The cost of lung transplantation in the United States: How high is too high?

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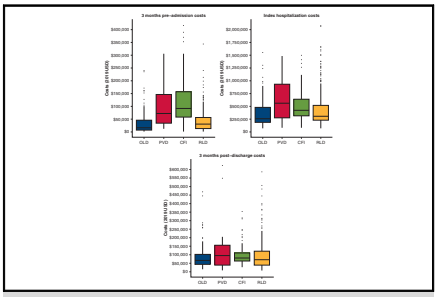
ABSTRACT

Objectives: To identify patient and process factors that contribute to the high cost of lung transplantation (LTx) in the perioperative period, which may allow transplant centers to evaluate situations in which transplantation is most cost-effective to inform judicious resource allocation, avoid futile care, and reduce costs.

Methods: The MarketScan Research databases were used to identify 582 privately insured patients undergoing single or bilateral LTx between 2013 and 2019. The patients were subdivided into groups by disease etiology using the United Network of Organ Sharing classification system. Multivariable generalized linear models using a gamma distribution with a log link were fit to examine the associations between the etiology of lung disease and costs during the index admission, 3 months before admission, and 3 months after discharge.

Results: Our results indicate that the index admission contributed the most to the total transplantation costs compared to the 3 months before admission and after discharge. The regression-adjusted mean index hospitalization cost was 35% higher for patients with pulmonary vascular disease compared to those with obstructive lung disease ($527,156 vs $389,055). The use of extracorporeal membrane oxygenation, mechanical ventilation, and surgical complications in the post-transplantation period were associated with higher costs during the index admission. Surprisingly, age $\geq$55 was associated with lower costs during the index admission.

Conclusions: This analysis identifies pivotal factors influencing the high cost of LTx, emphasizing the significant impact of the index admission, particularly for patients with pulmonary vascular disease. These insights offer transplant centers an opportunity to enhance cost-effectiveness through judicious resource allocation and service bundling, ultimately reducing overall transplantation costs. (JTCVS Open 2024;18:407-31)



Index hospitalization costs were highest for patients with pulmonary vascular disease.

CENTRAL MESSAGE

The use of ECMO and mechanical ventilation was associated with significantly higher index hospitalization costs. These insights may allow providers to decrease healthcare costs through service bundling or developing new screening measures to improve pretransplantation readiness.

PERSPECTIVE

Lung transplantation (LTx) is the preferred treatment option for patients with end-stage lung disease. However, LTx carries numerous postoperative complications, increasing the use of healthcare resources, threatening survival for patients, worsening quality of life, and contributing to high healthcare costs.

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Abbreviations and Acronyms

CF = cystic fibrosis
CFI = cystic fibrosis and immunodeficiency disorders
CI = confidence interval
CR = cost ratio
ECMO = extracorporeal membrane oxygenation
ESLD = end-stage lung disease
GLM = generalized linear model
ICU = intensive care unit
LTx = lung transplantation
LV = left ventricular
OLD = obstructive lung disease
PVD = pulmonary vascular disease
TO = textbook outcome
VTE = venous thromboembolic event
VWI = Van Walraven Elixhauser comorbidity score

Lung transplantation (LTx) is the preferred treatment for patients with end-stage lung disease (ESLD), offering survival and quality of life benefits compared to remaining on the waitlist.[1-3] Owing to advancements in technology, donor selection criteria, and perioperative and postoperative management, the number of LTxs performed and the median survival among transplant recipients continue to rise.[4,5] Nevertheless, complications are common after LTx that threaten survival, worsen quality of life, and contribute to high healthcare costs.[6] Consequently, LTx lags behind other forms of solid organ transplantation in terms of long-term outcomes and costs.

In 2014, an analysis of Medicare expenditures related to solid organ transplantation identified LTx as the most expensive and least cost-effective form of solid organ transplantation.[7] Recently, we examined our institutional experience to understand costs associated with LTx in the modern era. We found that patients who suffered perioperative complications and those who received lungs preserved with ex vivo lung perfusion incurred higher inpatient charges than their counterparts. Moreover, patients with vascular and restrictive lung diseases and those who were sicker at the time of LTx were more likely to experience complications.[8] Although these data offer important preliminary evidence to help understand patient and process factors that contribute to high LTx costs, further investigation in a large, multicenter cohort is imperative to highlight areas for improvement.

Prior MarketScan analyses have identified healthcare utilization patterns in a variety of disease processes to initiate conversations around promoting cost-conscious care.[9,10] The present study is the first to use MarketScan databases to evaluate costs and healthcare utilization patterns incurred during the care of LTx recipients, which is essential for optimizing LTx as the best treatment option for a growing number of transplant candidates, especially as sicker patients continue to be prioritized for transplantation. Accordingly, our primary objective was to leverage the MarketScan database, a novel claims-based national resource with more than 20 years of data and access to approximately 200 million privately insured patients in the United States, to determine the healthcare costs associated with LTx.[10] We hypothesized that the index admission would contribute most to total costs compared to the preadmission and postdischarge periods, and that younger patients with a greater comorbidity burden would drive higher LTx costs.

METHODS

Data Source

We conducted this retrospective cohort study using insurance claims between January 1, 2013, and December 31, 2019, from the IBM MarketScan Commercial and Medicare Supplemental databases. The IBM MarketScan CCAE and Medicare Supplemental databases include adjudicated claims data from active employees, early retirees, COBRA continuees, dependents under employer plans, and Medicare-eligible retirees with employer-sponsored Medicare supplement plans. Data for this study comprised paid adjudicated claims for inpatient and outpatient services. Date of service, International Classification of Diseases, Ninth Revision or Tenth Revision diagnosis codes, Current Procedural Terminology codes, and financial variables were available for outpatient and inpatient service claims (Figure E1). Institutional Review Board approval was not required for this study.

Study Population

Patients age ≥12 years who underwent isolated LTx were identified using outpatient and inpatient service claims between 2013 and 2019. We defined the index admission as the time from the admission date to the discharge date of the first LTx admission. Because LTx candidates age ≥12 years are prioritized by the same lung allocation system, this study included patients age ≥12 years at the time of index admission. We also restricted patients with an index admission date after March 1, 2013, or before September 30, 2019, so that study patients had at least 3 months preadmission and 3 months postdischarge follow-up. Patients who underwent multiorgan transplants during the index hospitalization were excluded (see Table E1 for procedure codes).

Patients who were continuously enrolled in the insurance plans from 3 months preadmission to 3 months postdischarge and had pharmacy claims fully captured by MarketScan were included. Because we focused on the cost in this study, patients with capitated insurance plans or with invalid costs (negative service or pharmacy costs on any given day during the study period) were excluded. After a preliminary investigation, patients with an index hospitalization cost <$50,000, a length of stay <5 days for LTx, or without any service claims with lung disease etiology diagnosis codes (Table E1) from 3 months preadmission to the index admission date were excluded, as the study team did not believe that these patients truly had LTx. Detailed inclusion and exclusion criteria can be found in Appendix E1.

Outcomes

The primary outcome was the total cost for LTx, separated by the following time periods: 3 months preadmission, index hospitalization, and 3 months postdischarge. All costs were converted to 2019 USD using

the Consumer Price Index for All Urban Consumers from the US Bureau of Labor Statistics. The secondary outcome was textbook outcome (TO), a novel approach adopted by our group that considers various postoperative endpoints that collectively signify an optimal or exemplary hospitalization experience.[11,12] Here TO was defined as freedom from the following conditions during the index hospitalization: dialysis, stroke, intubation, tracheostomy, arrhythmias, and reoperation (see Table E1 for codes).[11,12]

Exposures and Additional Variables

The primary exposure was the etiology of lung disease: obstructive lung disease (OLD), pulmonary vascular disease (PVD), cystic fibrosis and immunodeficiency disorders (CFI), or restrictive lung disease (RLD). We used the principal diagnosis of the index hospitalization to classify patients into these disease groups to mirror the classification scheme developed by the United Network for Organ Sharing. Table E2 provides diagnosis codes. The secondary explanatory variable was the number of different types of surgical complications during the index hospitalization after the date of LTx (including LTx date except for pneumonia, sepsis, and CMV infection; see Table E3 for codes).

Statistical Analysis

For each disease group, demographic data, clinical characteristics, and costs were summarized using descriptive statistics. All costs reported excluded outliers (<1st percentile or > 99th percentile of cost).

Multivariable generalized linear models (GLMs) using a gamma distribution with a log link were fit to assess the associations of lung disease etiology or surgical complications with total cost. Separate models were constructed for preadmission, index hospitalization, and postdischarge costs. All models accounted for age group, sex, year of LTx, insurance type, use of extracorporeal membrane oxygenation (ECMO) during the index hospitalization, mechanical ventilation during the index hospitalization, and Van Walraven Elixhauser comorbidity score (VWI). For preadmission cost outcome, the model was further adjusted for residential regions. For index hospitalization and postdischarge cost outcomes, the model was further adjusted for the index transplant hospital region. Cost ratios (CRs) and 95% confidence intervals (CIs) were estimated to compare costs between disease groups using OLD as the reference group. Regression-adjusted mean costs were calculated from the GLMs to estimate the average marginal effects for each disease group.

All statistical analyses were performed using SAS 9.4 (SAS Institute). All figures were created using the ggplot2 package in R 4.1.0 (R Foundation for Statistical Computing). All statistical tests were 2-sided and assessed at a level of significance of 0.05.

RESULTS

Study Population

Table 1 describes the study cohort of 582 patients, including 114 patients (19.6%) classified with OLD, 25 (4.3%) classified with PVD, 67 (11.5%) classified with CFI, and 376 (64.6%) classified with RLD.

Total Transplantation Costs

Index admission costs were the main contributor to total transplantation costs (Figure 1). During the index hospitalization, PVD had the highest mean cost ($639,141), followed by CFI ($520,418), RLD ($429,553), and OLD ($354,429).

Cost Drivers

Results from the GLM highlight the most important contributors to variations in cost. We divided these significant results into their corresponding time periods. During the 3-month preadmission period, compared to patients with OLD, the 3-month preadmission cost was 77% higher for patients with PVD (CR, 1.77; 95% CI, 1.18-2.66; $P = .006$), 130% higher for patients with CFI (CR, 2.3; 95% CI, 1.7-3.13; $P < .001$), and 30% higher for patients with RLD (CR, 1.3; 95% CI, 1.07-1.57; $P = .009$). Prolonged mechanical ventilation use during the index hospitalization and higher VWI scores were associated with higher 3-month preadmission costs.

During the index hospitalization, compared to patients with OLD, the index hospitalization cost was 35% higher for patients with PVD (CR, 1.35; 95% CI, 1.02-1.79; $P = .03$), 15% higher but not significant for patients with CFI (CR, 1.15; 95% CI, 0.94-1.41; $P = .17$), and 13% higher but not significant for patients with RLD (CR, 1.13; 95% CI, 0.99-1.28; $P = .06$). Regional differences in index hospitalization costs were detected (Figure 2), with higher costs in hospitals in the Northeast compared to other regions. Post-LTx ECMO and mechanical ventilation use during the index hospitalization were associated with higher index hospitalization costs. Notably, higher VWI scores were not associated with higher index hospitalization costs.

There was no evidence of differing 3-month postdischarge costs among the disease groups. ECMO use during the index hospitalization was associated with a 22% increase in 3-month postdischarge costs (CR, 1.22; 95% CI, 1.03-1.45; $P = .02$). Given that index hospitalization costs significantly outweighed those of the preadmission or postdischarge periods, we limited the models displayed to this period only (Table 2). Preadmission and postdischarge data are provided in Tables E4 to E6.

