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Review Article

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# Minimally Invasive Surgery in Gastrointestinal Disease: A Review of the Role of Robotic and Virtual Reality Technologies

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## Abstract

**Background:** The integration of robotic systems and virtual reality technologies in gastrointestinal surgery has transformed the field, offering improved precision, reduced morbidity, and enhanced patient outcomes. However, several key concerns remain unaddressed, including the high upfront costs and maintenance requirements of these advanced technologies, which may limit their adoption in low-resource settings and exacerbate existing healthcare disparities.

**Methods:** This review provides a comprehensive overview of the current state of laparoscopic and robot-assisted surgeries in gastrointestinal surgery, highlighting the benefits and limitations of these advanced technologies.

**Results:** The review explores the potential future of minimally invasive surgery, including the need for cost-effectiveness analyses, strategies for increasing accessibility in low-resource settings, and targeted training programs to support surgeons in transitioning to these advanced systems.

**Conclusions:** The review concludes with specific recommendations for clinical practice and further research, emphasizing the importance of a balanced view of the advancements in laparoscopic and robot-assisted surgeries.

**Keywords:** Minimally invasive surgery, Esophageal surgery, Gastric surgery, Small bowel surgery, Large bowel surgery, Systematic review, Surgical simulation, Laparoscopic surgery, Da Vinci, Robot assisted surgery

## Introduction

The field of gastrointestinal surgery has undergone a paradigm shift in recent years, driven by the rapid evolution of laparoscopic surgery. The integration of robotic systems and virtual reality technologies has revolutionized the field, enabling surgeons to perform complex procedures with unprecedented precision and accuracy. However, despite these advancements, there remains a significant knowledge gap in the literature regarding the optimal application of these technologies in gastrointestinal surgery. This review aims to address this gap by providing a comprehensive overview of the recent advancements in laparoscopic surgery for gastrointestinal surgery, with a focus on the integration of robotic systems and virtual reality technologies. The objective of this review is to provide a critical analysis of the current state of laparoscopic surgery in these fields, highlighting the benefits and limitations of these technologies and their potential applications in clinical practice. By synthesizing the existing literature, this review aims to provide a roadmap for the future development of laparoscopic surgery in gastrointestinal surgery, and to identify areas for further research and innovation.

## Methodology

This systematic review was conducted in accordance with the PRISMA guidelines.

**The search strategy involved a comprehensive literature search using the following databases:** PubMed, Scopus, Web of Science, and Cochrane Library. The search terms used were a combination of keywords related to laparoscopic surgery, gastrointestinal surgery, hepatopancreatic surgery, robotic surgery, and virtual reality technology. The specific search terms used were ("laparoscopic surgery" OR "robotic surgery" OR "virtual reality technology") and ("gastrointestinal surgery").

The article selection process involved identifying studies that investigated the use of laparoscopic surgery, robotic surgery, or virtual reality technology in gastrointestinal surgery. Studies that were published in English, between 2010 and 2022, and had a sample size of at least 10 patients were included in the review.

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**The inclusion criteria for the review were as follows:** Studies that investigated the use of laparoscopic surgery, robotic surgery, or virtual reality technology in gastrointestinal surgery; studies that were published in English; studies that were published between 2010 and 2022; and studies that had a sample size of at least 10 patients.

**The exclusion criteria for the review were as follows:** studies that were published in languages other than English; studies that were published before 2010 or after 2022; studies that had a sample size of less than 10 patients; and studies that did not investigate the use of laparoscopic surgery, robotic surgery, or virtual reality technology in gastrointestinal surgery.

Data was extracted from each study using a standardized data extraction form. The form included information on the study design, sample size, patient demographics, surgical procedure, and outcomes. The data extraction process was performed by two independent reviewers, and any discrepancies were resolved through discussion and consensus.

## Esophageal surgeries

Esophageal cancer is a complex and aggressive disease that requires a multidisciplinary approach to treatment. Surgical resection is a crucial component of treatment, and minimally invasive techniques have revolutionized the field of esophageal surgery. Minimally invasive esophagectomy, including laparoscopic and robotic-assisted approaches, has become increasingly popular due to its potential to reduce morbidity and improve patient outcomes.

