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Outcomes of Open Versus Minimally Invasive Ivor-Lewis Esophagectomy for Cancer: A Propensity-Score Matched Analysis of NSQIP Database

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ABSTRACT

Introduction. We conducted this analysis to compare the outcomes of open transthoracic esophagectomy (OTTE) and minimally invasive transthoracic esophagectomy (MITTE) when performed for oncologic indications.

Methods. The NSQIP esophagectomy-targeted database during 2-year period was used. Only patients who underwent elective TTE for oncologic indications were included. Patients were matched per a propensity score for the likelihood of receiving OTTE versus MITTE.

Results. Overall, 2098 esophagectomies were reported; 576 met the inclusion criteria. A total of 161 purely OTTE patients were matched 1:1 with patients who received purely MITTE. OTTE was associated with higher reported rates of abdominal and mediastinal lymphadenectomies (LAD) (26.7% vs. 3.1% and 38.5% vs. 16.1%, respectively; $p < 0.001$) and had shorter mean operative time (329 vs. 414 min; $p < 0.001$). However, OTTE patients had higher rates of wound infection (7.5% vs. 1.9%), longer median hospitalization (10 vs. 8 days), more non-home discharges (18.0 vs. 8.1%), and a tendency toward higher rates of postoperative transfusion (13.0% vs. 6.8%; $p = 0.092$). The overall complications rate was higher in OTTE (46.0% vs. 33.5%; $p = 0.028$). No difference was noted in the rates of anastomotic leak, negative margins, reoperation, readmission, or mortality. Laparoscopic versus robotic approaches were uniformly comparable, except for higher rates of reported abdominal LAD in laparoscopic and higher rates of reported mediastinal LAD in robotic approach.

Conclusions. MITTE is comparable to OTTE for oncologic indications in immediate postoperative outcomes. A concern is raised regarding the oncologic outcome given the lower reported rates of lymphadenectomies. Comparison of long-term outcomes is essential to address this concern.

Esophageal cancer is the eighth most common cancer and the sixth most common cause of cancer deaths worldwide.[1] Squamous cell carcinoma is the most common type globally, whereas adenocarcinoma is the dominant pathology in the United States.[2,3] While each type is considered a distinct biologic and pathologic entity, in addition to other malignancies that can arise in the esophagus, the principles of therapy are similar.[4] Complete surgical resection is the current standard of care for nonmetastatic esophageal cancer and the cornerstone for cure. Esophagectomy, as a major surgical procedure, has high risks of morbidity and mortality, which approach 40–50% and 2–8%, respectively.[5]

The advancement of technology and surgical tools in the past few decades have allowed surgeons to perform many major operations using minimally invasive approaches. Minimally invasive esophagectomy (MIE) was initially described in the mid-1990s[6] and has since become increasingly popular. Multiple variations have been introduced, including laparoscopic, totally thoracoscopic, robotic, and hybrid approaches.[7]

The controversy of the comparison between MIE and open esophagectomy (OE) stems from the wide technical variability of the esophagectomy, in addition to the discrepancy in the reported results. Some studies report

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evident superiority of the minimally invasive resections,[8,9] whereas others advocate for equivalency in short-term outcomes between the two approaches.[10,11] However, most of these results are derived from case–control studies with data collection spanning over several decades without regards to the technical variations of the procedure. Two randomized trials from Europe[12,13] revealed decreased rates of immediate pulmonary postoperative complications with some variants of MIE. To date, no study has reported a direct comparison between a purely open and purely minimally invasive approaches of a certain esophageal resection rather than a general OE versus MIE design with a wide range of technical variability within each comparison group.

With the recent release of an esophagectomy-targeted database by the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP®), we sought to investigate the controversy surrounding the topic by analyzing the data from esophagectomies performed in all participating United States hospitals during the fiscal years of 2016 and 2017. We focused our analysis on the Transthoracic Esophagectomy (TTE), also known as Ivor-Lewis esophagectomy, as the most commonly performed procedure for esophageal cancer in the United States. To our knowledge, this is the first study to compare directly purely open to purely minimally invasive TTE in an American population.

METHODS

Study Design

The main NSQIP database reports 274 variables collected from more than 600 participating hospitals across the United States. The esophagectomy-targeted database included esophagectomies reported by 71 participant hospitals with an additional 19 variables related to the pertinent outcomes of this procedure. By merging the databases, perioperative characteristics and 30-day postoperative outcomes could be extracted for patients who underwent esophagectomies between January 1, 2016, and December 31, 2017. Of note, the NSQIP database is established and maintained by trained and certified surgical reviewers who collect and enter the data, and the web-based database is audited periodically to ensure the highest quality.

Patient Selection

Only patients who underwent Ivor-Lewis esophagectomy (or TTE) were included. This was identified in the database per the Current Procedure Terminology (CPT) code 43,117 (partial esophagectomy, distal two-thirds, with thoracotomy and separate abdominal incision, with or without proximal gastrectomy). We then selected patients who had the TTE for malignant indications and excluded those who had benign or unknown pathologies. Patients who were reported to have received this procedure under emergent settings also were removed from the dataset. For the purposes of this study, only patients who underwent open TTE (OTTE) in both the abdominal and thoracic portions were compared to those who underwent minimally invasive TTE (MITTE) in both portions of the procedure as well. Patients who had a combined approach (i.e., hybrid) in addition to patients who were diagnosed with metastatic disease were excluded from the analysis.

