Relative Incremental Cost of Postoperative Complications of Esophagectomy

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The purpose of this study was to quantify the cost impact of complications of esophagectomy and identify opportunities for reducing costs while optimizing outcomes. Patients undergoing esophagectomy at a single institution between 2002 and 2017 were included. Complications were tabulated from clinical data. Direct hospital costs were determined for all encounters between the day of surgery and postoperative day 90. Risk factors were assessed using logistic regression. The relative incremental cost of complications was assessed using multivariable linear regression. A total of 761 patients were included in this study. 428 patients (56%) experienced at least 1 complication. Factors associated with increased likelihood of complications included age ($P < 0.001$), female sex ($P = 0.005$), pack-years ($P = 0.006$), cerebrovascular disease ($P = 0.021$), and diabetes ($P = 0.052$). The most common complications were atrial arrhythmia (18%), transfusion (15%), and atelectasis requiring bronchoscopy (8%). The complications incurring the greatest incremental cost per event were anastomotic complications requiring surgical treatment (200%, $P < 0.001$) or those treated nonoperatively (96%, $P < 0.001$), and renal failure (178%, $P < 0.001$). Pneumonia increased costs by 40% ($P < 0.001$) and other major pulmonary complications increased costs by 75% ($P < 0.001$). Though the cost of complications was unaffected by surgical approach (minimally invasive esophagectomy vs open), MIE was associated with decreased cost vis-à-vis a lower complication rate (41% vs 60%, $P < 0.001$). Complications accounted for 28% of the aggregate 90-day direct hospital cost for all patients. Pulmonary complications accounted for 35% of all complication-attributable costs, while anastomotic complications accounted for 17%. Anastomotic and pulmonary complications after esophagectomy with gastric conduit reconstruction represent high-yield targets for cost reduction and quality improvement.

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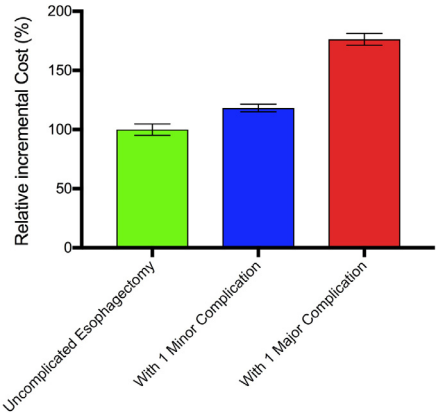
Keywords: Esophagectomy, Complications, Cost, Outcomes



Relative incremental cost impact of major vs minor complications of esophagectomy.

Central Message

Surgical complications increase the cost of care for patients undergoing esophageal resection. High-cost complications represent priorities for quality improvement and cost reduction.

Perspective Statement

Postoperative complications have received increasing scrutiny as markers of surgical quality and hospital performance, but the cost impact of complications of esophagectomy is poorly characterized. This study aims to quantify the relative incremental cost of complications of esophagectomy, thereby relating quality improvement to cost reduction.

Abbreviations: ASGS, Accordion Severity Grading System; CDC, Clavien-Dindo classification; CI, confidence interval; ERP, enhanced recovery pathway; FEV_1, forced expiratory volume in 1 s; ICG, indocyanine green; ICU, intensive care unit; LOS, length of stay; MIE, minimally invasive esophagectomy; OR, odds ratio; RR, risk ratio; STS, Society of Thoracic Surgeons; U.S., United States

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INTRODUCTION

Unsustainable healthcare spending in the United States has spurred new interest in quantifying the cost of medical care, and in relating costs to quality measures. Healthcare spending increased 4.3% in 2016, totaling $3.3 trillion and accounting for nearly 18% of the U.S. gross domestic product.[1] It is estimated that nearly 1 of every 3 healthcare dollars is spent on surgical care,[2] and thus a thorough understanding of the true costs of surgery and its complications is critical to the development and implementation of best practices to contain costs while improving quality. Complications and their associated costs have received increased scrutiny as indicators of surgical quality. Esophageal cancer represents a growing source of morbidity and mortality among thoracic surgical patients, and its incidence in the United States has recently been on the rise.[3] Esophagectomy, along with neoadjuvant chemoradiotherapy, represents the mainstay of curative treatment for locally advanced esophageal cancer, and is a major operation associated with significant morbidity. It is well accepted that complications increase the cost of care for surgical patients, including those undergoing esophagectomy. Yet targeted approaches to curbing costs without compromising quality require a more detailed understanding of the complication-cost relationship. With the exception of anastomotic leak, the attributable costs of specific complications of esophagectomy have not been well characterized. Here, we investigate the relative incremental cost of many commonly encountered complications after esophagectomy to provide further detail about the specific and varying ways in which surgical complications impact the cost of care.