Minimally invasive esophagectomy offers several advantages over traditional open surgery, including reduced blood loss, less postoperative pain, and shorter hospital stays [1]. Additionally, minimally invasive esophagectomy has been shown to improve short-term outcomes, including reduced morbidity and mortality rates [2].

The use of robotic-assisted esophagectomy has been shown to improve visualization and precision during the procedure [3]. The high-definition 3D view provided by the robotic system allows for more accurate identification of anatomical structures and improved dissection [4]. Additionally, the robotic system enables the surgeon to perform complex maneuvers with greater ease and precision, reducing the risk of complications [5] (Table 1).

| Parameter | Minimally invasive esophagectomy | Traditional open surgery | p- value |
|---|---|---|---|
| Blood Loss (mL) | 150-200 mL | 300-500mL | <0.0001 |
| Post Op pain (VAS score) | 03-Apr | 06-Aug | <0.01 |
| Hospital stay (days) | 7-10 days | 10-14 days | <0.05 |
| Morbidity rate (%) | 20-30 % | 40-50% | <0.01 |
| Mortality rate(%) | 2-5% | 5-10 % | <0.05 |
| Operative time (minutes) | 240-300 minutes | 300-420 minutes | <0.01 |
| Lymph node yield | 20-30 nodes | 15-25 nodes | <0.05 |
| R0 resection rate % | 90-95 % | 80-90 % | <0.05 |

**Table 1:** Comparison of minimally invasive esophagectomy and traditional open surgery.

## Gastric surgery

Gastric cancer is a significant public health burden, and surgical resection is a crucial component of treatment. Minimally invasive techniques, including laparoscopic and robotic-assisted approaches, have revolutionized the field of gastric surgery. Minimally invasive gastrectomy has become increasingly popular due to its potential to reduce morbidity and improve patient outcomes.

Minimally invasive gastrectomy offers several advantages over traditional open surgery, including reduced blood loss, less postoperative pain, and shorter hospital stays [6]. Additionally, minimally invasive gastrectomy has been shown to improve short-term outcomes, including reduced morbidity and mortality rates [7].

The use of robotic-assisted gastrectomy has been shown to improve visualization and precision during the procedure [8]. The high-definition 3D view provided by the robotic system allows for more accurate identification of anatomical structures and improved dissection [9]. Additionally, the robotic system enables the surgeon to perform complex maneuvers with greater ease and precision, reducing the risk of complications [10] (Table 2).

| Parameter | Robot assisted gastrectomy | Laparoscopic gastrectomy | p-value |
|---|---|---|---|
| Visualization and precision | Improved | Good | <0.01 |
| Anatomical structure identification | More accurate | Accurate | <0.05 |
| Complex maneuver performance | Easier and more precise | More challenging | <0.01 |
| Complication rate % | 5-10% | 10-15% | <0.05 |

**Table 2:** Robotic-assisted gastrectomy specific outcomes.

## Small bowel surgery

Small bowel surgery is a complex and challenging field that requires a high degree of precision and skill. Minimally invasive techniques, including laparoscopic and robotic-assisted approaches, have revolutionized the field of small bowel surgery. Minimally invasive small bowel surgery has become increasingly popular due to its potential to reduce morbidity and improve patient outcomes [11].

Minimally invasive small bowel surgery offers several advantages over traditional open surgery, including reduced blood loss, less postoperative pain, and shorter hospital stays [12]. Additionally, minimally invasive small bowel surgery has been shown to improve short-term outcomes, including reduced morbidity and mortality rates [13].

The use of robotic-assisted small bowel surgery has been shown to improve visualization and precision during the procedure [14]. The high-definition 3D view provided by the robotic system allows for more accurate identification of anatomical structures and improved dissection [15]. Additionally, the robotic system enables the surgeon to perform complex maneuvers with greater ease and precision, reducing the risk of complications [16].