Statistical Analysis

IBM SPSS v22 (Armonk, NY) was used for the entire analysis of the database. After application of the inclusion/exclusion criteria, a propensity score was calculated for the likelihood of undergoing OTTE versus MITTE using a multivariable logistic regression model of the patients' perioperative characteristics, including the following predictors: sex, age, race, body mass index (BMI), significant weight loss (> 10% in 6 months), diabetes mellitus (DM), hypertension (HTN), chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), chronic steroid use, American Society of Anesthesiology (ASA) functionality class, type of malignancy, and neoadjuvant chemotherapy/radiation. We also included the intraoperative data of additional visceral resections as a predictor in the model. These variables that account toward the propensity score are factors known to exert an impact on the surgical outcome, yet they are not attributed to the surgical approach of OTTE versus MITTE per se. Patients who underwent conversions of their MITTE into OTTE were classified based on the intention-to-treat.

Patients were then matched 1:1 based on the propensity score by following the nearest neighbor method with a caliper width of 0.1 standard deviations. The matched pairs were included in the final comparison of outcomes.

The primary goal of the study was to compare the immediate major postoperative complications between OTTE and MITTE, including mortality.

As a secondary goal, a subgroup analysis was performed to compare the outcomes of laparoscopic versus robotic TTE. A propensity score was calculated based on the same set of perioperative predictors as described earlier. Patients were then matched on a 2:1 ratio based on the propensity score. The matched dataset was used to compare the immediate postoperative outcomes.

Baseline characteristics were compared using logistic regression for matched and unmatched cases to assess for adequate balance after the matching. Conditional logistic regression was applied for comparison of categorical variables and mixed effect modeling for continuous variables. Statistical significance was set at < 0.05 throughout the analysis.

RESULTS

The NSQIP esophagectomy-targeted database contained 2098 reported cases in 2016–2017 from participating hospitals. After application of the inclusion/exclusion criteria, 526 patients were identified to have received an elective TTE for oncologic indications via a totally OTTE ($N = 259$) or totally MITTE ($N = 267$). Patients who had any deviation from the standard operation, such as repair or a tracheoesophageal fistula or the use of a free jejunal graft, were removed from the study population. In the unmatched dataset, OTTE patients demonstrated higher rates of significant preoperative weight loss (29.3% vs. 16.1%; $p < 0.001$) and lower rates of neoadjuvant radiation (51.7% vs. 69.7%; $p < 0.001$). They also demonstrated a trend toward higher rates of smoking (31.3% vs. 24.3%; $p = 0.080$) and lower rates of neoadjuvant chemotherapy (68.3% vs. 75.3%; $p = 0.081$) compared with MITTE patients.

A propensity score was calculated for the likelihood of receiving an OTTE versus MITTE based on the set of perioperative factors described above. A total of 161 pairs of patients were matched from each group on a 1:1 ratio following the nearest neighbor method and a caliper width of 0.1 standard deviation. Figure 1 demonstrates a flow diagram of the steps of patients' selection and matching. Table 1 demonstrates the preoperative characteristics of the matched and unmatched datasets. The standardized difference (SD) is reported for each variable and all SDs were uniformly < 0.1 reflecting an adequate balance between the matched groups per the matching caliper of 0.1.

Upon comparison of surgical outcomes, OTTE was reported to be associated with higher rates of reported abdominal lymphadenectomy (LAD) and mediastinal LAD (26.7% vs. 3.1%, and 38.5% vs. 16.1%, respectively; $p < 0.001$). Mean operative time was significantly shorter in the OTTE group (311 ± 91 vs. 423 ± 133 min, $p < 0.001$). In regards to postoperative complications, OTTE patients had higher rates of superficial surgical site infections (SSSI) (7.5% vs. 1.9%; $p = 0.031$). No difference was noted in anastomotic leak, status of resection margins, cardiopulmonary complications, reoperation, or unplanned readmission. Postoperative mortality was not different between the study groups (3.1% vs. 0.6%; $p = 0.214$). Notably, OTTE patients had a longer median postoperative hospitalization (10 vs. 8 days; $p = 0.002$) and a higher likelihood of nonhome discharges (18.0% vs. 8.1%; $p = 0.012$). Results of intraoperative findings and postoperative outcomes of OTTE versus MITTE are summarized in Tables 2 and 3.

The secondary goal of the study was to conduct a subgroup analysis of surgical outcomes between laparoscopic and robotic TTE. Similarly, we calculated a propensity score for receiving laparoscopic versus robotic TTE based on the same set of predictors and matched the patients on a 2:1. Eighty-two patients from the laparoscopic group were matched to 41 patients from the robotic group. Table 4 demonstrates the preoperative demographics and characteristics of the unmatched and matched datasets.

