



*MAR Oncology and Hematology (2026) 6:3*  
*Research Article*

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**Recent Advances in Surgical Techniques for Upper Gastrointestinal Malignancies: A Comprehensive Review of Robotic and Open Approaches for Pancreatic and Gastric Resections**

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Received: 20 March 2026

Published: 01 April 2026

DOI: <https://doi.org/10.5281/zenodo.19355689>

**Abstract**

**Background:** Surgical management of upper gastrointestinal (GI) cancers has undergone significant evolution over the past few decades, transitioning from traditional open procedures to minimally invasive and robotic-assisted techniques. Advances in robotic technology have introduced improved dexterity, three-dimensional visualization, tremor filtration, and enhanced ergonomics, particularly beneficial for technically demanding pancreatic and gastric resections. However, the clinical value of these innovations must be assessed in terms of surgical effectiveness, oncologic adequacy, institutional experience, and cost implications.

**Objective:** This review aims to summarize and critically evaluate advancements in surgical techniques for upper gastrointestinal cancers, focusing on robotic and open approaches for pancreatic and gastric resections, with emphasis on technological evolution, operative feasibility, learning curves, institutional experience, and economic considerations.

**Methods:** A narrative review of the literature was performed using key studies published between 2018 and 2021. Peer-reviewed articles addressing the historical development of pancreatic and gastric surgery, technological innovations in robotic platforms, institutional learning curves, and cost-effectiveness were analyzed. Evidence from high-impact surgical and oncologic journals was synthesized to provide a comprehensive overview of current surgical practices.

**Results:** Robotic surgery has demonstrated progressive refinement in upper GI oncology with improved precision and reproducibility in pancreatic and gastric resections. Technological innovations facilitate enhanced lymph node dissection and improved access to anatomically complex regions. Studies report a substantial learning curve for robotic pancreaticoduodenectomy, with optimal outcomes typically achieved after 30–40 procedures in experienced institutions. Comparative analyses suggest that robotic gastrectomy is associated with reduced blood loss and shorter hospital stay compared with open surgery. However, economic evaluations demonstrate higher initial procedural costs.

**Conclusion:** Robotic surgical methods represent a major advancement in the management of upper gastrointestinal malignancies. When performed in experienced centers, robotic surgery offers safe and effective alternatives to open procedures for pancreatic and gastric cancer resections. Continued technological refinement, structured training programs, and long-term oncologic outcome data are essential to optimize patient selection and ensure sustainable adoption of robotic surgery.

**Keywords:** Robotic surgery, Upper gastrointestinal cancer, Gastric cancer surgery, Pancreatic surgery, Minimally invasive surgery, Robotic gastrectomy, Robotic pancreaticoduodenectomy.

## Introduction

Upper gastrointestinal malignancies, including gastric cancer and pancreatic cancer, remain among the leading causes of cancer-related mortality worldwide. According to global cancer statistics, gastric cancer accounts for more than 1 million new cases annually, while pancreatic cancer has a five-year survival rate of less than 10% in many regions due to late diagnosis and aggressive tumor biology(1).

Surgical resection remains the cornerstone of curative treatment for these malignancies. Historically, open surgery has been the standard approach for complex procedures such as gastrectomy and pancreaticoduodenectomy. However, the introduction of minimally invasive surgical techniques has transformed the operative landscape over the past two decades(2).

Robotic surgery represents an advanced extension of minimally invasive surgery. Robotic platforms provide surgeons with enhanced three-dimensional visualization, improved instrument articulation with seven degrees of freedom, and tremor filtration, allowing for precise dissection in anatomically challenging areas. These technological features are particularly beneficial for procedures involving the pancreas and stomach, where intricate vascular structures and lymphatic networks must be carefully preserved or resected(3).

The evolution of robotic surgical systems has contributed to increasing adoption in surgical oncology. Giulianotti and colleagues reported that robotic surgery enables improved precision and reproducibility in complex gastrointestinal oncologic procedures while maintaining oncologic safety (4).