Resource Utilization by Disease Etiology

Table 3 shows healthcare resource utilization by disease group. In the preadmission period, all the procedures assessed were rarely used, except that 10.4% of the patients with CFI had a lung biopsy and 8% of the patients with PVD received mechanical ventilation and intubation. During the index hospitalization, patients with PVD had substantially higher use of healthcare resources than patients in the other 3 groups. One-third (32%) of patients with PVD underwent ECMO (compared with 17.2% across all groups), 28% underwent lung biopsy (all groups, 17.5%), 36% received intubation (all groups, 13.9%), and 36% underwent tracheostomy (all groups, 14.9%). In the postdischarge period, all procedures assessed were used in <10% of patients except lung biopsy, which was performed in 86% of patients.

Complications After Surgery

On average, patients experienced 3 distinct surgical complications during the index hospitalization, with a

TABLE 1. Demographic characteristics by disease etiology

Characteristic	Obstructive lung disease (N = 114)	Pulmonary vascular disease (N = 25)	Cystic fibrosis and immunodeficiency disorders (N = 67)	Restrictive lung disease (N = 376)	Total (N = 582)
Age at index hospitalization, y					
Mean (SD)	57.1 (11.0)	47.2 (12.0)	33.0 (11.0)	56.6 (10.3)	53.6 (13.1)
Median (range)	60.0 (20.0-75.0)	47.0 (22.0-65.0)	32.0 (13.0-58.0)	59.0 (17.0-78.0)	58.0 (13.0-78.0)
Sex, n (%)					
Male	55 (48.2)	11 (44.0)	37 (55.2)	249 (66.2)	352 (60.5%)
Female	59 (51.8)	14 (56.0)	30 (44.8)	127 (33.8)	230 (39.5%)
LOS for the index hospitalization					
Mean (SD)	30.1 (41.8)	38.2 (31.4)	30.9 (25.4)	30.9 (28.1)	31.0 (31.1)
Median (range)	19.0 (6.0-406.0)	30.0 (6.0-146.0)	23.0 (9.0-173.0)	21.0 (8.0-224.0)	21.0 (6.0-406.0)
Urban vs rural residency, n (%)					
Rural	20 (17.5)	5 (20.0)	7 (10.4)	52 (13.8)	84 (14.4)
Urban	88 (77.2)	20 (80.0)	58 (86.6)	303 (80.6)	469 (80.6)
Unknown	6 (5.3)	0 (0.0)	2 (3.0)	21 (5.6)	29 (5.0)
Residential region, n (%)					
Northeast region	16 (14.0)	5 (20.0)	13 (19.4)	65 (17.3)	99 (17.0)
North Central region	35 (30.7)	8 (32.0)	20 (29.9)	83 (22.1)	146 (25.1)
South region	43 (37.7)	7 (28.0)	24 (35.8)	174 (46.3)	248 (42.6)
West region	20 (17.5)	5 (20.0)	9 (13.4)	50 (13.3)	84 (14.4)
Unknown region	0 (0.0)	0 (0.0)	1 (1.5)	4 (1.1)	5 (0.9)
UNOS region of the transplant hospital, n (%)					
Nation/unknown	1 (0.9)	2 (8.0)	4 (6.0)	16 (4.3)	23 (4.0)
Region 1	4 (3.5)	0 (0.0)	0 (0.0)	15 (4.0)	19 (3.3)
Region 2	7 (6.1)	2 (8.0)	9 (13.4)	34 (9.0)	52 (8.9)
Region 3	13 (11.4)	1 (4.0)	8 (11.9)	47 (12.5)	69 (11.9)
Region 4	20 (17.5)	5 (20.0)	3 (4.5)	58 (15.4)	86 (14.8)
Region 5	13 (11.4)	5 (20.0)	8 (11.9)	39 (10.4)	65 (11.2)
Region 6	5 (4.4)	0 (0.0)	1 (1.5)	9 (2.4)	15 (2.6)
Region 7	11 (9.6)	1 (4.0)	1 (1.5)	21 (5.6)	34 (5.8)
Region 8	5 (4.4)	1 (4.0)	10 (14.9)	9 (2.4)	25 (4.3)
Region 9	2 (1.8)	4 (16.0)	3 (4.5)	26 (6.9)	35 (6.0)
Region 10	24 (21.1)	4 (16.0)	6 (9.0)	58 (15.4)	92 (15.8)
Region 11	9 (7.9)	0 (0.0)	14 (20.9)	44 (11.7)	67 (11.5)
Van Walraven Elixhauser comorbidity score					
Mean (SD)	11.3 (7.6)	17.3 (7.1)	14.2 (8.0)	9.5 (7.7)	10.7 (7.9)
Median (range)	10.0 (−4.0 to 35.0)	19.0 (2.0-29.0)	13.0 (0.0-33.0)	8.0 (−5.0 to 36.0)	10.0 (−5.0 to 36.0)

Although unbalanced groups are shown, the percentage split in the paper mirrors the true percentage split for transplantations performed nationwide. *SD*, Standard deviation; *LOS*, length of stay; *UNOS*, United Network of Organ Sharing.

maximum of 13. Overall, patients with PVD had the most surgical complications (mean of 4.2 ± 2.3 per patient), whereas patients with OLD had the fewest (mean of 2.4 ± 2.1 per patient). The most common complications were acute pulmonary edema/failure (66%), followed by acute cardiac events (47.1%), pneumonia (24.1%), acute renal failure (21.1%), and venous thromboembolism (17.4%). As shown in Table 4, patients with no surgical complications had significantly lower regression-adjusted mean costs ($316,883) during the index admission than those with 2 to 4 ($380,419) or 5 or more ($623,969) complications.

Textbook Outcome

Only 28.4% of the patients achieved TO (Table 5). This percentage increased to 57.7% when excluding arrhythmias. The highest rate of TO was seen in patients with OLD; the lowest, in patients with PVD.

DISCUSSION

The sole treatment for patients with ESLD, LTx is a costly form of solid organ transplantation.[11] The introduction of the Lung Allocation Score in 2005 has led to prioritizing the sickest patients for LTx at the cost of increased healthcare resource utilization in the perioperative period.[12]

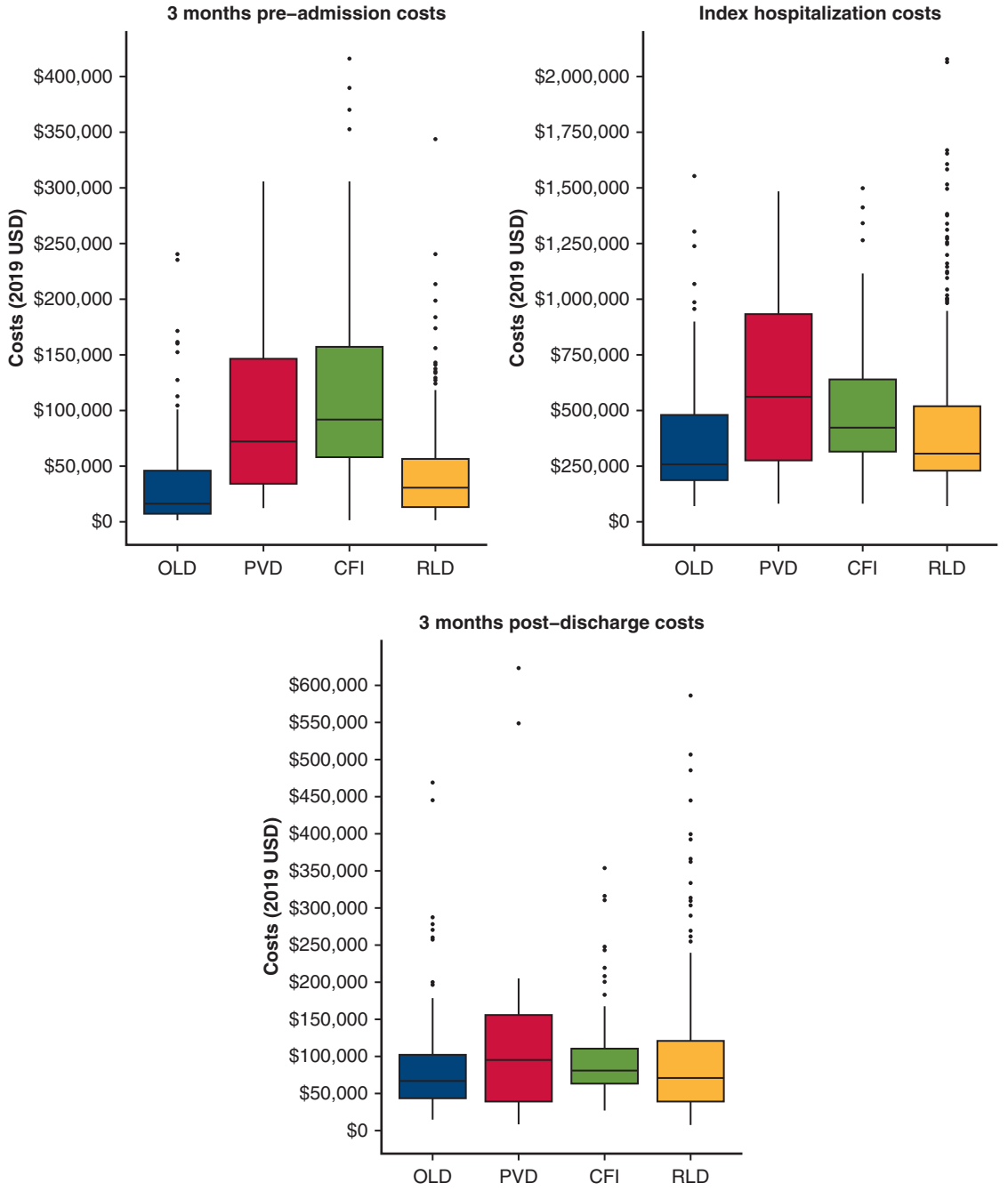

FIGURE 1. Cost by disease etiology and treatment period. Index hospitalization costs were the most significant drivers of total transplantation costs, especially for patients with pulmonary vascular disease (*PVD*). *OLD*, Obstructive lung disease; *CFI*, cystic fibrosis and immunodeficiency disorders; *RLD*, restrictive lung disease.

