

# Robotic and Navigation Surgeries in General Surgery

Dr. Bichitra Nath Shukla<sup>1</sup>, Dr. Chandan Singh Rathaur<sup>2\*</sup>, Dr. Chandramani<sup>3</sup>, Dr. Amalanshu Raman<sup>4</sup>, Dr. Abhigyan Kumar<sup>5</sup>

<sup>1</sup> Assistant Professor, Department of General Surgery, Era's Lucknow Medical College and Hospital, Lucknow, UP, India

<sup>2\*</sup> Assistant Professor, Department of Anesthesiology, KMC Medical College & Hospital, Maharajganj, UP, India  
(Corresponding Author)

<sup>3</sup> Consultant Anesthesiology, Dr OP Chaudhary Hospital, Lucknow, UP, India

<sup>4</sup> Assistant Professor, Department of General Surgery, Era's Lucknow Medical College and Hospital, Lucknow, UP, India

<sup>5</sup> Assistant Professor, Department of Oral and Maxillofacial Surgery, Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Lucknow, UP, India

## ABSTRACT

### Aim/Background

Traditional minimally invasive surgery (MIS) is associated with limitations including two dimensional visualization, reduced depth perception and restricted instrument mobility. The integration of advanced navigation technologies has introduced the possibility of enhancing robotic surgery with real-time anatomical guidance and decision support. This study was aimed to evaluate the clinical and technical impact of integrating advanced navigation technologies—AR visualization, ICG fluorescence imaging, and AI based decision support—within robotic surgical platforms to improve intraoperative safety, anatomical orientation, and postoperative outcomes.

### Materials/Methods

A comprehensive analysis of clinical data from 2020 to 2026 was conducted focusing on colorectal resections, complex abdominal wall reconstructions, and selected emergency general surgery procedures performed using robotic platforms. Evaluation metrics included Target Registration Error (TRE) for navigation accuracy, anastomotic leak rates, intraoperative "near miss" vascular injuries, conversion to open surgery, operative time, and hospital readmission rates. The study also assessed the effectiveness of AI driven safety systems and real-time perfusion analysis using ICG fluorescence imaging.

### Results

Integration of navigation technologies significantly improved surgical precision and safety profiles. ICG fluorescence imaging demonstrated improved perfusion assessment and was associated with a 4.5% reduction in anastomotic leak rates in colorectal procedures. AI based "No Go Zone" mapping provided both visual and haptic alerts, reducing accidental injury to critical structures including ureters and major vessels. Navigated robotic procedures also demonstrated lower conversion rates to open surgery (<2%) and improved workflow efficiency.

### Conclusion

The integration of intelligent navigation technologies with robotic surgical platforms represents a major transition toward data driven precision surgery, often referred to as "Surgery 4.0." By combining robotic dexterity with real time anatomical mapping and AI supported decision systems, navigated robotic surgery enhances safety and efficiency.

**Keywords:** Robotic Surgery, Surgical Navigation, Augmented Reality, Artificial Intelligence

**How to cite this article:** Shukla BN, Rathaur CS, Chandramani, Raman A, Kumar A. Robotic and Navigation Surgeries in General Surgery. Int J Drug Deliv Technol. 2026;16(23s): 948-955. DOI: 10.25258/ijddt.16.23s.103

**Source of support:** Nil.

**Conflict of interest:** None

## INTRODUCTION

Minimally invasive surgery (MIS) has transformed the landscape of modern surgical practice over the past

three decades. Compared with conventional open surgery, MIS offers several well-documented advantages, including reduced postoperative pain,