METHODS

Patients and Data Collection

This retrospective cohort study included patients undergoing esophagectomy at a single institution between mid-2002 and mid-2017. Patients were initially selected from a prospectively maintained institutional database of esophagectomy patients. Information for this database is sourced directly from medical records by a trained professional research nurse and undergoes periodic audits for data quality. The database contains clinical variables, including demographic and other patient information, comorbidities, diagnoses, procedures, operative time and approach, length of stay (LOS), and intraoperative and postoperative complications for each patient. All clinical data and any missing data were sourced directly from patients' medical records by the authors. Patients were selected from a single institution to maintain consistency of the complication-cost relationship. Patients were excluded if clinical or cost data were incomplete for the full 90 days following surgery. To relate complications to costs, hospital billing records were independently queried for cost data, which was concatenated with the clinical data. Direct hospital costs—both fixed and variable—were used for this study; indirect costs were not considered. Direct costs include such things as surgical supplies, medications, hospital stay, and operating room time. Indirect costs include utilities, IT support, administrative costs, depreciation, etc.—items not directly attributable to that encounter. Costs were reported on a per-encounter basis; the costs of all encounters, beginning at the index surgical encounter (during which the esophagectomy was performed) and ending on postoperative day 90, were summarized to a single total 90-day direct hospital cost for each patient.

Outcomes

Outcomes measured in this study included the incidence of commonly encountered complications following esophagectomy, the relative incremental cost impact of major vs minor complications (ie, the attributable cost above baseline), and the relative incremental cost of specific complications grouped by organ system(s). Complication incidence is reported both as a percentage of all complications incurred (defined as the number of complications of interest divided by the total number of complications in the cohort) and as a percentage of patients affected (defined as the number of patients incurring that complication divided by the total number of patients). Complications were designated as either major or minor according to Society of Thoracic Surgeons (STS) criteria.

Statistical Analysis

The cost of major vs minor complications was modeled with multivariable linear regression using total 90-day direct hospital cost as the dependent variable, and total number of major and minor complications as categorical independent variables. The impact of specific groups of complications on cost was then modeled using multivariable linear regression to determine the attributable incremental cost of each group. All costs are reported as relative incremental costs, defined as cost divided by the cost of an uncomplicated esophagectomy, expressed as a percentage. By definition, a relative incremental cost of 100% refers to the direct hospital cost of the encounter containing one esophagectomy and zero complications. Included in the estimate of the cost of an uncomplicated esophagectomy is some contribution from hospital stay, ancillary services, etc., which are inevitable components of the encounter for even an uncomplicated esophagectomy, and were not separated out for this study, but rather considered "expected" costs of care. Lastly, the impact of each complication on total 90-day direct hospital cost over the entire cohort—and on total complication-attributable cost—was estimated using the incremental costs identified during multivariate linear regression. Due to regional variability in healthcare spending and pricing models, costs are reported as percentages rather than absolute dollars for the sake of greater generalizability. Results are reported as means with 95% confidence intervals (CI). Figures display means with error bars representing 95% CIs.

Risk factors for complications were first analyzed with Student's *t*, Mann-Whitney U, chi-square, and Fisher's exact tests,

where appropriate. Factors found to be significant or nearly significant on univariate analyses were included in the multivariable logistic regression model using dichotomous outcomes "zero complications" and "one or more complications." Results are reported as adjusted odds ratios (OR). Approval for this study was obtained from the Partners Human Research Committee Institutional Review Board (IRB #2006P002188, activated November 14, 2006), which waived the need for informed consent.

RESULTS

Patient Characteristics

This retrospective cohort study included 761 patients with a mean ± SD age of 63.3 ± 10 years (Table 1). Six hundred thirty-two patients (83%) were male and 728 patients (96%) were Caucasian. Five hundred seventy-eight patients (76%) were either current or former smokers with a mean ± SD smoking history of 37.8 ± 26.4 pack-years. Twenty-one patients (3%) underwent neoadjuvant chemotherapy and an additional 437 patients (57%) received neoadjuvant chemoradiotherapy. Seventy-eight percent of patients underwent open esophagectomy, while 22% underwent minimally invasive esophagectomy (MIE). Median length of hospital stay was 7 days (interquartile range 5−9 days) for patients undergoing MIE vs 10 days (IQR 6−14 days) for patients undergoing open esophagectomy ($P < 0.001$). Operative mortality was 0.8% for the entire cohort.