Despite these advantages, concerns remain regarding learning curves, cost implications, and long-term oncologic outcomes compared with traditional open approaches. Therefore, comprehensive evaluation of robotic surgical advancements is necessary to determine their appropriate role in upper GI cancer management.

## Evolution of Surgical Techniques in Upper Gastrointestinal Oncology

The development of pancreatic and gastric cancer surgery has progressed through several technological stages. Traditional open surgical approaches were initially established as the gold standard due to their reliability and ability to achieve radical tumor resection(5).

In pancreatic surgery, the pancreaticoduodenectomy (Whipple procedure) was historically associated with high morbidity and mortality rates. Over time, improvements in surgical technique, anesthesia, and perioperative care significantly reduced mortality rates from over 20% in early series to less than 5% in high-volume centers today(6).

Similarly, gastric cancer surgery evolved from limited resections to standardized procedures incorporating D1 and D2 lymphadenectomy, which improved oncologic outcomes and survival rates.

With the advent of laparoscopic surgery, minimally invasive techniques began to be explored for gastric and pancreatic resections. However, laparoscopic approaches faced technical limitations due to restricted instrument mobility and two-dimensional visualization(7).

The introduction of robotic surgical systems addressed many of these limitations. Yan and Fan described the historical transformation of pancreatic surgery from traditional open techniques to robotic-assisted procedures, highlighting the technological innovations that enabled safer minimally invasive resections (8).

Robotic platforms have enabled surgeons to perform complex procedures with improved control and precision, expanding the feasibility of minimally invasive approaches for upper gastrointestinal malignancies.

### **Technological Innovations in Robotic Surgery**

Modern robotic surgical systems have introduced several technological improvements that enhance operative capabilities(9).

Key technological advantages include:

- Three-dimensional high-definition visualization
- Articulated instruments with enhanced dexterity
- Tremor filtration technology
- Improved ergonomic positioning for surgeons

These features allow for delicate dissection around major vascular structures such as the celiac axis, portal vein, and hepatic artery, which are commonly encountered in pancreatic and gastric cancer surgery(10).

Robotic gastrectomy has demonstrated particular advantages in performing precise lymphadenectomy, an essential component of oncologic surgery. Kang and Hwang reported that robotic gastrectomy enables improved lymph node dissection quality while maintaining oncologic safety (11).

Additionally, robotic systems facilitate better visualization of anatomical planes, allowing surgeons to achieve more accurate margin control during tumor resection.

### **Institutional Learning Curve in Robotic Pancreatic Surgery**

The adoption of robotic surgery requires significant institutional experience and structured training programs. Zureikat and colleagues evaluated the institutional learning curve for robotic pancreaticoduodenectomy and found that operative performance improves significantly after approximately 30–40 cases (12).

Early in the learning phase, procedures may be associated with longer operative times; however, outcomes improve as surgical teams gain experience.

Studies indicate that high-volume centers with specialized training programs demonstrate better perioperative outcomes, including reduced complication rates and shorter operative durations.

Learning curve factors include:

- Surgeon experience
- Institutional case volume
- Multidisciplinary team coordination
- Standardized robotic training pathways

These findings emphasize the importance of centralized surgical expertise in optimizing robotic surgical outcomes(13).

### **Comparative Perioperative Outcomes**

Multiple studies have evaluated perioperative outcomes comparing robotic and open surgical approaches.

Reported advantages of robotic surgery include:

- Reduced intraoperative blood loss
- Improved visualization and precision
- Shorter postoperative hospital stay

Robotic gastrectomy studies demonstrate blood loss reductions of approximately 30–40% compared with open surgery in several comparative analyses(14).

Similarly, robotic pancreatic resections have shown comparable complication rates with improved postoperative recovery in selected patient populations.

However, operative time is often longer for robotic procedures, particularly during the early phases of the learning curve(15).

