

Safety and oncological efficacy of minimally invasive McKeown esophagectomy: A 10-year single-center experience of 808 consecutive patients operated by a single surgeon

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Abstract

Objective

The objective of this study was to assess perioperative safety and oncological efficacy following minimally invasive McKeown esophagectomy (MIE-McKeown) in a large single-center cohort, providing evidence for the standardized clinical practice of this procedure.

Methods

Cumulatively, 808 patients with esophageal cancer who underwent MIE-McKeown performed by a single surgeon at our hospital from March 2016 to December 2025 were enrolled. Collected perioperative indicators and follow-up data were analyzed to determine overall survival (OS) and disease-free survival (DFS) using the Kaplan–Meier approach, while log-rank testing was performed to identify intergroup survival disparities.

Results

All procedures were completed successfully without intraoperative death or open conversion, with an R0 resection rate of 98.1%. The cohort exhibited a median operative duration of 240 minutes, median estimated intraoperative hemorrhage of 50 milliliters, median postoperative hospitalization of 11 days and a median 9-day interval prior to initial oral liquid intake. The perioperative mortality was 0.6%, with anastomotic leakage and pulmonary complication rates of 3.6% and 12.6%, respectively. The cohort demonstrated 1-, 3-, and 5-year OS probabilities of 93.9%, 72.3%, and 60.1%, alongside respective DFS probabilities of 82.9%, 64.1%, and 55.5%. Females and early-stage patients had superior survival. Patients who received neoadjuvant chemoimmunotherapy had an equivalent 3-year OS but a superior 3-year DFS than those who received neoadjuvant chemotherapy alone or who did not receive neoadjuvant therapy ($P = 0.029$). Preoperative underweight reduced OS without affecting DFS, and thoracic duct ligation did not influence long-term survival.

Conclusion

MIE-McKeown is safe and oncologically effective. Individualized management based on tumor stage, preoperative nutritional status and neoadjuvant regimens helps optimize long-term patient prognosis.

1. Background

Esophageal cancer is a prevalent gastrointestinal malignancy with striking geographic variation in terms of its epidemiologic distribution. Globally, it is ranked 11th in incidence (5.0 per 100,000) and 7th in mortality (4.3 per 100,000) in 2022 ^[1]. Nationwide epidemiological data from China shows an incidence

of 15.87 per 100,000 population (7th) and a mortality rate of 13.28 per 100,000 population (5th), with newly diagnosed cases accounting for approximately 43.8% of the global total [2, 3]. Compared with females, males carry higher risks of incidence and mortality [2, 3]. Among esophageal malignancies, esophageal squamous cell carcinoma (ESCC) is the prevailing subtype, which manifests aggressive progression, substantial risks of lymph node metastasis and dismal overall prognosis [4]. Despite remarkable advances in screening, diagnostic techniques and comprehensive therapeutic strategies in recent decades, long-term overall survival (OS) and disease-free survival (DFS) have not reached optimal levels, resulting in substantial challenges for clinical management [5].

Currently, multimodal treatment centered on radical esophagectomy plus systematic lymphadenectomy represents the standard paradigm for treating esophageal cancer [6, 7]. Propelled by innovations in minimally invasive technology, conventional thoracotomy has been progressively superseded by minimally invasive approaches. Owing to less surgical trauma, fewer complications and faster postoperative recovery, video-assisted minimally invasive esophagectomy (VAMIE) has become the dominant surgical approach with proven oncological equivalence to open procedures [8–11]. While robotic-assisted minimally invasive esophagectomy enables more meticulous dissection and lymph node retrieval [12, 13], high procurement and running costs restrict its popularization. Consequently, VAMIE, especially minimally invasive McKeown esophagectomy (MIE-McKeown), remains the prevailing surgical modality [14, 15].

This retrospective study included 808 consecutive patients who underwent MIE-McKeown at our institution between March 2016 and December 2025. Leveraging our center's high surgical volume and standardized management protocol, perioperative parameters and follow-up data were collected to comprehensively evaluate the safety, feasibility and oncologic prognosis of MIE-McKeown, providing real-world evidence for its standardized clinical promotion and application.

2. Materials and Methods

2.1 Study Design and Patient Selection

Clinical data of patients receiving esophagectomy at the Department of Thoracic Surgery, Sir Run Run Shaw Hospital, Zhejiang University from March 2016 to December 2025 were retrospectively analyzed in this study.

The inclusion criteria were as follows: (1) preoperative endoscopy and pathological confirmation of esophageal carcinoma; (2) receipt of McKeown esophagectomy; (3) at least lymph node dissection in two fields of the chest and abdomen; and (4) all operations performed by a single attending surgeon.

The exclusion criteria were as follows: (1) underwent robot-assisted McKeown esophagectomy; (2) underwent cervical esophagectomy combined with laryngectomy; and (3) had incomplete clinical and follow-up datasets.

Based on the predefined inclusion and exclusion standards, 808 successive subjects receiving MIE-McKeown were incorporated into this cohort. Multidisciplinary tumor board conferences formulated individualized therapeutic regimens for every patient, fully complying with both National Comprehensive Cancer Network (NCCN) recommendations and domestic clinical practice guidelines for esophageal carcinoma. Each participant signed written informed consent prior to surgical intervention. The hospital's ethical review committee granted official approval and conducted continuous oversight of the study protocol.