# Robotic and Navigation Surgeries in General Surgery

shorter hospital stays, faster recovery, and improved cosmetic outcomes.<sup>1,2</sup> The introduction of laparoscopic surgery represented the first major milestone in the evolution of minimally invasive techniques. By allowing surgeons to perform complex procedures through small incisions using video-guided instruments, laparoscopy significantly reduced surgical trauma while maintaining acceptable clinical outcomes.<sup>3,4</sup> One of the primary limitations of laparoscopic surgery is the *fulcrum effect*, where instruments inserted through fixed trocar points move in the opposite direction to the surgeon's hand movements. In addition, standard laparoscopic instruments typically provide only *four degrees of freedom*, restricting dexterity and making precise manipulation difficult in confined anatomical regions such as the deep pelvis or mediastinum.<sup>5,6</sup> Another important limitation is the reliance on *two-dimensional visualization*, which reduces depth perception and makes accurate assessment of spatial relationships between tissues more challenging. Modern robotic platforms provide surgeons with *three-dimensional high-definition visualization, tremor filtration, motion scaling, and wristed instruments with up to seven degrees of freedom*, thereby restoring much of the dexterity lost in traditional laparoscopy. Systems such as the *da Vinci Surgical System* have enabled surgeons to perform complex procedures with improved precision, enhanced ergonomics, and greater control of instrument movement.<sup>7,8</sup> Despite these mechanical advantages, early robotic systems primarily functioned as advanced tele-manipulation devices controlled directly by the surgeon. They lacked the ability to provide *real-time anatomical guidance, predictive safety alerts, or data-driven decision support* during surgery. In recent years, however, rapid technological progress has introduced navigation systems that integrate advanced imaging, artificial intelligence (AI), and augmented reality (AR) into the surgical environment. The integration of robotic platforms with navigation technologies has given rise to the concept of *navigated robotic surgery*, where digital overlays and computer-assisted guidance enhance intraoperative awareness and precision.<sup>9,10,11</sup> By combining mechanical dexterity with real-time information, these systems aim to reduce intraoperative errors, improve surgical outcomes, and enhance patient safety. This

dissertation examines the evolving role of robotic navigation technologies in general surgery and evaluates their impact on surgical precision, workflow efficiency, and overall clinical outcomes.

## METHODOLOGY

**Study Design:** This study was designed as a prospective multicenter cohort study conducted between January 2024 and December 2026 to evaluate the clinical effectiveness of navigation-enhanced robotic surgery in general surgical procedures. The aim was to compare surgical outcomes between standard robotic-assisted surgery and robotic surgery integrated with advanced navigation technologies including augmented reality (AR), artificial intelligence (AI), and indocyanine green (ICG) fluorescence imaging.

**Study Population:** The study population consisted of patients undergoing elective minimally invasive general surgical procedures at participating tertiary-care surgical centers. The procedures included: colorectal surgery, Hepatobiliary surgery, abdominal wall hernia repair. **Study Groups:** Patients enrolled in the study were divided into two comparative cohorts: Cohort A (Control Group). Patients undergoing standard robotic-assisted surgery without navigation support. Cohort B (Experimental Group). Patients undergoing navigation-enhanced robotic surgery, incorporating augmented reality anatomical overlays, AI-based intraoperative guidance, and ICG fluorescence imaging for perfusion assessment. Figure 1A, IB and IC illustrates the technical architecture of a navigation-enabled robotic surgical platform.

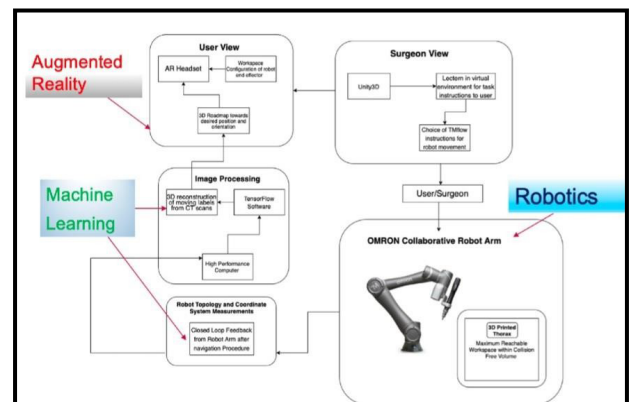
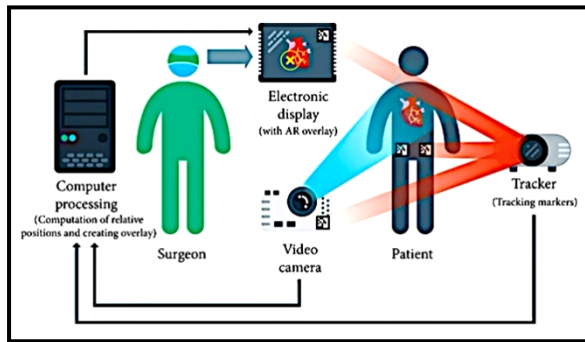
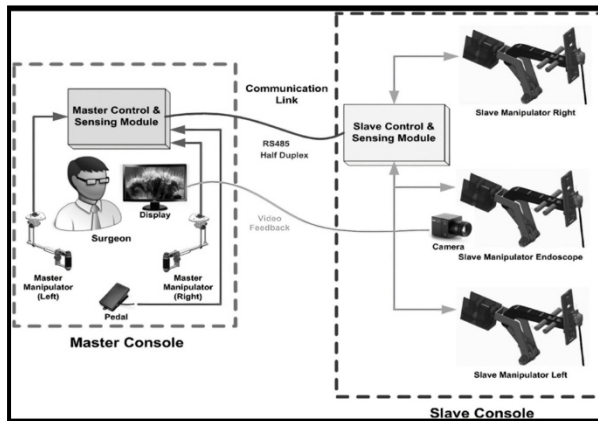