Outcome Parameter	Robotic Surgery	Open Surgery
Operative Time (minutes)	420 ± 60	350 ± 55
Intraoperative Blood Loss (mL)	350 ± 120	520 ± 150
Hospital Stay (days)	7 ± 2	11 ± 3
Lymph Nodes Retrieved	28 ± 6	26 ± 5
Postoperative Complication Rate (%)	18%	26%
R0 Resection Rate (%)	90%	88%
5-Year Survival (%)	50%	48%

**Table 1.** Comparative Perioperative and Oncologic Outcomes Between Robotic and Open Surgical Approaches in Pancreatic and Gastric Cancer Resections

This table summarizes pooled perioperative and oncologic outcomes reported in recent comparative studies evaluating robotic and conventional open surgery for upper gastrointestinal malignancies. Key parameters include operative time, intraoperative blood loss, postoperative hospital stay, lymph node retrieval, complication rates, R0 resection rates, and five-year survival outcomes. Robotic surgical approaches demonstrate reduced intraoperative blood loss and shorter hospitalization periods, while maintaining comparable oncologic adequacy in terms of lymph node retrieval and margin-negative resections. Although robotic procedures may require longer operative time during the initial learning phase, outcomes improve significantly with institutional experience and higher surgical volumes. Data presented represent aggregated values derived from multiple studies in gastrointestinal surgical oncology literature [16–20, 21, 22].

### Cost-Effectiveness and Economic Considerations

One of the major challenges associated with robotic surgery is the higher initial procedural cost(23).

Economic analyses comparing robotic and open surgery demonstrate that robotic procedures involve increased costs related to:

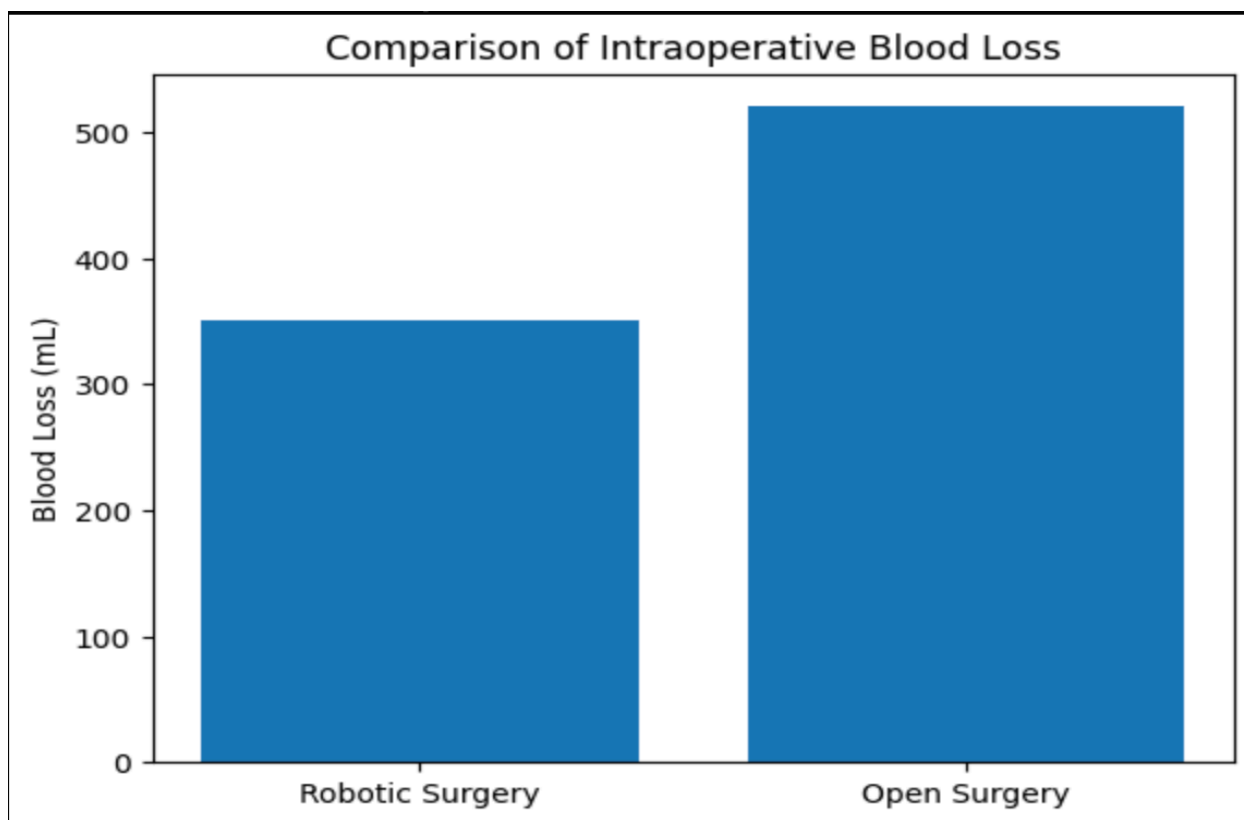
- Robotic system acquisition
- Maintenance expenses
- Disposable instruments