Complications and Risk Factors

A total of 959 complications (including major and minor designation) were recorded for the entire cohort, affecting 56% of all patients (Table 1). Fifty-one percent of affected patients incurred only a single complication, while the other 49% experienced multiple complications. Major complications affected 19% of all patients. The most common complications were atrial arrhythmia (n = 136, 18%), transfusion requirement (n = 135, 15.4%), and atelectasis requiring bronchoscopy (n = 64, 8.4%; Fig. 1). On univariate analysis, significant or near-significant ($P < 0.1$) risk factors associated with complications included age ($P < 0.001$), female sex ($P = 0.005$), number of pack-years ($P = 0.006$), coronary artery disease ($P = 0.095$), cerebrovascular disease ($P = 0.021$), diabetes ($P = 0.052$), 0 and surgical approach ($P < 0.001$). In multivariate analysis, only age ($P = 0.011$) and surgical approach ($P = 0.016$) maintained independent associations with complications (Table 2).

Cost of Complications

The relative incremental cost impact of major vs minor complications was modeled using multivariable linear regression, and results are shown in Figure 2. The mean relative incremental cost of major complications was 76.4% per event. In other words, the total 90-day direct hospital cost of esophagectomy increased by an average of 76.4% above baseline for each major complication incurred. Similarly, the mean relative incremental cost of minor complications was 18.2% per event. These costs were not significantly affected by surgical approach (ie, the cost of a major or minor complication was no different between patients who had undergone MIE vs open esophagectomy).

The cost of specific complications was modeled using multivariable linear regression, and results are shown in Figure 3. Anastomotic complications requiring reoperation (2.5% all patients) increased costs by 200% above baseline ($P < 0.001$), representing the highest per-event incremental cost. Anastomotic complications that were managed nonoperatively occurred in 1.4% of patients (11/761) and increased costs by 96% per event ($P < 0.001$). Renal failure affected 0.8% of patients (6/761) and increased costs by 178% per event ($P < 0.001$). Per STS standards, a diagnosis of renal failure required that patients met 2 conditions: (1) creatinine > 2.0 and (2) creatinine greater than twice the patient's baseline, measured preoperatively. Pneumonia, which occurred in 6.4% of patients (49/761), increased cost by 40% per event ($P < 0.001$) and other major pulmonary complications (a category which includes reintubation, tracheostomy, prolonged air leak, tracheoesophageal fistula, acute respiratory distress syndrome, and complicated pleural effusion), affected 6.2% of patients and increased cost by 75% ($P < 0.001$). The two most common complications—atrial arrhythmia and transfusion requirement—increased costs by 11.6% ($P = 0.008$) and 5.6% ($P = 0.16$), respectively. Other types of complications and their associated costs are shown in Figure 3. Complications requiring reoperation (excluding anastomotic leak, which was modeled separately) occurred in 4% of patients and increased cost by 95% per event ($P < 0.001$). One-fourth of these reoperations were thoracic duct ligations for chyle leak. Though the cost of complications was unaffected by surgical approach (MIE vs open), MIE was associated with decreased 90-day cost, likely vis-à-vis a decreased incidence of complications. After controlling for the cost of complications, surgical approach was not a significant predictor of increased hospital cost in the overall cohort ($P = 0.863$). Moreover, in the subset of patients experiencing no postoperative complications, there was no significant difference in mean 90-day cost ($P = 0.062$). However, patients who underwent MIE experienced a lower overall rate of complications than patients who underwent open esophagectomy (40.9% vs 60.3% respectively, $P < 0.001$).

Complications alone increased the total 90-day direct hospital cost of esophagectomy by 37% above baseline.[1] Twenty-seven percent of all costs incurred in the cohort overall were attributable to complications alone (Fig. 4). Of all complication-attributable costs, 37% were due solely to pulmonary complications (7% to pneumonia, 16% to other major events, and 14% to minor events). Complications requiring reoperation accounted for 25% of all complication-attributable costs

[1]This figure represents total cost attributable to complications expressed as a percentage of total cost attributable to 762 uncomplicated esophagectomies, based on the incremental cost estimates generated from the multivariate linear regression model summarized in Figure 3.