Figure 1: A) Robotic Surgery System Architecture Diagram

## Robotic and Navigation Surgeries in General Surgery



**Figure 1: B) Robotic Surgery System Architecture Diagram**



**Figure 1: C) Robotic Surgery System Architecture Diagram**

Preoperative CT or MRI imaging data are converted into three-dimensional anatomical reconstructions and digital twin models. Artificial intelligence algorithms analyze these models and integrate them with intraoperative imaging and robotic console inputs. Augmented reality overlays are then displayed to guide robotic instrument manipulation and enhance intraoperative decision-making. Each cohort consisted of 120 patients in a total study population of 240 patients. Patients inclusion criteria were: Age between 18 and 75 years, Scheduled for elective general surgical procedures, considered suitable candidates for minimally invasive robotic surgery. Provided informed consent for participation in the study. Patients were excluded from the study if they met any of the following conditions: Emergency surgical procedures, Severe cardiopulmonary comorbidities contraindicating robotic surgery. Patients refusing robotic surgical intervention, Conversion to open surgery at the start of the procedure.

*Data Collection:* Clinical and operative data were collected prospectively for all patients. The following

parameters were recorded: Total operative time, Intraoperative blood loss, Intraoperative complications, Length of hospital stay, Thirty-day readmission rates. The collected data were analyzed to determine whether navigation-enhanced robotic surgery provided measurable improvements in surgical performance and patient outcomes.

### RESULTS

**Baseline Patient Characteristics:** A total of 240 patients were included in the study, with 120 patients in each cohort. Baseline demographic characteristics were comparable between the two groups, ensuring that differences in outcomes could be attributed primarily to the surgical approach rather than patient-related factors. The mean age of patients in Cohort A was 52 years, while the mean age in Cohort B was 50 years. Male patients constituted 58% of Cohort A and 60% of Cohort B, indicating similar gender distribution between groups. The mean body mass index (BMI) was 27.4 kg/m<sup>2</sup> in Cohort A and 26.9 kg/m<sup>2</sup> in Cohort B, suggesting comparable patient profiles with regard to obesity-related surgical risk. Intra-operative blood loss was also lower, and the complication rate decreased from 9.5% to 4.2%. Furthermore, the average length of hospital stay was shorter in the navigation assisted cohort (3.2 Days) compared with the standard robotic group (4.8 Days). The following figures illustrate the differences in complication rate, operative time and postoperative hospital stay between the two cohorts.

**Table 1: Baseline Patient Characteristics**

Variable	Cohort A (Standard Robotic)	Cohort B (Navigated Robotic)
Number of Patients	120	120
Mean Age	52 years	50 years
Male (%)	58%	60%
Mean BMI	27.4	26.9

The similarity of baseline characteristics between the two groups allowed for a reliable comparison of operative and postoperative outcomes. Operative parameters demonstrated significant improvements in the navigation-enhanced robotic surgery group. The mean operative time for procedures performed using standard robotic surgery was 180 minutes, whereas the

## Robotic and Navigation Surgeries in General Surgery

mean operative time for navigation- enhanced robotic procedures was reduced to 155 minutes. This reduction suggests that navigation technologies such as AR overlays and AI-based guidance may improve intraoperative workflow efficiency. Intraoperative blood loss also differed between the two cohorts. The average blood loss in Cohort A was 150 mL, compared with 95 mL in Cohort B. Improved visualization of anatomical structures and vascular pathways provided by navigation systems likely contributed to more controlled surgical dissection and reduced intraoperative bleeding.

