Debunking the July Effect in lung transplantation recipients

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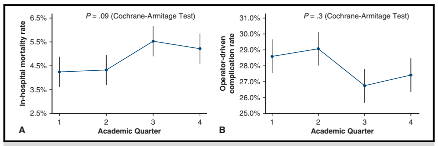
ABSTRACT

Objective: The "July Effect" is a theory that the influx of trainees from July to September negatively impacts patient outcomes. We aimed to study this theoretical phenomenon in lung transplant recipients given the highly technical nature of thoracic procedures.

Methods: Adult lung transplant hospitalizations were identified within the National Inpatient Sample (2005-2020). Recipients were categorized as academic Q1 (July to September) or Q2-Q4 (October to June). In-hospital mortality, operator-driven complications (pneumothorax, dehiscence including wound dehiscence, bronchial anastomosis, and others, and vocal cord/diaphragm paralysis, all 3 treated as a composite outcome), length of stay, and inflation-adjusted hospitalization charges were compared between both groups. Multivariable logistic regression was performed to assess the association between academic quarter and in-hospital mortality and operator-driven complications. The models were adjusted for recipient demographics and transplant characteristics. Subgroup analysis was performed between academic and nonacademic hospitals.

Results: Of 30,788 lung transplants, 7838 occurred in Q1 and 22,950 occurred in Q2-Q4. Recipient demographic and clinical characteristics were similar between groups. Dehiscence (n = 922, 4% vs n = 236, 3%), post-transplant cardiac arrest (n = 532, 2% vs n = 113, 1%), and pulmonary embolism (n = 712, 3% vs n = 164, 2%) were more common in Q2-Q4 versus Q1 recipients (all $P < .05$). Other operator-driven complications, in-hospital mortality, and resource use were similar between groups ($P > .05$). These inferences remained unchanged in adjusted analyses and on subgroup analyses of academic versus nonacademic hospitals.

Conclusions: The "July Effect" is not evident in US lung transplantation recipient outcomes during the transplant hospitalization. This suggests that current institutional monitoring systems for trainees across multiple specialties, including surgery, anesthesia, critical care, nursing, and others, are robust. (JTCVS Open 2024;18:376-99)



Mortality and complication rates versus academic quarter for lung transplant recipients.

CENTRAL MESSAGE

The "July Effect" is not evident in US lung transplant recipient outcomes during the transplant hospitalization.

PERSPECTIVE

Because of greater vigilance and increased personnel, patients undergoing lung transplantation during the July to September months may be at lower risk for complications. Patients and clinicians should be more at ease with lung transplantation procedures occurring during these months, which is a testament to the robustness of the academic surgery model and the multidisciplinary care teams for these patients.

During the beginning of the academic quarter (July to September), an influx of trainees fills residency and fellowship programs nationwide. The "July Effect" is a theoretical phenomenon that worse patient outcomes occur during this period because of inexperienced trainees coming into their newfound role. Given the intricate, technical nature of surgical procedures, there has been concern that the surgical populations might be at even higher risk of the July Effect. However, the presence of this effect has not yet been evaluated for one of the most highly technical surgical procedures: lung transplantation.

Prior efforts to evaluate the July Effect in other surgical populations have produced conflicting results. A study of more than 60,000 general surgery patients in the American College of Surgeons National Surgical Quality

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Abbreviations and Acronyms

aOR	= adjusted odds ratio
HCUP	= Healthcare Cost and Utilization Project
ICD-9	= International Classification of Diseases, 9th Revision
ICD-10	= International Classification of Diseases, 10th Revision
IQR	= interquartile range
NIS	= National Inpatient Sample

Improvement Program database found a higher risk of surgical morbidity and mortality up to 30 days postsurgery during the first academic quarter compared with the other quarters.[1] This study noted that surgical operations depend on technical expertise and precise communication more than other specialties, which may explain their findings and give impetus to future studies in other surgical specialties like thoracic surgery. In contrast, a study of approximately 1.4 million patients in the National Inpatient Sample (NIS) originating from the Healthcare Cost and Utilization Project (HCUP) who underwent emergency general surgery suggested that rates of in-hospital mortality and complications were slightly lower in patients managed by trainees in July and August compared with other months.[2] Other studies in cardiac,[3,4] trauma,[5] orthopedic,[6] and neurological surgery[7,8] populations also show conflicting results about the reality of the July Effect. Nevertheless, literature on this concept is lacking in lung transplant recipients, who are at high risk of operator-driven complications and increased mortality due to the high technicality and complexity of these procedures and thus steep learning curve for trainees.[9]

Using the largest administrative database of all-payer information in the United States, we aimed to evaluate whether in-hospital mortality and operator-driven complications were higher for lung transplants performed in the months of July to September compared with the rest of the academic year. We also sought to identify risk factors for increased rates of in-hospital mortality and operator-driven complications.

MATERIALS AND METHODS

Study Design and Population

Records were obtained from the NIS originating from the HCUP database. The NIS represents a 20% stratified sample of all nonfederal, acute-care hospitals in the United States. Weighted estimates were obtained by applying discharge weights to each sample discharge. HCUP NIS is the largest publicly available, all-payer registry for inpatient care in the United States, capturing approximately 7 million hospitalizations and estimating 35 million hospitalizations nationally annually based on discharge sample weights.[10] We accounted for the sampling methodology change in discharge weights in 2012 by using the appropriate weighted variable. The NIS provides demographic, clinical, and socioeconomic information for each admission. This study was approved by the Johns Hopkins University Institutional Review Board with a waiver of informed consent (IRB00221778) on August 29, 2019. All procedures were followed in accordance with the ethical standards of the responsible committee on human experimentation (institutional or regional) and with the Helsinki Declaration of 1975.

We included all lung transplant surgery index hospital admissions between 2005 and 2020 for adult (≥18 years of age) recipients. We identified lung transplant recipients using International Classification of Diseases, 9th Revision (ICD-9) and International Classification of Diseases, 10th Revision (ICD-10) procedure codes (336, 3350, 3351, 3352, 0BYC0Z0, 0BYC0Z1, 0BYC0Z2, 0BYD0Z0, 0BYD0Z1, 0BYD0Z2, 0BYF0Z0, 0BYF0Z1, 0BYF0Z2, 0BYG0Z0, 0BYG0Z1, 0BYG0Z2, 0BYH0Z0,0BYH0Z1, 0BYH0Z2, 0BYJ0Z0, 0BYJ0Z1, 0BYJ0Z2,0BYK0Z0, 0BYK0Z1, 0BYK0Z2, 0BYL0Z0, 0BYL0Z1, 0BYL0Z2, 0BYM0Z0, 0BYM0Z1, 0BYM0Z2) (Table E1).[11] We excluded recipients missing admission month.

Data Collection and Definitions

We stratified the hospital admissions into 2 groups: academic quarter 1 (Q1, July to September) versus academic quarters 2 to 4 (Q2-Q4, October to June). In a sensitivity analysis, we also compared Q1 (least experienced trainees, July to September) with Q4 (most experienced trainees, April to June) directly. In a supplementary analysis, we performed comparisons between other academic quarters.