Table 1. Incidence of Postoperative Complications

Complication	n	Percentage of All Complications (n = 959)	Percentage of Patients Affected (n = 761)
Ileus	24	2.5	3.2
Stricture requiring dilation	23	2.4	2.9
Gastric outlet obstruction	18	1.5	2.2
Anastomotic complication treated surgically	19	1.9	2.5
Anastomotic complication treated nonoperatively	11	1.1	1.4
Other GI complication	44	4.6	5.2
Major pulmonary	109	11.4	10.9
Pneumonia	49	5.1	6.4
Reintubation	34	3.5	4.5
Tracheostomy	17	1.8	2.2
Prolonged air leak	6	0.6	0.8
Tracheoesophageal fistula	0	0	0
Complicated pleural effusion	1	0.1	0.1
ARDS	1	0.1	0.1
Minor pulmonary	139	14.5	15.6
Atelectasis	64	6.7	8.4
Pneumothorax	5	0.5	0.7
Continued ventilator requirement	3	0.3	0.4
Other pulmonary complication	68	7.1	8.8
Major cardiovascular	38	4.0	4.8
Ventricular arrhythmia	17	1.8	2.2
Deep venous thrombosis	12	1.3	1.6
Pulmonary embolism	6	0.6	0.8
Myocardial infarction	2	0.2	0.3
Cardiac tamponade	2	0.2	0.3
Acute thromboembolic limb ischemia	1	0.1	0.1
Minor cardiovascular	166	17.3	20.5
Atrial arrhythmia	136	14.2	17.7
Other cardiovascular complication	30	3.1	4.0
Major neurologic	11	1.1	1.4
RLN paresis	10	1.0	1.3
CNS event	1	0.1	0.1
Minor neurologic	50	5.2	6.6
Delirium	29	3.0	3.8
Other neurologic	21	2.2	2.8
Bleeding/hematologic	139	14.5	15.9
Transfusion requirement	135	14.1	15.4
Other hematologic complication	4	0.4	0.5
Major infection	23	2.4	2.9
Sepsis	20	2.1	2.6
Empyema	1	0.1	0.1
Deep organ space infection	2	0.2	0.3
Minor infection	57	5.9	7.1
UTI	37	3.9	4.9
SSI	10	1.0	1.3
Other infection	10	1.0	1.3
Renal failure	6	0.6	0.8
Other major complication	36	3.8	4.0
Chylothorax treated surgically	8	0.8	1.1
Other event treated surgically	24	2.5	2.7
Other minor complication	60	6.3	7.5
Chylothorax treated medically	5	0.5	0.7
Other event treated medically	48	5.0	6.3

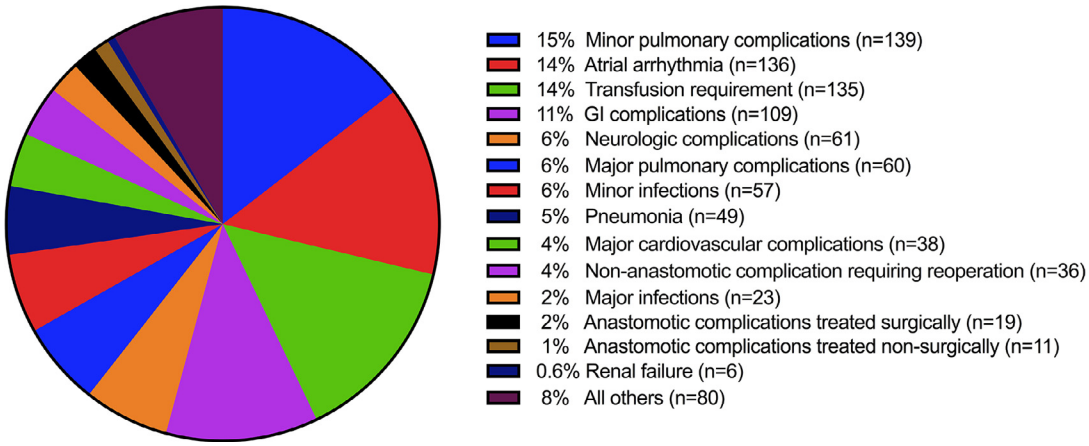

Figure 1. Relative incidence of commonly occurring complications of esophagectomy, reported as a percentage of all complications recorded.

(13% due to anastomotic complications and 12% due to others). The combined cost of anastomotic complications—including those treated conservatively—accounted for 17% of all complication-attributable costs. Of note, the 2 most commonly occurring complications—atrial arrhythmia and transfusion requirement—accounted for only 5.6% and 2.8% of all complication-attributable costs, respectively. Renal failure, which increased costs by 178% per event, only occurred in 6 patients, and thus only accounted for 3.8% of all complication-attributable costs.

DISCUSSION

This study quantifies the incidence and relative cost impact of complications most commonly experienced by patients undergoing esophagectomy for esophageal cancer. While a handful of other studies have begun to investigate the cost impact of complications following esophagectomy,[4–9] this study utilizes a more comprehensive 90-day postoperative window, and all cost and clinical data are taken directly from hospital records, rather than extrapolated from national datasets.

The current study identifies several complications that significantly impact postoperative morbidity and 90-day hospital costs following esophagectomy. Though atrial arrhythmia and transfusion requirement both incurred only modest per-event incremental costs (11.6% and 5.6%, respectively), they affected a high proportion of patients in the cohort (17.7% and 15.4%, respectively), and thus approaches to reduce the need for transfusion or rate of atrial arrhythmia could significantly reduce the total burden of complications in esophagectomy patients. Renal failure was associated with a very high per-event incremental cost (178%) in our study, but affected only 6 patients. All 6 of these patients experienced renal failure in the setting of a complicated and protracted postoperative course involving sepsis (3 patients) and/or shock (4 patients). The median LOS for these patients was 37 days (vs 9 days for patients without renal failure, $P = 0.026$). Thus, renal failure may function somewhat as a surrogate for other significant events that often involve extended periods of high-level and costly care. Despite this, renal failure only accounted for a small fraction of all complication-attributable costs (3.8%).