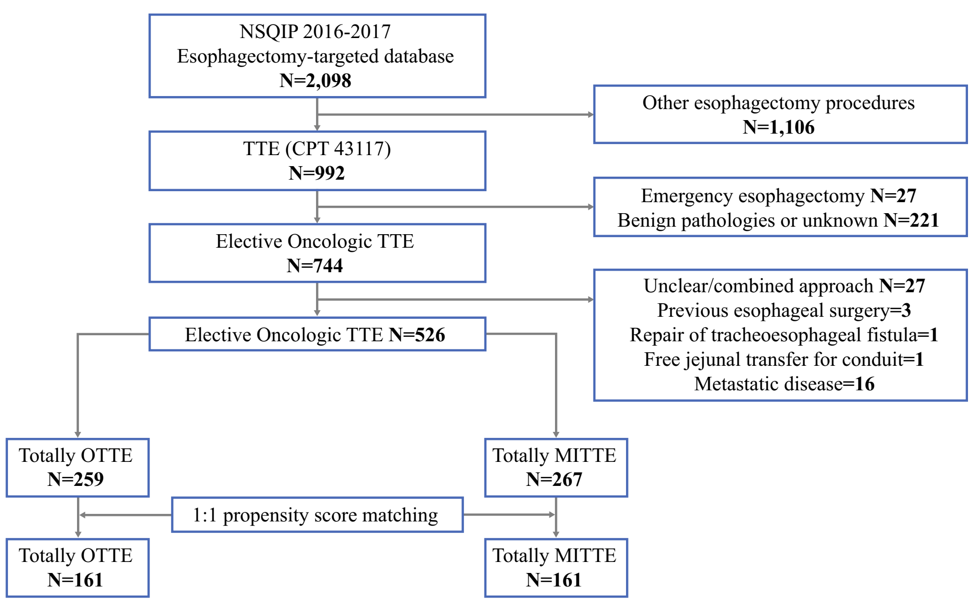

FIG. 1 Patient selection and application of inclusion/exclusion criteria. *OTTE* open transthoracic esophagectomy; *MITTE* minimally invasive transthoracic esophagectomy; *TTE* transthoracic esophagectomy

TABLE 1 Baseline demographic and preoperative characteristics of the patient population

	Unmatched dataset				1:1 Matched dataset			
	OTTE	MITTE	SD	*p*	OTTE	MITTE	SD	*p*
Sample size	259	267			161	161		
Age	63.39 ± 9.61	64.95 ± 9.02	0.095	0.155	64.12 ± 9.41	63.86 ± 9.17	0.057	0.797
Sex				0.262				0.869
Male	218 (84.2%)	234 (87.6%)	0.055		141 (87.6%)	139 (86.3%)	0.006	
Female	41 (15.8%)	33 (12.4%)	0.052		20 (12.4%)	22 (13.7%)	0.006	
Race				0.213				0.784
White	187 (72.2%)	184 (68.9%)	0.061		119 (73.9%)	114 (70.8%)	0.009	
Black	1 (0.4%)	6 (2.2%)	0.009		1 (0.6%)	6 (3.7%)	0.042	
Other	71 (27.4%)	77 (28.9%)	0.077		41 (25.5%)	41 (25.5%)	0.000	
BMI	27.60 ± 6.07	27.99 ± 5.60	0.048	0.447	27.78 ± 6.16	27.47 ± 5.93	0.025	0.648
Comorbidities								
Diabetes mellitus	54 (20.8%)	42 (15.7%)	0.097	0.143	27 (16.8%)	25 (15.5%)	0.012	0.880
COPD	23 (8.9%)	17 (6.4%)	0.007	0.325	9 (5.6%)	13 (8.1%)	0.005	0.508
Heart failure	1 (0.4%)	0 (0.0%)	0.002	0.492	0 (0.0%)	0 (0.0%)	0.000	0.999
HTN	127 (49.0%)	129 (48.3%)	0.004	0.930	86 (53.4%)	80 (49.7%)	0.019	0.577
Bleeding disorder	9 (3.5%)	8 (3.0%)	0.004	0.809	4 (2.5%)	5 (3.1%)	0.019	0.913
Smoker	81 (31.3%)	65 (24.3%)	0.121	0.080	44 (27.3%)	46 (28.6%)	0.003	0.901
Chronic steroids	7 (2.7%)	4 (1.5%)	0.055	0.376	3 (1.9%)	4 (2.5%)	0.004	0.982
Weight loss (> 10%)	76 (29.3%)	43 (16.1%)	0.169	< 0.001	39 (24.2%)	35 (21.7%)	0.008	0.691
Preoperative albumin	3.89 ± 0.41	3.88 ± 0.45	0.008	0.715	3.86 ± 0.41	3.86 ± 0.45	0.013	0.879
Preoperative Hct	35.81 ± 17.48	34.30 ± 22.39	0.035	0.390	34.68 ± 21.84	33.57 ± 24.28	0.021	0.665
Neoadjuvant chemo	177 (68.3%)	201 (75.3%)	0.091	0.081	124 (77.0%)	118 (73.3%)	0.038	0.519
Neoadjuvant radiation	134 (51.7%)	186 (69.7%)	0.206	< 0.001	110 (68.3%)	106 (65.8%)	0.026	0.722
ASA classification				0.385				0.232
I	2 (0.8%)	0 (0.0%)	0.010		2 (1.2%)	0 (0.0%)	0.008	
II	40 (15.4%)	50 (18.7%)	0.083		28 (17.4%)	20 (12.4%)	0.020	
III	206 (79.5%)	207 (77.5%)	0.074		125 (77.6%)	137 (85.1%)	0.016	
IV	11 (4.2%)	10 (3.7%)	0.018		6 (3.7%)	4 (2.5%)	0.011	
Diagnosis								0.506
Adenocarcinoma	231 (89.2%)	246 (92.1%)	0.009		147 (91.3%)	146 (90.7%)	0.012	
SCC	21 (8.1%)	20 (7.5%)	0.031		11 (6.8%)	14 (8.7%)	0.001	
Other malignancy	7 (2.7%)	1 (0.4%)	0.044	0.187	3 (1.9%)	1 (0.6%)	0.036	
Conversion to OTTE	NA	15 (5.6%)	NA	NA	NA	10 (6.2%)	NA	NA
Clinical *T* stage				0.135				0.219
c*T*1	80 (30.8%)	92 (34.4%)	0.011		53 (32.9%)	52 (32.3%)	0.015	
c*T*2	47 (18.1%)	57 (21.3%)	0.062		27 (16.8%)	37 (23.0%)	0.076	
c*T*3	121 (46.7%)	103 (38.6%)	0.088		72 (44.7%)	64 (39.8%)	0.046	
c*T*4	3 (1.2%)	0 (0.0%)	0.014		3 (1.9%)	0 (0.0%)	0.017	
c*T*x	8 (3.1%)	15 (5.6%)	0.025		6 (3.7%)	8 (5.0%)	0.034	
Clinical *N* stage				< 0.00				0.003
c*N*0	131 (50.6%)	151 (56.6%)	0.072	1	85 (52.8%)	92 (57.1%)	0.019	
c*N*1	58 (22.4%)	56 (21.0%)	0.015		33 (20.5%)	33 (20.5%)	0.027	
c*N*2	36 (13.9%)	36 (13.5%)	0.051		17 (10.6%)	22 (13.7%)	0.036	
c*N*3	27 (10.4%)	3 (1.1%)	0.002		20 (12.4%)	2 (1.2%)	0.000	
cNx	7 (2.7%)	21 (7.9%)	0.121		6 (3.7%)	12 (7.5%)	0.022	