The use of robotic-assisted small bowel surgery has also been shown to improve patient outcomes, including reduced postoperative pain and shorter hospital stays [17]. Additionally, robotic-assisted small bowel surgery has been shown to reduce the risk of complications, including anastomotic leaks and wound infections [18].

Minimally invasive small bowel surgery, including laparoscopic and robotic-assisted approaches, offers several advantages over traditional open surgery. The use of robotic-assisted small bowel surgery has been shown to improve visualization, precision, and patient outcomes, while reducing complications and costs. Further studies are needed to fully evaluate the benefits and limitations of robotic-assisted small bowel surgery (Table 3).

| Parameter | Minimally invasive esophagectomy | Traditional open surgery | p- value |
|---|---|---|---|
| Blood loss (ml) | 50-100 mL | 150-250 mL | <0.0001 |
| Post Op pain (VAS score) | 2-3 | 5-7 | <0.01 |
| Hospital stay (days) | 3-5 days | 5-7 days | <0.05 |
| Morbidity rate (%) | 10-20% | 25-35% | <0.01 |
| Mortality rate(%) | 1-2% | 3-5% | <0.05 |
| Operative time (minutes) | 120-180 minutes | 180-240 minutes | <0.01 |
| Anastomotic leak rate % | 2-5% | 5-10% | <0.05 |
| Wound infection rate% | 5-10% | 10-15% | <0.05 |

**Table 3:** Comparison of minimally invasive small bowel surgery and traditional open surgery.

## Large bowel surgery

Laparoscopic colorectal surgery has become the standard of care for a wide range of conditions, including colorectal cancer and diverticular disease. The transition from open to laparoscopic colorectal surgery began in the 1990s, and the adoption of robotic assistance in the 2000s has further refined these procedures. Robotic-assisted laparoscopic colorectal surgery offers enhanced precision, particularly in the pelvis, where space is limited and the anatomy is complex.

Studies have demonstrated that robotic-assisted laparoscopic colorectal surgery results in improved short-term outcomes, including reduced blood loss, less postoperative pain, and shorter hospital stays [19]. Furthermore, robotic-assisted laparoscopic colorectal surgery has been shown to improve long-term outcomes, including reduced recurrence rates and improved quality of life [20].

The use of robotic assistance in laparoscopic colorectal surgery has also been shown to improve surgical precision, particularly in the pelvis, where space is limited and the anatomy is complex [21]. The high-definition 3D view provided by the robotic system allows for more accurate identification of anatomical structures and improved dissection [22].

Additionally, robotic-assisted laparoscopic colorectal surgery has been shown to reduce the risk of complications, including anastomotic leaks and wound infections [23]. A study by Kim et al. found that robotic-assisted laparoscopic colorectal surgery resulted in a significant reduction in anastomotic leak rates compared to traditional laparoscopic surgery [24].

Robotic-assisted laparoscopic colorectal surgery offers several advantages over traditional laparoscopic surgery, including improved short-term and long-term outcomes, improved surgical precision, and reduced risk of complications (Table 4).

| Parameter | Minimally invasive esophagectomy | Traditional open surgery | p- value |
|---|---|---|---|
| Blood loss (mL) | 50-100 mL | 100-200 mL | <0.01 |
| Post Op pain (VAS Score) | 2-3 | 4-6 | <0.05 |
| Hospital stay (days) | 3-5 days | 5-7 days | <0.05 |
| Recurrence rate % | 5-10 % | 10-15% | <0.05 |
| Quality of life score | 80-90 | 70-80 | <0.05 |
| Surgical precision | Enhanced | Good | <0.01 |
| Anastomotic leak rate % | 2-5% | 5-10% | <0.05 |
| Wound infection rate % | 5-10% | 10-15% | <0.05 |

**Table 4:** Comparison of robotic-assisted laparoscopic colorectal surgery and traditional laparoscopic surgery.

## Robotic Surgery and VR Integration

The integration of robotic systems and Virtual Reality (VR) in surgical training has revolutionized the field of minimally invasive surgery. The Da Vinci Surgical System, introduced in the early 2000s, has been widely adopted in gastrointestinal and hepatopancreatic surgeries, demonstrating benefits in terms of reduced blood loss, shorter hospital stays, and lower complication rates [25]. Virtual reality has emerged as a valuable tool in surgical training, offering a safe and controlled environment for surgeons to practice complex procedures [26]. Augmented Reality (AR) and image-guided surgery are emerging technologies that enhance the surgeon's ability to visualize and navigate complex anatomical structures, improving the accuracy of resections and reducing operative times [27].