2.2 Surgical techniques

MIE-McKeown was performed under video-assisted thoracoscopic guidance.

Thoracic phase: Patients were placed in a left semiprone position with routine single-lumen intubation. Four trocars were placed in a rhomboid configuration on the right hemithorax. Dissection proceeded cephalad along the vagus nerve to the right subclavian artery with concurrent right recurrent laryngeal nerve (RLN) station lymphadenectomy. The proximal esophagus was mobilized caudally with careful preservation of the thoracic duct and membranous trachea. The distal esophagus was dissected craniocaudally, followed by systematic lymphadenectomy of the paraesophageal, subcarinal and left RLN lymph nodes. After the diaphragmatic esophageal hiatus was exposed, hemostasis and intraoperative cavity irrigation were conducted with routine placement of the mediastinal and thoracic drainage tubes.

Abdominal phase: Patients were shifted to the lithotomy position after abdominal access was established via four arc-shaped abdominal trocars under CO₂ pneumoperitoneum. Division of the gastrocolic ligament was performed, followed by dissection of the greater omentum extending from the right gastroepiploic vessel origin to the gastric fundus. The left gastric vascular pedicle was isolated, ligated and accompanied by perigastric lymphadenectomy. Upon completing dissection and separation of the hepatogastric ligament together with the lesser omentum, the abdominal esophagus was mobilized with regional lymphadenectomy, and the bilateral diaphragmatic crura was incised to establish a thoracoabdominal channel.

Cervical phase: The cervical esophagus was transected extracorporeally. A linear cutting stapler was used for gastric conduit formation, which was subsequently mobilized to the left cervical region to perform end-to-side esophagogastric reconstruction.

2.3 Study endpoints

The primary endpoints were 1-, 3- and 5-year OS and PFS. Secondary endpoints consisted of short-term perioperative parameters: operative duration, intraoperative blood loss, R0 resection rate, total retrieved lymph nodes, postoperative hospitalization, interval to initial oral liquid intake and postoperative complications.

2.4 Postoperative management

After extubation, the majority of patients were sent to general wards, while high-risk individuals presenting challenging extubation conditions or hemodynamic instability were admitted to the intensive care unit (ICU). Postoperative care followed our institutional enhanced recovery after surgery (ERAS) protocol for esophageal cancer: central venous parenteral nutrition was initiated on postoperative day 1, and chest drains were routinely removed on postoperative day 2, with postponement for complicated cases. Upper gastrointestinal contrast examination on postoperative day 6 confirmed anastomotic integrity prior to gradual oral feeding, and mediastinal drains were withdrawn thereafter.

2.5 Follow-up evaluation and survival definitions

Postoperative surveillance consisted of outpatient physical assessment, laboratory profiling, thoracoabdominal computed tomography, cervical ultrasonography and cranial magnetic resonance imaging. Follow-up visits were arranged quarterly within the first postoperative year and semiannually thereafter. For patients whose in-clinic evaluation was unavailable, semiannual telephone follow-up was implemented to document survival status, disease recurrence and all-cause mortality. Individuals who did not attend regular postoperative re-evaluations and could not be reached by telephone were deemed loss-to-follow-up subjects, and their most recent documented follow-up time was recorded as censored data for statistical calculations. The cutoff date for follow-up was February 28, 2026.

DFS referred to the time interval between curative resection and initial tumor relapse, any death event or the latest follow-up. OS was defined as the period from operative treatment to all-cause death or censored follow-up. Recurrence patterns were stratified into three subtypes: locoregional recurrence (involving cervical, mediastinal or abdominal lymph nodes and the anastomotic site), distant recurrence (hematogenous metastasis, intrathoracic, intra-abdominal or pericardial seeding) and mixed locoregional plus distant recurrence.

2.6 Statistical analysis

We applied descriptive statistics to characterize patients' baseline demographic and clinical profiles. Frequencies and proportions were adopted for categorical variables, whereas median values alongside interquartile ranges were used for non-normally distributed continuous data. Kaplan–Meier survival curves were generated to evaluate OS and DFS, and the log-rank test was utilized for intergroup survival comparisons. Statistical computations were completed using SPSS 26.0 software (SPSS Inc., Chicago, IL, USA), and statistical significance was set at a P-value threshold of 0.05.

3. Results

3.1 Demographic parameters and clinical characteristics

This study enrolled 808 patients receiving MIE-McKeown esophagectomy, with their baseline clinical profiles summarized in Table 1. The cohort comprised 714 men and 94 women, whose median age was 67 years (range, 43–92 years). After stratification by body mass index (BMI), 115 patients were underweight (BMI $\leq$ 18.5), 128 were overweight or obese (BMI $\geq$ 25), and the remaining 565 had a normal

BMI. Hypertension was the most common comorbidity, followed by diabetes mellitus and cardiovascular diseases. More than half of the patients had a history of tobacco smoking (53.8%) and alcohol intake (54.7%). Twenty-two individuals previously underwent endoscopic submucosal dissection and subsequently underwent radical surgical resection due to positive resection margins or intraoperative perforation. Among patients with advanced esophageal carcinoma, 66 individuals underwent neoadjuvant chemotherapy, 179 individuals underwent neoadjuvant chemoimmunotherapy and neoadjuvant chemoradiotherapy was administered to 6 cases. The tumor was distributed in the upper esophagus (n=66), middle esophagus (n=255) and lower esophagus (n=487).