Demographics included lung transplant recipient age, sex, race/ethnicity, and comorbidities; region of hospital admission; primary insurance payer; and median household income (based on ZIP code and grouped into quartiles). Race/ethnicity was defined as Asian/Pacific Islander, Black, Hispanic, Native American, White, or Other. Region of the hospital was categorized using the US Census Divisions: New England (Division 1), Middle Atlantic (Division 2), East North Central (Division 3), West North Central (Division 4), South Atlantic (Division 5), East South Central (Division 6), West South Central (Division 7), Mountain (Division 8), and Pacific (Division 9). ICD clinical codes were used to ascertain all comorbidities including diabetes, hypertension, and congestive heart failure (Table E2). ICD procedure codes were used to identify lung transplant type (single, double, or heart-lung) and use of extracorporeal membrane oxygenation, ex vivo lung perfusion, and mechanical ventilation (Table E3). Operator-driven complications included pneumothorax, dehiscence, and vocal cord/diaphragm paralysis. Dehiscence was defined as both wound dehiscence and other types of dehiscence such as bronchial anastomosis. Other in-hospital complications included myocardial infarction, atrial fibrillation, complete heart block, cardiogenic shock, cardiac arrest, pleural effusion, pulmonary edema, pulmonary embolism, deep vein thrombosis, acute kidney injury, stroke, gastroparesis, and cytomegalovirus. Table E4 provides ICD clinical codes for each complication. Discharge disposition included routine activities (discharge to home/self-care, court/law enforcement, or a planned acute care in-hospital inpatient readmission), home health care, transfer to short-term hospital, transfer to a facility (skilled nursing, intermediate care, or other), leaving the hospital against medical advice, or in-hospital death.

Academic hospitals were defined as a hospital having at least 1 Accreditation Council for Graduate Medical Education approved residency program, being a member of the Council of Teaching Hospitals, or having a proportion of full-time equivalent interns and residents to beds of 1/4 or higher. Nonacademic hospitals were all other hospitals within NIS that did not fulfill any of the aforementioned requirements to be an academic hospital.

Outcomes

Our primary outcome was the difference of in-hospital mortality between lung transplant recipients hospitalized in Q1 and Q2-Q4. Our secondary outcomes were the differences in operator-driven complications (pneumothorax, dehiscence, and vocal cord/diaphragm paralysis), length of stay, discharge disposition, total hospitalization charges, and other in-hospital complications between Q1 and Q2-Q4. Subgroup analysis was conducted between academic versus nonacademic institutions.

Statistical Analysis

Continuous variables were reported as median with interquartile range (IQR), and categorical variables were stated as absolute numbers with corresponding percentages. Weighted Wilcoxon rank-sum (design-based) and chi-square (Rao-Scott correction) tests were used to compare continuous and categorical variables, respectively. The Cochrane-Armitage test was used to assess statistical significance of trends for in-hospital mortality and operator-driven complications throughout admission months and academic quarters. A difference-in-difference estimate was generated to compare in-hospital mortality between academic and nonacademic institutions. Total hospitalization charges were adjusted for inflation to 2020 United States dollars by the Consumer Price Index through the World Bank.[12] Analyses accounted for stratification and clustering of data by using survey commands. Survey-based methodology from 20% of actual data was used to extrapolate the remaining 80% of national hospitalizations. Our analysis of the July Effect was performed based on previously validated methodology in published studies assessing this phenomenon in other populations.[3,13,14]

The number of transplant centers and average number of transplant hospitalizations per center in each US census division region were calculated in HCUP NIS by the unique hospital identifier number to better understand the effect of transplant center region on associated mortality and operator-driven complications in our adjusted analyses. The average number of transplants per center in each census division region was then calculated by the total number of transplant hospitalizations in the region divided by the number of transplant centers in the same region.

In a center-level clustering analysis, we calculated a Gini coefficient between each institution based on the outcome of any operator-driven complication (pneumothorax, dehiscence, and vocal cord/diaphragm paralysis) to determine if the distribution of operator-driven complication errors was equitable or inequitable between each institution.

For logistic regression, multiple imputation was used to handle missingness through 5 individually imputed datasets (Rubin's Rules)[15] to augment statistical power. Continuous, unordered categorical, and dichotomous missing variables were imputed via regression with predictive mean matching, polytomous logistic regression, and logistic regression, respectively.

Multivariable logistic regression was performed to ascertain if academic quarter was associated with in-hospital mortality and to identify additional risk factors. Covariates in the adjusted regression model were selected a priori to have an association with in-hospital mortality and included recipient age, sex, and race/ethnicity; region of hospitalization; median household income by ZIP code; and lung transplant type (single, double, or heart-lung).

Multivariable logistic regression was also performed to ascertain if academic quarter was associated with operator-driven complications (pneumothorax, dehiscence, and vocal cord/diaphragm paralysis), in which all 3 complications were treated as a singular composite outcome. Adjusted variables were hypothesized a priori to have an association with operator-driven complications, including recipient age, sex, and race/ethnicity; region of hospitalization; median household income by ZIP code; and lung-transplant type (single, double, or heart-lung).

Adjusted odds ratios (aORs) with 95% CIs were presented. All statistical analyses were performed using R Studio (R 4.1.2, www.r-project.org).

RESULTS

Study Population (Q1 vs Q2-Q4)

We identified 30,788 (extrapolated) total lung transplant recipients who met inclusion criteria, including 7838 in Q1 (July-September) and 22,950 in Q2-Q4 (October-June, Figure 1). Overall, baseline demographics and clinical characteristics were similar by academic quarter(s) (Q1 and Q2-Q4) (Table 1) and remained the same on sensitivity analysis of Q1 versus Q4 recipients (Table E5). Recipient age, sex, race/ethnicity, and Charlson Comorbidity Index scores were similar between the 2 groups. Recipient hospital region, primary insurance type, and median household income were similar for Q1 and Q2-Q4 recipients.

Unadjusted In-Hospital Mortality, Complications, and Resource Use (Q1 vs Q2-Q4)

Overall, unadjusted in-hospital mortality, complications, and resource use (total hospitalization charges and length of stay) were similar between Q1 and Q2-Q4 recipients (Table 2). The likelihood of in-hospital mortality was not different between Q1 versus Q2-Q4 recipients (n = 335 [4%] vs n = 1152 [5%], *P* = .22 (Figure 2, *A*, and Table 2). This inference remained unchanged on sensitivity analysis of Q1 versus Q4 recipients (n = 335 [4%] vs n = 407 [5%], *P* = .23) (Table E6). Dehiscence was more common among Q2-Q4 versus Q1 recipients (n = 922, 4% vs n = 236, 3%, *P* = .045), although this difference might not reach clinical significance (Figure 2, *B*). The prevalence of pneumothorax (n = 1790, 23% vs n = 4918, 21%, *P* = .25) and vocal cord/diaphragm paralysis was similar in both groups (n = 407, 5% vs n = 1148, 5%, *P* = .76).

Cardiac arrest and pulmonary embolism were more prevalent in Q2-Q4 versus Q1 recipients (n = 532, 2% vs n = 113, 1%, *P* = .02; n = 712, 3% vs n = 164, 2%, *P* = .03, respectively), although this difference might not reach clinical significance. Other major in-hospital complications were similar between Q1 and Q2-Q4 recipients. Length of stay, discharge disposition, lung transplant type, extracorporeal membrane oxygenation, ex vivo lung perfusion, and mechanical ventilation use were similar between Q1 and Q2-Q4 recipients (all *P* > .05).

Adjusted Rate of In-Hospital Mortality and Associated Risk Factors

After adjusting for recipient and transplant characteristics, Q1 admission was still not associated with in-hospital mortality compared with Q2-Q4 admission (aOR, 0.86, 95% CI, 0.66-1.12, *P* = .27) (Table 3 and Figure 3).