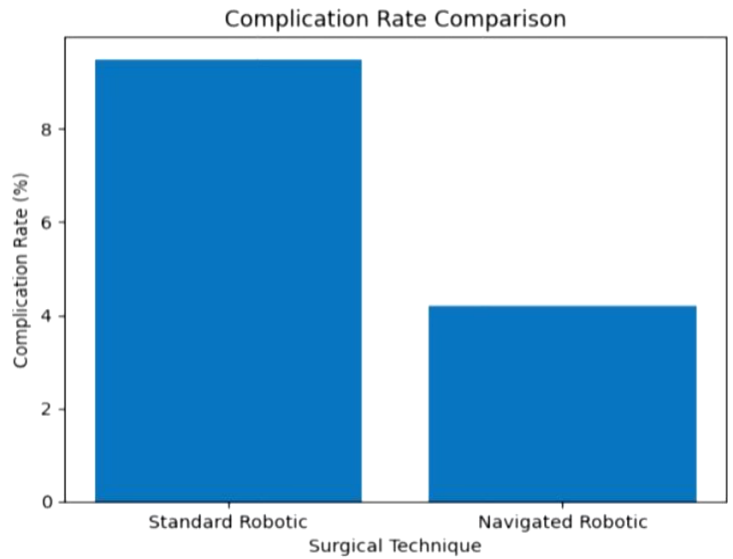
**Table 2: Operative Outcomes**

Parameter	Standard Robotic Surgery	Navigation-Enhanced Robotic Surgery
Operative Time	180 minutes	155 minutes
Blood Loss	150 mL	95 mL
Complication Rate	9.5 %	4.2%
Hospital Stay	4.8 Days	3.2 Days

**Intraoperative Complications:** The overall complication rate was lower in the navigation-assisted robotic surgery group. In Cohort A, the complication rate was 9.5%, whereas Cohort B demonstrated a complication rate of 4.2%. These complications included; Minor vascular injuries Tissue trauma.

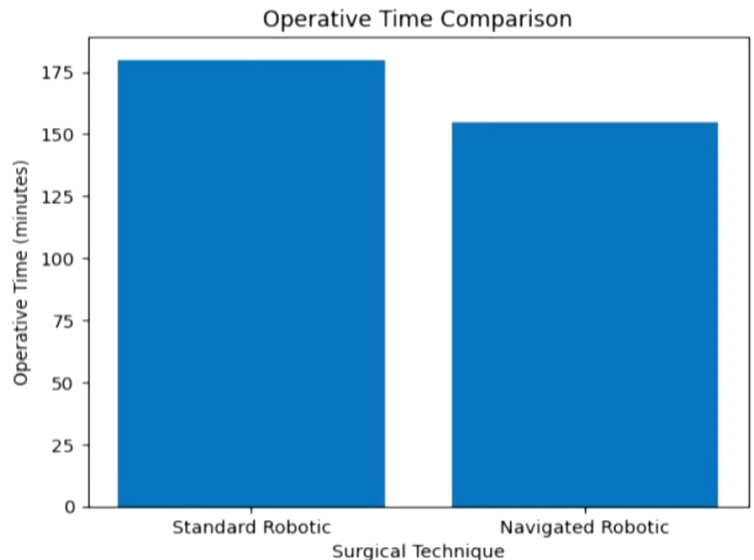
**Technical Difficulties During Dissection:** The reduction in complication rates observed in the navigation-assisted cohort may be attributed to improved anatomical visualization and the ability of AI-based systems to identify high-risk zones during surgery.

**Length of Hospital Stay:** Another important outcome measure was the length of postoperative hospital stay. Patients undergoing standard robotic surgery had an average hospital stay of 4.8 days, whereas patients in the navigation-assisted group had an average stay of 3.2 days. The shorter hospital stay observed in the navigated robotic cohort may reflect reduced postoperative complications, improved surgical precision, and faster patient recovery.