Table 1 The demographics and tumor characteristics of the overall cohort

Characteristics	Value
Age (y)	67(61,71)
Gender, n (%)	
Male	714(88.4)
Female	94(11.6)
BMI (kg/m ²)	
≤18.5	115(14.2)
18.5-25	565(69.9)
≥25	128(15.9)
ASA, n (%)	
I	1(0.1)
II	770(95.3)
III	37(4.6)
Comorbidity, n (%)	
Diabetes mellitus	68(8.4)
Hypertension	286(35.4)
Cardiovascular disease	59(7.3)
Obstructive lung disease	13(1.6)
Cerebrovascular disease	28(3.5)
Other Comorbidity	3(0.4)
Smoking history, n (%)	442(54.7)
Alcohol consumption history, n (%)	435(53.8)
History of malignant tumor, n (%)	21(2.6)
Previous thoracic surgery, n (%)	9(1.1)
Endoscopic submucosal dissection, n (%)	22(2.7)
Neoadjuvant chemotherapy alone, n (%)	66(8.2)
Neoadjuvant chemotherapy with immunotherapy, n (%)	179(22.2)
Neoadjuvant chemotherapy with radiotherapy, n (%)	6(0.7)
Tumor location, n (%)	

Upper	66(8.2)
Middle	255(31.6)
Lower	487(60.3)

ASA: American Society of Anesthesiologists; BMI: body mass index.

Categorical variables are expressed as frequencies (percentages), and continuous variables are expressed as medians (interquartile ranges).

3.2 Prioperative outcomes

The perioperative clinical and pathological parameters were summarized in Table 2. All enrolled patients successfully underwent MIE-McKeown; no intraoperative mortality or open conversion was recorded, with an overall R0 resection rate of 98.1%. The median operative duration was 240 min, and the median intraoperative blood loss was 50 mL. Gastrointestinal reconstruction was performed using the gastric conduit in the whole cohort. In 801 participants, the gastric conduit was advanced alongside the esophageal bed to complete cervical anastomosis, while the remaining seven cases underwent gastrointestinal reconstruction via the retrosternal route. Thoracic duct ligation was performed in 248 patients owing to tumor invasion or accidental duct injury, and allogeneic blood transfusion was administered to 10 patients with substantial intraoperative hemorrhage. The median length of postoperative hospitalization was 11 days and patients resumed liquid oral feeding at a median of 9 days after surgery. The overall median yield of retrieved lymph nodes was 32, comprising 18 thoracic and 12 abdominal lymph nodes.

Pathological assessments confirmed ESCC as the dominant histologic subtype (95.5%), with rare histologies comprising the remainder. Lymphovascular invasion and perineural invasion were detected in 20.0% and 18.2% of the patients, respectively. Tumor differentiation was graded as poorly differentiated (28.3%), moderately differentiated (46.7%), or well differentiated (25.0%). Two patients presented with preoperative hepatic metastases (clinical stage M1) and underwent simultaneous resection of hepatic metastatic lesion. The pathological stage distribution was as follows: stage I (221 cases; 27.4%), stage II (264 cases; 32.7%), stage III (300 cases; 37.1%), and stage IV (23 cases; 2.8%).

Table 2 Operative and pathological outcomes of the overall cohort

Characteristics	Value
Operation duration (min)	240(210,270)
Intraoperative blood loss (mL)	50(50,100)
Gastrointestinal reconstruction, n (%)	
Via esophageal bed	801(99.1)
Via retrosternal tunnel	7(0.9)
Thoracic duct ligation, n (%)	248(30.7)
Blood transfusion, n (%)	10(1.2)
Restore fluid diet time (d)	9(7,10)
Postoperative hospitalization (d)	11(10,13)
Lymphadenectomy	
Two field	724(89.6)
Three field	84(10.4)
R0 esophagectomy, n (%)	793(98.1)
Total harvested lymph nodes	32(23,42)
Harvested intrathoracic lymph nodes	18(12,25)
Harvested abdominal lymph nodes	12(8,12)
Lymph nodes harvested around the right RLN	3(1,5)
Lymph nodes harvested around the left RLN	2(0,4)
Histology classification, n (%)	
Squamous cell carcinoma	772(95.5%)
Adenocarcinoma	18(2.2%)
Adenosquamous carcinoma	9(1.1%)
Sarcomatoid carcinoma	3(0.4%)
Neuroendocrine carcinoma	2(0.3%)
Malignant melanoma	1(0.1%)
Gastrointestinal stromal tumor	1(0.1%)
Mixed carcinoma	2(0.3%)
lymphovascular invasion, n (%)	162(20.0%)

perineural invasion, n (%)	147(18.2%)
pT stage, n (%)	
T1	264(32.7%)
T2	140(17.3%)
T3	398(49.3%)
T4	6(0.7%)
pN stage, n (%)	
N0	411(50.9%)
N1	222(27.5%)
N2	130(16.1%)
N3	45(5.6%)
pM stage, n (%)	
M0	806(99.8%)
M1	2(0.2%)
Grade, n (%)	
Poorly differentiated	229(28.3%)
Moderately differentiated	377(46.7%)
Well differentiated	202(25.0%)
Pathological stage, n (%)	
Stage I	221(27.4%)
Stage II	264(32.7%)
Stage III	300(37.1%)
Stage IV	23(2.8%)

RLN: recurrent laryngeal nerve.