ASA American society of anesthesiology; *COPD* chronic obstructive pulmonary disease; *Chemo* chemotherapy; *Hct* hematocrit; *HTN* hypertension requiring medication; *MITTE* minimally invasive transthoracic esophagectomy; *NA* not applicable; *OTTE* open transthoracic esophagectomy; *SCC* squamous cell carcinoma; *SD* standard difference

TABLE 2 Intraoperative findings and 30-day surgical morbidities of OTTE versus MITTE in the matched dataset

	OTTE (n = 161)	MITTE (n = 161)	HR [95% CI]	p
Reported abdominal LAD	43 (26.7%)	5 (3.1%)	0.595 [0.453–0.772]	< 0.001
Reported mediastinal LAD	62 (38.5%)	26 (16.1%)	0.890 [0.794–0.942]	< 0.001
Pathologic *T* stage			1.165 [0.700–1.681]	0.261
Early (p*T*0–p*T*2)	86 (53.4%)	97 (60.2%)		
Locally advanced (p*T*3–p*T*4)	75 (46.6%)	64 (39.8%)		
Pathologic *N* stage			0.873 [0.528–1.095]	0.087
Early (p*N*0–p*N*1)	124 (77.0%)	137 (85.1%)		
Locally advanced (p*N*2–p*N*3)	37 (23.0%)	24 (14.9%)		
Additional visceral resection	4 (2.5%)	4 (2.5%)	0.994 [0.998–1.001]	0.999
Operative time (min, mean ± SD)	311 ± 91	423 ± 133	+ 96.4 (+ 80.2, + 131.6)	< 0.001
Operative time > 300 min	77 (47.8%)	127 (78.9%)	6.263 [3.859–10.164]	< 0.001
Postoperative complications				
Superficial SSI	12 (7.5%)	3 (1.9%)	0.015 [0.004–0.059]	0.031
Deep SSI	0 (0.0%)	2 (1.2%)	N/A	0.498
Organ space SSI	23 (14.3%)	17 (10.6%)	1.142 [0.501–2.466]	0.389
Wound dehiscence	1 (0.6%)	0 (0.0%)	N/A	0.998
Pneumonia	28 (17.4%)	19 (11.8%)	0.871 [0.416–1.826]	0.206
Unplanned reintubation	18 (11.2%)	15 (9.3%)	1.210 [0.754–1.469]	0.714
Ventilation > 48 h	17 (10.6%)	9 (5.6%)	0.710 [0.537–1.288]	0.151
Sepsis	9 (5.6%)	6 (3.7%)	1.011 [0.917–1.354]	0.598
Septic shock	15 (9.3%)	9 (5.6%)	0.938 [0.786–1.919]	0.289
Deep vein thrombosis	2 (1.2%)	3 (1.9%)	1.253 [0.497–2.792]	0.991
Pulmonary embolism	1 (0.6%)	3 (1.9%)	0.925 [0.907–2.885]	0.623
Clostridium difficile infection	3 (1.9%)	2 (1.2%)	0.918 [0.888–1.137]	0.951
Cerebrovascular accident	0 (0.0%)	0 (0.0%)	N/A	0.999
Myocardial infarction	4 (2.5%)	2 (1.2%)	0.795 [0.152–1.296]	0.685
Anemia requiring transfusion	21 (13.0%)	11 (6.8%)	0.846 [0.316–1.077]	0.092
Overall complications	74 (46.0%)	54 (33.5%)	0.698 [0.485–0.814]	0.028
Anastomotic leak	25 (15.6%)	21 (13.0%)	1.267 [0.644–2.493]	0.176
Grade I (no intervention)	3 (1.9%)	0 (0.0%)		
Grade II (minor intervention)	8 (5.0%)	12 (7.5%)		
Grade III (major intervention)	14 (8.7%)	9 (5.6%)		