Age, sex, and race/ethnicity were not associated with in-hospital mortality for lung transplants performed in Q1 versus Q2-Q4. Relative to lung transplantations performed in the East North Central region, transplantations performed in the Middle Atlantic (aOR, 0.61, 95% CI, 0.41-0.90, *P* = .01), West North Central (aOR, 0.43, 95% CI, 0.20-0.92, *P* = .03), Mountain (aOR, 0.50, 95% CI, 0.31-0.81, *P* < .001), and Pacific (aOR, 0.58, 95% CI, 0.34-0.98, *P* = .04) regions were associated with reduced odds of in-hospital mortality. Relative to double-lung transplants,

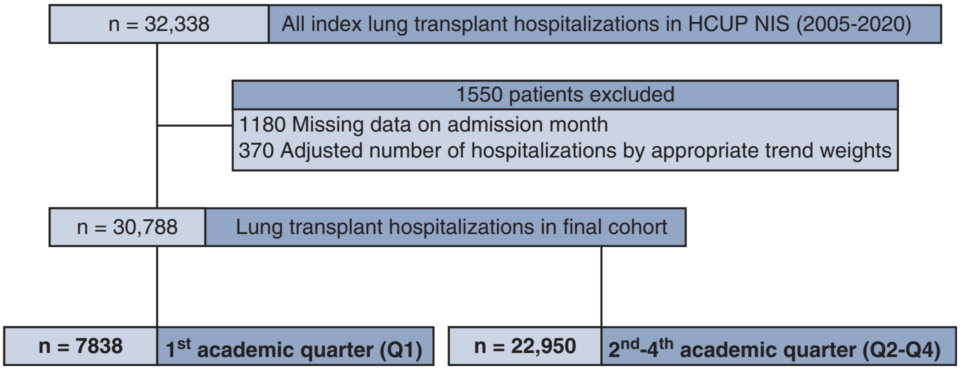

FIGURE 1. Creation of study cohort from the HCUP NIS database (2005-2020). *HCUP*, Healthcare Cost and Utilization Project; *NIS*, National Inpatient Sample.

heart-lung transplants were associated with higher odds of in-hospital mortality (aOR, 5.30, 95% CI, 2.56-10.98, $P < .001$). In a sensitivity analysis, Q1 admission was not associated with a difference in in-hospital mortality compared with Q4 admission (aOR, 0.81, 95% CI, 0.57-1.14, $P = .22$, Table E7).

Adjusted Rate of Operator-Driven Complications and Associated Risk Factors

After adjusting for recipient and transplant characteristics, odds of an operator-driven complication (pneumothorax, dehiscence, vocal cord/diaphragm paralysis) remained similar for Q1 versus Q2-Q4 admissions (aOR, 1.06, 95% CI, 0.93-1.20, $P = .42$) (Table E8 and Figure 4). Relative to lung transplants performed in the East North Central region, lung transplants performed in the West North Central (aOR, 1.57, 95% CI, 1.02-2.43, $P = .04$) and South Atlantic (aOR, 1.51, 95% CI, 1.08-2.11, $P = .02$) regions were associated with increased odds of operator-driven complications. Relative to double-lung transplants, single-lung transplants were associated with lower odds of operator-driven complications (aOR, 0.72, 95% CI, 0.62-0.85, $P < .001$). In sensitivity analysis, Q1 admission was also not associated with operator-driven complications versus Q4 admission only (aOR, 1.08, 95% CI, 0.93-1.26, $P = .32$) (Table E9).

Number of Transplant Centers, Total Number of Transplant Hospitalizations, and Average Number of Transplants per Center in Each Census Division Region

In HCUP NIS, Division 1 (New England) had 7 total transplant centers and 966 total transplant hospitalizations, and the average number of transplants per center was 138. Division 2 (Middle Atlantic) had 14 transplant centers and 4684 total transplant hospitalizations, and the average number of transplants per center was 335. Division 3 (East North Central) had 20 transplant centers and 5790 total transplant hospitalizations, and the average number of transplants per center was 290. Division 4 (West North Central) had 7 transplant centers and 1813 total transplant hospitalizations, and the average number of transplants per center was 259. Division 5 (South Atlantic) had 21 transplant centers and 5355 total transplant hospitalizations, and the average number of transplants per center was 255. Division 6 (East South Central) had 8 transplant centers and 1320 total transplant hospitalizations, and the average number of transplants per center was 165. Division 7 (West South Central) had 19 transplant centers and 4295 total transplant hospitalizations, and the average number of transplants per center was 226. Division 8 (Mountain) had 7 transplant centers and 2469 total transplant hospitalizations, and the average number of transplants per center was 353. Division 9 (Pacific) had 23 transplant centers and 4584 total transplant hospitalizations, and the average number of transplants per center was 199.

Center-Level Clustering Analysis

In a center-level clustering analysis, the Gini coefficient for any operator-driven complication between each institution was 0.3, suggesting that there was relative equality of operator-driven complication errors between each institution.

Subgroup Analysis: Academic Versus Nonacademic Hospitals

In-hospital mortality, operator-driven complications, as well as length of stay and total hospitalization charges were also similar between academic versus nonacademic institutions (all $P > .05$). The difference-in-differences estimate for in-hospital mortality between Q1 versus Q2-Q4 recipients in academic versus nonacademic institutions was not significant (estimate = 0.006, 95% CI, −0.006 to 0.02, $P = .31$). In the HCUP NIS, the total number of academic and nonacademic institutions was 80 and 38, respectively. The total number of lung transplant hospitalizations

TABLE 1. Demographics and clinical characteristics of quarter 1 versus quarters 2-4 lung transplant recipient hospitalizations

Variables	All quarters N = 30,788	Quarter 1 (July-September) N = 7838	Quarters 2-4 (October-June) N = 22,950	*P* value
Demographics				
Age, y (median, IQR)	59 (50-65)	60 (50-65)	59 (50-65)	.26
Female	12,549 (40%)	3173 (40%)	9286 (40%)	.99
Race/ethnicity (n = 27,650)				.43
White	21,557 (70%)	5469 (70%)	16,088 (70%)	
Black	2520 (8%)	644 (8%)	1876 (8%)	
Hispanic	2244 (7%)	647 (8%)	1597 (7%)	
Asian or Pacific Islander	471 (2%)	123 (2%)	348 (2%)	
Native American	131 (1%)	21 (1%)	110 (1%)	
Other	727 (2%)	162 (2%)	565 (3%)	
Comorbidities				
Charlson Comorbidity Index (median, IQR)	0 (0-1)	0 (0-1)	0 (0-1)	.88
Diabetes	660 (2%)	150 (2%)	510 (2%)	.45
Hypertension	12,438 (40%)	3258 (42%)	9180 (40%)	.26
Coronary artery disease	6486 (21%)	1762 (22%)	4724 (21%)	.08
Congestive heart failure	3584 (12%)	917 (12%)	2667 (12%)	.93
Alpha-1-antitrypsin	1111 (4%)	254 (3%)	857 (4%)	.33
Chronic pulmonary disease	12,966 (42%)	3236 (41%)	9730 (42%)	.40
Cystic fibrosis	3177 (10%)	782 (10%)	2395 (10%)	.60
Pulmonary fibrosis	9662 (31%)	2505 (32%)	7157 (31%)	.56
Pulmonary hypertension	10,670 (35%)	2786 (36%)	7884 (34%)	.42
Sarcoidosis	1744 (6%)	422 (5%)	1322 (6%)	.54
Region (n = 30,787)*				.96
New England	967 (3%)	246 (3%)	721 (3%)	
Middle Atlantic	4679 (15%)	1171 (15%)	3508 (15%)	
East North Central	5790 (19%)	1511 (19%)	4279 (19%)	
West North Central	1813 (6%)	451 (6%)	1362 (6%)	
South Atlantic	4871 (16%)	1232 (16%)	3639 (16%)	
East South Central	1320 (4%)	357 (5%)	963 (4%)	
West South Central	4295 (14%)	1058 (13%)	3237 (14%)	
Mountain	2468 (8%)	663 (8%)	1805 (8%)	
Pacific	4584 (15%)	1149 (15%)	3435 (15%)	
Primary payer (n = 30,734)				.54
Medicare	13,083 (42%)	3316 (42%)	9767 (43%)	
Medicaid	2032 (7%)	552 (7%)	1480 (6%)	
Private insurance	14,323 (47%)	3566 (45%)	10,757 (47%)	
Self-pay	244 (1%)	69 (1%)	175 (1%)	
No charge	5 (1%)	0 (0%)	5 (1%)	
Other	1047 (3%)	315 (4%)	732 (3%)	
Median household income by ZIP code (quartiles, n = 28,854)				.98
Quartile 1	5529 (18%)	1392 (18%)	4137 (18%)	
Quartile 2	7183 (23%)	1809 (23%)	5374 (23%)	
Quartile 3	7895 (26%)	2029 (26%)	5866 (26%)	
Quartile 4	8247 (27%)	2106 (27%)	6141 (27%)	

DSA, Donation service area; *IQR*, interquartile range. *Region was defined as 1 of the 9 US Census Bureau Census Divisions.

at academic and nonacademic institutions was 26,891 and 350, respectively, with the remaining 3547 hospitalizations missing information on institution type.