Categorical variables are expressed as frequencies (percentages), and continuous variables are expressed as medians (interquartile ranges).

3.3 Postoperative complications

Postoperative complications were detailed in Table 3. Anastomotic leakage was documented in 29 patients, with an overall incidence of 3.6%. Hoarseness occurred in 25 patients: 23 patients achieved

complete resolution within 6 months following conservative interventions, while 2 patients developed permanent vocal cord dysfunction. Postoperative chylothorax was identified in 6 patients: 2 patients underwent reexploration for thoracic duct ligation due to refractory chylous effusion, and the remaining 4 patients achieved clinical cure with conservative management. Pleural effusion was the most prevalent postoperative complication (15.2%), and all patients achieved adequate symptom resolution after therapeutic drainage. Pneumonia was the second most common complication (12.6%), and all affected individuals received increased broad-spectrum antimicrobial therapy combined with supportive care tailored to clinical severity.

A total of 5 patients underwent reoperation: two for refractory chylothorax requiring thoracic duct ligation, one for debridement and closure of severe abdominal wound infection, one for hemostasis of intrathoracic hemorrhage and one for hemostasis of cervical hemorrhage. Five perioperative deaths were recorded. One patient died on postoperative day 105 from cachexia secondary to refractory anastomotic leakage, and the remaining four patients died of respiratory failure attributable to severe pneumonia.

Table 3 Postoperative complications of the overall cohort

Characteristic	Value
Anastomosis leakage	29(3.6)
Hoarseness	25(3.1)
Wound infection	18(2.2)
Pleural effusion	123(15.2)
Pneumonia	102(12.6)
Chylothorax	6(0.7)
Arrhythmia	19(2.4)
Pneumothorax	9(1.1)
Unplanned secondary surgery	5(0.6)
Liver dysfunction	10(1.2)
Acute kidney dysfunction	3(0.4)
Pulmonary embolism	3(0.4)
Acute intestinal obstruction	2(0.2)
Unplanned ICU stay	31(4.0)
Hospital mortality	5(0.6)

Data are expressed as numbers (percentages).

3.4 Recurrence characteristics and survival outcomes

The recurrence characteristics of the cohort were summarized in Table 4. A total of 783 patients achieved complete follow-up by the final cutoff, corresponding to a 96.9% follow-up rate. The median follow-up duration was 34 months (range, 1–119 months). The overall recurrence rate and mortality rate were 26.5% and 25.7%, respectively. Distant metastasis was the predominant recurrence pattern, followed by locoregional recurrence and combined locoregional plus distant recurrence. For the entire cohort, the 1-year, 3-year, and 5-year OS rates were 93.9%, 72.3%, and 60.1%, respectively (Fig. 1A), and the corresponding 1-year, 3-year, and 5-year DFS rates were 82.9%, 64.1%, and 55.5%, respectively (Fig. 1B). The 5-year OS rates were 81.0%, 70.1%, 45.4%, and 22.7% for stages I, II, III, and IV, respectively ($P < 0.001$; Fig. 1C). The corresponding 5-year DFS rates were 78.0%, 67.5%, 39.0%, and 18.2%, respectively ($P < 0.001$; Fig. 1D). Statistically significant differences in both OS and DFS were detected across stage subgroups.

When stratified by gender, the 5-year OS rates were 59.2% for males and 67.5% for females ($P = 0.032$; Fig. 2A), while the corresponding 5-year DFS rates were 54.6% and 62.5%, respectively ($P = 0.034$; Fig. 2B). Compared with males, females had significantly better OS and DFS.

When patients were stratified by the neoadjuvant regimen, the 3-year OS rates were 69.4% for patients who received neoadjuvant chemotherapy, 77.4% for those who received neoadjuvant chemoimmunotherapy and 71.9% for patients who underwent no neoadjuvant intervention. No statistically significant intergroup difference in OS was identified (Fig. 2C). The corresponding 3-year DFS rates were 54.8%, 67.7%, and 64.9%, respectively. Patients who received neoadjuvant chemoimmunotherapy achieved markedly superior DFS compared with that of patients who received no neoadjuvant therapy ($P = 0.029$; Fig. 2D).

After stratification by preoperative BMI, no statistically significant intergroup differences in DFS were observed among patients with a BMI ≤ 18.5 , a BMI ≥ 25 , or a BMI between 18.5 and 25 (Fig. 3B). However, patients with a BMI ≤ 18.5 had significantly poorer OS than patients in the other two cohorts did ($P=0.001$; Fig. 3A). Subsequent subgroup analysis according to intraoperative thoracic duct ligation revealed comparable OS and DFS between patients who underwent thoracic duct ligation and those who did not (Fig. 3C and 3D).

Table 4 Recurrence analysis of the overall cohort

Characteristic	Value
Total recurrence (n, %)	214(26.5)
Recurrence type (n, %)	
Regional recurrence	64(7.9)
Distant recurrence	99(12.3)
Combined recurrence	51(6.3)
Death (n, %)	208(25.7)

Categorical variables were expressed as frequencies (percentages).