As sicker patients continue to be prioritized for transplantation, it is imperative to understand which factors contribute most to the cost of LTx to avoid futile care and reduce overall costs without sacrificing access or outcomes. In this analysis, we used for the first time a national insurance database to compare the costs of LTx among 4 recipient groups during the preadmission, index admission, and postdischarge hospitalization phases of their care. We found that patients with PVD had the highest costs, and patients with OLD had the lowest. These findings are consistent with other studies suggesting that LTx recipients with PVD are at increased risk for complications and greater resource utilization.[13]

In the 3-month period prior to the index hospitalization, patients with CFI incurred the highest costs and patients

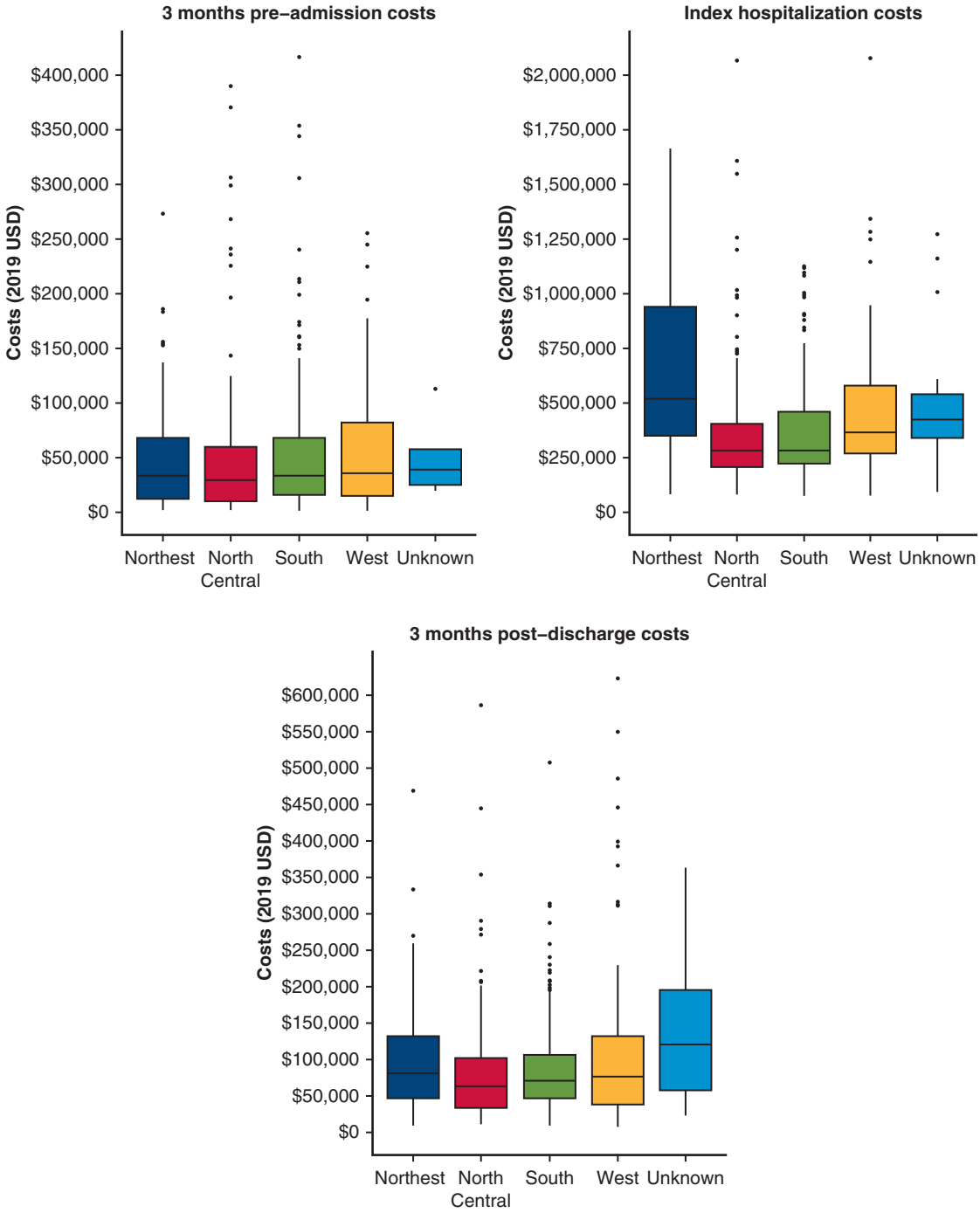

FIGURE 2. Costs by hospital region and treatment period. Index hospitalization costs were significantly higher in the Northeast than in any other region. Preadmission and postdischarge costs were similar across regions.

with OLD incurred the lowest. On average, recipients with CFI used noninvasive respiratory support at a higher rate than the other groups during this period. One possible explanation for these findings is that cystic fibrosis (CF) patients tend to use noninvasive respiratory support outside of respiratory failure as a means of airway clearance, exercise, and nighttime support.[11] Additionally, there are significantly more therapeutic options for CF compared to PVD, OLD, and RLD.[13,14] Another possibility is that patients with CFI have multisystem involvement because of their disease process resulting in extrapulmonary comorbidities that may increase overall care needs.[15] Although patients

TABLE 2. GLM results during index hospitalization

Covariate	Level	3-mo preadmission cost		Index hospitalization cost		3-mo postdischarge cost	
		CR estimate (95% CI)	*P* value	CR estimate (95% CI)	*P* value	CR estimate (95% CI)	*P* value
Disease etiology group	Group A, obstructive lung disease	Reference	.	Reference	.	Reference	.
	Group B, pulmonary vascular disease	1.77 (1.18-2.66)	.006	1.35 (1.02-1.79)	.03	1.15 (0.82-1.63)	.42
	Group C, cystic fibrosis and immunodeficiency disorders	2.30 (1.70-3.13)	<.001	1.15 (0.94-1.41)	.17	1.04 (0.79-1.36)	.8
	Group D, restrictive lung disease	1.30 (1.07-1.57)	.009	1.13 (0.99-1.28)	.06	1.01 (0.86-1.19)	.91
Age at index hospitalization	12-35 y	Reference	.	Reference	.	Reference	.
	36-54 y	0.79 (0.60-1.04)	.1	0.85 (0.72-1.01)	.06	0.94 (0.74-1.19)	.61
	55+ y	0.60 (0.45-0.79)	<.001	0.74 (0.62-0.88)	<.001	0.88 (0.69-1.12)	.29
Sex	Male	Reference	.	Reference	.	Reference	.
	Female	1.06 (0.91-1.24)	.45	1.10 (0.99-1.22)	.06	0.91 (0.80-1.04)	.15
Index year	2013	Reference	.	Reference	.	Reference	.
	2014	1.06 (0.83-1.37)	.64	1.09 (0.93-1.28)	.31	1.09 (0.88-1.34)	.44
	2015	1.46 (1.12-1.90)	.005	1.02 (0.86-1.21)	.81	0.99 (0.79-1.23)	.91
	2016	1.18 (0.91-1.54)	.21	1.24 (1.05-1.47)	.01	1.18 (0.94-1.47)	.15
	2017	1.31 (0.99-1.73)	.06	1.09 (0.91-1.31)	.34	1.03 (0.82-1.31)	.77
	2018	1.88 (1.41-2.50)	<.001	1.15 (0.96-1.38)	.14	1.13 (0.89-1.44)	.31
	2019	1.42 (1.02-1.97)	.04	1.10 (0.89-1.37)	.37	0.90 (0.68-1.19)	.45
Region*	Northeast	Reference	.	Reference	.	Reference	.
	North Central	1.05 (0.83-1.33)	.67	0.63 (0.54-0.73)	<.001	0.89 (0.73-1.08)	.23
	South	1.17 (0.95-1.43)	.14	0.58 (0.50-0.67)	<.001	0.89 (0.74-1.07)	.22
	West	1.19 (0.92-1.55)	.18	0.77 (0.65-0.92)	.003	1.17 (0.93-1.46)	.18
	Unknown	1.52 (0.70-3.31)	.29	0.75 (0.57-0.97)	.03	1.26 (0.90-1.78)	.18
Insurance type	CDHP or HDHP	Reference	.	Reference	.	Reference	.
	Comprehensive	0.83 (0.63-1.10)	.2	0.63 (0.52-0.76)	<.001	0.67 (0.52-0.86)	.002
	EPO or HMO	1.07 (0.77-1.49)	.68	0.84 (0.68-1.03)	.1	1.13 (0.86-1.48)	.38
	POS or PPO	1.28 (1.03-1.59)	.03	0.91 (0.79-1.05)	.2	1.09 (0.91-1.31)	.36
ECMO use during index hospitalization	No	Reference	.	Reference	.	Reference	.
	Yes	0.98 (0.80-1.19)	.81	1.41 (1.23-1.61)	<.001	1.22 (1.03-1.45)	.02
Mechanical ventilation use during index hospitalization	No	Reference	.	Reference	.	Reference	.
	Yes	1.27 (1.03-1.58)	.03	1.41 (1.23-1.62)	<.001	1.14 (0.95-1.37)	.17
Van Walraven Elixhauser comorbidity score		1.04 (1.03-1.05)	<.001	1.00 (1.00-1.01)	.55	1.01 (1.00-1.01)	.19

Generalized linear modeling shows that the CRs are statistically significantly higher for patients with pulmonary vascular disease compared to patients with obstructive lung disease, women compared to men, patients in the Northeast region compared to all other regions, and for patients who were mechanically ventilated or on ECMO. Costs were decreased for patients age ≥55 years compared to those age 12 to 35 years. *CR*, Cost ratio; *CI*, confidence interval; *CDHP*, consumer driven health plan; *HDHP*, high deductible health plan; *EPO*, exclusive provider organization; *HMO*, health maintenance organization; *POS*, point of service; *PPO*, preferred provider organization; *ECMO*, extracorporeal membrane oxygenation. *Region is the patient residential region for the preadmission period and the census region of the transplant hospital for the index hospitalization and postdischarge period.

TABLE 3. Healthcare resource utilization by disease group

Resource	Obstructive lung disease (N = 114), n (%)	Pulmonary vascular disease (N = 25), n (%)	Cystic fibrosis and immunodeficiency disorders (N = 67), n (%)	Restrictive lung disease (N = 376), n (%)	Total (N = 582), n (%)
3-mo preadmission period, n (%)					
ECMO use	0 (0.0)	0 (0.0)	2 (3.0)	3 (0.8)	5 (0.9)
Mechanical ventilation use	4 (3.5)	2 (8.0)	1 (1.5)	5 (1.3)	12 (2.1)
Noninvasive respiratory support use	2 (1.8)	1 (4.0)	7 (10.4)	8 (2.1)	18 (3.1)
Lung biopsy	1 (0.9)	0 (0.0)	0 (0.0)	3 (0.8)	4 (0.7)
Stenting	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.3)	1 (0.2)
Balloon dilation	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.3)	1 (0.2)
Bronchial thermoplasty	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Dialysis	0 (0.0)	1 (4.0)	0 (0.0)	0 (0.0)	1 (0.2)
Intubation	3 (2.6)	2 (8.0)	3 (4.5)	10 (2.7)	18 (3.1)
Tracheostomy	1 (0.9)	1 (4.0)	1 (1.5)	2 (0.5)	5 (0.9)
Index hospitalization, n (%)					
ECMO use	6 (5.3)	8 (32.0)	13 (19.4)	73 (19.4)	100 (17.2)
Mechanical ventilation use	14 (12.3)	3 (12.0)	4 (6.0)	59 (15.7)	80 (13.7)
Noninvasive respiratory support use	1 (0.9)	0 (0.0)	4 (6.0)	5 (1.3)	10 (1.7)
Lung biopsy	19 (16.7)	7 (28.0)	10 (14.9)	66 (17.6)	102 (17.5)
Stenting	1 (0.9)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.2)
Balloon dilation	2 (1.8)	0 (0.0)	0 (0.0)	5 (1.3)	7 (1.2)
Bronchial thermoplasty	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Dialysis	1 (0.9)	1 (4.0)	2 (3.0)	11 (2.9)	15 (2.6)
Intubation	7 (6.1)	9 (36.0)	10 (14.9)	55 (14.6)	81 (13.9)
Tracheostomy	11 (9.6)	9 (36.0)	10 (14.9)	57 (15.2)	87 (14.9)
3-mo postdischarge period					
ECMO use	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Mechanical ventilation use	3 (2.6)	1 (4.0)	1 (1.5)	16 (4.3)	21 (3.6)
Noninvasive respiratory support use	1 (0.9)	0 (0.0)	1 (1.5)	6 (1.6)	8 (1.4)
Lung biopsy	99 (86.8)	17 (68.0)	64 (95.5)	321 (85.4)	501 (86.1)
Stenting	3 (2.6)	0 (0.0)	0 (0.0)	10 (2.7)	13 (2.2)
Balloon dilation	6 (5.3)	2 (8.0)	3 (4.5)	24 (6.4)	35 (6.0)
Bronchial thermoplasty	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Dialysis	1 (0.9)	0 (0.0)	1 (1.5)	6 (1.6)	8 (1.4)
Intubation	2 (1.8)	2 (8.0)	1 (1.5)	14 (3.7)	19 (3.3)
Tracheostomy	2 (1.8)	2 (8.0)	1 (1.5)	9 (2.4)	14 (2.4)

19.4% of patients with restrictive lung disease and cystic fibrosis underwent ECMO during their index hospitalization. 86% of all patients underwent lung biopsy within the 3 months after discharge. *ECMO*, Extracorporeal membrane oxygenation.

with CFI had the highest preadmission costs, our analysis suggests that the preadmission period does not contribute significantly to total transplantation costs.