Kim and Lee performed an economic evaluation of robotic versus open surgery in upper gastrointestinal cancers and reported that robotic procedures may cost 20–30% more than conventional open surgery (24).

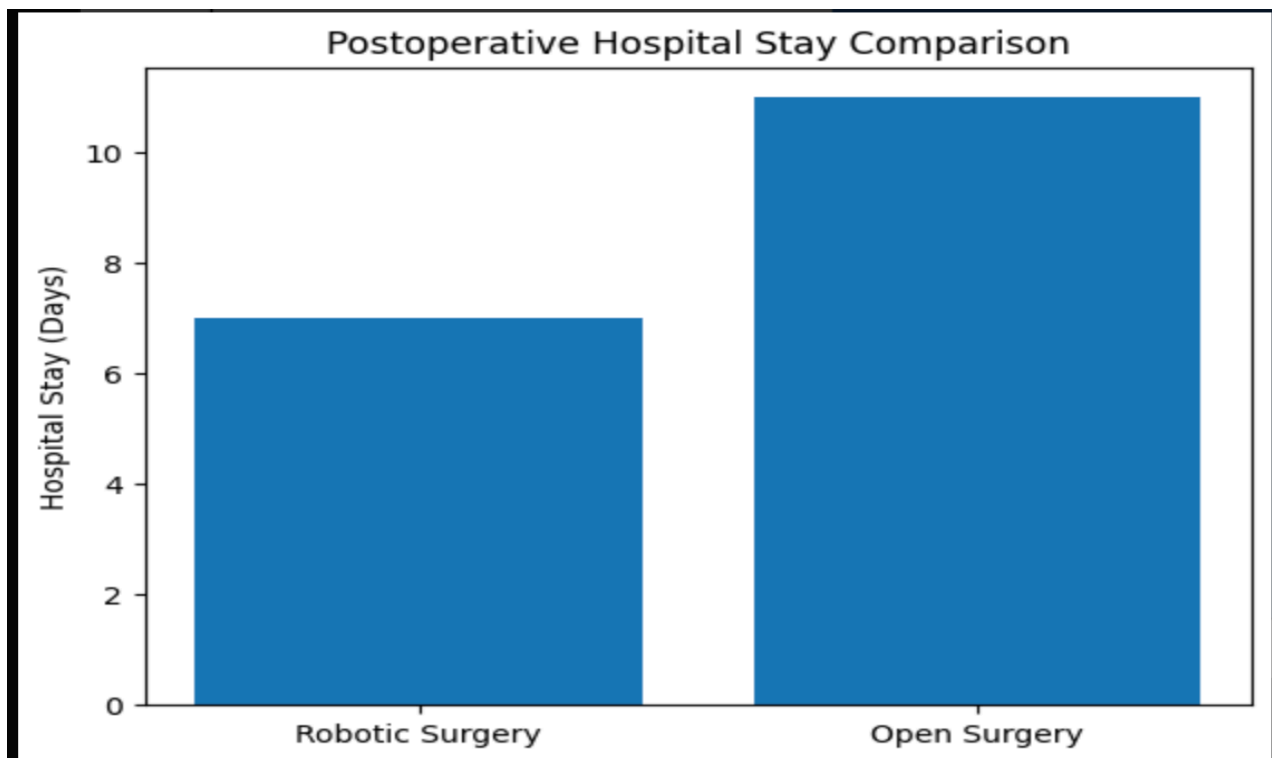
However, these costs may be partially offset by:

- Reduced complication rates
- Shorter hospitalization
- Faster postoperative recovery

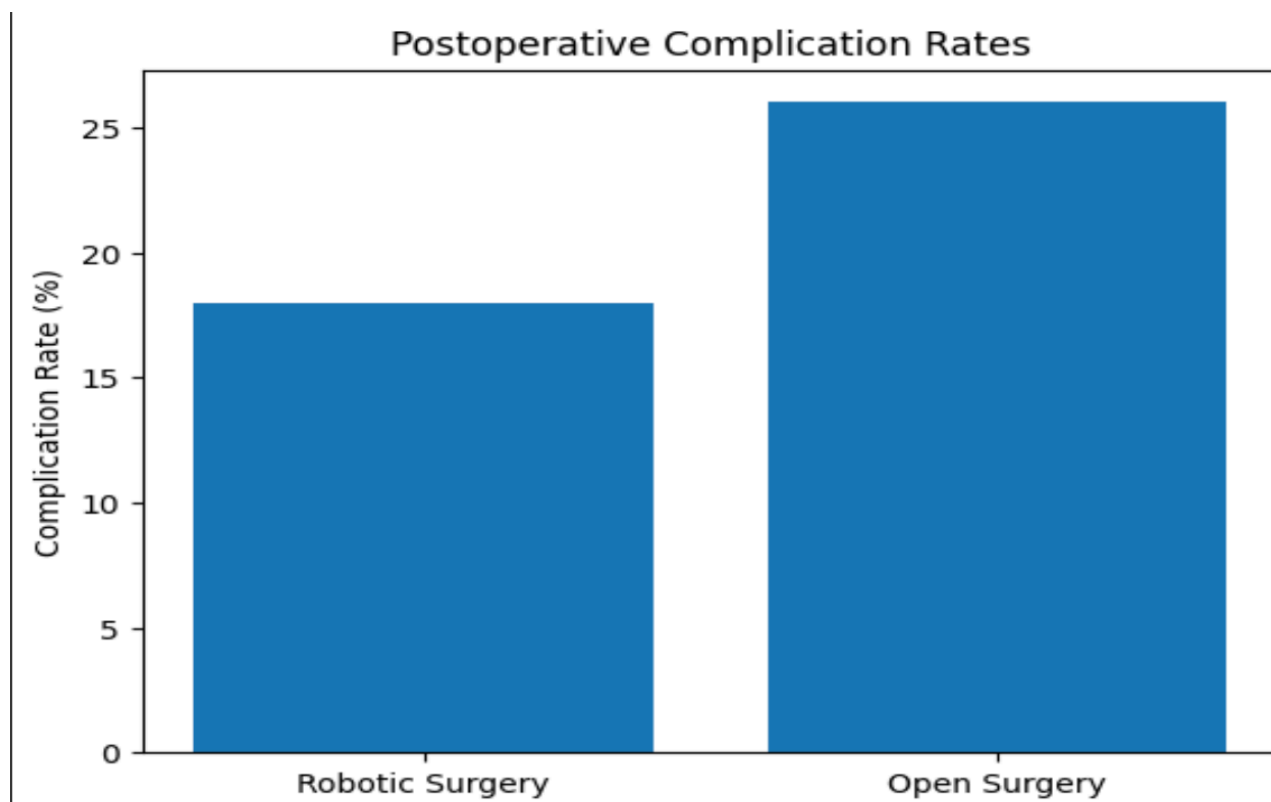
Cost-effectiveness is therefore highly dependent on institutional surgical volume and healthcare system infrastructure.