Supplementary Analysis: Other Academic Quarter Comparisons

We also compared clinical outcomes and resource use between other academic quarters (Tables E10-E14). Dehiscence and cardiac arrest were more common among Q2 versus Q1 recipients (n = 336, 4% vs n = 236, 3%, *P* = .029; n = 183, 2% vs n = 113, 1%, *P* = .02). Cardiac arrest was more common among Q3 versus Q1 recipients (n = 187, 2% vs n = 113, 1%, *P* = .02). Cytomegalovirus was more common among Q2 versus Q3 recipients (n = 274, 4% vs n = 155, 2%, *P* = .009). Stroke was more common among Q4 versus Q2 recipients

TABLE 2. Comparisons of in-hospital mortality and complications, and resource use between quarter 1 and quarters 2-4 lung transplant recipient hospitalizations

Variables	Quarter 1 (July-September) N = 7838	Quarters 2-4 (October-June) N = 22,950	*P* value
In-hospital mortality	335 (4%)	1152 (5%)	.22
In-hospital operator-driven complications			
Pneumothorax	1790 (23%)	4918 (21%)	.25
Vocal cord/diaphragm paralysis	407 (5%)	1148 (5%)	.76
Dehiscence‡	236 (3%)	922 (4%)	**.045**
In-hospital other major complications			
Myocardial infarction	124 (2%)	280 (1%)	.29
Atrial fibrillation	2381 (30%)	7252 (32%)	.37
Complete heart block	5 (1%)	69 (1%)	.10
Cardiogenic shock	295 (4%)	875 (4%)	.93
Cardiac arrest	113 (1%)	532 (2%)	**.02**
Pleural effusion	1135 (14%)	3119 (14%)	.37
Pulmonary edema	575 (7%)	1608 (7%)	.65
Pulmonary embolism	164 (2%)	712 (3%)	**.03**
Deep vein thrombosis	493 (6%)	1659 (7%)	.24
Acute kidney injury	2793 (36%)	7676 (33%)	.13
Stroke	211 (3%)	610 (3%)	.93
Gastroparesis	313 (4%)	857 (4%)	.64
Cytomegalovirus	200 (3%)	624 (3%)	.75
Length of stay, d (median, IQR)	17 (12-31)	18 (12-33)	.24
Discharge disposition			.62
Routine*	3466 (44%)	10,296 (45%)	
Short-term hospital	109 (1%)	295 (1%)	
Care facility	1331 (17%)	3948 (17%)	
Home health care	2597 (33%)	7249 (32%)	
Against medical advice	0 (0%)	10 (1%)	
Died	335 (4%)	1152 (5%)	
Total hospitalization charges†, (median, IQR)	$562,721 ($364,423-$958,993)	$557,106 ($361,511-$936,615)	.59
Type of lung transplant			.81
Single	2267 (29%)	6539 (28%)	
Double	5348 (68%)	15,672 (68%)	
Heart-lung	34 (1%)	130 (1%)	
Unknown	189 (2%)	609 (3%)	
Procedures			
ECMO	1265 (16%)	3600 (16%)	.65
EVLP	100 (1%)	260 (1%)	.67
Mechanical ventilation	1290 (16%)	3795 (17%)	.94

Statistically significant *P*-values (*P* <.05) are bolded. *DSA*, Donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion; *IQR*, interquartile range. *Routine includes discharge to home/self-care, court/law enforcement, still being a patient, or a planned acute care in-hospital inpatient readmission. †All charges were adjusted for inflation to 2020 United States dollars. ‡Dehiscence was defined as both wound dehiscence and other types of dehiscence such as bronchial anastomosis.

(n = 250, 3% vs n = 151, 2%, *P* = .02). Although these differences reached statistical significance, we note that they may not have reached clinical significance.

DISCUSSION

In this national analysis of the July Effect on US lung transplantation recipients, we provided the first evidence that lung transplant morbidity, mortality, and resource use (total hospitalization charges and length of stay) did not differ between the months of July to September (first academic quarter) versus October to June (second through fourth academic quarter) in this high-risk population (Figure 5). These findings persisted even after adjustment for risk factors related to in-hospital mortality and

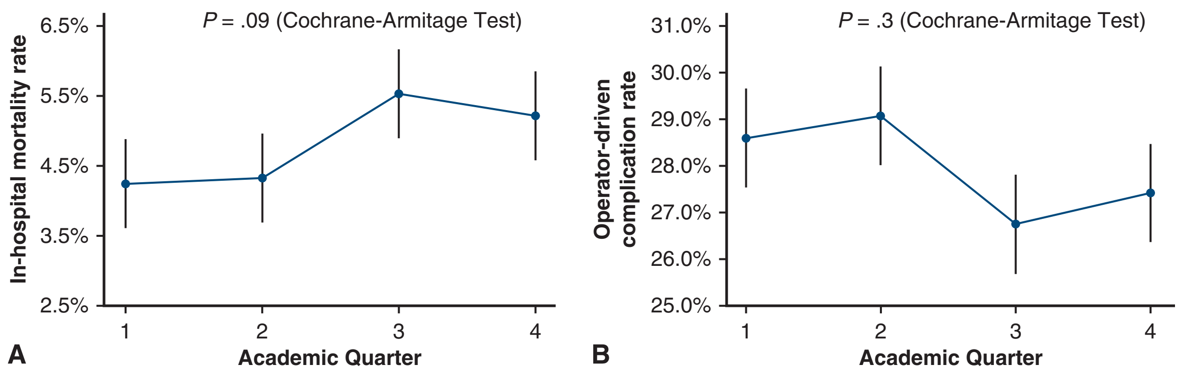

FIGURE 2. Mortality rate versus month of admission (A) and operator-driven complication rate versus month of admission for lung-transplant recipients (B). Q1 = July to September; Q2 = October to December; Q3 = January to March; Q4 = April to June.

operator-driven complications, as well as on a sensitivity analysis comparing the "most experienced" (Q4) and "least experienced" (Q1) trainees and finally on subgroup analysis of academic versus nonacademic institutions. These findings suggest that performing lung transplants with less experienced trainees did not negatively impact recipient

TABLE 3. Multivariable logistic regression model for adjusted in-hospital mortality of lung transplant recipient hospitalizations (2005-2020) with prespecified risk factors for quarter 1 versus quarters 2-4

Variables	aOR	SE	Lower 95% CI	Upper 95% CI	*P* value
Quarter 1	0.86	1.15	0.66	1.12	.27
Age	1.00	1.01	0.99	1.01	.71
Female sex	0.88	1.14	0.68	1.15	.35
Race/ethnicity					
White (reference)					
Black	1.03	1.24	0.67	1.59	.89
Hispanic	0.92	1.29	0.55	1.52	.74
Asian or Pacific Islander	1.29	1.60	0.51	3.28	.59
Native American	1.07	2.87	0.13	8.49	.95
Other	1.15	1.48	0.53	2.50	.73
Region*					
East North Central (reference)					
New England	1.19	1.25	0.77	1.85	.43
Middle Atlantic	0.61	1.22	0.41	0.90	**.01**
West North Central	0.43	1.48	0.20	0.92	**.03**
South Atlantic	0.99	1.22	0.67	1.47	.96
East South Central	0.45	1.63	0.17	1.17	.10
West South Central	0.71	1.31	0.42	1.21	.21
Mountain	0.50	1.28	0.31	0.81	**<.001**
Pacific	0.58	1.31	0.34	0.98	**.04**
Median household income by ZIP code (quartiles)					
Quartile 1 (reference)					
Quartile 2	0.93	1.20	0.65	1.34	.70
Quartile 3	0.87	1.20	0.61	1.24	.44
Quartile 4	0.97	1.22	0.66	1.43	.88
Type of lung transplant					
Double (reference)					
Single	0.93	1.17	0.68	1.27	.66
Heart-lung	5.30	1.45	2.56	10.98	**<.001**

Statistically significant *P*-values (*P* <.05) are bolded. *aOR*, Adjusted odds ratio; *DSA*, donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion. *Region was defined as 1 of the 9 US Census Bureau Census Divisions.