During the index hospitalization, PVD patients incurred the highest costs, 35% higher than OLD patients. In part, this is secondary to the higher rate of ECMO use in patients with PVD during the index hospitalization, likely due to higher rates of pre-LTx bridging with ECMO as well as higher rates of primary graft dysfunction necessitating ECMO rescue post-LTx.[16] Prior cost analyses have shown

TABLE 4. Regression-adjusted mean costs by number of complications

No. of complications	3 mo preadmission, $, mean (range)	Index hospitalization, $, mean (range)	3 mo postdischarge, $, mean (range)
0	43,011 (33,728-52,293)	316,883 (276,794-356,972)	88,020 (72,677-103,363)
1	60,766 (49,985-71,547)	360,238 (321,391-399,086)	93,710 (79,762-107,658)
2-4	48,314 (42,631-53,996)	380,419 (355,839-404,999)	92,318 (83,938-100,697)
5+	61,598 (52,177-71,018)	623,969 (567,485-680,453)	104,242 (90,720-117,765)

Reducing lung transplantation complications, particularly during the index hospitalization, is essential to control costs. Each additional complication during the index hospitalization can cost the healthcare system anywhere from $20,000 to $50,000.

TABLE 5. Textbook outcomes

Outcome	Obstructive lung disease (N = 114), n (%)	Pulmonary vascular disease (N = 25), n (%)	Cystic fibrosis and immunodeficiency disorders (N = 67), n (%)	Restrictive lung disease (N = 376), n (%)	Total (N = 582), n (%)
Textbook outcomes	42 (36.8)	4 (16.0)	15 (22.4)	104 (27.7)	165 (28.4)
Textbook outcomes without considering arrhythmias	79 (69.3)	6 (24.0)	37 (55.2)	214 (56.9)	336 (57.7)
Dialysis before or during index hospitalization	1 (0.9)	2 (8.0)	2 (3.0)	11 (2.9)	16 (2.8)
Stroke during index hospitalization	3 (2.6)	3 (12.0)	2 (3.0)	19 (5.1)	27 (4.6)
Intubation during index hospitalization	7 (6.1)	9 (36.0)	10 (14.9)	55 (14.6)	81 (13.9)
Tracheostomy during index hospitalization	11 (9.6)	9 (36.0)	10 (14.9)	57 (15.2)	87 (14.9)
Arrhythmias during index hospitalization	54 (47.4)	13 (52.0)	36 (53.7)	223 (59.3)	326 (56.0)
Reoperation during index hospitalization	31 (27.2)	12 (48.0)	27 (40.3)	123 (32.7)	193 (33.2)

Excluding arrhythmias, nearly 70% of patients with obstructive lung disease achieved a textbook outcome, compared with only 24% of patients with pulmonary vascular disease.

that the use of ECMO during the index hospitalization increases total hospitalization costs by >50%, suggesting this as one of the greatest drivers of total cost.[17,18] This trend aligns with prior cost analyses in heart transplantation, underscoring the substantial impact of mechanical-circulatory support as a major driver of hospital costs.[19] Therefore, reducing ECMO-associated costs through best practices and clinical bundles may serve as a potential strategy to decrease overall transplantation costs in PVD patients. One analysis demonstrated that when ECMO bridging to LTx is required for critically ill patients, active rehabilitation while on ECMO significantly reduced the patients' recovery time compared to bridging but no rehabilitation.[20]

LTx recipients with PVD had nearly a 6-fold higher rate of reintubation and a 4-fold higher rate of tracheostomy during the index hospitalization compared to the OLD group. Although there are costs associated with a procedure such as tracheostomy, prior studies show that early tracheostomy following complicated LTx is associated with an overall decreased lengths of stay in the intensive care unit (ICU) and the hospital in patients in poor preoperative condition.[21] Therefore, ICU bundles and procedural cost savings around minimizing the costs of tracheostomy and further delineating high-risk patients that may benefit from earlier tracheostomy to reduce ICU and hospital length of stay may lead to reduced index hospitalization costs.

Interestingly, although other studies have shown that patients with PVD are more likely to use and require longer post-LTx mechanical ventilation, our work shows comparable rates among all 4 groups.[9] However, our analysis is limited without the ability to quantify the duration of ventilation, and it is possible that variations in ventilation time contribute significantly to index hospitalization costs, which would be consistent with prior analyses.

Rates of surgical complications were highest in the PVD group, with 96% of patients experiencing at least 1 surgical complication and an average of 4.2 complications per patient. During the index hospitalization, patients with PVD also had higher rates of acute cardiac events, which can be explained in part by the complex physiologic changes that occur in patients with PVD following LTx. In the immediate postoperative period, the normalization of pulmonary vascular resistance leads to increases in cardiac output and left ventricular (LV) filling, predisposing patients to LV failure.[22] A single-center study showed that over 4 years, nearly one-third of PVD LTx recipients developed LV dysfunction in the immediate postoperative period.[23] Measures to reduce this risk include incorporating the use of ECMO into the postoperative period, which increases the total cost of LTx, as noted previously.

We also found that nearly 81% of patients who experienced an acute cardiac event also experienced 4 or more additional surgical complications during their hospitalization. Although the data are unclear, the benefits of ECMO may outweigh its cost by minimizing the risk of an acute cardiac event, which may prevent or reduce the risk of other associated complications. PVD patients also were found to have nearly double the rate of venous thromboembolic events (VTEs) compared to the obstructive group. Prior

work has suggested that prolonged mechanical ventilation, which may occur in patients with PVD, serves as a predictor of VTEs during hospitalization.[24,25] One study showed that total costs for any medical illness were 2.5-fold higher when VTEs occurred during or after hospitalization, when adjusting for potential covariates.[26] In our cohort, patients with 5 or more types of surgical complications during the index hospitalization had the highest mean cost ($690,112), followed by those with 2 to 4 types ($380,951), 1 type ($332,037), and no complications ($278,992), suggesting that complications are significant drivers of cost. This underscores the importance of reducing complication rates, likely through the implementation of more stringent criteria to assess readiness for transplantation, and is consistent with findings from analyses of heart transplant costs.[27]

The PVD group also incurred the highest postdischarge costs. We found that the use of ECMO during the index hospitalization was associated with increased costs in the postdischarge period. Likewise, patients who experienced stroke during the index hospitalization had significantly higher regression-adjusted mean costs in the post-transplant period ($145,081 vs $94,976), with a higher rate of stroke in PVD patients than in OLD patients (12% vs 2.6%). The reasons for this higher incidence of stroke are unclear but may be explained by prior work suggesting that bridging and intraoperative use of ECMO is a predictor of stroke following LTx.[28] Likewise, an increased rate of tracheostomy during the index hospitalization was associated with increased costs after transplant, and as noted previously, the PVD group underwent this procedure at nearly 4 times the rate of the OLD group during the index hospitalization. This analysis clearly shows that certain events during the index hospitalization (eg, ECMO use, stroke, VTE, etc) identify a group of patients likely to experience greater health care resource utilization after discharge. These data may help providers more closely manage patients after discharge.

We also examined the impact of achieving TO on overall cost for LTx recipients. TO is a composite measure that describes optimal surgical outcomes during the index hospitalization for complex surgical procedures.[9] In the current analysis, the PVD group had the lowest rate of achieving TO. In a single-center study, we previously showed that patients who achieved TO during LTx incurred nearly $630,000 less in total LTx costs compared to patients who did not achieve TO.[9] In this analysis, we found that patients with TO had lower mean costs ($320,968) than those without TO ($477,366) during the index hospitalization. Examining individual TO components, patients with stroke, tracheostomy, or reoperation had significantly higher regression-adjusted mean costs during the index hospitalization compared to those without these complications. Surprisingly, there was no statistical difference in post-transplant costs between patients who achieved TO and those who did not. At our institution, defining TO and elucidating which factors contribute most to total costs has been useful in the perioperative evaluation and screening of patients prior to LTx. Further studies are needed to understand whether and, if so, how more widespread adoption of TO could result in greater screening capabilities, better resource utilization, and lower transplantation costs.

Limitations

This study has several strengths and limitations. To our knowledge, this is the first study to use the IBM MarketScan Research databases to examine costs associated with LTx, allowing us to provide insights that may be generalizable to many transplant centers. Importantly, we examined transplant-related costs during different phases of care for 4 different disease groups, allowing for an in-depth and detailed analysis. Several of the limitations that we encountered are inherent when using a large claims-based database. In our study, we required patients to be continuously enrolled with their insurance provider during the 3 months before admission and the 3 months after discharge, which may limit the generalizability of our findings. Thus, patients who did not survive until 3 months postdischarge were not included, potentially biasing some of our cost data. Patients also were excluded from the database if they lost insurance during the 3-month postdischarge period. Similarly, our use of a claims database made it difficult to identify causes of loss of patient follow-up, as this could be attributed to either death or loss of insurance. However, the continuous enrollment criterion was crucial to preclude us from underestimating healthcare resource utilization.

One major limitation of our analysis is the small sample size in the PVD group (n = 25) compared to the other 3 groups. However, it is important to note that the proportion of sample sizes in the 4 groups is consistent with the proportions of the total number of LTxs performed by disease group according to data from the United Network of Organ Sharing's Organ Procurement and Transplantation Network.[5]

CONCLUSIONS

In summary, LTx remains an effective but costly treatment option for patients with ESLD (Figure 3). In this analysis, we found that patients with underlying PVD had significantly higher total LTx-related expenses compared to patients with OLD. Importantly, we found that the greatest contributors to the increased costs during the index hospitalization were surgical complications and the use of ECMO. Given these findings, patients with PVD may require a greater degree of scrutiny to assess for fitness before undergoing LTx to maximize the effectiveness of transplantation in this population and reduce undue burdens on the health system. Although this may be a challenge in an era where we can and are transplanting sicker and sicker patients, it is essential that providers understand the burden

