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CONTEMPORARY MINIMALLY INVASIVE ESOPHAGECTOMY: COMPARATIVE ANALYSIS OF SURGICAL APPROACHES, TECHNIQUES AND CLINICAL OUTCOMES

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INTRODUCTION

Esophageal cancer remains one of the leading causes of cancer-related mortality worldwide despite continuous advances in diagnosis and multimodal treatment. Surgical resection continues to represent the cornerstone of curative treatment for patients with localized and locally advanced disease. However, conventional open esophagectomy is associated with considerable perioperative morbidity due to the complexity of the procedure and the need for extensive surgical exposure.

The introduction of minimally invasive esophagectomy (MIE) has transformed the surgical management of esophageal cancer. By combining laparoscopic, thoracoscopic, and, more recently, robot-assisted techniques, MIE aims to minimize surgical trauma while preserving oncological radicality. Several operative strategies have evolved, including transhiatal esophagectomy, Ivor Lewis esophagectomy, McKeown esophagectomy, hybrid minimally invasive procedures, and robot-assisted minimally invasive esophagectomy (RAMIE). These techniques differ in the combination of cervical, thoracic, and abdominal surgical access, the site of anastomosis, the extent of lymphadenectomy, and perioperative outcomes.

Over the past decade, numerous randomized controlled trials, systematic reviews, and meta-analyses have compared these surgical techniques. Although minimally invasive approaches consistently demonstrate lower perioperative morbidity than conventional open surgery, controversy remains regarding the optimal operative strategy for different clinical scenarios. The selection of an appropriate technique depends on tumor location, oncological requirements, patient characteristics, and the experience of the surgical team.

The aim of this review is to summarize and critically analyze contemporary evidence regarding minimally invasive esophagectomy, comparing transhiatal, Ivor Lewis, McKeown, hybrid, and robot-assisted techniques with respect to their surgical

characteristics, perioperative outcomes, postoperative complications, oncological effectiveness, and current clinical indications.

Keywords: minimally invasive esophagectomy; esophageal cancer; transhiatal esophagectomy; Ivor Lewis esophagectomy; McKeown esophagectomy; robot-assisted surgery; surgical approach.

Methodology

This review was designed to provide a comprehensive comparative analysis of contemporary minimally invasive esophagectomy techniques used in the surgical treatment of esophageal cancer. The review focused on evaluating the perioperative safety, technical characteristics, postoperative outcomes, and oncological effectiveness of currently available minimally invasive approaches, including transhiatal esophagectomy, Ivor Lewis esophagectomy, McKeown esophagectomy, hybrid minimally invasive esophagectomy, and robot-assisted minimally invasive esophagectomy (RAMIE).

A structured literature search was conducted in the PubMed, Scopus, and Web of Science databases to identify relevant studies published between 2015 and 2025. In addition, landmark randomized controlled trials and highly cited studies published before 2015 were included because of their major contribution to the development of minimally invasive esophageal surgery.

The search strategy combined Medical Subject Headings (MeSH) and free-text terms, including “minimally invasive esophagectomy,” “esophageal cancer,” “Ivor Lewis,” “McKeown,” “transhiatal esophagectomy,” “hybrid esophagectomy,” “robot-assisted minimally invasive esophagectomy,” “RAMIE,” “thoracoscopic esophagectomy,” and “esophageal surgery.”

Eligible publications included systematic reviews, meta-analyses, randomized controlled trials, prospective and retrospective comparative studies, multicenter investigations, and international clinical practice guidelines. Editorials, conference abstracts, case reports, technical notes without clinical outcome data, duplicate publications, and studies with insufficient methodological information were excluded from the review.

Data extraction focused on predefined outcome measures, including operative time, intraoperative blood loss, conversion to open surgery, number of harvested lymph nodes, R0 resection rate, anastomotic leakage, pulmonary complications, overall postoperative morbidity, 30-day mortality, length of hospital stay, and short- and long-term oncological outcomes.

Evidence synthesis was performed by qualitatively comparing the findings across the included studies. Greater emphasis was placed on high-quality systematic reviews, meta-analyses, randomized controlled trials, and international guidelines. When

several studies reported comparable outcomes, the consistency of findings, methodological quality, sample size, and clinical relevance were considered during interpretation. Areas of agreement and disagreement between studies were identified to provide a balanced evaluation of the current evidence.

The methodological approach was designed to summarize the available literature, identify the strengths and limitations of each minimally invasive technique, and provide an evidence-based comparison of contemporary surgical strategies for esophageal cancer.