4. Discussion

For resectable esophageal malignancies, esophagectomy combined with systematic lymphadenectomy serves as the standard curative therapeutic strategy^[5–8]. MIE has been globally popularized to reduce open esophagectomy-related morbidity and mortality, with the advantages of less intraoperative bleeding, fewer pulmonary complications, a shorter hospital stay and faster postoperative recovery^[16–18]. The McKeown and Ivor Lewis procedures were the prevailing surgical options. Although prior studies have demonstrated higher risks of RLN injury, anastomotic leakage and pulmonary complications after MIE-McKeown than after the Ivor Lewis procedure^[19, 20], this technique provides unique oncologic benefits. It facilitated three-field lymphadenectomy to retrieve more lymph nodes, which achieved accurate pathological staging and optimized long-term survival outcomes. Additionally, the technique yielded longer proximal surgical margins, increasing the R0 resection rate for cervical and upper thoracic esophageal malignancies. Furthermore, cervical anastomosis reduced the incidence of fatal mediastinitis originating from anastomotic leakage and facilitated subsequent clinical management^[18–22]. Accordingly, MIE-McKeown has been widely adopted in high-incidence regions and large Chinese cancer centers^[15].

This single-center retrospective cohort study enrolled 808 consecutive esophageal carcinoma patients who received MIE-McKeown surgery performed by a single attending surgeon. No intraoperative death or open conversion occurred across all the patients. The R0 resection rate reached 98.1%, and adequate lymphadenectomy was achieved. The cohort featured a low postoperative complication rate and a perioperative mortality of merely 0.6%, with satisfactory postoperative recuperation. Survival analysis yielded 5-year OS and DFS rates of 60.1% and 55.5%, respectively. The perioperative profiles and long-term oncologic survival of our cohort were largely consistent with the existing domestic and overseas literature, while several indicators presented superior performance^[16–22]. Collectively, these results corroborate the safety and clinical practicality of MIE-McKeown and its ability to predict favorable long-term oncologic prognosis.

Survival analysis of the 808 enrolled patients revealed 1-, 3-, and 5-year OS rates of 93.9%, 72.3%, and 60.1%, alongside corresponding 1-, 3-, and 5-year DFS rates of 82.9%, 64.1%, and 55.5%, respectively. Sex was a notable prognostic factor: females had 5-year OS and DFS rates of 67.5% and 62.5%, respectively, which were significantly superior to the respective rates of 59.2% and 54.6% in males. Sex-driven survival disparities have been well documented across multiple malignancies. As reported by Haupt et al., males generally have higher incidence and mortality risks for non-genital cancers, presumably attributable to inherent sex differences in DNA repair capacity and genomic stability^[23]. From a clinical perspective, heavier tobacco and alcohol exposure among male patients may further widen the prognostic gap between sexes.

Pathological staging strongly affects the long-term survival of patients with esophageal cancer. In our cohort, the 5-year OS rates for patients with stage I, II, III and IV disease were 81.0%, 70.1%, 45.4% and 22.7%, respectively, with corresponding 5-year DFS rates of 78.0%, 67.5%, 39.0% and 18.2%, respectively. Statistically significant differences in both OS and DFS were detected across stage subgroups. Progressive deterioration in both OS and DFS was identified with advancing pathological stage. Early-stage malignancies are characterized by superficial invasion and a low likelihood of distant metastasis, enabling radical resection and minimizing postoperative recurrence to maintain a superior long-term prognosis. Conversely, intermediate and advanced tumors frequently feature deep mural infiltration, extensive lymphatic dissemination or systemic metastasis. Even after curative surgery, occult residual tumor foci substantially increase the risk of disease relapse and metastasis, ultimately impairing long-term survival^[16–20]. Collectively, these observations validated pathological staging as the paramount independent prognostic factor for patients with esophageal carcinoma.

With respect to the neoadjuvant strategy, no significant intergroup differences in 3-year OS were observed. Patients treated with neoadjuvant chemoimmunotherapy exhibited significantly better 3-year DFS ($P = 0.029$) relative to those undergoing neoadjuvant chemotherapy or primary surgery. This evidence corroborated that this combined regimen suppresses occult micrometastasis and reduces postoperative recurrence^[24, 25]. Mechanistically, chemotherapy debulked tumors, while immunotherapy reshaped the immunosuppressive tumor microenvironment, enhanced intratumoral effector T-cell infiltration and eradicated occult micrometastases to improve DFS^[26]. Multiple domestic phase III multicenter trials have validated improved DFS following neoadjuvant chemoimmunotherapy for locally advanced ESCC^[25]. Nevertheless, the limited follow-up duration, second-line salvage treatment, intrinsic tumor heterogeneity, variations in patients' baseline nutritional status and follow-up compliance hindered the translation of the superiority of DFS to evident 3-year OS gains^[24–28]. Neoadjuvant chemoimmunotherapy is preferentially recommended for locally advanced individuals to mitigate recurrence and optimize oncologic outcomes.

Chylothorax is a common postoperative complication of esophagectomy that may necessitate reoperation in severe cases. Six patients in our cohort developed chylothorax: two recovered after secondary thoracic duct ligation and the remaining four improved with conservative management.