CI confidence interval; *HR* hazard ratio; *LAD* lymphadenectomy; *MITTE* minimally invasive transthoracic esophagectomy; *min* minutes; *OTTE* open transthoracic esophagectomy; *SD* standard deviation; *SSI* surgical site infection

Laparoscopic TTE was associated with higher rates of reported abdominal LAD (14.6% vs. 0.0%; $p < 0.008$) and lower rates of reported mediastinal LAD (18.3% vs. 34.1%; $p = 0.044$) compared with robotic TTE. Otherwise, no difference was detected between the groups in terms of postoperative morbidity including anastomotic leak, mortality, resection margins, length of hospitalization, reoperation, and readmission rates. Patients were discharged to their homes (or their admission source) on similar rates from each group (86.6% vs. 92.7%; $p = 0.382$). Table 5 summarizes the postoperative outcomes of laparoscopic versus robotic TTE.

DISCUSSION

This is the first propensity-matched study comparing pure open to minimally invasive Ivor-Lewis esophagectomy in a national cohort. In the current study, we demonstrate that MITTE was associated with significantly lower rates of overall complications compared to OTTE. The improved individual outcomes consisted of fewer superficial surgical site infections, shorter length of stay, and more frequent home discharges. There was no difference in anastomotic leak or 30-day mortality.

TABLE 3 Thirty-day postoperative outcomes of OTTE versus MITTE in the matched dataset

	OTTE (n = 161)	MITTE (n = 161)	HR [95% CI]	p
Postoperative mortality	5 (3.1%)	1 (0.6%)	0.667 [0.398–1.174]	0.214
Median LOS in days (IQR)	10 (9.25–11.25)	8 (7–10.5)	−2.933 (−4.816, −1.537)	0.002
LOS > 10 days	80 (49.7%)	56 (34.8%)	0.551 [0.388–0.780]	0.009
LOS > 30 days	9 (5.6%)	5 (3.1%)	0.429 [0.111–1.657]	0.413
Unplanned reoperation	26 (16.1%)	24 (14.9%)	0.948 [0.637–1.478]	0.878
Disposition				
Home/facility home	132 (82.0%)	148 (91.9%)	1.161 [0.922–1.571]	0.012
Nonhome	29 (18.0%)	13 (8.1%)		
Margins			0.763 [0.249–1.273]	0.963
Negative	146 (90.7%)	148 (91.9%)		
Distal	3 (1.9%)	2 (1.2%)		
Proximal	4 (2.5%)	2 (1.2%)		
Radial	4 (2.5%)	5 (3.1%)		
Both	3 (1.9%)	3 (1.9%)		
Unknown	1 (0.6%)	1 (0.6%)		
Unplanned readmission	23 (14.3%)	18 (11.2%)	0.856 [0.406–1.337]	0.504

CI confidence interval; *HR* hazard ratio; *IQR* interquartile range; *MITTE* minimally invasive transthoracic esophagectomy; *LOS* length of stay; *OTTE* open transthoracic esophagectomy; *SD* standard deviation

Most systematic reviews, single-center studies, and clinical trials collect data over years to decades, during which significant variations in surgical technique and patient management are discovered and adopted. This introduces chronological bias, which is particularly important when evaluating minimally invasive techniques that are in constant flux, because it can interfere with the ability to accurately compare outcomes between control and experimental arms.[14] The NSQIP esophagectomy-targeted database collects data from multiple hospitals, allowing us to access a large sample size during the short duration of 2016–2017. As such, it is very likely that the surgical techniques and management approaches used during this timeframe were homogeneous.

The Ivor-Lewis transthoracic esophagectomy is the most commonly performed procedure in the United States for esophageal malignancies, accounting for 47.5% of all oncologic cases in the NSQIP database. In esophageal resection, the surgical approach and location of the anastomosis imply a great influence on the postoperative complication profile and therefore should be taken into consideration when attempting to compare outcomes across studies. In the TIME trial, albeit the MIE group was purely minimally invasive, surgeons had the option of performing an additional cervical incision and anastomosis.[12] This study reported statistically significant fewer pulmonary complications. Remarkably, however, 64% of the anastomoses were eventually reported to be cervical, hence these data do not accurately translate into ours where a thoracic anastomosis was performed uniformly in our patient population. A recent study of the Dutch national registry compared OE to MIE during 4 years of data collection and concluded no difference in the incidence of overall or pulmonary complications, but the rates of anastomotic leak and reoperation were significantly higher in the MIE group.[15] A closer look at the data shows that patients in the MIE group had more thoracic anastomoses than those in the open group (51% vs. 36%).