The reported rates of complications found in this study are largely similar to those reported elsewhere. Most published series report a postoperative complication rate between 48% and 60% following esophagectomy.[5,6,10–13] The lack of consensus regarding how best to measure complications—and even which complications to measure—constitutes a significant barrier to comparing across different studies. Luketich et al, for example, reporting on an impressive 1011 esophagectomy patients, found a 24.7% morbidity rate, yet the limited repertoire of complications reported includes only major complications while excluding minor complications.[14] Two other series that focused only on major complications reported rates of 28%[7] and 36%.[15] In our current study, major complications affected 19% of all patients. Low et al reported on a comprehensive repertoire of postesophagectomy complications in a multicenter study involving 2704 patients to benchmark the rates of various adverse events.[13] The authors tracked 48 different complications (vs 42 in our study) and reported an overall complication rate of 59% (vs 56% in our study). The authors also report that the incidence of atrial arrhythmia (among the most common complications reported) was 14.5%, similar to the rate of 17.7% identified in our cohort.

As the cost of surgical care has garnered increased attention in recent years, a handful of studies have sought to quantify the cost of esophagectomy and its related complications. Our findings are corroborated by Goense et al, who found an 82% increase in the mean cost of esophagectomy following major complications, and 22% following minor complications, in a cohort of 201 esophagectomy patients.[8] The authors categorized complication severity according to the Clavien-Dindo classification (CDC) rubric, where grades ≤3A were considered minor and ≥3B were considered major. This methodology differs from that used in our study, which categorically designates complications as either major or minor according to accepted

Table 2. Patient Characteristics and Risk Factors for Complications

Patient Characteristic	All Patients (n = 761)	No Complications (n = 333)	≥1 Complication (n = 428)	*P* Value	Multivariate OR	*P* Value
Age,* mean ± SD	63.3 ± 10	61.8 ± 9.8	64.4 ± 10.1	<0.001	1.03	0.025
Gender,* % female	17.0	12.6	20.3	0.005	0.673	0.158
Race, % non-White	4.3	5.1	3.7	0.338	–	–
BMI, mean ± SD	27.5 ± 5.3	27.5 ± 5.1	27.5 ± 5.4	0.976	–	–
ECOG score, %						
0	4.7	5.8	3.8	0.204	–	–
1	95.3	94.2	96.2		–	–
Smoking status, %						
Never smoker	22.9	26.1	20.3	0.218	–	–
Past smoker	64.5	61.0	67.3		–	–
Current smoker	11.4	12.0	11.0		–	–
Pack-years,*,† mean ± SD	37.8 ± 26.4	33.6 ± 23.3	40.5 ± 28.0	0.006	1.01	0.056
Comorbidities, %						
Hypertension	47.6	45.3	49.4	0.279	–	–
CHF	0.1	0.3	0.0	0.438	–	–
CAD*	16.0	13.5	18.0	0.095	1.10	0.712
PVD	4.5	3.6	5.1	0.309	–	–
CVD*	2.8	1.2	4.0	0.021	1.60	0.445
Diabetes*	14.8	12.0	17.1	0.052	1.31	0.343
COPD	3.9	3.3	4.4	0.424	–	–
Other comorbidities	3.7	2.1	4.9	0.041	–	–
Pre-op steroids	1.3	1.2	1.4	1.00	–	–
Neoadjuvant chemoradiation*	57.4	61.9	54.0	0.072	1.10	0.333
Surgical approach,* %						
Open	77.8	39.7	60.3	<0.001	1	Reference
MIE	22.2	59.1	40.9		0.554	0.016
LOS, days [median (IQR)]	9 (8–12)	7 (6–8)	10 (7–13)	<0.001	–	–
Operative mortality, %	0.8	0.0	1.4	0.038	–	–

BMI, body mass index; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVD, cerebrovascular disease; ECOG, Eastern Cooperative Oncology Group; IQR, interquartile range; LOS, length of stay; MIE, minimally invasive esophagectomy; OR, odds ratio; PVD, peripheral vascular disease; SD, standard deviation.

*Factors that were significant or near significant on univariate analyses were included in the multivariable model.

†Calculated only for past or current smokers.