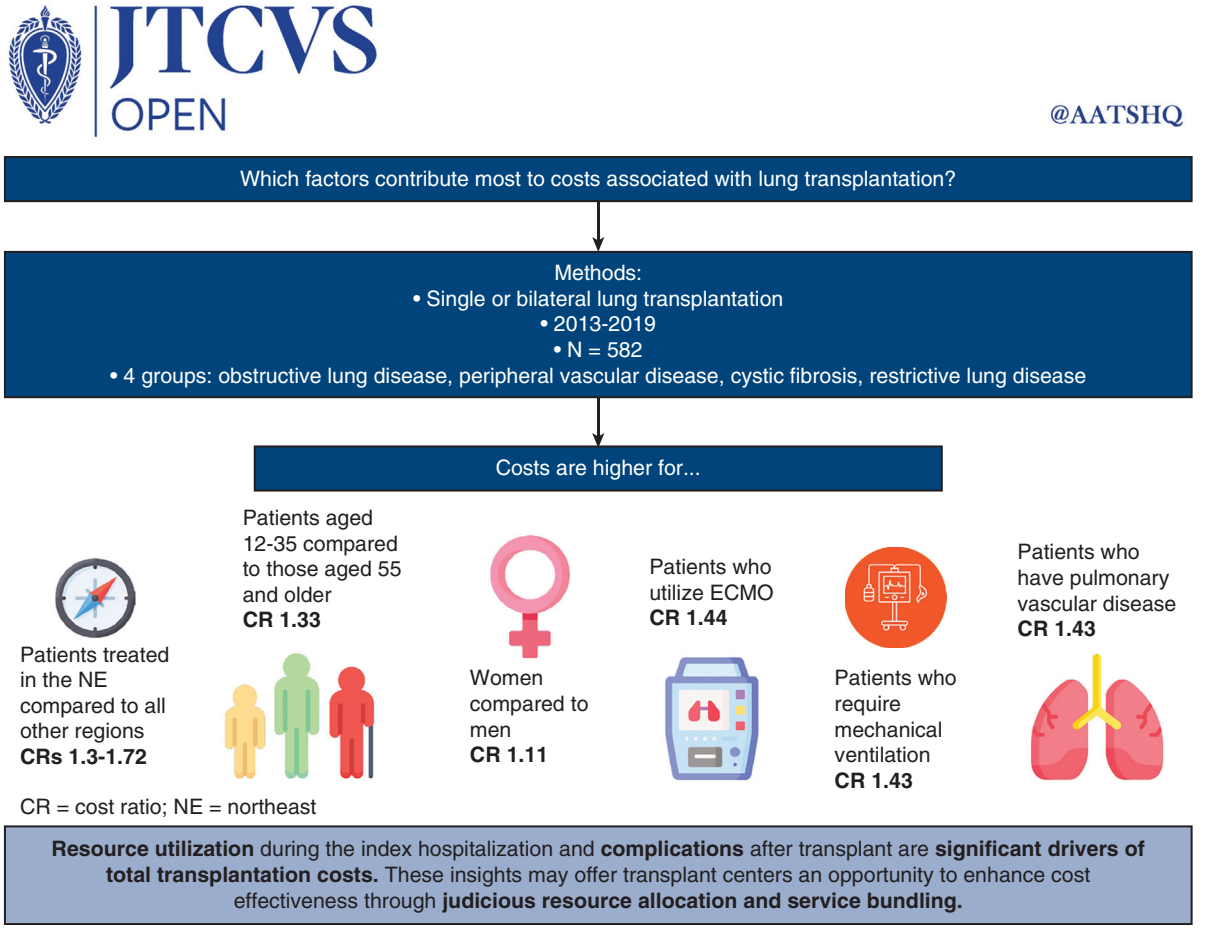

FIGURE 3. Graphical abstract. Understanding factors that contribute to lung transplantation costs. *ECMO*, Extracorporeal membrane oxygenation; *CR*, cost ratio; *NE*, northeast.

that this can present to the healthcare system to ensure its longevity and find creative solutions to reducing overall costs.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: cost, lung transplantation, surgical complication, resource utilization

APPENDIX E1. INCLUSION AND EXCLUSION CRITERIA

Because LTx candidates age ≥12 years are prioritized by the same lung allocation system, this study included patients age ≥12 years at the time of index admission. We also restricted patients with the index admission date after March 1, 2013, and index discharge date before September 30, 2019, so that patients had at least 3 months preadmission and 3 months postdischarge follow-up. For patients who had LTx identified from an outpatient claim and then admitted the next day, the index admission was defined from the day of LTx. For patients who were discharged on the day of LTx and then admitted the same day, the index admission included the two admission records. Patients who were not admitted to a hospital the day or the next day of LTx were excluded.

Patients who were continuously enrolled in the insurance plans from 3 months pre-admission to 3 months postdischarge and had fully captured pharmacy claims by MarketScan were included. Because we focused on the cost in this study, patients with capitated insurance plans or with invalid costs (negative service or pharmacy costs on any given day during the study period) were excluded. After a preliminary investigation, patients with an index hospitalization cost < $50,000, or a length of stay < 5 days for LTx, or without any service claims with lung disease etiology diagnosis codes (see Table E1) from 3-month preadmission to the index admission date were further excluded as the study team did not believe that these patients truly had LTx.

If the principal diagnosis of the index hospitalization did not include a lung disease code, we used the service claims from the 3-month pre-admission to the index admission date. If patients had diagnosis codes in multiple groups, we classified the patients based on the following order: restrictive lung disease > pulmonary vascular disease > cystic fibrosis and immunodeficiency disorders > obstructive lung disease, because patients with restrictive lung disease have the highest priority in lung allocation, and physicians would assign those patients with this diagnosis in the allocation system to optimize their chance of receiving LTx.

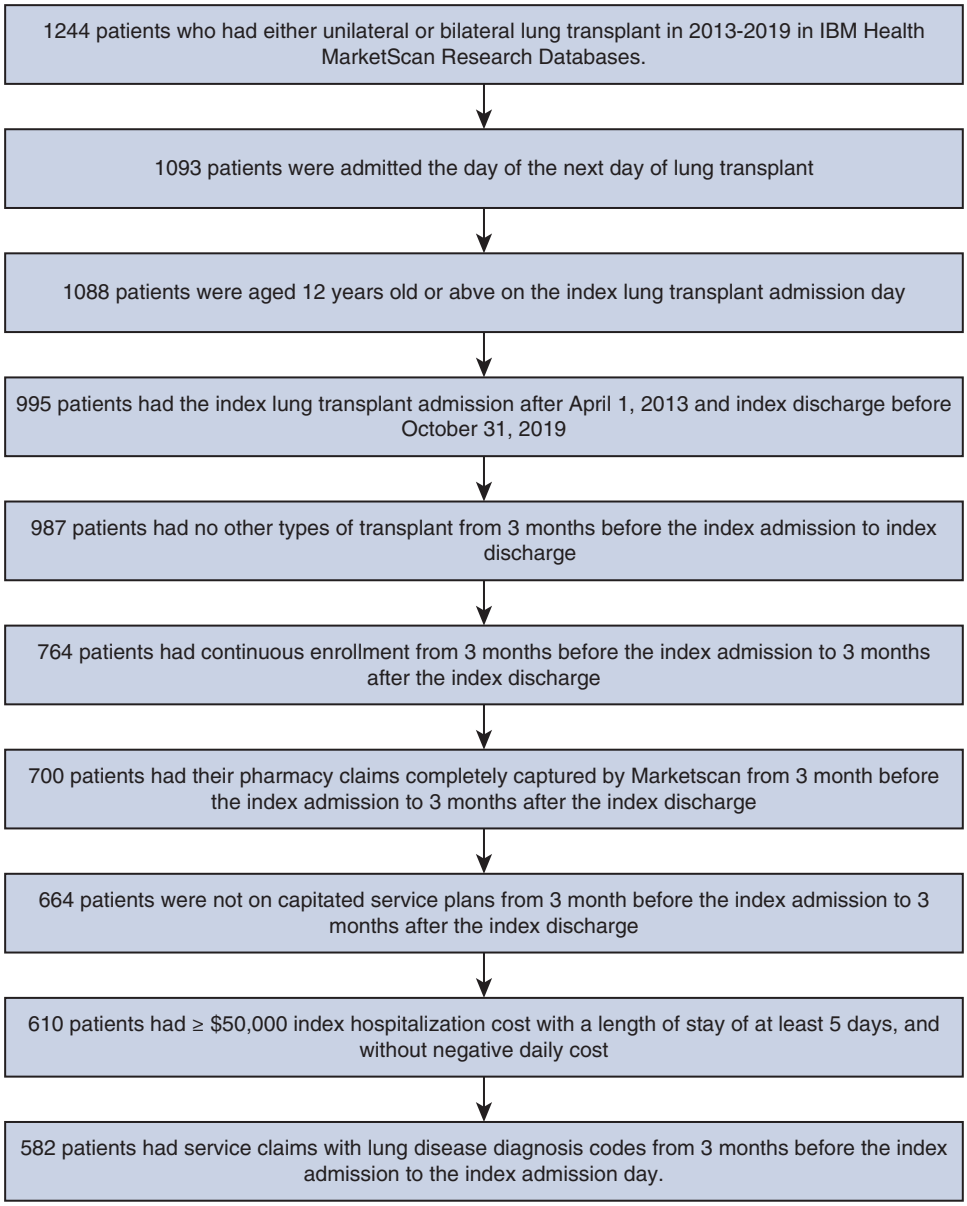

FIGURE E1. Flow diagram for patient selection. *IBM*, International Business Machines Corporation.

TABLE E1. Diagnosis and procedure codes to define textbook outcomes

Description	Type of code	Codes
Dialysis	CPT	90935, 90937, 90940, 90945, 90947, 90997, 90999
	HCPCS	G0257, G0491, G0492
Stroke	ICD-9-DX	431.x-434.x
	ICD-10-DX	I60.x-I66.x
Intubation	CPT	31500, 94002, 94003, 94004
Tracheostomy	ICD-9-DX	519.0x
	ICD-10-DX	J95.0x
	ICD-9-PCS	31.1, 31.2x
	ICD-10-PCS	0B110F4, 0B110Z4, 0B113F4, 0B113Z4, 0B114F4, 0B114Z4
	CPT	31600, 31603, 31605, 31610
Arrhythmias	ICD-9-DX	426.0, 426.13, 426.7, 426.9, 426.10, 426.12, 427.0-427.4, 427.6-427.9, 785.0
	ICD-10-DX	I44.1-I44.3, I45.6, I45.9, I47.x-I49.x, R00.0, R00.1, R00.8
Reoperation	CPT	When having one of the following CPT codes on the same day of LTx, it is considered reoperation: 21750–Closure of median sternotomy separation with or without debridement (separate procedure) 21825–Open treatment of sternum fracture with or without skeletal fixation 31600–Tracheostomy, planned (separate procedure) 32120–Thoracotomy; for postoperative complications 32160–Thoracotomy; with cardiac massage 35201–Repair blood vessel, direct; neck 35206–Repair blood vessel, direct; upper extremity 35211–Repair blood vessel, direct; intrathoracic, with bypass 35226–Repair blood vessel, direct; lower extremity 35276–Repair blood vessel with graft other than vein; intrathoracic, without bypass 35820–Exploration for postoperative hemorrhage, thrombosis or infection; chest 39501–Repair, laceration of diaphragm, any approach 47361–Management of liver hemorrhage; exploration of hepatic wound, extensive debridement, coagulation and/or suture, with or without packing of liver
	ICD-9-PCS	Having the following ICD-9-PCS codes during index hospitalization: 31.2x–Permanent tracheostomy 32.59–Other and unspecified pneumonectomy 33.34–Thoracoplasty 33.39–Other surgical collapse of lung 33.91–Bronchial dilation 34.03–Reopening of recent thoracotomy site 34.51–Decortication of lung 34.84–Other repair of diaphragm 39.31–Suture of artery 39.56–Repair of blood vessel with tissue patch graft
	ICD-10-PCS	Having the following ICD-10-PCS codes during index hospitalization: 07QK3ZZ–Repair thoracic duct, percutaneous approach 0B110F4–Bypass trachea to cutaneous with tracheostomy device, open approach 0B770DZ–Dilation of left main bronchus with intraluminal device, open approach 0BDN0ZZ–Extraction of right pleura, open approach 0BDP0ZZ–Extraction of left pleura, open approach 0BNL0ZZ–Release left lung, open approach 0BNK0ZZ–Release right lung, open approach 0BNM0ZZ–Release bilateral lung, open approach 0BNN0ZZ–Release right pleura, open approach 0BNP0ZZ–Release left pleura, open approach 0BQT4ZZ–Repair diaphragm, percutaneous endoscopic approach

(Continued)

TABLE E1. Continued

Description	Type of code	Codes
		0BTL0ZZ–Resection of left lung, open approach
		0BTK0ZZ–Resection of right lung, open approach
		0BTM0ZZ–Resection of bilateral lungs, open approach
		0WU80JZ–Supplement chest wall with synthetic substitute, open approach
	HCUP surgery flag software	Any "major therapeutic procedure" done after the day of LTx is considered a reoperation.