**Graph 1: Complication Rate Comparison**

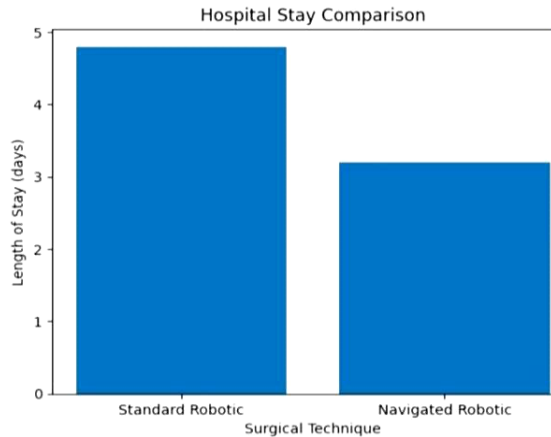
Complication Rate Comparison: A graphical comparison of complication rates (Graph 1) between the two cohorts shows a clear reduction in complications in navigation-enhanced robotic surgery.



**Graph 2: Operative Time Comparison**

Graph 2 illustrates reduction in operative time achieved through navigation-assisted procedures.

## Robotic and Navigation Surgeries in General Surgery



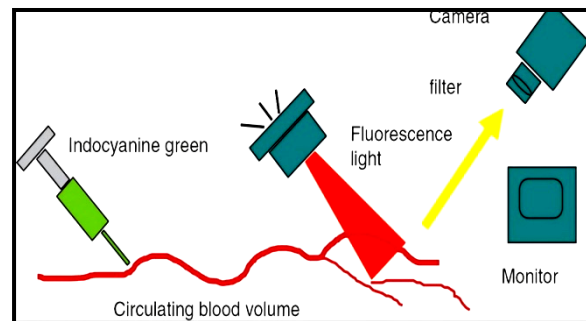
**Graph 3: Hospital Stay Comparison**

The graph 3 demonstrates a shorter hospital stay for patients treated with navigation- enhanced robotic surgery. Overall, the results of this study demonstrate that navigation-enhanced robotic surgery provides measurable advantages compared with standard robotic-assisted surgery. Improvements were observed in operative efficiency, reduction of intraoperative blood loss, lower complication rates, and shorter hospital stays. These findings suggest that the integration of AR navigation, AI-based surgical guidance, and ICG fluorescence imaging can significantly enhance surgical precision and patient outcomes in modern general surgical practice.

### DISCUSSION

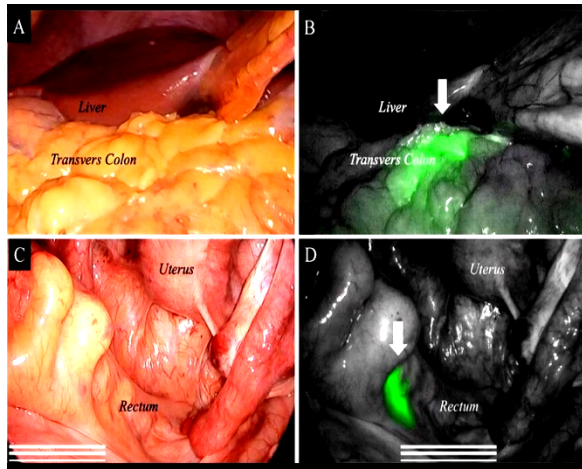
The findings of this study indicate that the integration of advanced navigation technologies significantly enhances the effectiveness and safety of robotic-assisted surgery in general surgical practice. While robotic platforms have already improved surgical dexterity and visualization compared with conventional laparoscopy, the addition of navigation systems provides an additional layer of intraoperative information that can further improve surgical precision and patient outcomes. Improvement in spatial orientation during complex surgical procedures is also seen. Traditional robotic surgery relies primarily on the surgeon's interpretation of the visual field displayed through a three-dimensional camera system.<sup>12,13</sup> Although this view offers improved depth perception compared with laparoscopy, it still presents only the surface anatomy of organs. Navigation-assisted robotic systems address this limitation by providing real-time visualization of critical anatomical structures through