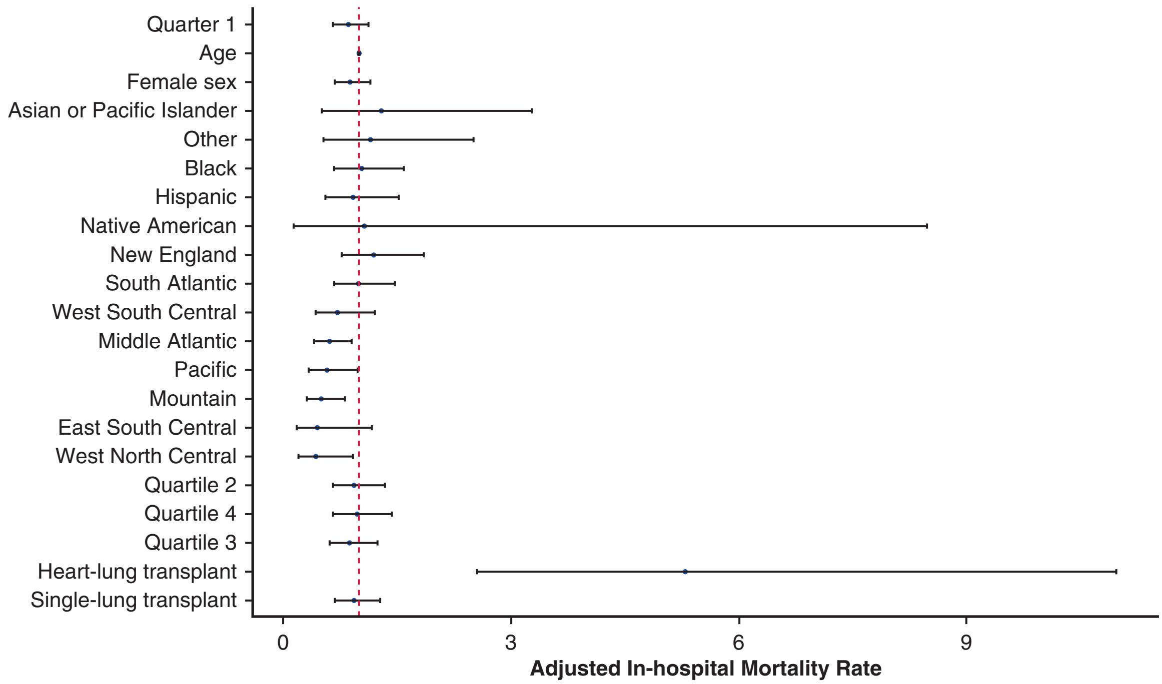

FIGURE 3. Forest plot of adjusted logistic regression model for in-hospital mortality for academic quarter 1 vs. quarters 2-4. aORs with 95% CIs are presented. Quartile refers to median household income quartile.

outcomes. We found that cardiac arrest, pulmonary embolism, and dehiscence were more common for transplants performed in Q2-Q4 versus Q1.

Our findings that the July Effect was absent for lung transplant recipient outcomes is consistent with prior literature evaluating the July Effect in cardiac surgery patients, a

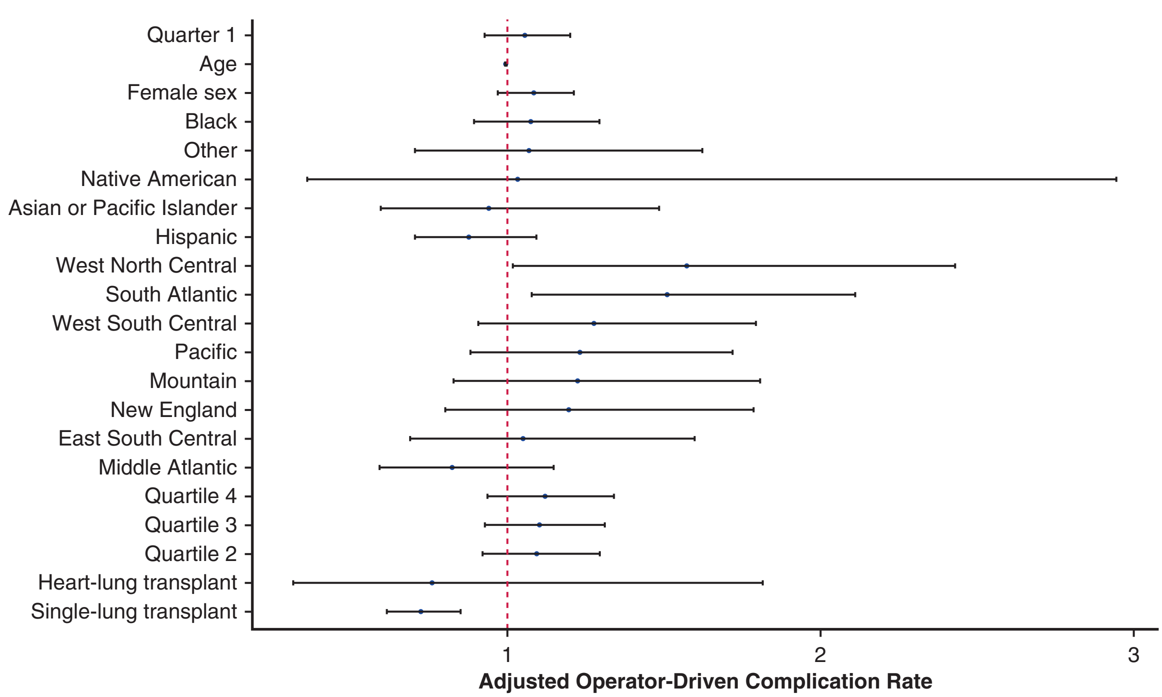

FIGURE 4. Forest plot of adjusted logistic regression model for operator-driven complications (pneumothorax, dehiscence, vocal cord/diaphragm paralysis) for academic quarter 1 versus quarters 2-4. aORs with 95% CIs are presented. Quartile refers to median household income quartile.

patient population who also receive highly technical care from cardiothoracic surgery trainees. In a NIS study looking at various cardiac surgery procedures, in-hospital mortality was also similar between Q1 versus Q4 recipients both overall and after risk adjustment.[3] However, they did find that patients admitted for aortic valve replacement during Q1 were more likely to experience operator-driven complications such as hemopericardium and tamponade compared with Q4 recipients. This finding contrasts with our study, which found that operator-driven complications including pneumothorax and vocal cord/diaphragm paralysis were similar between Q1 and Q2-Q4, whereas dehiscence was actually higher in Q2-Q4 versus Q1. Likewise, another NIS study investigating adults undergoing structural heart interventions found no difference in rates of in-hospital mortality or post-procedural complications such as stroke, major bleeding, acute kidney injury, pacemaker placement, or vascular complications between Q1 and Q4 recipients.[13] Given that cardiothoracic surgery training programs have rigorous 1-on-1 mentorship and monitoring systems in place,[16,17] these results may not be surprising. Additionally, the care of lung transplantation recipients is multidisciplinary, extending beyond just trainees and the attending surgeon to include anesthesiologists, critical care specialists, pulmonologists, nurses, and others. Therefore, the mitigation of mortality and complications likely originates from this continuity of care even beyond the operating room as the vigilance on the part of other members of the care team likely compensates for inexperience of new trainees, limiting their impact on recipient outcomes. This finding is in line with the "Swiss Cheese Model" as applied to patient safety and is consistent with a July Effect study in emergency general surgery patients.[2,18] Accordingly, the extremely multidisciplinary nature of lung transplant could make this procedure more or less susceptible to trainee errors, but this was not able to be evaluated because the HCUP NIS database does not provide data on which provider types were specifically involved in the care of specific patients.