CPT, Current Procedural Terminology; *HCPCS*, Healthcare Common Procedure Coding System; *ICD-9*, International Classification of Diseases, Ninth Revision; *ICD-10*, International Classification of Diseases, Tenth Revision; *DX*, diagnosis; *PCS*, procedure; *LTx*, lung transplantation; *HCUP*, Healthcare Cost and Utilization Project.

TABLE E2. Codes used to identify patients with transplantation procedures and disease etiology

Description	Type of code	Codes	Detailed description of the code
LTx, double	CPT	32853	Lung transplant, double; without cardiopulmonary bypass
		32854	Lung transplant, double; with cardiopulmonary bypass
	ICD-9-PCS	33.52	Bilateral lung transplant
	ICD-10-PCS	0BYM0Z0	Transplantation of bilateral lungs, allogeneic, open approach
		0BYM0Z1	Transplantation of bilateral lungs, syngeneic, open approach
LTx, single	CPT	32851	Lung transplant, single; without cardiopulmonary bypass
		32852	Lung transplant, single; with cardiopulmonary bypass
	ICD-9-PCS	33.50	Lung transplantation, not otherwise specified
		33.51	Unilateral lung transplantation
	ICD-10-PCS	0BYK0Z0	Transplantation of right lung, allogeneic, open approach
		0BYK0Z1	Transplantation of right lung, syngeneic, open approach
		OBYL0Z0	Transplantation of left lung, allogeneic, open approach
		OBYL0Z1	Transplantation of left lung, syngeneic, open approach
Obstructive lung disease	ICD-9-DX	011.x	Pulmonary tuberculosis, granulomatous lung disease
		117.3	Aspergillosis, allergic bronchopulmonary aspergillosis
		273.4	Alpha 1 antitrypsin deficiency
		484.6	Pneumonia in aspergillosis, allergic bronchopulmonary aspergillosis
		491.x	Chronic bronchitis, COPD
		492.x	Emphysema, COPD
		493.2x	Chronic obstructive asthma, COPD
		494.x	Bronchiectasis
		496	Chronic airway obstruction, not elsewhere classified, COPD
		516.4	Lymphangioleiomyomatosis
		518.6	Allergic bronchopulmonary aspergillosis
		756.83	Ehlers-Danlos syndrome
		759.3	Situs inversus, Kartagener syndrome
		759.5	Tuberous sclerosis
		770.7	Chronic respiratory disease arising in the perinatal period, bronchopulmonary dysplasia
		947.1	Burn of larynx, trachea, and lung, inhalation burns/trauma
	ICD-10-DX	A15.x	Respiratory tuberculosis, granulomatous lung disease
		B44.x	Aspergillosis, allergic bronchopulmonary aspergillosis
		E88.01	Alpha-1-antitrypsin deficiency
		J41.x	Simple and mucopurulent chronic bronchitis, COPD
		J42.x	Unspecified chronic bronchitis, COPD
		J43.x	Emphysema, alpha 1 antitrypsin deficiency/COPD
		J44.x	Chronic obstructive pulmonary disease
		J47.x	Bronchiectasis
		J84.81	Lymphangioleiomyomatosis

(Continued)

TABLE E2. Continued

Description	Type of code	Codes	Detailed description of the code
		P27.1	Bronchopulmonary dysplasia originating in the perinatal period
		Q79.6	Ehlers-Danlos syndrome
		Q85.1	Tuberous sclerosis
		T27.x	Burn and corrosion of respiratory tract, inhalation burns/trauma
		Q89.3	Situs inversus, Kartagener syndrome
Pulmonary vascular disease	ICD-9-DX	416.0	Primary pulmonary hypertension, pulmonary hypertension
		416.8	Other chronic pulmonary heart diseases, pulmonary hypertension
		415.1x	Pulmonary embolism and infarction, pulmonary thromboembolic disease
		745.x	Bulbus cordis anomalies and anomalies of cardiac septal closure, Eisenmenger syndrome
		746.83	Infundibular pulmonic stenosis, pulmonic stenosis
		747.0	Patent ductus arteriosus, Eisenmenger syndrome
		747.32	Pulmonary arteriovenous malformation
		747.60	Anomaly of the peripheral vascular system, unspecified site
		748.3	Other anomalies of larynx, trachea, and bronchus, congenital malformation
		748.5	Agenesis, hypoplasia, and dysplasia of lung, congenital malformation
		748.60	Anomaly of lung, unspecified, congenital malformation
		748.61	Congenital bronchiectasis, congenital malformation
		748.69	Other congenital anomalies of lung, congenital malformation
		759.0-759.4, 759.6-759.9	Other and unspecified congenital anomalies, congenital malformation
	ICD-10-DX	I27.0	Primary pulmonary hypertension, pulmonary hypertension
		I27.2x	Other secondary pulmonary hypertension, pulmonary hypertension
		I26.x	Pulmonary embolism, pulmonary thromboembolic disease
		I27.83	Eisenmenger syndrome
		Q21.x	Congenital malformations of cardiac septa, Eisenmenger syndrome
		Q24.3	Pulmonary infundibular stenosis, pulmonic stenosis
		Q25.0	Patent ductus arteriosus, Eisenmenger syndrome
		Q25.72	Congenital pulmonary arteriovenous malformation
		Q27.9	Congenital malformation of peripheral vascular system, unspecified
		Q32.x	Congenital malformations of trachea and bronchus, congenital malformation
		Q33.x	Congenital malformations of lung, congenital malformation
Cystic fibrosis and immunodeficiency disorder	ICD-9-DX	277.0x	Cystic fibrosis
		279.00	Hypogammaglobulinemia, unspecified
		279.04	Congenital hypogammaglobulinemia
		279.06	Common variable immunodeficiency
	ICD-10-DX	E84.xx	Cystic fibrosis
		D80.0	Hereditary hypogammaglobulinemia
		D80.1	Nonfamilial hypogammaglobulinemia
		D83.x	Common variable immunodeficiency
Restrictive lung disease	ICD-9-DX	135	Sarcoidosis
		277.3x	Amyloidosis
		279.5x	Graft-versus-host disease
		446.4	Wegener granulomatosis
		448.0	Hereditary hemorrhagic telangiectasia
		495.9	Unspecified allergic alveolitis and pneumonitis, hypersensitivity pneumonitis
		500	Coal workers' pneumoconiosis
		501	Asbestosis
		502	Pneumoconiosis due to other silica or silicates, silicosis

(Continued)

TABLE E2. Continued

Description	Type of code	Codes	Detailed description of the code
		503	Pneumoconiosis due to other inorganic dust
		504	Pneumonopathy due to inhalation of other dust
		505	Pneumoconiosis, unspecified
		515	Postinflammatory pulmonary fibrosis
		516.0	Pulmonary alveolar proteinosis
		516.1	Idiopathic pulmonary hemosiderosis, idiopathic interstitial pneumonia
		516.3x	Idiopathic interstitial pneumonia, idiopathic interstitial pneumonia
		516.63	Surfactant mutations of the lung, surfactant protein B/C deficiency
		516.8	Other specified alveolar and parietoalveolar pneumonopathies
		517.2	Lung involvement in systemic sclerosis, scleroderma
		518.3	Pulmonary eosinophilia, eosinophilic granulomatosis
		519.2	Mediastinitis, fibrosing mediastinitis
		710.1	Systemic sclerosis, CREST
		710.2	Sjögren syndrome
		710.3	Dermatomyositis
		710.4	Polymyositis
		714.81	Rheumatoid lung, rheumatoid disease
		996.84	Complications of transplanted lung, lung retransplant or graft failure
	ICD-10-DX	D86.x	Sarcoidosis
		D89.81x	Graft-versus-host disease
		E85.x	Amyloidosis
		M31.3x	Wegener granulomatosis
		I78.0	Hereditary hemorrhagic telangiectasia
		J60	Coalworkers' pneumoconiosis
		J61	Pneumoconiosis due to asbestos and other mineral fibers
		J62	Pneumoconiosis due to dust containing silica, silicosis
		J63	Pneumoconiosis due to other inorganic dusts
		J64	Unspecified pneumoconiosis
		J66	Airway disease due to specific organic dust
		J67.9	Hypersensitivity pneumonitis due to unspecified organic dust
		J80	Acute respiratory distress syndrome
		J82	Pulmonary eosinophilia, not elsewhere classified, eosinophilic granulomatosis
		J84.x	Other interstitial pulmonary diseases, idiopathic interstitial pneumonia
		J98.5x	Diseases of mediastinum, not elsewhere classified, fibrosing mediastinitis
		M05.1x	Rheumatoid lung disease with rheumatoid arthritis
		M32.1x	Systemic lupus erythematosus with organ or system involvement
		M33.11	Other dermatomyositis with respiratory involvement
		M33.2x	Polymyositis
		M33.91	Dermatopolymyositis, unspecified with respiratory involvement
		M34.x	Systemic sclerosis, CREST/scleroderma
		M35.0x	Sjögren syndrome
		T86.810	Complications of lung transplant–lung transplant rejection, lung retransplant or graft failure
		T86.811	Complications of lung transplant–lung transplant failure, lung retransplant or graft failure
Other types of transplant			
Kidney transplant	CPT	50360	Renal allotransplantation, implantation of graft; without recipient nephrectomy
		50365	Renal allotransplantation, implantation of graft; with recipient nephrectomy
	ICD-9-PCS	55.6x	Transplant of kidney
	ICD-10-PCS	0TY00Z[0/1]	Transplantation of right kidney, (allogeneic/syngeneic), open approach
		0TY10Z[0/1]	Transplantation of left kidney, (allogeneic/syngeneic), open approach

(Continued)