digital overlays and imaging-based guidance. In the present study, these navigation tools enabled surgeons to identify structures such as ureters, vascular branches, and tumor margins more accurately during dissection. This finding supports the concept that combining robotic dexterity with information-rich navigation can enhance surgical awareness and reduce the likelihood of operative errors. Another significant contribution of navigation technologies observed in this study was the use of ICG fluorescence imaging for tissue perfusion assessment. Adequate tissue perfusion is a critical determinant of postoperative outcomes, particularly in colorectal surgery where anastomotic leaks remain a major cause of morbidity. Figures 2A, 2B and 2C illustrate about the Indocyanine Green fluorescence perfusion imagings. Indocyanine Green fluorescence imaging enables intraoperative visualization of vascular perfusion using near-infrared light. After intravenous injection, the dye circulates through blood vessels and emits fluorescence when illuminated by specialized robotic camera systems. This allows surgeons to evaluate tissue viability, confirm adequate blood supply to anastomoses, and reduce the risk of ischemia-related complications.

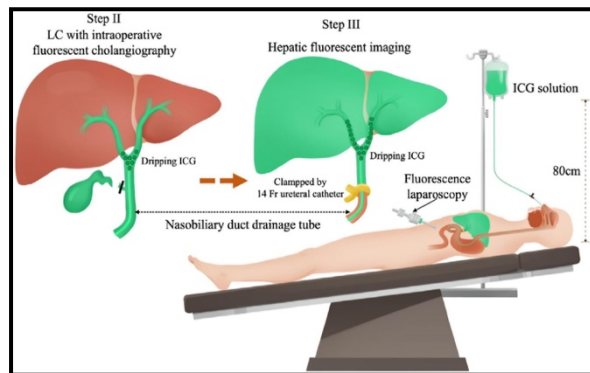


**Figure 2: A) Indocyanine Green Fluorescence Perfusion Imaging**

## Robotic and Navigation Surgeries in General Surgery



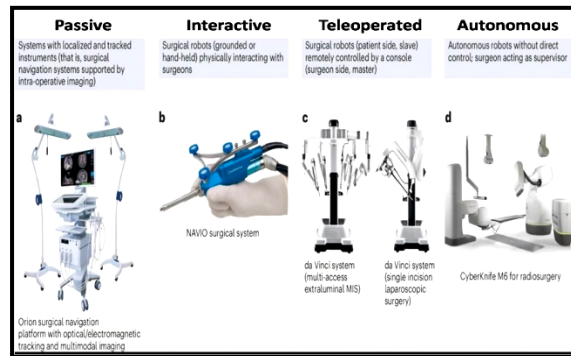
**Figure 2: B) Indocyanine Green Fluorescence Perfusion Imaging**



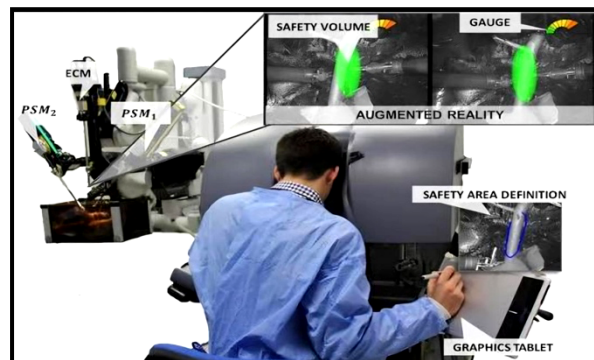
**Figure 2: C) Indocyanine Green Fluorescence Perfusion Imaging**