RESULTS

Following the literature search, the selected studies were analyzed according to predefined eligibility criteria, allowing a direct comparison of clinical outcomes reported for minimally invasive esophagectomy. The included publications comprised systematic reviews, meta-analyses, randomized controlled trials, and multicenter cohort studies evaluating transthoracic, transhiatal, hybrid, and robot-assisted minimally invasive esophagectomy in patients with esophageal cancer. This study selection provided a comprehensive basis for comparative analysis of perioperative and oncological outcomes.

The evidence consistently demonstrated that minimally invasive esophagectomy was associated with improved short-term postoperative outcomes compared with open surgery. Across the included studies, reductions in pulmonary complications, intraoperative blood loss, postoperative pain, and hospital length of stay were the most frequently reported findings. At the same time, oncological adequacy, including R0 resection rates and lymph node harvest, remained comparable between minimally invasive and open approaches.

Comparisons among different minimally invasive techniques revealed several important differences. Robotic-assisted esophagectomy demonstrated lower conversion rates and improved visualization during mediastinal lymphadenectomy in several studies, whereas hybrid and thoracoscopic approaches achieved similar oncological outcomes with shorter operative time and wider clinical availability. Although operative duration was generally longer for robotic procedures, this difference was not consistently associated with higher postoperative morbidity.

Postoperative endpoints were primarily focused on overall complications, pulmonary morbidity, anastomotic leakage, 30-day mortality, lymph node harvest, and long-term survival. Most systematic reviews and meta-analyses reported significantly lower pulmonary complication rates following minimally invasive esophagectomy, while no consistent differences were observed in anastomotic leak, R0 resection, or overall survival. Variability between studies was mainly related to differences in surgical expertise, institutional volume, patient selection, and perioperative management protocols.

Overall, the available evidence supports minimally invasive esophagectomy as a safe and oncologically effective alternative to conventional open surgery. Despite some heterogeneity among studies, the overall direction of evidence favors minimally invasive techniques for reducing perioperative morbidity while maintaining equivalent oncological outcomes.

Table 1. Characteristics of the studies included in the review

Study	Year	Study design	Intervention	Main outcomes evaluated
Luketich et al.	2012	Literature review	MIE	Safety, perioperative outcomes
Biere et al.	2012	Randomized controlled trial	MIE vs Open	Postoperative complications, pulmonary complications
Van der Sluis et al.	2019	Randomized controlled trial	RAMIE vs Open	Complications, quality of life, oncological outcomes
Markar et al.	2015	Systematic review and meta-analysis	MIE vs Open	Morbidity, mortality, lymph node harvest
Mariette et al.	2019	Randomized controlled trial	Hybrid MIE vs Open	Major postoperative complications
Van der Sluis et al.	2022	Long-term follow-up of RCT	RAMIE vs Open	Overall survival, disease-free survival
Deng et al.	2014	Meta-analysis	MIE vs Open	Operative and postoperative outcomes
Zhang et al.	2021	Comparative cohort study	RAMIE vs Thoracoscopic MIE	Early postoperative outcomes
Guo et al.	2021	Meta-analysis	MIE vs Open	Postoperative complications
Li et al.	2022	Propensity score-matched study	Total MIE vs HYBRID MIE	Surgical and oncological outcomes
Wang et al.	2023	Systematic review and meta-analysis	Robotic vs Thoracoscopic MIE	Perioperative outcomes
Zhang et al.	2024	Multicenter cohort study	MIE	Short-term outcomes

Table 2. Summary of clinical outcomes reported in the included studies

Outcome	Overall findings
Overall postoperative complications	Lower after minimally invasive esophagectomy compared with open surgery in most studies
Pulmonary complications	Consistently reduced after minimally invasive approaches
Anastomotic leakage	No significant difference between techniques in most studies
Intraoperative blood lost	Reduced in minimally invasive surgery
Operative time	Generally longer for robotic-assisted procedures

Length of hospital stay	Shorter after minimally invasive esophagectomy
Lymph node harvest	Comparable or slightly higher in robotic procedures
R0 resection rate	Similar across surgical approaches
30-day mortality	Comparable between minimally invasive and open surgery
Overall survival	No significant long-term differences between minimally invasive techniques

Table 3. Comparative advantages and limitations of minimally invasive esophagectomy techniques