Although we investigated major complications such as stroke, bleeding, and acute kidney injury, we also evaluated operator-driven complications. We hypothesized that if the July Effect was present, operator-driven complications would occur more frequently with new trainees who inherently have less lung transplant operative experience. For example, the occurrence of pneumothorax may be elevated by a less-experienced surgeon who may incorrectly remove the central catheter or pleural drain within the patient.[19] Overall operator-driven complications were not significantly different between Q1 and Q2-Q4 recipients, with the exception of a higher likelihood of dehiscence in Q2-Q4 versus Q1 recipients. We also found a higher occurrence of pulmonary embolism in Q2-Q4 versus Q1 recipients. This finding may be explained by reasons beyond clinical experience of trainees as other studies have suggested that higher sedentariness during cooler months contributes to higher likelihood of clot formation.[20] Likewise, the higher occurrence of cardiac arrest during Q2-Q4 may be due to increased vasoconstriction, higher blood pressure, blood viscosity, and fibrinogen levels.[21,22] Given these findings and previous research suggesting higher rates of complications during winter months,[23] future research may be warranted to investigate clinical outcomes in lung transplant recipients during the winter months.[24,25] Nevertheless, it should be duly noted that although dehiscence, pulmonary embolism, and cardiac arrest were statistically significantly more prevalent in Q2-Q4 versus Q1, the prevalence of each of these complications from a clinical standpoint may be less important.

Finally, we identified independent risk factors for increased in-hospital mortality and operator-driven complications during lung transplant hospitalization. We observed a 5.27 times higher risk of in-hospital mortality in heart-lung transplant recipients compared with double-lung transplant recipients. This finding may be due to the critically ill state of recipients requiring both organs to be transplanted simultaneously. Interestingly, hospital region was also associated with odds of operator-driven complications. These findings may be explained by the South Atlantic regions having lower unadjusted and adjusted lung transplant rates per active person-year, relative to other regions, suggesting less overall operative experience for the entire multidisciplinary team.[26] Additionally, the single-lung transplant procedure may be associated with a lower likelihood of operator-driven complications because it is shorter and less complex than the double-lung transplant procedure. Accordingly, new trainees may experience more procedural errors with the double-lung transplant.

Study Limitations

Although previously validated, the use of survey-based methodology to extrapolate to the national population does not replace having complete data. However, a previous study comparing the lung transplant recipient population in the Scientific Registry of Transplant Recipients with the inferred population from the HCUP NIS database found the 2 groups to be similar.[27] NIS classifies all rural hospitals as nonacademic because they state that rural teaching hospitals were rare in the database. Additionally, proper methodology in using NIS data was followed.[28] Readmission rates could not be calculated because NIS only includes the index hospitalization with no unique linkage variable to connect hospitalizations from the same patient, which could be higher with new trainees. We are limited in our analysis and ability to draw conclusions by the limited granularity of NIS; in particular, NIS does not contain information regarding trainee involvement with each transplant procedure. Because of the complexity of the lung transplant procedure, we recognize that errors committed by trainees

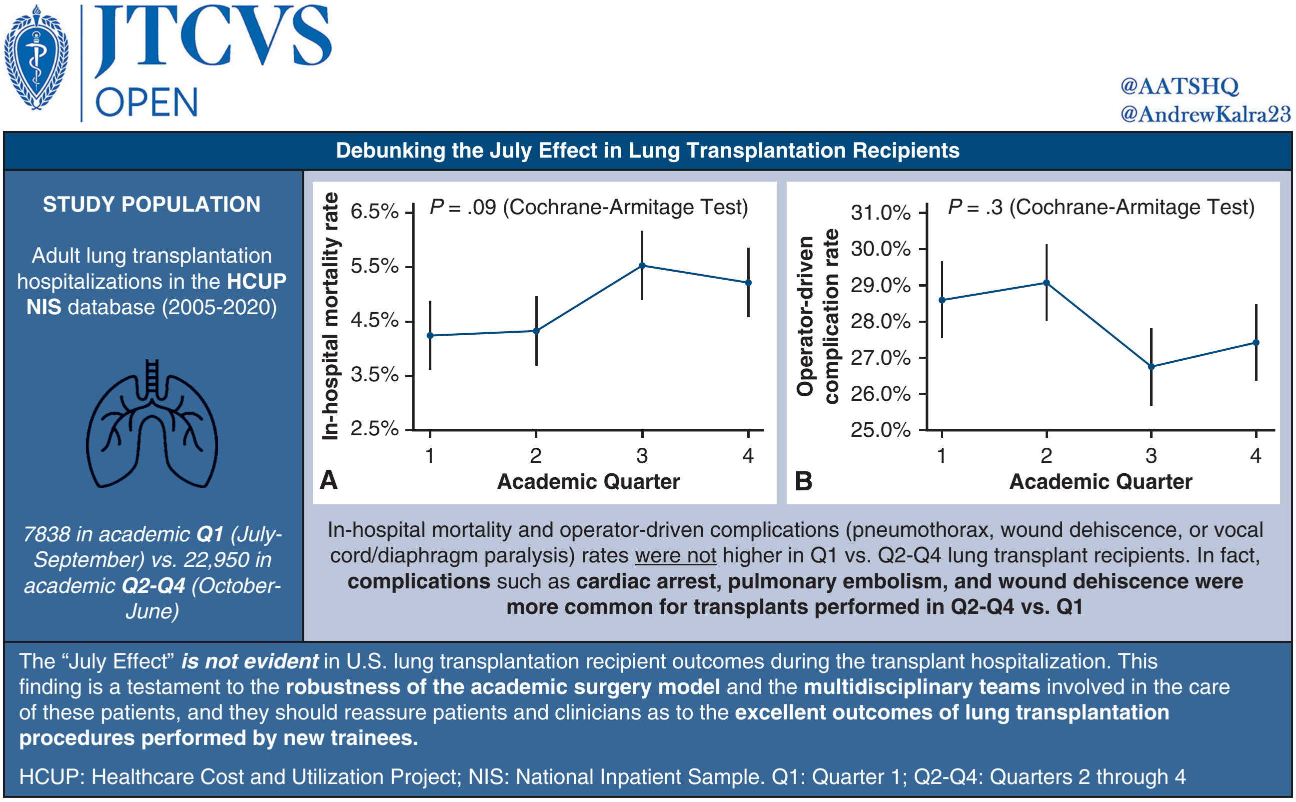

FIGURE 5. Graphical abstract. Summary of the study's key findings. In-hospital mortality and operator-driven complications were not higher during academic quarter 1 compared with quarters 2 to 4 in lung transplant recipient index hospitalizations. *Q1*, Academic quarter 1; *Q2-Q4*, academic quarters 2 to 4.