Dissection along the esophageal mesentery and periductal lymphadenectomy carry inherent risks of thoracic duct injury and subsequent chylothorax. Prophylactic intraoperative thoracic duct ligation remains controversial for chylothorax prevention^[29]. We selectively performed ligation only when the duct was invaded by the tumor or intraoperatively injured. The long-term prognostic impact of thoracic duct ligation remains debated. Most studies have shown equivalent survival with or without ligation; some have linked prophylactic ligation to poor survival and high nodal recurrence, whereas others have reported survival gains^[29, 30]. Our survival analysis revealed comparable OS and DFS between patients with and without thoracic duct ligation, confirming that this procedure has no meaningful long-term prognostic influence.

Patients were grouped by preoperative BMI. DFS was similar among the groups, whereas the underweight group had markedly poorer OS ($P = 0.001$). Preoperative nutritional status barely influenced tumor recurrence, yet malnutrition served as an independent adverse prognostic factor for long-term survival. Insufficient nutritional reserve and impaired immunity in underweight patients increase postoperative complications, reduce adjuvant therapy tolerance and increase noncancer mortality^[31, 32]. Preoperative nutritional screening and personalized nutritional intervention are essential for improving survival among patients with a low BMI.

Several inherent limitations of the present study merit acknowledgment. First, this single-center retrospective study carried selection bias and lacks external validation for generalizability. Second, nonrandomized neoadjuvant regimen assignment may be confounded. Third, data on postoperative quality of life, functional recovery and cost-effectiveness were not collected, limiting comprehensive benefit assessment. Finally, no comparison with open esophagectomy or MIE-Ivor Lewis was performed.

5. Conclusions

MIE-McKeown is safe and oncologically effective. Individualized management based on tumor stage, preoperative nutritional status and neoadjuvant regimens helps optimize long-term patient prognosis.

Declarations

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Conflict of Interest: Dr. Luo Raojun, He Zhengfu, Cai Jingwei, Lin Zhongjie, Yan Peijian, Zhu Ziyi and Miss. Xu Weifang have no conflicts of interest or financial ties to disclose.

Author Contributions: All authors contributed to the study conception and design. Administrative support was performed by He Zhengfu. Material preparation and data collection were performed by Xu Weifang, Cai Jingwei, Lin Zhongjie and Yan Peijian. Data analysis was performed by Luo Raojun, He Zhengfu and Zhu Ziyi. The first draft of the manuscript was written by Luo Raojun, Xu Weifang, He

Zhengfu, Cai Jingwei and Zhu Ziyi and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval: This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Sir Run Run Shaw Hospital, School of Medicine, Zhejiang University (NO. 2026-2509-01).

Consent to participate: Informed consent was obtained from all individual participants included in the study.

Consent to publish: The authors affirm that human research participants provided informed consent for publication of the images in Figure 1, 2 and 3.

Data availability: All figures and supporting images generated in this study are readily available from the corresponding author upon reasonable request. The de-identified perioperative surgical data, pathological diagnosis results and summary statistical data supporting the findings of this study are included in this paper and its supplementary materials. Detailed human clinical data, including esophageal cancer patients' clinical pathological characteristics, complete postoperative follow-up records and perioperative outcome data, are not publicly available via online repositories due to strict ethical policies and patient privacy protection requirements (Ethical approval number: NO. 2026-2509-01 issued by Research Ethics Committee of Sir Run Run Shaw Hospital, School of Medicine, Zhejiang University). These restricted clinical data can be obtained by qualified researchers upon reasonable request to the corresponding author at zhuziyicn@zju.edu.cn, with the formal approval of the above Ethics Committee and compliance with relevant national biomedical research ethical regulations.

Clinical trial number not applicable.