TABLE E2. Continued

Description	Type of code	Codes	Detailed description of the code
Liver transplant	CPT	47135	Liver allotransplantation; orthotopic, partial or whole, from cadaver or living donor, any age
		47136	Liver allotransplantation; heterotopic, partial or whole, from cadaver or living donor, any age
	ICD-9-PCS	50.5x	Liver transplant
	ICD-10-PCS	0FY00Z[0/1]	Transplantation of liver, (allogeneic/syngeneic), open approach
Pancreas transplant	CPT	48160	Pancreatectomy, total or subtotal, with autologous transplantation of pancreas or islet cells
		48554	Transplantation of pancreatic allograft
	ICD-9-PCS	52.8x	Transplant of pancreas
	ICD-10-PCS	0FYG0Z[0/1]	Transplantation of pancreas, (allogeneic/syngeneic), open approach
Heart transplant	CPT	33945	Heart transplant, with or without recipient cardiectomy
	ICD-9-PCS	37.51	Heart transplantation
	ICD-10-PCS	02YA0Z0	Transplantation of heart, allogenic, open approach
		02YA0Z1	Transplantation of heart, syngeneic, open approach
Heart-lung transplant	CPT	33935	Heart-lung transplant with recipient cardiectomy-pneumonectomy
	ICD-9-PCS	33.6	Combined heart-lung transplantation
Esophagus transplant	ICD-10-PCS	0DY50Z0	Transplantation of esophagus, allogeneic, open approach
		0DY50Z1	Transplantation of esophagus, syngeneic, open approach
Intestine transplant	HCPCS	S2053	Transplantation of small intestine and liver allografts
	ICD9-PCS	46.97	Transplantation of intestine
	ICD-10-PCS	0DY80Z0	Transplantation of small intestine, allogeneic, open approach
		0DY80Z1	Transplantation of small intestine, syngeneic, open approach
		0DYE0Z0	Transplantation of large intestine, allogeneic, open approach
		0DYE0Z1	Transplantation of large intestine, syngeneic, open approach
Spleen transplant	ICD9-PCS	41.94	Transplantation of spleen
	ICD-10-PCS	07YP0Z0	Transplantation of spleen, allogeneic, open approach
		07YP0Z1	Transplantation of spleen, syngeneic, open approach
Stomach transplant	ICD-10-PCS	0DY60Z0	Transplantation of stomach, allogeneic, open approach
		0DY60Z1	Transplantation of stomach, syngeneic, open approach
Thymus transplant	ICD9-PCS	07.94	Transplantation of thymus
	ICD-10-PCS	07YM0Z0	Transplantation of thymus, allogeneic, open approach
		07YM0Z1	Transplantation of thymus, syngeneic, open approach
Other transplant-related procedures			
Non-invasive respiratory support	CPT	99504	Home visit for mechanical ventilation care
	ICD-9-PCS	93.90	Noninvasive mechanical ventilation
	ICD-10-PCS	5A09357	Assistance with respiratory ventilation for <24 consecutive hours, continuous positive airway pressure
		5A09457	Assistance with respiratory ventilation for 24-96 consecutive hours, continuous positive airway pressure
		5A09557	Assistance with respiratory ventilation for >96 consecutive hours, continuous positive airway pressure
VV/VA ECMO	CPT	33946	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; initiation, veno-venous
		33947	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; initiation, veno-arterial
		33948	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; daily management, each day, veno-venous
		33949	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; daily management, each day, veno-arterial
		33952	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; insertion of peripheral (arterial and/or

(Continued)

TABLE E2. Continued

Description	Type of code	Codes	Detailed description of the code
			venous) cannula(e), percutaneous, 6 y and older (includes fluoroscopic guidance, when performed)
		33954	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; insertion of peripheral (arterial and/or venous) cannula(e), open, 6 y and older
		33956	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; insertion of central cannula(e) by sternotomy or thoracotomy, 6 y and older
		33958	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; reposition peripheral (arterial and/or venous) cannula(e), percutaneous, 6 y and older (includes fluoroscopic guidance, when performed)
		33962	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; reposition peripheral (arterial and/or venous) cannula(e), open, 6 y and older (includes fluoroscopic guidance, when performed)
		33964	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; reposition central cannula(e) by sternotomy or thoracotomy, 6 y and older (includes fluoroscopic guidance, when performed)
		33966	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; removal of peripheral (arterial and/or venous) cannula(e), percutaneous, 6 y and older
		33984	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; removal of peripheral (arterial and/or venous) cannula(e), open, 6 y and older
		33986	Extracorporeal membrane oxygenation/extracorporeal life support provided by physician; removal of central cannula(e) by sternotomy or thoracotomy, 6 y and older
	ICD-9-PCS	39.65	Extracorporeal membrane oxygenation
	ICD-10-PCS	5A15223	Extracorporeal membrane oxygenation, continuous
		5A1522F	Extracorporeal oxygenation, membrane, central
		5A1522G	Extracorporeal oxygenation, membrane, peripheral veno-arterial
		5A1522H	Extracorporeal oxygenation, membrane, peripheral veno-venous
		5A15A2F	Extracorporeal oxygenation, membrane, central, intraoperative
		5A15A2G	Extracorporeal oxygenation, membrane, peripheral veno-arterial, intraoperative
		5A15A2H	Extracorporeal oxygenation, membrane, peripheral veno-venous, intraoperative
Mechanical ventilation	CPT	4168F	Patient receiving care in the ICU and receiving mechanical ventilation for ≤24 h (CRIT)
		4169F	Patient either not receiving care in the ICU or not receiving mechanical ventilation or receiving mechanical ventilation for >24 h (CRIT)
	ICD-9-PCS	96.70	Continuous mechanical ventilation of unspecified duration
		96.71	Continuous invasive mechanical ventilation for <96 consecutive hours
		96.72	Continuous invasive mechanical ventilation for 96 consecutive hours
	ICD-10-PCS	5A1935Z	Respiratory ventilation for <24 consecutive hours
		5A1945Z	Respiratory ventilation for 24-96 consecutive hours
		5A1955Z	Respiratory ventilation for >96 consecutive hours

(Continued)

TABLE E2. Continued

Description	Type of code	Codes	Detailed description of the code
Lung biopsy	CPT	31625	Bronchoscopy, rigid or flexible, including fluoroscopic guidance, when performed; with bronchial or endobronchial biopsy(s), single or multiple sites
		31628	Bronchoscopy, rigid or flexible, including fluoroscopic guidance, when performed; with transbronchial lung biopsy(s), single lobe
		31632	Bronchoscopy, rigid or flexible, including fluoroscopic guidance, when performed; with transbronchial lung biopsy(s), each additional lobe (list separately in addition to code for primary procedure)

CPT, Current Procedural Terminology; *ICD-9*, International Classification of Diseases, Ninth Revision; *ICD-10*, International Classification of Diseases, Tenth Revision; *PCS*, procedure; *DX*, diagnosis; *ICU*, intensive care unit.

TABLE E3. Diagnosis and procedure codes to define surgical complications

Description	Type of code	Codes
Post-transplantation lymphoproliferative disorder	ICD-9-DX	238.77
	ICD-10-DX	D47.Z1
Tracheostomy or tracheostomy complications	ICD-9-DX	519.0x
	ICD-10-DX	J95.0x
	ICD-9-PCS	31.1, 31.2x
	ICD-10-PCS	0B110F4, 0B110Z4, 0B113F4, 0B113Z4, 0B114F4, 0B114Z4
	CPT	31600, 31603, 31605, 31610
Surgical operation with transplant of whole organ causing abnormal patient reaction, or later complication, without mention of misadventure at time of operation	ICD-9-DX	E878.0
	ICD-10-DX	Y83.0
Acute cardiac event	ICD-9-DX	410.x, 411.x, 415.0, 420.x, 421.x, 422.x, 427.1, 427.2, 427.3x, 427.4x, 427.5, 427.8x, 427.9, 428.x
	ICD-10-DX	I20, I21, I22, I24, I46, I48, I50, I97.121, I97.131, I97.711
Acute cerebrovascular event	ICD-9-DX	997.0x
	ICD-10-DX	G97.81, G97.82, I97.811, I97.821, G03.8, G97.0
Acute hepatic failure	ICD-9-DX	570.x
	ICD-10-DX	K72.00, K76.2, K91.82
Acute pulmonary edema/failure	ICD-9-DX	514, 518.4, 518.5
	ICD-10-DX	J95.812, J81.0, J90, R06.03, R06.09, R06.81, R09.0, R09.2, J95.811, J95.821, J95.88, J95.89
Acute renal failure	ICD-9-DX	584
	ICD-10-DX	N17.x
Foreign body	ICD-9-DX	998.4
	ICD-10-DX	T81.509A, T81.519A, T81.529A, T81.539A
Gastrointestinal bleed	ICD-9-DX	530.82, 531.0, 531.1, 531.2, 531.4, 531.60, 531.61, 532.0, 532.1, 532.2, 532.4, 532.6, 533.0, 533.1, 533.2, 533.4, 533.6, 534.0, 534.1, 534.2, 534.4, 534.6, 535.01, 535.11, 535.21, 535.31, 535.41, 535.51, 535.61, 578.9
	ICD-10-DX	K26.0, K26.2, K27.0, K27.1, K27.2, K28.0, K28.1, K28.2, K29.01, K29.51, K29.61. K29.21, K29.71, K29.81, K29.91, K92.2

(Continued)

TABLE E3. Continued

Description	Type of code	Codes
Hemorrhage, hematoma, or seroma	ICD-9-DX	998.1x
	ICD-10-DX	D78.02, D78.22, D78.32, D78.34, E89.811, E89.821, E89.823, G97.32, G97.52, G97.62, G97.64, I97.42, I97.62x, J95.831, J95.861, J95.863, K91.84x, K91.87x, L76.22, L76.32, L76.34, M96.81x, M96.83x, M96.84x, N99.821, N998.41, N99.843, T88.8XXA
Pneumonia	ICD-9-DX	480, 481, 482, 483, 485, 487.0, 997.31, 507.0,
	ICD-10-DX	J13.x, J14.x, J15.x, J16.x, J17.x, J18.x, J69.0, A22.1, A48.1, B25.0, B44.0
Nonhealing surgical wound, other unspecified procedural complications	ICD-9-DX	998.83, 998.81, 998.89, 998.9, 999.9
	ICD-10-DX	T81.82XA, T81.89XA, T81.9XXA, T88.8XXA, T88.9XXA
Accidental perforation or laceration of blood vessel, nerve, or organ	ICD-9-DX	998.2
	ICD-10-DX	D78.11, D78.12, E36.11, E36.12, G97.48, G97.49, H59.219, H59.229, H95.31, H95.32, I97.51, I97.52, J95.71, J95.72, K91.71, K91.72, L76.11, L76.12, M96.820, M96.821, N99.71, N99.72
Postoperative bowel obstruction	ICD-9-DX	997.4x, 569.7x
	ICD-10-DX	K91.3x, K91.80, K91.81, k91.85, K91.86, K91.89
Postoperative fistula	ICD-9-DX	998.6
	ICD-10-DX	T81.83XA
Postoperative infection/surgical site infection	ICD-9-DX	958.3, 998.5x
	ICD-10-DX	T79.8XXA, T81.4x-T81.6x, T82.7x, T85.7, K68.11
Sepsis	ICD-9-DX	995.9, 038.x, 999.3
	ICD-10-DX	A40.x, A41.x, R65.x, A04.x, G00.x, I31.x, O86.x, Y95.x
Shock	ICD-9-DX	998.0x
	ICD-10-DX	T81.1x, T88.2XXA, R57.x
Urinary tract infection	ICD-9-DX	599.0, 996.64, 996.31, 595.0, 595.8x, 595.9, 590.80, 597.89, 599.70
	ICD-10-DX	N30.0, N30.8, N30.9, N39.0, N12, N34.2, R31.9, T83.5x, T83.09x
Delirium	ICD-9-DX	293.0, 293.1, 293.8, 293.9
	ICD-10-DX	F05, F06
Cytomegalovirus infection	ICD-9-DX	078.5
	ICD-10-DX	B25.9
VTE	ICD-9-DX	415.1, 451.1x, 451.2, 451.81, 453.8
	ICD-10-DX	I26.x, I82.0, I82.1, I82.210, I82.220, I82.290, I82.3x, I82.4x, I82.6x, I82.A1x, I82.B1x, I82.C1x, I82.90
Wound dehiscence	ICD-9-DX	998.3x
	ICD-10-DX	T81.3x
Misadventures to patients during surgical and medical care	ICD-9-DX	E872, E873, E875, E876
	ICD-10-DX	Y62, Y63, Y64, Y65, Y66, Y69
Stenting	CPT	31631, 31636, 31636, 31638
Balloon dilation	CPT	31630
Bronchial thermoplasty	CPT	31660, 31661

ICD-9, International Classification of Diseases, Ninth Revision; *ICD-10*, International Classification of Diseases, Tenth Revision; *PCS*, procedure; *DX*, diagnosis; *CPT*, Current Procedural Terminology.