Our study eliminates this within-group-variance bias by comparing purely minimally invasive (laparoscopy and thoracoscopy) to purely open (laparotomy and thoracotomy) transthoracic esophagectomies. While multiple studies have compared both approaches, the minimally invasive arm is generally highly variable. A single-center series from China in 2018 showed decreased rates of wound and respiratory complications after MIE in 158 patients over a 22-year period.[16] Comparison with our results shows that their statistical significance was more likely attributed to an unusually high rate of pulmonary complications in the open group (55%) than by a true reduction in the minimally invasive group (29%). In our cohort, pulmonary complications were seen in 24.8% of open cases and 18.6% of minimally invasive cases.

The results of our study are consistent with the findings of meta-analyses comparing OE to MIE. A recent meta-analysis showed that MIE was associated with significantly decreased pulmonary complications (17.1% vs. 22.6%) as well as in-hospital mortality (3.8% vs. 4.5%) compared with OE.[17] While our pulmonary complication and mortality rates showed a similar trend to those above, we likely did not reach statistical significance due to our smaller sample size difference (322 vs. 14,781 patients). As

TABLE 4 Demographic and perioperative characteristics of laparoscopic TTE versus robotic TTE

	Unmatched dataset				Matched dataset 2:1			
	Lap. TTE	Rob. TTE	SD	*p*	Lap. TTE	Rob. TTE	SD	*p*
Sample size	214	53			82	41		
Age	65.22 ± 8.86	63.85 ± 9.65	0.029	0.847	63.27 ± 9.28	62.76 ± 9.98	0.006	0.983
Sex				0.642				0.999
Males	186 (86.9%)	48 (90.6%)	0.065		72 (87.8%)	36 (87.8%)	0.001	
Females	28 (13.1%)	5 (9.4%)	0.061		10 (12.2%)	5 (12.2%)	0.001	
Race				< 0.001				0.762
White	134 (62.6%)	50 (94.3%)	0.185		75 (91.5%)	39 (95.1%)	0.018	
Black	4 (1.9%)	2 (3.8%)	0.114		3 (3.7%)	1 (2.4%)	0.011	
Other/unknown	76 (35.5%)	1 (1.9%)	0.193		4 (4.8%)	1 (2.4%)	0.035	
BMI	28.03 ± 5.59	27.83 ± 5.72	0.017	0.526	27.98 ± 5.60	27.80 ± 6.19	0.020	0.479
Comorbidities								
Diabetes mellitus	30 (14.0%)	12 (22.6%)	0.028	0.141	17 (20.7%)	6 (14.6%)	0.002	0.417
COPD	15 (7.0%)	2 (3.8%)	0.083	0.538	2 (2.4%)	2 (4.9%)	0.041	0.600
Hear failure	0 (0.0%)	0 (0.0%)	0.000	0.999	0 (0.0%)	0 (0.0%)	0.000	0.999
HTN	107 (50.0%)	22 (41.5%)	0.016	0.286	50 (61.0%)	25 (61.0%)	0.001	0.999
Bleeding disorder	7 (3.3%)	1 (1.9%)	0.007	0.900	0 (0.0%)	0 (0.0%)	0.000	0.999
Smoker	48 (22.4%)	17 (32.1%)	0.091	0.155	21 (25.6%)	12 (29.3%)	0.055	0.672
Chronic steroids	3 (1.4%)	1 (1.9%)	0.013	0.950	2 (2.4%)	1 (2.4%)	0.000	0.999
Weight loss (> 10%)	36 (16.8%)	7 (13.2%)	0.076	0.677	10 (12.2%)	7 (17.1%)	0.012	0.580
Preoperative albumin	3.88 ± 0.40	3.88 ± 0.64	0.081	0.136	3.86 ± 0.38	3.83 ± 0.61	0.068	0.352
Preoperative Hct	33.71 ± 23.07	36.66 ± 19.43	0.065	0.519	34.44 ± 21.61	35.63 ± 21.97	0.022	0.922
Neoadjuvant Chemo	160 (74.8%)	41 (77.4%)	0.018	0.859	62 (75.6%)	30 (73.2%)	0.016	0.827
Neoadjuvant Radiation	145 (67.8%)	41 (77.4%)	0.074	0.187	56 (68.3%)	30 (73.2%)	0.009	0.678
ASA classification				0.053				0.916
I	0 (0.0%)	0 (0.0%)	0.000		0 (0.0%)	0 (0.0%)	0.000	
II	45 (21.0%)	5 (9.4%)	0.061		11 (13.4%)	5 (12.2%)	0.011	
III	163 (76.2%)	44 (83.0%)	0.038		68 (82.9%)	35 (85.4%)	0.008	
IV	6 (2.8%)	4 (7.5%)	0.024		3 (3.7%)	1 (2.4%)	0.006	
Diagnosis				0.883				0.601
Adenocarcinoma	197 (92.1%)	49 (92.5%)	0.034		76 (92.7%)	37 (90.2%)	0.009	
SCC	16 (7.5%)	4 (7.5%)	0.042		5 (6.1%)	4 (9.8%)	0.018	
Other malignancy	1 (0.5%)	0 (0.0%)	0.000		1 (1.2%)	0 (0.0%)	0.000	
T stage				0.188				0.677
*T*1	77 (35.9%)	15 (28.3%)	0.039		32 (39.0%)	13 (31.7%)	0.031	
*T*2	40 (18.7%)	17 (32.1%)	0.065		17 (20.7%)	12 (29.3%)	0.073	
*T*3	83 (38.9%)	20 (37.7%)	0.188		31 (37.8%)	16 (39.0%)	0.088	
*T*4	0 (0.0%)	0 (0.0%)	0.000		0 (0.0%)	0 (0.0%)	0.000	
*T*x	14 (6.5%)	1 (1.9%)	0.274		2 (2.4%)	0 (0.0%)	0.111	
N stage				0.152				0.307
*N*0	114 (53.3%)	37 (69.8%)	0.017		52 (63.4%)	28 (68.3%)	0.007	
*N*1	47 (22.0%)	9 (17.0%)	0.074		13 (15.9%)	8 (19.5%)	0.001	
*N*2	31 (14.5%)	5 (94%)	0.032		14 (17.1%)	4 (9.8%)	0.014	
*N*3	2 (0.9%)	1 (1.9%)	0.021		0 (0.0%)	1 (2.4%)	0.020	
*N*x	20 (9.3%)	1 (1.9%)	0.182		3 (3.7%)	0 (0.0%)	0.079	