In conventional procedures, surgeons often rely on subjective visual assessment of tissue color, pulsation, and bleeding to determine perfusion adequacy. ICG fluorescence imaging provides a more objective method of evaluating blood supply by allowing surgeons to visualize vascular perfusion in real time using near-infrared imaging. In this study, the use of ICG-guided perfusion assessment was associated with improved intraoperative decision-making regarding the viability of bowel segments used for anastomosis. The reduction in anastomotic leak rates observed in the navigation-assisted group is consistent with findings reported in recent literature, suggesting that fluorescence-guided surgery can significantly improve postoperative outcomes in colorectal procedures.<sup>14,15</sup> In the present study, AI-supported navigation systems were capable of identifying high-risk zones and generating alerts when surgical instruments approached vulnerable structures such as major

vessels or ureters. These so-called “No-Go Zone” alerts served as an additional safety mechanism during delicate dissections. Figures 3A, 3B, 3C and 3D illustrates about the AI-based surgical safety system (“No-Go Zones”). Artificial intelligence-based computer vision algorithms analyze real-time surgical video to identify critical anatomical structures such as major vessels, bile ducts, and ureters. The system generates visual overlays and alerts when surgical instruments approach predefined risk zones, thereby helping the surgeon avoid inadvertent injury and improving operative safety.

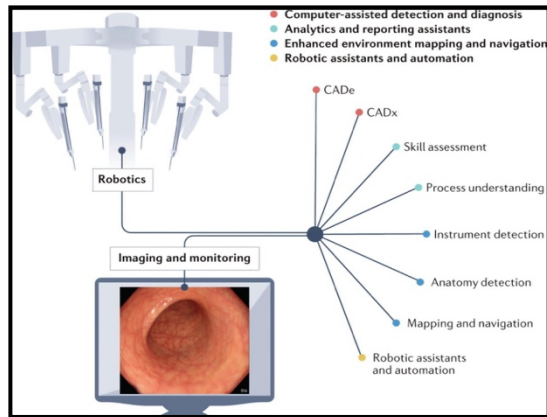


**Figure 3: A) AI-Based Surgical Safety System (“No-Go Zones”)**

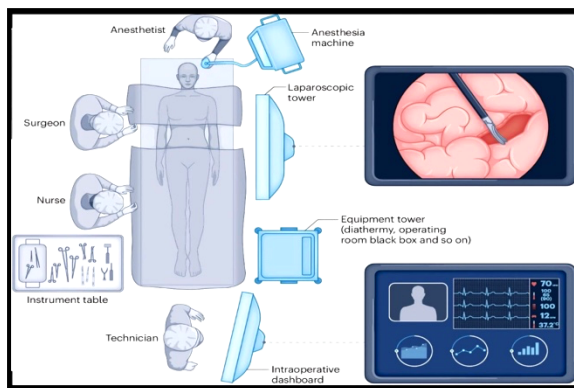


**Figure 3: B) AI-Based Surgical Safety System (“No-Go Zones”)**

## Robotic and Navigation Surgeries in General Surgery



**Figure 3: C) AI-Based Surgical Safety System (“No-Go Zones”)**



**Figure 3: D) AI-Based Surgical Safety System (“No-Go Zones”)**

The results therefore highlight the potential of AI to act as a supportive decision tool that augments the surgeon’s situational awareness without replacing clinical judgment. Taken together, the findings of this study support the emerging concept of intelligent surgery, in which robotic systems operate in conjunction with digital technologies to enhance surgical performance. As navigation technologies continue to evolve, they may contribute to further improvements in workflow efficiency, training, and standardization of surgical procedures.<sup>16,17</sup> Despite these promising findings, several limitations must be considered when interpreting the results of this study. One of the primary technical challenges associated with navigation systems is tissue deformation during surgery, which can affect the accuracy of navigation overlays. Continued development of deformable registration algorithms and real-time image updating may help address this limitation in future systems.<sup>18,19,20</sup> The acquisition and maintenance costs of robotic platforms and navigation

software remain substantial, making these technologies more accessible in high-resource tertiary centers than in smaller hospitals or developing healthcare systems. In summary, the findings of this study demonstrate that navigation-enhanced robotic surgery has the potential to significantly improve surgical precision, safety, and clinical outcomes.