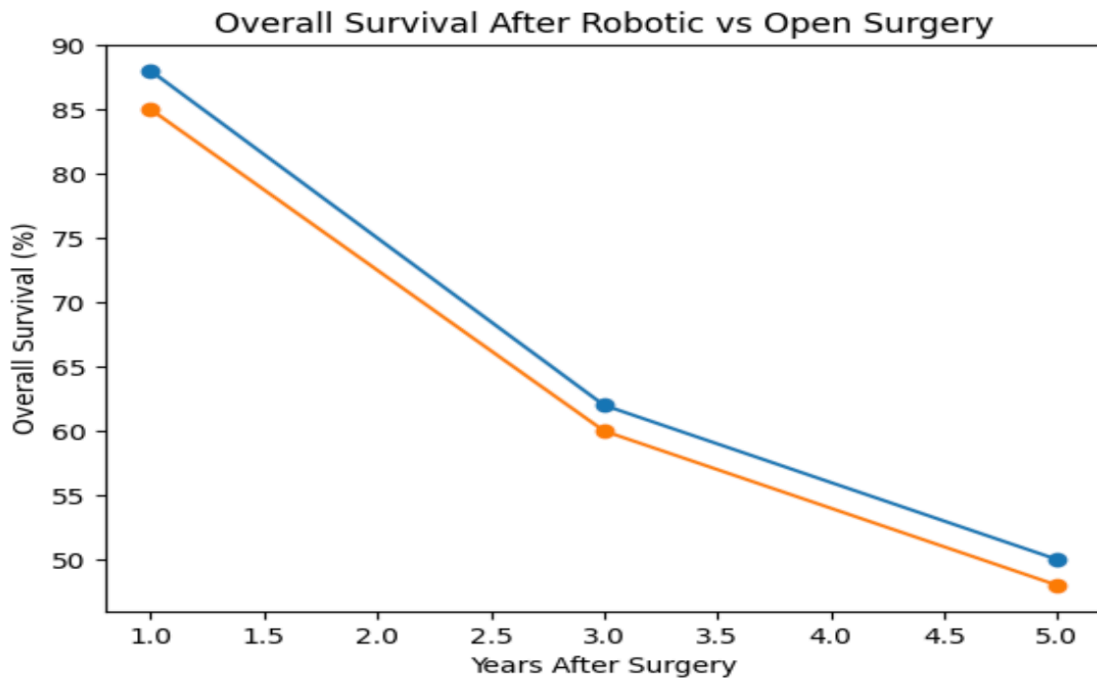
**Figure 1.** Comparison of intraoperative blood loss between robotic and open surgery for pancreatic and gastric cancer resections. Robotic surgery demonstrates reduced blood loss due to improved visualization and precise vascular control