STS consensus guidelines. Carrott et al reported on the cost impact of 29 different complications of esophagectomy and similarly found an increase in hospital cost from no complications to minor complications, and from minor to major complications, yet the incremental cost of complications is reported by complication severity rather than type.[6] The authors utilized the Accordion Severity Grading System (ASGS), which assigns severity scores to complications based on the intensity of care required for their management, rather than a categorical major/minor designation based on complication type. Both the CDC and ASGS grading systems stratify complications based on the intensity of treatment required for their management, a surrogate for complication severity. This provides an advantage that our grading system lacks, particularly as the cost of complications likely depends somewhat on their severity. Despite this advantage, we felt that the STS guidelines were more applicable, given our focus of identifying actionable targets for quality improvement and cost reduction. They have the advantage of identifying specific complications deserving of our attention that can become the focus of targeted quality improvement initiatives. With respect to identifying high-impact complications (eg, those associated with high morbidity and cost) as high-yield targets, the STS definitions used here offer a more intuitive and useful framework (eg, "incidence of pneumonia" is a more actionable target than "ASGS grade 4 complications").

The recognition of surgical complications as potentially modifiable sources of morbidity was followed in short order by the development of various "enhanced recovery pathways" (ERPs) to improve postoperative care vis-à-vis protocolized approaches to postsurgical patient management. Of note, no ERP protocols were employed in our cohort. ERPs have been implemented for esophagectomy patients with inconsistent results. An early systematic review, including 1240 aggregated patients, identified reductions in the rates of anastomotic leak and pulmonary complications associated with ERP use (OR 0.61 and 0.52, respectively, $P < 0.05$ for both).[16] More recent studies, however, have failed to demonstrate a clear benefit of ERPs. Two recent meta-analyses found decreases in mean LOS associated with ERPs, but failed to show significant reduction

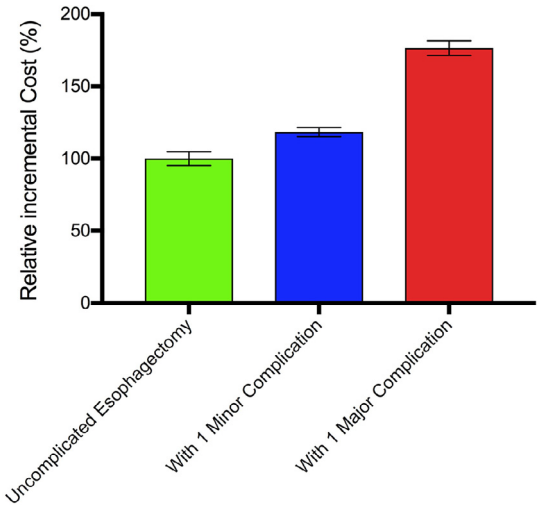

Figure 2. Relative incremental cost impact of major vs minor complications, compared to the mean cost of esophagectomy without complications. Values represent means with 95% confidence intervals.

in complication rates.[17,18] ERPs generally focus on optimizing perioperative care pathways from a global perspective, but often do not employ strategies to anticipate and preemptively target specific complications; by nature, they do not adapt to the risk factors of individual patients.

On the other hand, strategies targeting specific complications have shown promising results in improving surgical outcomes. Reducing the incidence of pulmonary complications after esophagectomy should be a high priority of quality improvement strategies. Increased use of minimally invasive techniques, when feasible, may reduce rates of pulmonary complications.[19] In the current study, pulmonary complications occurred in 12% of patients undergoing MIE compared to 23% of patients undergoing open resection ($P = 0.003$). Preoperative pulmonary training is a low-risk strategy that may hold benefit in certain patients, particularly those deemed high risk for pulmonary complications. In a prospective randomized study, Yamana et al demonstrated that intensive preoperative respiratory rehabilitation (60 minutes/day for ≥7 days preoperatively) led to a statistically significant decrease in the rate of CDC grade ≥2 postoperative pulmonary complications compared to the untrained group (27% vs 60%) or CDC grade ≥3 complications (10% vs 17%; $P = 0.014$).[20] A recent Cochrane review of 12 trials containing 695 aggregated patients concluded that preoperative pulmonary training was associated with a reduction in postoperative atelectasis (RR 0.53, $P < 0.05$) pneumonia (RR 0.45, $P < 0.05$), and LOS (mean difference −1.33 days, $P < 0.05$) in patients undergoing cardiac and major abdominal surgery, but determined its effect on all-cause postoperative mortality was uncertain ($P > 0.05$).[21]. Our study identified advanced age and surgical approach as risk