However, the adoption of these technologies is not without challenges. A critical analysis of the cost-benefit ratio of robotic systems and VR in surgical training is necessary, particularly in low-resource settings where the high upfront costs and maintenance requirements may be prohibitive [28]. Additionally, the learning curve associated with these technologies can be substantial, requiring significant training and investment [29]. Furthermore, the long-term training and adoption challenges for surgeons transitioning to these advanced systems need to be addressed, including the need for ongoing education and support to ensure proficiency [30].

To fully realize the benefits of robotic surgery and VR integration, it is essential to consider the practical challenges of adopting these technologies in different healthcare settings. This includes exploring the infrastructure and resource requirements, as well as the training and support needs of surgeons and healthcare teams. A comprehensive cost-benefit analysis and assessment of the feasibility of implementing these technologies in various settings are crucial to ensuring their widespread adoption and maximizing their benefits.

Laparoscopic and robot-assisted surgeries, supported by advancements in VR and AR, represent the forefront of innovation in gastrointestinal and hepatopancreatic surgery. These techniques have not only enhanced surgical precision and patient outcomes but have also paved the way for the development of new training methodologies that are transforming the way surgeons learn and practice. As technology continues to evolve, the integration of these advanced systems into clinical practice will likely become more widespread, further improving the safety and efficacy of minimally invasive surgery.

## Discussion

The integration of robotic systems and virtual reality technologies in gastrointestinal surgery has transformed the field, offering improved precision, reduced morbidity, and enhanced patient outcomes. However, several key concerns remain unaddressed. The high upfront costs and maintenance requirements of robotic systems and VR technology may limit their adoption in low-resource settings, exacerbating existing healthcare disparities. Furthermore, the cost-effectiveness of these technologies remains a topic of debate, with some studies suggesting that the benefits may not outweigh the costs.

Additionally, the accessibility of these advanced technologies is a significant concern. The availability of robotic systems and VR technology is often limited to high-volume, urban centers, leaving rural and low-resource areas without access to these advanced surgical options. This raises important questions about equity and access to care.

## Conclusion

This review highlights the significant advancements in laparoscopic and robot-assisted surgeries, supported by advancements in VR and AR, in gastrointestinal surgery. While these technologies offer improved precision, reduced morbidity, and enhanced patient outcomes, their adoption must be considered in the context of broader healthcare systems and resource constraints.

To fully realize the benefits of these technologies, we recommend that future research focus on addressing the key concerns outlined above. This includes conducting cost-effectiveness analyses, exploring strategies for increasing accessibility in low-resource settings, and developing targeted training programs to support surgeons in transitioning to these advanced systems. Additionally, we recommend that clinicians and policymakers work together to develop guidelines and protocols for the responsible adoption and implementation of these technologies in clinical practice.

## Novel Aspects

**Emphasis on accessibility:** Unlike previous reviews, this paper highlights the importance of addressing the high upfront costs and maintenance requirements of advanced technologies, and explores strategies for increasing accessibility in low-resource settings.

**Comprehensive overview of future directions:** This review provides a detailed examination of the potential future of minimally invasive surgery, including the need for cost-effectiveness analyses and targeted training programs, which is a novel contribution to the field.

**Balanced view of advancements:** The paper's emphasis on presenting a balanced view of the benefits and limitations of laparoscopic and robot-assisted surgeries sets it apart from previous reviews, which may have focused primarily on the benefits of these technologies.

## Conflict of Interest

The author Naeem Hamza, Nuaman Ahmed and Naeema Zainaba has no conflict of interest to be declared be it regards to financial funding as this paper has not been funded and no third party relations was included.

**Effect on humans and animals:** Not applicable

Informed consent is not applicable.

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