Surgical approach	Main advantages	Main limitations
Thoracoscopic MIE	Lower blood loss, reduced pulmonary complications, shorter recovery	Technically demanding
Hybrid MIE	Lower postoperative morbidity than open surgery	Requires combined open and minimally invasive procedures
Robotic-assisted MIE	Superior visualization, precise lymph node dissection, lower conversion rate	Longer operative time, higher cost
Open esophagectomy	Broad availability and established technique	Greater surgical trauma, higher pulmonary morbidity

The included studies consistently demonstrated that minimally invasive esophagectomy provides favorable perioperative outcomes compared with conventional open surgery while maintaining comparable oncological effectiveness. Reduced pulmonary complications, lower intraoperative blood loss, and shorter hospital stay represented the most frequently reported benefits. Robotic-assisted procedures offered additional technical advantages in lymph node dissection and visualization, although they were generally associated with longer operative time and increased procedural cost. Despite methodological heterogeneity among studies, the overall body of evidence supports minimally invasive esophagectomy as a safe and effective treatment strategy for esophageal cancer.

DISCUSSION

The present literature review demonstrates that minimally invasive esophagectomy (MIE) has become an established alternative to open esophagectomy for the surgical treatment of esophageal cancer. Across the included studies, minimally invasive techniques were consistently associated with reduced perioperative morbidity, particularly lower pulmonary complication rates, decreased intraoperative blood loss, shorter hospital stay, and faster postoperative recovery, while maintaining comparable oncological outcomes. These findings support the growing adoption of minimally invasive approaches in specialized esophageal surgery centers [1,4,7].

One of the most consistent observations among randomized controlled trials and meta-analyses was the reduction in pulmonary complications following minimally

invasive esophagectomy. The TIME trial by Biere et al. demonstrated significantly fewer respiratory complications after MIE compared with open esophagectomy, while preserving equivalent oncological radicality [2]. Similar conclusions were confirmed in subsequent systematic reviews and meta-analyses, indicating that reduced surgical trauma and improved postoperative respiratory function contribute substantially to enhanced recovery [4,7].

Robotic-assisted minimally invasive esophagectomy (RAMIE) represents one of the most important recent developments in esophageal surgery. Randomized studies have demonstrated that robotic systems provide superior visualization, enhanced dexterity, and more precise mediastinal lymph node dissection compared with conventional thoracoscopic techniques [3,6]. Several studies also reported lower conversion rates and reduced recurrent laryngeal nerve injury following RAMIE, although these benefits are accompanied by increased operative time, higher equipment costs, and a significant learning curve [8,11].

Hybrid minimally invasive esophagectomy has also demonstrated favorable perioperative outcomes. The MIRO trial showed that combining laparoscopic gastric mobilization with open thoracotomy significantly reduced major postoperative complications compared with conventional open surgery while preserving oncological quality [5]. These findings suggest that hybrid procedures may represent an effective compromise for institutions transitioning toward fully minimally invasive techniques.

Despite improvements in perioperative outcomes, long-term oncological effectiveness remains comparable among minimally invasive and open surgical approaches. The majority of included studies reported similar R0 resection rates, lymph node harvest, disease-free survival, and overall survival, indicating that minimally invasive surgery does not compromise oncological radicality when performed by experienced surgical teams [3,6,9].

Several limitations should be considered when interpreting the available evidence. Considerable heterogeneity exists regarding patient selection, tumor stage, neoadjuvant treatment protocols, surgical expertise, and institutional experience. Furthermore, many observational studies remain susceptible to selection bias and residual confounding despite statistical adjustment. Future multicenter randomized trials with standardized perioperative protocols and long-term follow-up are required to further define the optimal surgical strategy and clarify the comparative effectiveness of emerging minimally invasive technologies.

CONCLUSION

Minimally invasive esophagectomy has become an important component of modern surgical management for esophageal cancer. Current evidence demonstrates that minimally invasive approaches reduce perioperative morbidity, particularly

pulmonary complications, blood loss, and postoperative recovery time, while maintaining oncological outcomes comparable to conventional open esophagectomy.

Robotic-assisted and hybrid minimally invasive techniques provide additional technical advantages in selected patients; however, their successful implementation depends on surgical expertise, institutional resources, and careful patient selection.

Overall, the available evidence supports wider adoption of minimally invasive esophagectomy in experienced centers. Future high-quality multicenter randomized studies should focus on long-term survival, quality of life, cost-effectiveness, and optimization of patient selection to further improve surgical outcomes.

References

1. Luketich et al., 2012
2. Biere et al., 2012 (TIME Trial)
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