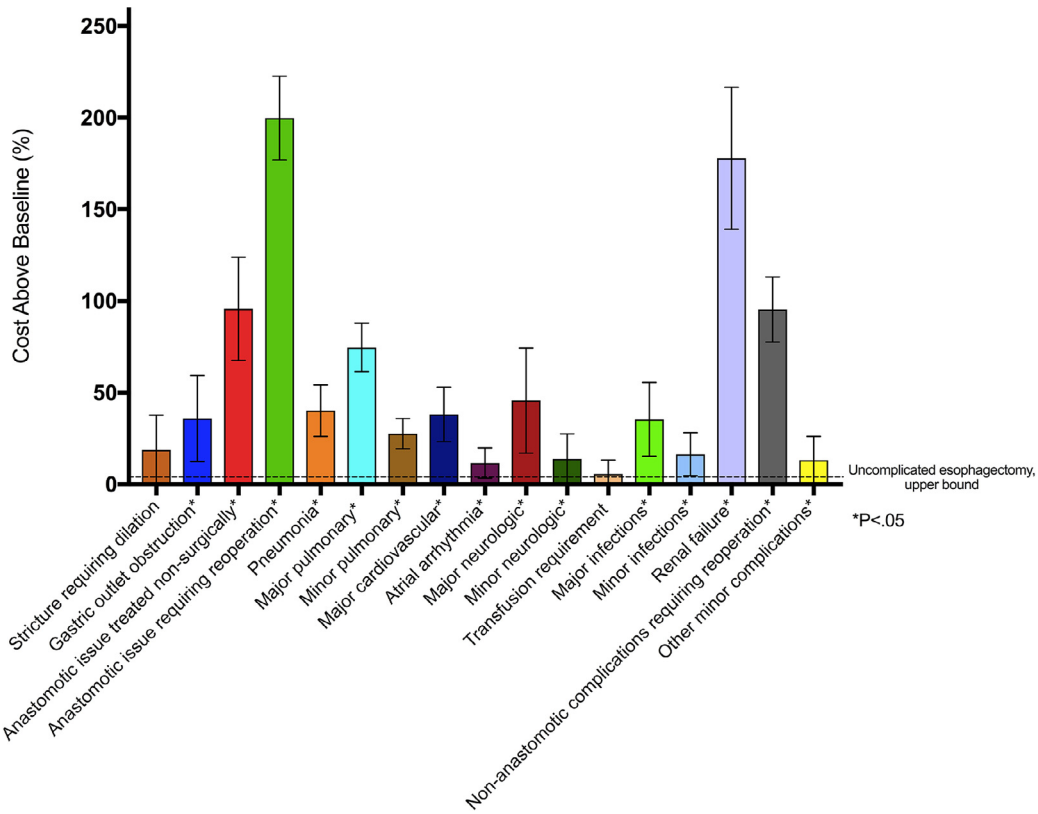

Figure 3. Relative incremental cost of specific complications of esophagectomy. Values represent means with 95% confidence intervals.