could occur at numerous steps in the transplant procedure, including during lung procurement, the transplant operation, or postoperative management. However, this degree of temporal data granularity and data on whether and how trainees were involved in an individual's care were not available in the NIS dataset. Furthermore, NIS does not contain information on lung transplant donors, which influences clinical outcomes as well. However, we still adjusted for several clinically relevant risk factors in our models. Because hospitalizations are categorized by month of admission and information on the length of preoperative stay was also not available in NIS, we note that the month of actual operation may be slightly different than the month of admission. However, it is unclear how using the month of admission would systematically bias the results to favor a specific outcome. Furthermore, we used previously validated methodology in NIS in which the July Effect was assessed in other surgical populations.[3,13,29,30] Additionally, a single-center study of 448 lung transplant recipients at an experienced center demonstrated that only 25% (n = 114) of their cohort was hospitalized pretransplant,[31] further suggesting that most lung transplant recipients are not hospitalized pretransplant and therefore do not reflect the majority of this patient population. Finally, ICD codes were used to identify complications, which resulted in limited granularity and are prone to undercoding.[32]

CONCLUSIONS

Overall, the July effect was not evident in US lung transplant recipients in the HCUP NIS database. We did not observe increased in-hospital mortality or operator-driven complication rates from July to September. Although new cardiothoracic trainees enter surgical programs during the July months, we recognize they may not participate in lung transplant surgeries during that period. Nevertheless, these findings suggest that current institutional supervision and monitoring systems in place are robust. However, given the limitations and lack of granularity of NIS, future studies with more granular data are required to further investigate the July Effect in lung transplant recipients.

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: HCUP NIS, July Effect, lung transplantation, outcomes, thoracic procedures, trainees

TABLE E1. International Classification of Diseases 9th and 10th Revision Procedure Coding System codes to identify lung transplant recipients in Healthcare Cost and Utilization Project National Inpatient Sample

Variables	ICD-9 codes	ICD-10 codes
Single-lung transplant	3351	0BYC0Z0, 0BYC0Z1, 0BYC0Z2, 0BYD0Z0, 0BYD0Z1, 0BYD0Z2, 0BYF0Z0, 0BYF0Z1, 0BYF0Z2, 0BYG0Z0, 0BYG0Z1, 0BYG0Z2, 0BYH0Z0,0BYH0Z1, 0BYH0Z2, 0BYJ0Z0, 0BYJ0Z1, 0BYJ0Z2,0BYK0Z0, 0BYK0Z1, 0BYK0Z2, 0BYL0Z0, 0BYL0Z1, 0BYL0Z2
Double-lung transplant	3352	0BYM0Z0, 0BYM0Z1, 0BYM0Z2,
Heart-lung transplant	336	N/A
Unspecified lung transplant	3350	N/A

ICD-9, International Classification of Diseases 9th Revision; *ICD-10*, International Classification of Diseases 10th Revision; *N/A*, not available.

TABLE E2. International Classification of Diseases 9th and 10th Revision Clinical Modification codes to identify comorbidities in Healthcare Cost and Utilization Project National Inpatient Sample

Variables	ICD-9 codes	ICD-10 codes
Alpha-1 antitrypsin	2734	E8801
Chronic pulmonary disease	490, 491, 492, 493, 494, 495, 496, 49121, 496, 4928, 49120, 490, 4920, 4941, 4940, 49122, 4918, 4959, 40492, 4919, 4958, 4951, 4952, 4950, 4911, 494, 495, 496	J40, J41, J42, J43, J44, J449, J441, J42, J439, J440, J40, J431, J432, J430, J438, J411, J418
Coronary artery disease	4111, 41181, 41189, 4130, 4131, 4139, 412, 41400, 41401, 4142, 4143, 4148, 4149, 4292, 41402, 41403, 41404, 41405, V4581, V4582	I2510, I25110, I25111, I25118, I25119, I252, I253, I2541, I2542, I255, I256, I25700, I25701, I25708 I25709, I25710, I25711, I25718, I25719, I25720, I25721, I25728, I25729, I25730, I25731, I25738, I25739, I25750, I25751, I25758, I26759, I25760, I25761, I25768, I25769, I25790, I25791, I25798, I25799, I25810, I25811, I25812, I2582, I2583, I2584, I2589, I259
Congestive heart failure	4280, 4289, 39891, 428, 4281, 4282, 42820, 42821, 42822,4283, 42830, 42831, 42832, 42823, 42840, 42841, 42842, 42843, 40401, 40411, 40491, 40201, 40211, 40291, 40403, 40413, 40493, 4148, 4254, 4255, 4259, 4252, 77989, 4258	I0981, I50814, I509, I501, I5020, I5021, I5022, I5030, I5031, I5032, I50810, I50811, I50812, I50813, I5082, I5083, I5084, I5089, I509, I5033, I5023, I5040, I5041, I5042, I5043, I509, I5033, I5023, I5040, I5041, I5042, I5043, I099, I110, I130, I132, I255, I420, I425, I426, I427, I428, I429, P290, I43, I50
Cystic fibrosis	27700, 27702	E849, E840
Diabetes	2500, 2501, 2502, 2503, 2508, 2509, 2504, 2505, 2506, 2507	E100, E101, E106, E108, E109, E110, E111, E116, E118, E119, E120, E121, E126, E128, E129, E130, E131, E136, E138, E139, E140, E141, E146, E148, E149, E102, E103, E104, E105, E107, E112, E113, E114, E115, E117, E122, E123, E124, E125, E127, E132, E133, E134, E135, E137, E142, E143, E144, E145, E147
Hypertension	401, 4010, 4011, 4019, 402, 4020, 40200, 40201, 4021, 40210, 40211, 4029, 40290, 40291, 403, 4030, 40301, 4031, 40310, 40311, 4039, 40390, 40391, 404, 4040, 40400, 40401, 40402, 40403, 4041, 40410, 40411, 40412, 40413, 4049, 40490, 40491, 40492, 40493, 405, 4050, 40509, 40501, 40511, 40519, 40591, 40599, 4051, 4059	I973, H40059, I10, I110, I119, I120, I129, I130, I1310, I1311, I132, I119, I150, I151, I152, I158, I159, I160, I161, I169, N262, I131, I139
Pulmonary fibrosis	515, 51631, 5163	J8410, V236, J701
Pulmonary hypertension	4168, 4160, 4161, 4169,	I270, I271, I272, I2721, I2722, I2723, I2724, I2729, I2720, I2781, I278, I279
Sarcoidosis	135, 3214	D860, D862, D861, D869, D86, D868, D863, D8681

ICD-9, International Classification of Diseases 9th Revision; *ICD-10*, International Classification of Diseases 10th Revision.

TABLE E3. International Classification of Diseases 9th and 10th Revision Procedure Coding System codes to identify procedures in Healthcare Cost and Utilization Project National Inpatient Sample

Variables	ICD-9 codes	ICD-10 codes
Extracorporeal membrane oxygenation	3965	5A15A2G, 5A15A2H, 5A15A2F, 5A1522F, 5A1522G, 5A1522H, 5A15A2F, 5A0522C, 5A15223
Perfusion of respiratory system donor organ, single (EVLP)	N/A	6ABB0BZ
Mechanical ventilation	9390, 9391, 9399, 967, 9670, 9671, 967	5A09357, 5A09457, 5A09557, 5A09358, 5A09458, 5A09558, 5A0935Z, 5A0945Z, 5A0955Z,5A1935Z, 5A1945Z, 5A1955Z

EVLP, Ex vivo lung perfusion; *ICD-9*, International Classification of Diseases 9th Revision; *ICD-10*, International Classification of Diseases 10th Revision; *N/A*, not available.