TABLE E4. Gamma regression to assess the association of disease etiology with 3-month preadmission costs

Outcome: 3-mo preadmission cost		All patients excluding cost outliers		Patients excluding cost outliers and unknown region	
Covariate	Level	CR estimate (95% CI)	*P* value	CR estimate (95% CI)	*P* value
Disease group	Restrictive lung disease	1.30 (1.07-1.57)	.009	1.29 (1.06-1.56)	.01
	Cystic fibrosis and immunodeficiency disorders	2.30 (1.70-3.13)	<.001	2.33 (1.72-3.17)	<.001
	Pulmonary vascular disease	1.77 (1.18-2.66)	.006	1.77 (1.18-2.65)	.006
	Obstructive lung disease	Reference	.	Reference	.
Age at index hospitalization	55+ y	0.60 (0.45-0.79)	<.001	0.60 (0.45-0.79)	<.001
	36-54 y	0.79 (0.60-1.04)	.1	0.80 (0.61-1.06)	.12
	12-35 y	Reference	.	Reference	.
Sex	Female	1.06 (0.91-1.24)	.45	1.05 (0.90-1.23)	.5
	Male	Reference	.	Reference	.
Index year	2019	1.42 (1.02-1.97)	.04	1.44 (1.03-2.00)	.03
	2018	1.88 (1.41-2.50)	<.001	1.91 (1.43-2.53)	<.001
	2017	1.31 (0.99-1.73)	.06	1.33 (1.01-1.75)	.04
	2016	1.18 (0.91-1.54)	.21	1.20 (0.92-1.56)	.18
	2015	1.46 (1.12-1.90)	.005	1.49 (1.14-1.93)	.003
	2014	1.06 (0.83-1.37)	.64	1.09 (0.85-1.41)	.49
	2013	Reference	.	Reference	.
Residential region	Unknown	1.52 (0.70-3.31)	.29		
	West	1.19 (0.92-1.55)	.18	1.19 (0.92-1.54)	.19
	South	1.17 (0.95-1.43)	.14	1.17 (0.95-1.43)	.14
	North Central	1.05 (0.83-1.33)	.67	1.05 (0.83-1.33)	.69
	Northeast	Reference	.	Reference	.
Insurance type	POS or PPO	1.28 (1.03-1.59)	.03	1.28 (1.03-1.59)	.03
	EPO or HMO	1.07 (0.77-1.49)	.68	1.07 (0.77-1.49)	.68
	Comprehensive	0.83 (0.63-1.10)	.2	0.84 (0.63-1.11)	.21
	CDHP or HDHP	Reference	.	Reference	.
ECMO use during index hospitalization	Yes	0.98 (0.80-1.19)	.81	0.98 (0.80-1.19)	.81
	No	Reference	.	Reference	.
Mechanical ventilation use during index hospitalization	Yes	1.27 (1.03-1.58)	.03	1.29 (1.04-1.60)	.02
	No	Reference	.	Reference	.
Van Walraven Elixhauser comorbidity score		1.04 (1.03-1.05)	<.001	1.04 (1.03-1.05)	<.001

CR, Cost ratio; *CI*, confidence interval; *CDHP*, consumer driven health plan; *HDHP*, high deductible health plan; *EPO*, exclusive provider organization; *HMO*, health maintenance organization; *POS*, point of service; *PPO*, preferred provider organization; *ECMO*, extracorporeal membrane oxygenation.

TABLE E5. Gamma regression to assess the association of disease etiology with 3-month postdischarge costs

Outcome: 3-mo post-index hospitalization cost		All patients excluding cost outliers		Patients excluding cost outliers and unknown region	
Covariate	Level	CR estimate (95% CI)	*P* value	CR estimate (95% CI)	*P* value
Disease etiology group	Restrictive lung disease	1.01 (0.86-1.19)	.91	1.00 (0.85-1.18)	.96
	Cystic fibrosis and immunodeficiency disorders	1.04 (0.79-1.36)	.8	1.12 (0.84-1.48)	.44
	Pulmonary vascular disease	1.15 (0.82-1.63)	.42	1.22 (0.85-1.74)	.28
	Obstructive lung disease	Reference	.	Reference	.
Age at index hospitalization	55 y+	0.88 (0.69-1.12)	.29	0.92 (0.72-1.19)	.54
	36-54 y	0.94 (0.74-1.19)	.61	0.98 (0.77-1.26)	.88
	12-35 y	Reference	.	Reference	.
Sex	Female	0.91 (0.80-1.04)	.15	0.93 (0.82-1.07)	.31
	Male	Reference	.	Reference	.
Index year	2019	0.90 (0.68-1.19)	.45	0.93 (0.70-1.22)	.59
	2018	1.13 (0.89-1.44)	.31	1.17 (0.92-1.49)	.2
	2017	1.03 (0.82-1.31)	.77	1.02 (0.80-1.29)	.87
	2016	1.18 (0.94-1.47)	.15	1.21 (0.97-1.52)	.09
	2015	0.99 (0.79-1.23)	.91	1.00 (0.80-1.26)	.97
	2014	1.09 (0.88-1.34)	.44	1.08 (0.87-1.35)	.47
	2013	Reference	.	Reference	.
Census region of index LTx hospital	Unknown	1.26 (0.90-1.78)	.18		
	West	1.17 (0.93-1.46)	.18	1.17 (0.93-1.47)	.18
	South	0.89 (0.74-1.07)	.22	0.91 (0.76-1.09)	.29
	North Central	0.89 (0.73-1.08)	.23	0.89 (0.73-1.09)	.27
	Northeast	Reference	.	Reference	.
Insurance type	POS or PPO	1.09 (0.91-1.31)	.36	1.13 (0.94-1.36)	.19
	EPO or HMO	1.13 (0.86-1.48)	.38	1.22 (0.92-1.61)	.16
	Comprehensive	0.67 (0.52-0.86)	.002	0.70 (0.54-0.89)	.005
	CDHP or HDHP	Reference	.	Reference	.
ECMO use during index hospitalization	Yes	1.22 (1.03-1.45)	.02	1.25 (1.05-1.50)	.01
	No	Reference	.	Reference	.
Mechanical ventilation use during index hospitalization	Yes	1.14 (0.95-1.37)	.17	1.14 (0.95-1.37)	.17
	No	Reference	.	Reference	.
Van Walraven Elixhauser comorbidity score		1.01 (1.00-1.01)	.19	1.01 (1.00-1.02)	.1

CR, Cost ratio; *CI*, confidence interval; *LTx*, lung transplant; *CDHP*, consumer driven health plan; *HDHP*, high deductible health plan; *EPO*, exclusive provider organization; *HMO*, health maintenance organization; *POS*, point of service; *PPO*, preferred provider organization; *ECMO*, extracorporeal membrane oxygenation.

TABLE E6. Generalized linear regression with a gamma distribution and a log link to assess the association of disease etiology with 3-month preadmission, index hospitalization, and 3-month postdischarge costs, including cost outliers

		3-mo preadmission cost		Index hospitalization cost		3-mo postdischarge cost	
Covariate	Level	CR estimate (95% CI)	*P* value	CR estimate (95% CI)	*P* value	CR estimate (95% CI)	*P* value
Disease etiology group	Group A, obstructive lung disease	Reference	.	Reference	.	Reference	.
	Group B, pulmonary vascular disease	2.20 (1.44-3.34)	<.001	1.47 (1.13-1.93)	.005	1.44 (1.01-2.05)	.05
	Group C, cystic fibrosis and immunodeficiency disorders	2.16 (1.57-2.99)	<.001	1.15 (0.93-1.42)	.19	1.06 (0.79-1.42)	.69
	Group D, restrictive lung disease	1.39 (1.13-1.70)	.002	1.08 (0.94-1.22)	.28	1.01 (0.85-1.21)	.87
Age at index hospitalization	12-35 y	Reference	.	Reference	.	Reference	.
	36-54 y	0.54 (0.41-0.71)	<.001	0.88 (0.74-1.06)	.18	0.94 (0.73-1.22)	.65
	55+ y	0.40 (0.30-0.53)	<.001	0.75 (0.63-0.90)	.002	0.97 (0.75-1.25)	.81
Sex	Male	Reference	.	Reference	.	Reference	.
	Female	1.13 (0.96-1.33)	.14	1.12 (1.01-1.25)	.03	0.99 (0.86-1.14)	.88
Index year	2013	Reference	.	Reference	.	Reference	.
	2014	0.97 (0.74-1.27)	.84	1.10 (0.93-1.31)	.25	1.01 (0.81-1.27)	.90
	2015	1.31 (0.99-1.73)	.06	1.11 (0.93-1.32)	.26	0.91 (0.72-1.16)	.46
	2016	1.23 (0.93-1.63)	.15	1.27 (1.07-1.52)	.007	1.17 (0.92-1.48)	.20
	2017	1.30 (0.97-1.74)	.08	1.12 (0.93-1.36)	.22	0.96 (0.75-1.22)	.72
	2018	1.72 (1.27-2.33)	<.001	1.15 (0.95-1.39)	.16	1.17 (0.91-1.51)	.22
	2019	1.37 (0.97-1.94)	.07	1.03 (0.83-1.29)	.79	0.83 (0.62-1.11)	.21
Region	Northeast	Reference	.	Reference	.	Reference	.
	North Central	1.11 (0.86-1.42)	.42	0.64 (0.55-0.75)	<.001	0.90 (0.73-1.11)	.33
	South	1.06 (0.85-1.32)	.62	0.61 (0.53-0.70)	<.001	0.82 (0.68-1.00)	.05
	West	1.21 (0.92-1.60)	.16	0.83 (0.69-0.99)	.04	1.13 (0.89-1.43)	.32
	Unknown	1.33 (0.58-3.03)	.50	0.82 (0.63-1.08)	.16	1.19 (0.83-1.71)	.34
Insurance type	CDHP or HDHP	Reference	.	Reference	.	Reference	.
	Comprehensive	0.81 (0.60-1.10)	.18	0.65 (0.54-0.80)	<.001	0.60 (0.46-0.78)	<.001
	EPO or HMO	0.92 (0.65-1.29)	.62	0.90 (0.72-1.12)	.33	1.05 (0.79-1.40)	.75
	POS or PPO	1.30 (1.03-1.63)	.03	0.96 (0.83-1.11)	.54	1.07 (0.88-1.30)	.49
ECMO use during index hospitalization	No	Reference	.	Reference	.	Reference	.
	Yes	1.01 (0.82-1.26)	.90	1.57 (1.37-1.80)	<.001	1.30 (1.08-1.56)	.005
Mechanical ventilation use during index hospitalization	No	Reference	.	Reference	.	Reference	.
	Yes	1.16 (0.93-1.45)	.19	1.41 (1.22-1.63)	<.001	1.20 (0.98-1.45)	.07
Van Walraven Elixhauser comorbidity score		1.04 (1.03-1.05)	<.001	1.00 (1.00-1.01)	.39	1.00 (0.99-1.01)	.51

CR, Cost ratio; *CI*, confidence interval; *LTx*, lung transplant; *CDHP*, consumer driven health plan; *HDHP*, high deductible health plan; *EPO*, exclusive provider organization; *HMO*, health maintenance organization; *POS*, point of service; *PPO*, preferred provider organization; *ECMO*, extracorporeal membrane oxygenation.