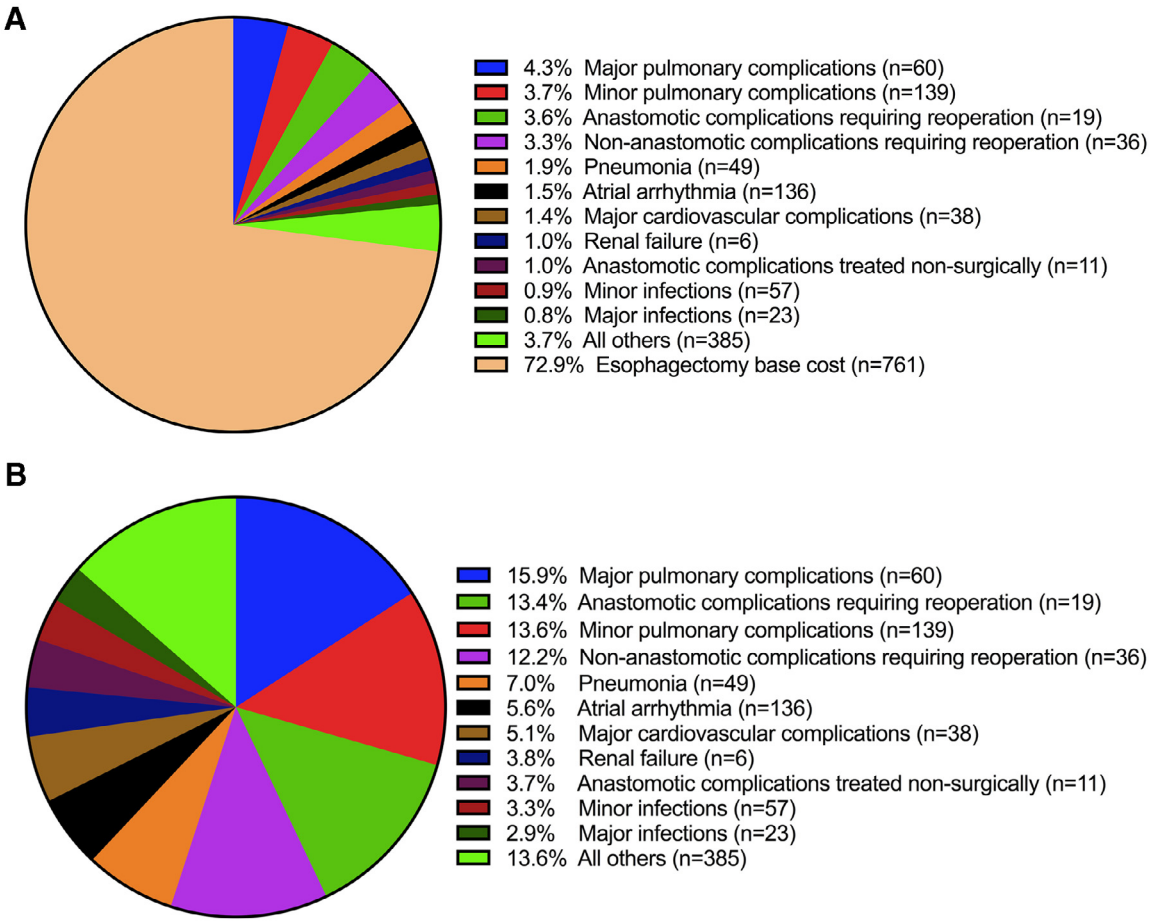

Figure 4. Aggregate cost impact of complications as a proportion of total 90-day direct hospital costs (A) or complication-attributable costs (B) over the entire cohort.

factors for complications, but low FEV_1 has also been reported as a significant predictor of any complications[22] and of pulmonary complications specifically.[23]

Anastomotic complications have also received considerable attention as a source of significant morbidity in patients undergoing esophageal resection. Indeed, these complications were among the costliest in our study; those managed conservatively increased costs by 96% while those requiring surgery increased costs by 200% per event. Though only 3.8% of patients in this cohort were affected, combined, these complications accounted for 17% of all complication-attributable costs. Reported rates of anastomotic leak range from 3% to 13%, with several major centers reporting around 3–5% incidence.[13,24–28] Anastomotic leak has been associated with adverse outcomes from prolonged hospital and ICU stay to pulmonary complications and death.[29,30] The mortality rate associated with anastomotic leak varies significantly, and has been reported as high as 26%.[31] Several studies have investigated potential risk factors for postoperative leak. Cooke et al reported active smoking history, higher mean number of comorbidities, advanced pathologic stage, postoperative arrhythmia, and prior esophagogastric surgery as significant factors predicting increased risk of anastomotic leak ($P < 0.05$ for all).[32] Others have similarly identified comorbidities (including hypertension and diabetes), elevated baseline creatinine, lower FEV_1, and tumor grade as significant predictors of anastomotic complications.[30] A theoretical unifying principle underlying these risk factors is the impairment of microcirculation to support anastomotic healing. Several studies have identified strategies to reduce the rate of anastomotic leak. These include intrathoracic anastomosis (vs cervical),[27] use of epidural anesthesia (vs nonepidural),[31,33] and omental flap reinforcement.[24] Sepesi et al found that omental flap reinforcement not only decreased the risk of anastomotic leak, but that leaks occurring in patients with omental reinforcement tended to be less severe than those in patients without omental reinforcement.[25]

The current study should be viewed in light of certain limitations. First, our institution is a major referral center, and patients experiencing complications may have presented to local emergency departments rather than to our hospital. Regional variability in healthcare costs and pricing may limit

the generalizability of these findings; we have sought to address this by reporting on *relative* incremental costs rather than absolute dollars. Assuming costs vary proportionally for all aspects of care, the fractional costs reported here allow surgeons to translate these findings in a context-appropriate way, whereas absolute dollar estimates are inherently region-specific. Another obstacle—which affects all aspects of surgical outcomes research—arises from the heterogeneity of outcome reporting across practices nationwide. The absence of a universally accepted standardized protocol for which complications to track and how to define them leads to significant variability in the reported morbidity associated with esophageal resection. Moreover, dissimilarities in postoperative care across institutions may affect the perceived rate of certain complications when, in fact, no differences exist. Institutions in which patients undergo a standard esophagram study and advancement of enteral nutrition prior to discharge are likely to identify more anastomotic leaks—particularly minor ones—than institutions with a practice of discharging patients *nil per os* with a jejunostomy feeding tube until the postdischarge follow-up visit. Standard practice at our institution involves a swallow study, typically between the 5th and 7th postoperative days, followed by per os diet advancement in the absence of clinical or radiographic evidence of leak. Jejunostomy feeding tubes are not routinely placed.

The focused study of surgical complications and their impact on patient outcomes and healthcare costs is increasingly recognized as a critical step in advancing successful quality improvement initiatives. Quantifying the incidence of various postoperative complications and relating their relative incremental and total attributable costs allows surgeons to develop more targeted approaches and best practices aimed at those complications identified as being the most high-yield. We believe the current study offers practicable insight into the complication-cost relationship at a level of detail necessary to inform quality improvement strategies.

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