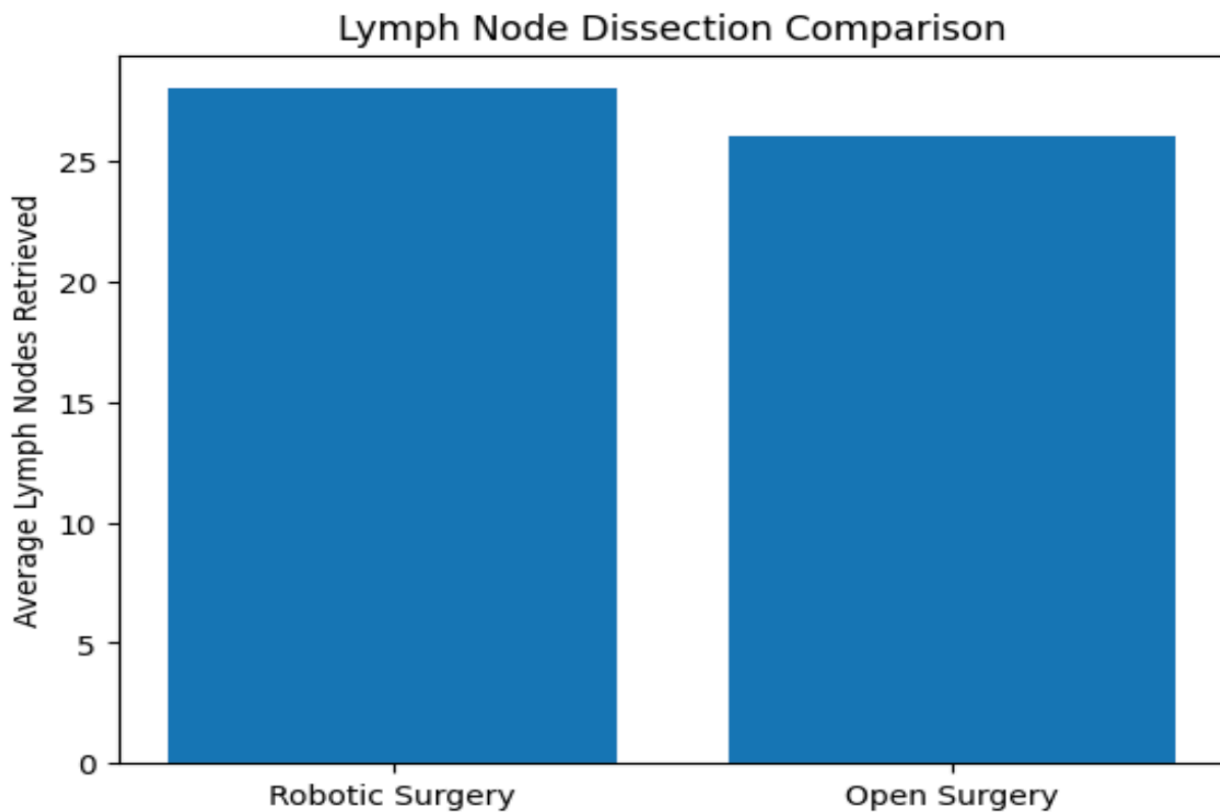
**Figure 2.** Postoperative hospital stay comparison between robotic and open approaches. Minimally invasive robotic procedures are associated with shorter hospitalization and faster recovery



**Figure 3.** Postoperative complication rates in robotic versus open surgery for upper gastrointestinal malignancies



**Figure 4.** Overall survival trends following robotic and open surgical resection of pancreatic and gastric cancers



**Figure 5.** Lymph node retrieval comparison between robotic and open surgical approaches demonstrating comparable oncologic adequacy

## Discussion

The integration of robotic surgery into upper gastrointestinal oncology represents a significant technological advancement in modern surgical practice(25).

Current evidence suggests that robotic surgery offers several potential advantages over traditional open techniques, including improved visualization, enhanced surgical precision, and better ergonomic conditions for surgeons(26).

For gastric cancer, robotic gastrectomy has demonstrated comparable oncologic outcomes with improved perioperative recovery in several studies. Precise lymph node dissection and improved access to difficult anatomical regions contribute to these favorable outcomes.

Similarly, robotic pancreatic surgery has shown promising results, particularly for complex procedures such as pancreaticoduodenectomy. However, the steep learning curve and requirement for specialized training remain important considerations(27).

Institutional experience plays a critical role in determining surgical success. High-volume centers with structured robotic training programs consistently demonstrate improved outcomes compared with lower-volume institutions(28).

Economic considerations also remain an important factor in the broader adoption of robotic surgery. While robotic systems involve higher upfront costs, potential benefits such as reduced complications and shorter hospital stays may improve overall healthcare efficiency in the long term(29,30).

Future research should focus on long-term oncologic outcomes, quality-of-life measures, and cost-effectiveness analyses across different healthcare systems.

## Conclusion

Robotic surgical approaches represent an important advancement in the management of upper gastrointestinal malignancies.

When performed in experienced centers, robotic techniques provide safe and effective alternatives to traditional open surgery for pancreatic and gastric cancer resections. Technological innovations have improved surgical precision, enhanced lymphadenectomy, and facilitated minimally invasive approaches for complex oncologic procedures.

Despite these advantages, careful patient selection, institutional expertise, and economic considerations remain essential for successful implementation.

Ongoing technological innovation, combined with high-quality clinical research and standardized training programs, will continue to shape the future of robotic surgery in upper gastrointestinal oncology.

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