ASA American Society of Anesthesiology; *COPD* chronic obstructive pulmonary disease; *Chemo* chemotherapy; *Hct* hematocrit; *HTN* hypertension requiring medication; *Lap* laparoscopic; *NA* not applicable; *Rob* robotic; *SCC* squamous cell carcinoma; *SD* standard difference; *TTE* transthoracic esophagectomy

TABLE 5 Perioperative characteristics of laparoscopic versus robotic TTE in the 2:1 matched dataset

	Lap TTE (*n* = 82)	Rob TTE (*n* = 41)	HR [95% CI]	*p*
Conversion to OTTE	7 (8.5%)	1 (2.4%)	1.015 [0.579–1.922]	0.267
Reported abdominal LAD	12 (14.6%)	0 (0.0%)	0.219 [0.081–0.476]	0.008
Reported mediastinal LAD	15 (18.3%)	14 (34.1%)	3.679 [1.149–13.934]	0.044
Additional visceral resection	2 (2.4%)	1 (2.4%)	0.947 [0.564–1.341]	0.999
Operative time (min, mean ± SD)	445 ± 96	449 ± 116	+ 15 [− 18, + 44]	0.445
Operative time > 480 min	31 (37.8%)	16 (39.0%)	0.885 [0.593–1.705]	0.995
Postoperative complications				
Superficial SSI	2 (2.4%)	0 (0.0%)	0.181 [0.003–10.463]	0.552
Deep SSI	1 (1.2%)	0 (0.0%)	N/A	0.999
Organ space SSI	14 (17.1%)	3 (7.3%)	15.162 [0.315–27.316]	0.173
Wound dehiscence	0 (0.0%)	0 (0.0%)	N/A	0.999
Pneumonia	16 (19.5%)	3 (7.3%)	0.776 [0.421–6.348]	0.112
Unplanned reintubation	9 (11.0%)	4 (9.8%)	0.044 [0.013–5.941]	0.552
Ventilation > 48 h	9 (11.0%)	3 (7.3%)	0.261 [0.008–8.726]	0.749
Sepsis	6 (7.3%)	1 (2.4%)	0.939 [0.813–2.202]	0.422
Septic shock	7 (8.5%)	2 (4.9%)	0.844 [0.180–5.238]	0.716
Deep vein thrombosis	1 (1.2%)	0 (0.0%)	N/A	0.999
Pulmonary embolism	2 (2.4%)	1 (2.4%)	1.261 [0.008–8.726]	0.999
Cerebrovascular accident	0 (0.0%)	0 (0.0%)	N/A	0.999
Myocardial infarction	0 (0.0%)	0 (0.0%)	N/A	0.999
Anemia requiring transfusion	2 (2.4%)	1 (1.2%)	4.024 [0.157–20.870]	0.999
Overall complications	28 (34.6%)	12 (29.3%)	0.821 [0.520–1.694]	0.290
Leak			0.952 [0.901–1.035]	0.226
No leak	65 (79.3%)	35 (85.4%)		
Grade I (no intervention)	3 (3.7%)	0 (0.0%)		
Grade II (minor intervention)	6 (7.3%)	5 (12.2%)		
Grade III (major intervention)	8 (9.8%)	1 (2.4%)		
Postoperative mortality	2 (2.4%)	0 (0.0%)	N/A	0.999
Median LOS in days (IQR)	8 (7–12.25)	7 (7–9.50)	− 1.92 [− 3.5, + 0.55]	0.143
LOS > 10 days	22 (26.8%)	8 (19.5%)	0.813 [0.131–2.667]	0.505
LOS > 30 days	6 (7.3%)	1 (2.4%)	0.702 [0.409–3.165]	0.422
Unplanned reoperation	15 (18.3%)	5 (12.2%)	0.692 [0.205–10.891]	0.448
Disposition				
Home/facility home	71 (86.6%)	38 (92.7%)	1.204 [0.853–2.161]	0.382
Non-home	11 (86.6%)	3 (7.3%)		
Margins			4.015 [0.409–39.391]	0.419
Negative	74 (90.2%)	35 (85.4%)		
Positive at anastomosis	6 (7.32%)	4 (9.76%)		
Positive radially	1 (1.2%)	2 (4.9%)		
Unknown	1 (1.2%)	0 (0.0%)		
Unplanned readmission	12 (14.6%)	6 (14.6%)	1.576 [0.636–4.805]	0.999

