facilities that made this review possible. No financial assistance was obtained in the writing of this manuscript.

Declaration of Generative AI and AI-Assisted Technologies: In the process of preparing this manuscript, the author employed OpenAI ChatGPT to assist in language editing, as well as the organization and polishing of the manuscript. The author checked and confirmed all information contained in the manuscript and is fully responsible for the accuracy and integrity of the manuscript.

Conflict of Interest: The author states that there is no conflict of interest that might have or could be construed as having any influence on the work presented in this manuscript.

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How to cite: Gjana A. Role of Artificial Intelligence in Minimally Invasive Surgery: Clinical Applications, Surgical Outcomes, and Ethical Challenges. Eur J Med Transl Biosci. 2026;1(1):100–106.