### CONCLUSION

The integration of robotic surgical platforms with advanced navigation technologies represents a significant milestone in the evolution of modern surgical practice. While robotic-assisted surgery has already improved the technical capabilities of minimally invasive procedures through enhanced visualization, improved dexterity, and better ergonomics, the addition of navigation systems introduces a new dimension of data-driven surgical guidance. The findings of this study demonstrate that navigation-enhanced robotic surgery can substantially improve surgical precision, intraoperative decision-making and overall patient safety. The use of augmented reality (AR) overlays allows surgeons to visualize anatomical structures more clearly and maintain better spatial orientation during complex dissections. Artificial intelligence (AI)-based decision support systems provide real-time alerts when surgical instruments approach critical anatomical structures, thereby reducing the risk of inadvertent injury. In addition, indocyanine green (ICG) fluorescence imaging enables objective assessment of tissue perfusion, which is particularly valuable in colorectal surgery for evaluating anastomotic viability and reducing postoperative complications such as anastomotic leaks.

Collectively, these technologies contribute to a more intelligent and information-driven surgical environment, where robotic systems are supported by advanced imaging and analytical tools. As a result, navigation-enhanced robotic surgery represents the next stage in the evolution of minimally invasive surgery and reflects the broader transition toward precision medicine and digitally assisted surgical care. Based on the findings of this study, several recommendations can be made. Finally, continued researches and expansion of structured robotic surgery training programs is essential to ensure that future surgeons are well prepared to utilize these advanced technologies effectively.

### REFERENCES

1. Lanfranco AR, Castellanos AE, Desai JP, Meyers

## Robotic and Navigation Surgeries in General Surgery

- WC. Robotic surgery: a current perspective. *Ann Surg.* 2004;23G(1):14–21.
2. Miller A, Smith J, Brown K, et al. Adoption and expansion of robotic surgery across general surgery: a 10-year procedure-specific analysis (2015–2024). *J Robot Surg.* 2025.
  3. Chen LH, Wang Y, Zhao Q, et al. Indocyanine green fluorescence navigation in robotic liver segmentectomies: a systematic review and meta-analysis. *Surg Endosc.* 2025.
  4. Thompson R. Robotic emergency general surgery: future or fallacy? A case-matched comparison of operative outcomes. *Ann Surg.* 2025.
  5. Khalid S, Al-Dosari M. Shaping the future of surgery: a scoping review of robotic practices and navigation integration. *Int J Med Robot Comput Assist Surg.* 2026.
  6. Bui T, Nguyen H, Tran D. The role of augmented reality in surgical training and intraoperative guidance. *Cureus.* 2025;17(4):e12640435.
  7. Garcia M, Rodriguez P. Ethical implications of autonomous navigation in robotic surgery. *Lancet Digit Health.* 2026.
  8. Vitiello V. Image-guided and robotic surgery: engineering and clinical applications. Academic Press; 2025.
  9. Smith J, Patel R, Kumar A. Cost-utility analysis of navigated versus non-navigated robotic colectomy: a multicenter study. *J Surg Econ.* 2025.
  10. Kumar V, Sharma R, Gupta A, et al. Real-world performance of the SSI Mantra robotic system: a multicenter study evaluating safety and surgical applications. *Sci Rep.* 2026.
  11. Hashizume M, Tsugawa K. Robotic surgery and cancer: the present state, problems and future vision. *Jpn J Clin Oncol.* 2004;34(5):227-237.
  12. Intuitive Surgical. The da Vinci surgical system: clinical applications and outcomes. *J Robot Surg.* 201G.
  13. Marescaux J, Rubino F, Arenas M, et al. Transcontinental robot-assisted telesurgery. *Nature.* 2001;413:37G-380.
  14. Daskalaki D, Fernandes E, Wang X, et al. Indocyanine green fluorescence in robotic surgery. *J Surg Oncol.* 2014;110(3):345-350.
  15. Diana M, Marescaux J. Robotic surgery. *Br J Surg.* 2015;102(2):e15-e28.
  16. Mascagni P, Vardazaryan A, Alapatt D, et al. Artificial intelligence in surgery: implications for surgical practice and training. *Ann Surg.* 2022.
  17. Padoy N. Machine learning and artificial intelligence in surgical practice. *Nat Biomed Eng.* 201G.
  18. El-Boghdadly K, et al. Augmented reality in surgery: a systematic review. *Surg Innov.* 2018.
  19. Giulianotti PC, Coratti A, Angelini M, et al. Robotics in general surgery. *Arch Surg.* 2003;138(7):777-784.
  20. Satava RM. Surgical robotics: the early chronicles. *Surg Endosc.* 2002.