CI confidence interval; *HR* hazard ratio; *IQR* interquartile range; *LAD* lymphadenectomy; *Lap* laparoscopic; *LOS* length of stay; *min* minutes; *OTTE* open transthoracic esophagectomy; *Rob* robotic; *SD* standard deviation; *SSI* surgical site infection

additional data become available in the NSQIP database over the next few years, it would be possible to see these trends become statistically significant. Another meta-analysis concluded a significant reduction in blood loss in the MIE technique, with increased operating time and equivalent rates of anastomotic leak in accordance with our findings.[18] In Europe, the MIRO randomized trial compared a hybrid minimally invasive technique (thoracotomy and laparoscopy) to open esophagectomy.[13] Their variant marginalizes the benefits attributed to avoiding a thoracotomy incision. A similar study from South Korea compared open with hybrid (thoracotomy with laparoscopy) Ivor-Lewis, with data showing equivalent rates of morbidity and mortality between both groups, suggesting that the intrathoracic portion of the operation may carry more morbidity than its intra-abdominal counterpart.[19]

An unexpected finding in our study pertains to the lymphadenectomy achieved by the open or minimally invasive approach. The data show a significantly higher rate of reported mediastinal and abdominal lymphadenectomy in OTTE. This is not supported in the literature where lymphadenectomy appears to be comparable in both approaches.[15,20,21] Some studies even reported a higher lymph node yield in the minimally invasive group.[22] While this discrepancy seems alarming, it could likely be explained by the inconsistency of CPT codes reporting by the operating surgeons. Other studies that evaluated the long-term results of both approaches reported equivalency in their oncological disease-free and overall survival, supporting the hypothesis of reporting bias rather than a true difference in the lymph node yield.[21,23]

This study also is the first to provide a propensity-matched analysis between laparoscopic and robotic MITTE for esophageal cancer. Our results show that both approaches are comparable in regards to postoperative complications. The only study to evaluate the outcomes of robotic-assisted TTE in a randomized, controlled setting demonstrated a decrease in overall complications compared with open esophagectomy (80% to 59%; $p = 0.02$).[24] However, these rates are markedly elevated for both groups, which can limit their generalizability to our population. As robotic esophagectomy is becoming increasingly more popular, additional data are warranted to outline the safety profile and outcomes of this technique.

The shortcomings of our study revolve around its retrospective nature and its dependency on a data registry, both of which convey inherent limitations. Moreover, the NSQIP database does not report on the volume or experience of the surgeons or centers that offer the operations. This is of paramount importance in this topic as MITTE is established to have learning curve of 50–70 operations.[25,26] Nonetheless, given the lower-than-average rates of morbidity and mortality in our data, it is likely that the data were collected from centers with high volume. Another limitation pertains to the sample size that was analyzed. During the conception of the study, the decision was to restrain the analysis to a specific type of operation (Ivor-Lewis) and to use propensity-matched analysis to eliminate the influence of all possible confounders that might be attributed to the variations in the techniques of the esophageal resection. As mentioned earlier, we applied strict inclusion criteria with removal of cases that reported any deviation from the standard described operation. Despite the reduced sample size, we matched patients with a very acceptable balance between the study groups except for nodal involvement which demonstrated on final pathology a trend toward higher rates of advanced disease in the OTTE group. Another limitation of our study is the limitation in variables and predictors to what is being provided, an inherent shortcoming of any registry-based study. Nonetheless, we believe that the procedure-targeted databases by NSQIP provide detailed and valuable information pertinent to each procedure, which significantly aids in understanding the true outcomes.

CONCLUSIONS

This is the first report of a propensity-matched study comparing open to minimally invasive Ivor-Lewis transthoracic esophagectomy for resectable esophageal cancer. Our data were effective at successfully matching and eliminating confounding variables between both groups. Our analysis demonstrated reduced rates of short-term postoperative complications in the MITTE group, particularly in superficial surgical site infections. This approach also allowed patients to have a shorter length of stay as well as fewer instances of nonhome discharges. On a critical note, OTTE patients had a trend toward higher rates of locally advanced nodal disease on final pathology (*N*2–*N*3), which generally correlates with higher rates of surgical morbidity and longer hospitalization. Mortality rates, pulmonary complications, and anemia requiring transfusion showed a favorable trend in the minimally invasive group but did not reach statistical significance. A subgroup analysis showed that laparoscopic and robotic transthoracic esophagectomies were equivalent in all studied outcomes.

Interestingly, there was a significant difference in the rate of reported lymphadenectomy (both abdominal and mediastinal), with significant results favoring the open approach. We believe that this is likely related to the CPT coding that is used by NSQIP for data collection, as numerous studies have showed that open and minimally invasive esophagectomy are equivalent in that respect. Further research is needed to address the oncologic outcomes, specifically in relation to lymphadenectomy, in open versus minimally invasive Ivor-Lewis esophagectomy.

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