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Figures

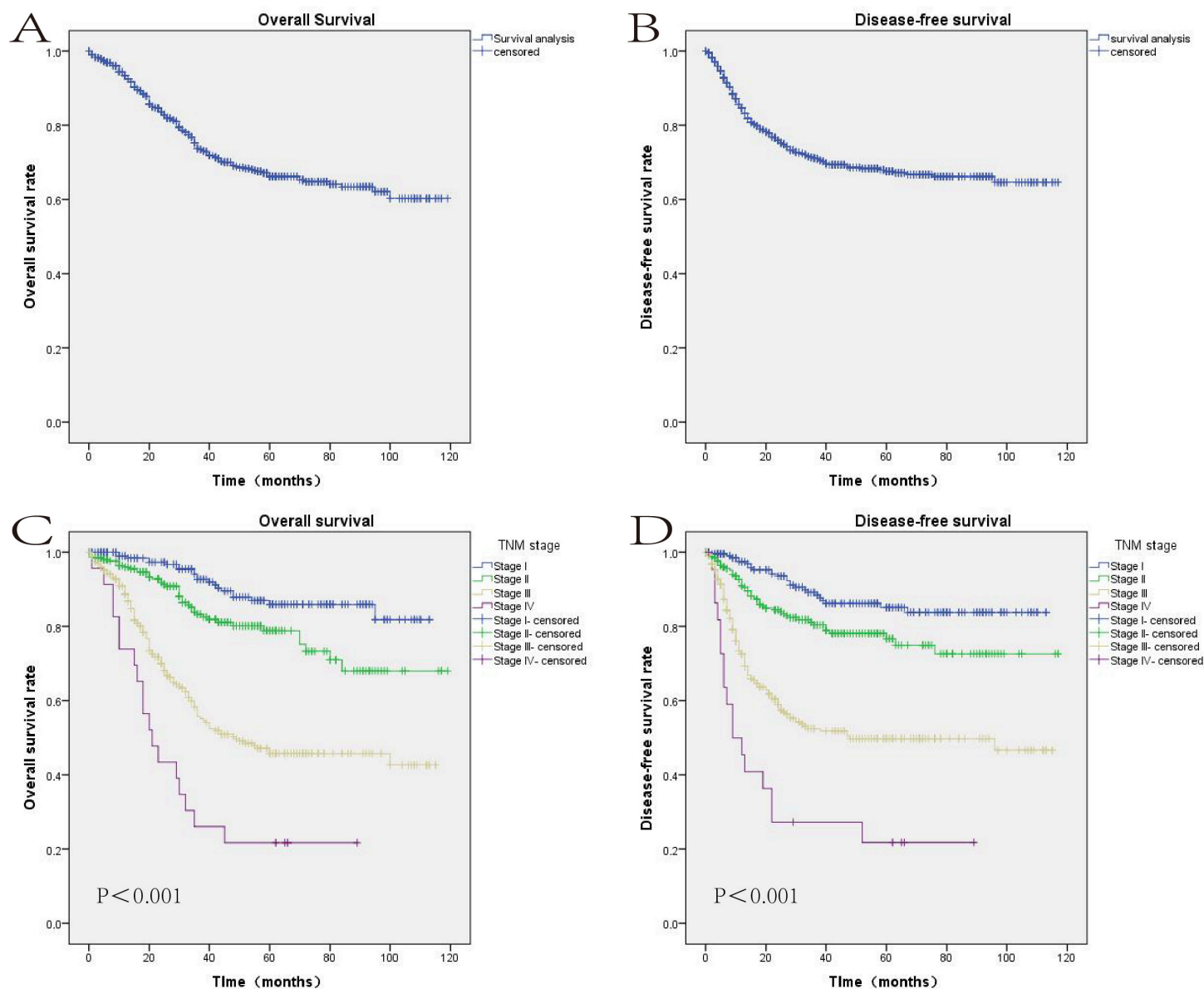


Figure 1

A Kaplan–Meier overall survival curves for the entire cohort. B Kaplan–Meier disease-free survival curves for the entire cohort. C TNM stage-stratified Kaplan–Meier curves of overall survival. D TNM stage-stratified Kaplan–Meier curves of disease-free survival.

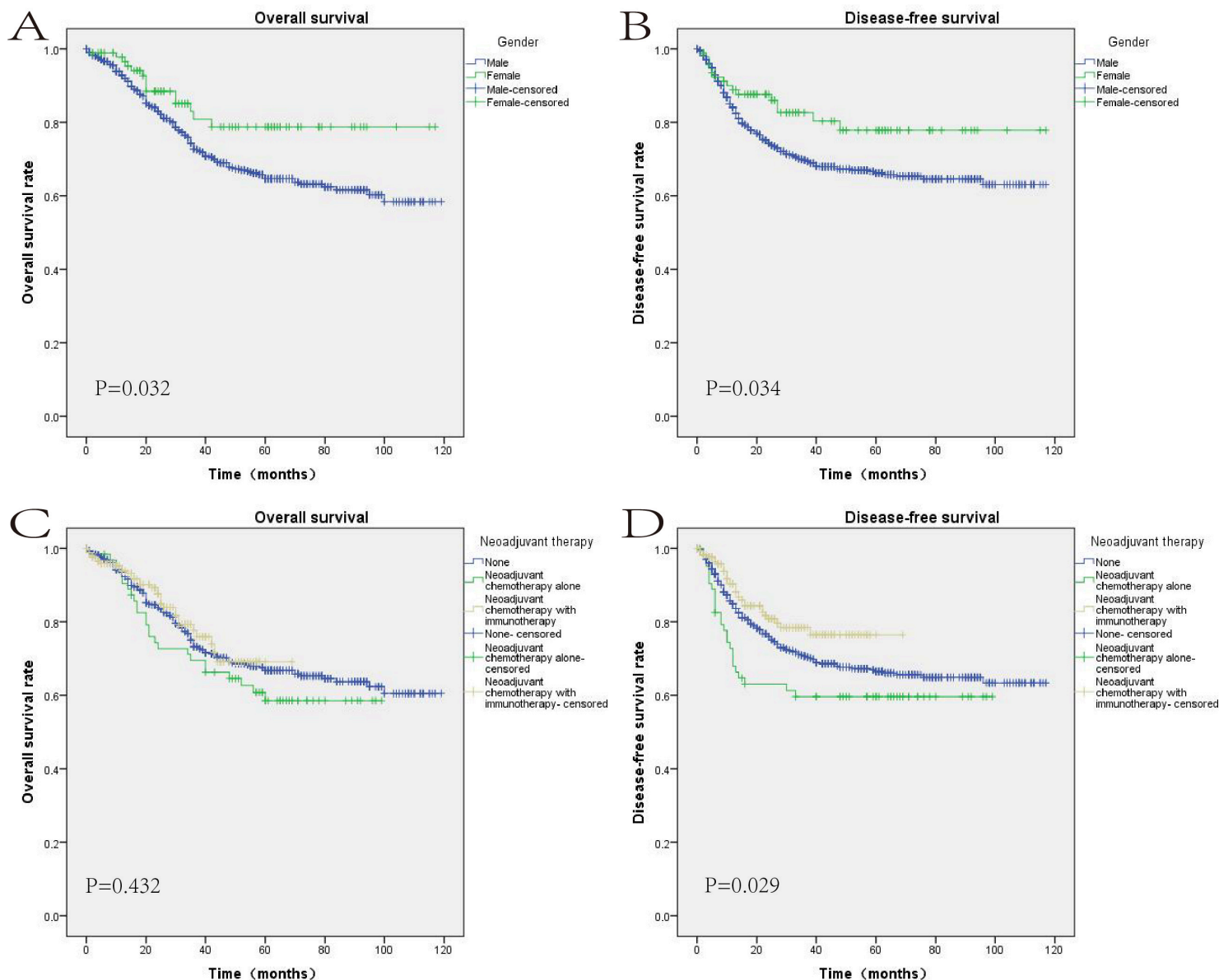


Figure 2

A Gender-stratified Kaplan–Meier curves for overall survival. B Gender-stratified Kaplan–Meier curves for disease-free survival. C Kaplan–Meier overall survival curves stratified according to preoperative therapeutic regimens. D Kaplan–Meier disease-free survival curves stratified according to preoperative therapeutic regimens.

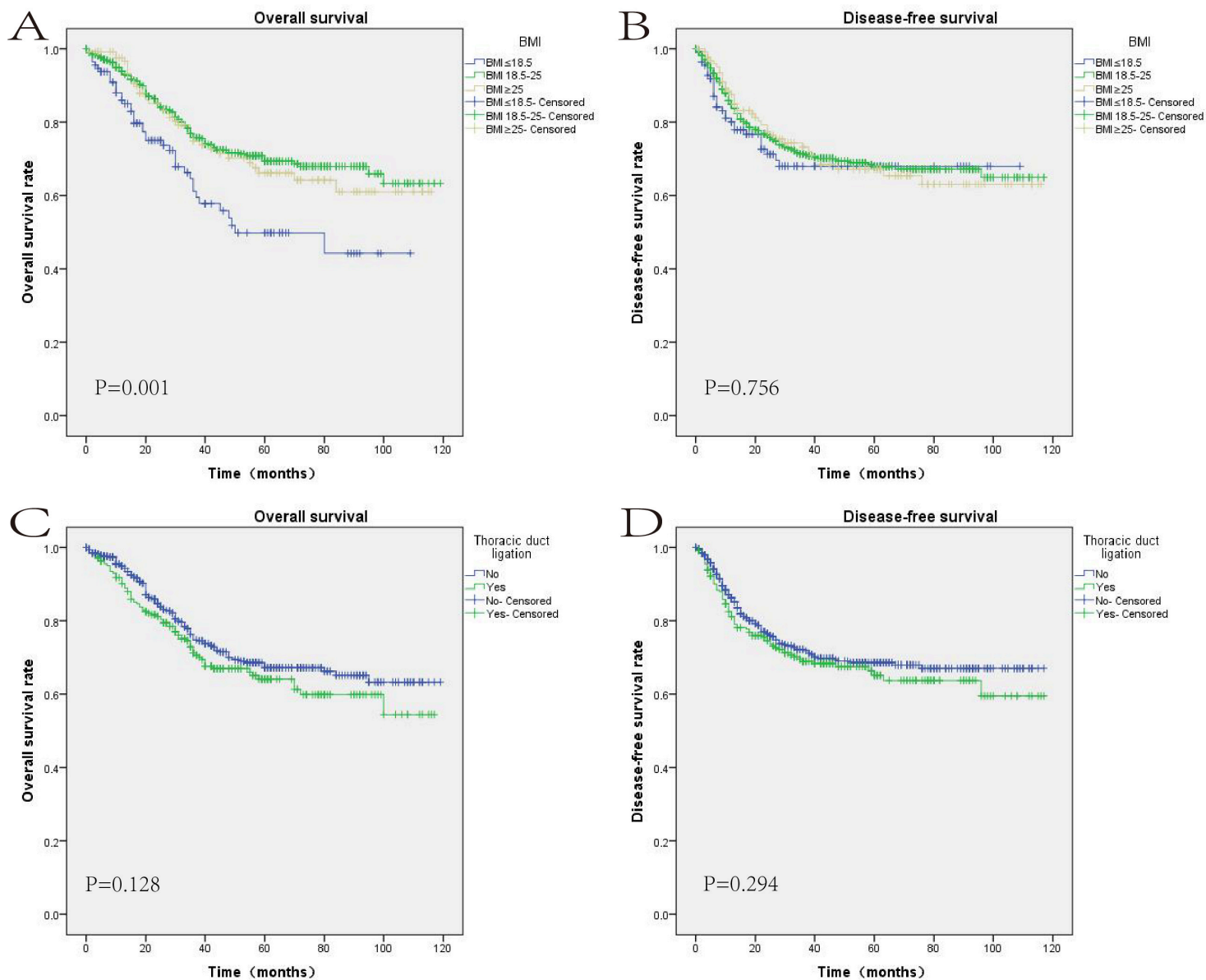


Figure 3

A BMI-stratified Kaplan-Meier curves for overall survival. B BMI-stratified Kaplan-Meier curves for disease-free survival. C Kaplan-Meier overall survival curves grouped by thoracic duct ligation status. D Kaplan-Meier disease-free survival curves grouped by thoracic duct ligation status.