TABLE E4. International Classification of Diseases 9th and 10th Revisions Clinical Modification codes to identify complications in Healthcare Cost and Utilization Project National Inpatient Sample

Variables	ICD-9 codes	ICD-10 codes
Pneumothorax	5121, 51284, 5122, 7802, 51289, 5120, 8600, 8604, 8605, 8601, 0117, 51281, 51282	J93, J930, J931, J9311, J9312, J938, J9381, J9382, J9383, J939, J9581, J95811, J95812
Vocal cord/diaphragm paralysis	3449, 5194	J380, J3800, J3801, J3802, 47830, 47831, 47832, 47833, 47834, G839, J986
Dehiscence	99830, 99831, 99832, 99833, 9583, 99859	T8130, T8130XA, T8130XD, T8130XS, T8131, T8131XA, T8131XD, T8131XS ,T8132, T8132XA, T8132XD, T8132XS, T8133, T8133XA, T8133XD, T8133XS, T814, T8140, T81401XA, T8140XD, T8140XS, T81500, T83718, T83728, T8141XA, T8141XD, T8141XS, T8142, T8142XA, T8142XD, T8142XS, T8143, T8143XA, T8143XD, T8143XS, T8144, T8144XA, T8144XD, T8144XS, T8149, T8149XA, T8149XD, T8149XS
Myocardial infarction	410, 41001, 41002, 4101, 41011, 41012, 4102, 41021, 41022, 4103, 41031, 41032, 4104, 41041, 41042, 4105, 41051, 41052, 4106, 41061, 41062, 4107, 41071, 41072, 4108, 410821, 41082, 4109, 41091, 41092	I21, I210, I2101, I2102, I2109, I211, I2111, I2119, I212, I2121, I2129, I213, I214, I219, I21A, I21A1, I21A9, I22, I220, I221, I222, I228, I228, I229
Acute kidney injury	5845, 5846, 5847, 5848, 5849	N17, N170, N171, N172, N178, N179
Complete heart block	4260	I442
Cardiogenic shock	785.51	R570
Cardiac arrest	4275	I46, I462, I468,I469
Stroke	99700, 99701, 99702, 9970, 36231, 36812, 7814, 43311, 43301, 431, 43321, 43321, 3446, 43331, 43381, 43391, 43401, 43411, 43491, 435, 4350, 4351, 4352, 4353, 4358, 4359	I610, I611, I612,I613, I614, I615, I616, I618, I619, I630, I631, I632, I633, I634, I635, I636, I638, I639, G459, I64 I6300, I6301, I63011, I63012, I63013, I63019, I6302, I63031, I63032, I63033, I63039, I6309, I6310, I63111, I63112, I63113, I63119, I6312, I63131, I63132, I63139, I6319, I6320, I63211, I63212, I63213, I63219, I6322, I63233, I63239, I6329, I6330, I63311, I63312,I63313, I63319, I63321, I63322, I63323, I63329, I63331, I63332, I63333, I63339, I63341, I63342, I63343, I63349, I6339, I6340, I6341, I63411, I63412, I63413, I63419, I63421, I63422, I63423, I63429, I63431, I63432, I63433, I63439, I63441, I63442, I63443, I63449, I6349, I6350, I63511, I63512, I63513, I63519, I63521, I63522, I63523, I63529, I63531, I63532, I63533, I63539, I63541, I63542, I63543, I63549, I6359,I636, I6381, I6389, I639
Pleural effusion	51181, 5111, 51189, 5119, 86229, 86239	J90, J91, J910
Atrial fibrillation	427.31, 42731, 42732, 427.32	I48, I4891, I4892, I4820, I4819, I480, I481, I482, I4821, I483, I484, I489, I4811

(Continued)

TABLE E4. Continued

Variables	ICD-9 codes	ICD-10 codes
Pulmonary embolism	4151, 41512, 41511, 41513, 41519	I2602, I2609, I2692, I2693, I2694, I2699,
Deep vein thrombosis	452, 453, 4354, 45340, 45341, 45342, 4530, 4533, 45183, 45184, 45189, 45372, 45373, 45374, 45375, 45376, 45377, 45382, 45383, 45384, 45385, 45386, 45387, 45389, 451, 4510, 4511, 4512, 4518, 4519, 4512, 4518, 45181, 45182, 45183, 45184, 45189, 4519, 4534, 4535, 45350, 45351, 45352, 4536, 4537, 45371, 45372, 45373, 45374, 45375, 45376, 45377, 45379, 4538, 45381, 45382, 45383, 45384, 45385, 45386, 45387, 45389, 4539	I801, I8010, I8011, I8012, I8013, I828, I8281, I8289, I82811, I82812, I82813, I812819, I82890, I82891, I829, I8290, I8291, I822, I820, I822, I8221, I8222, I8229, I82210, I82211, I82220, I82221, I82290, I82291, I802, I8020, I8021, I8022, I8023, I8024, I8025, I8029, I80201, I80202, I802023, I80209, I80211, I80212, I80213, I80219, I80221, I80222, I80223, I80229, I80231, I80232, I80233, I80239, I81, I82, I823
Pulmonary edema	5184, 5061, 514	J811, J810, J681, J881
Gastroparesis	5363	K3184
Cytomegalovirus	4841	B25, B250, B251, B252, B258, B259

ICD-9, International Classification of Diseases 9th Revision; *ICD-10*, International Classification of Diseases 10th Revision.

TABLE E5. Demographics and clinical characteristics of quarter 1 versus quarter 4 lung transplant recipient hospitalizations

Variables	Both quarter 1 and quarter 4 N = 15,647	Quarter 1 (July-September) N = 7838	Quarter 4 (April-June) N = 7809	*P* value
Demographics				
Age, y (median, IQR)	60 (50-65)	60 (50-65)	59 (50-65)	.36
Female	6321 (40%)	3173 (40%)	3148 (40%)	.93
Race/ethnicity (n = 14,077)				.70
White	10,941 (70%)	5469 (70%)	5472 (70%)	
Black	1301 (8%)	644 (8%)	657 (8%)	
Hispanic	1200 (8%)	647 (8%)	553 (7%)	
Asian or Pacific Islander	237 (2%)	123 (2%)	114 (1%)	
Native American	61 (1%)	21 (1%)	40 (1%)	
Other	337 (2%)	162 (2%)	175 (2%)	
Comorbidities				
Charlson Comorbidity Index (median, IQR)	0 (0-1)	0 (0-1)	1 (0-1)	.16
Diabetes	270 (2%)	150 (2%)	120 (2%)	.38
Hypertension	6372 (41%)	3258 (41%)	3114 (40%)	.31
Coronary artery disease	3391 (22%)	1761 (22%)	1630 (21%)	.25
Congestive heart failure	1774 (11%)	917 (12%)	857 (11%)	.54
Alpha-1-antitrypsin	528 (3%)	254 (3%)	274 (4%)	.65
Chronic pulmonary disease	6721 (43%)	3236 (41%)	3485 (45%)	.05
Cystic fibrosis	1529 (10%)	782 (10%)	747 (10%)	.69
Pulmonary fibrosis	4973 (32%)	2505 (32%)	2468 (32%)	.82
Pulmonary hypertension	5377 (34%)	2786 (36%)	2591 (33%)	.22
Sarcoidosis	923 (6%)	422 (5%)	501 (6%)	.19
Region (n = 15,646)*				.81
New England	501 (3%)	246 (3%)	255 (3%)	
Middle Atlantic	2254 (14%)	1171 (15%)	1083 (14%)	
East North Central	2889 (18%)	1511 (19%)	1378 (18%)	
West North Central	919 (6%)	451 (6%)	468 (6%)	
South Atlantic	2499 (16%)	1232 (16%)	1267 (16%)	
East South Central	731 (5%)	357 (5%)	374 (5%)	
West South Central	2169 (14%)	1058 (14%)	1111 (14%)	
Mountain	1305 (8%)	663 (8%)	642 (8%)	
Pacific	2379 (15%)	1149 (15%)	1230 (16%)	
Primary payer				.16
Medicare	6639 (42%)	3316 (42%)	3323 (43%)	
Medicaid	944 (6%)	552 (7%)	392 (5%)	
Private insurance	7325 (47%)	3566 (46%)	3759 (48%)	
Self-pay	132 (1%)	69 (1%)	63 (1%)	
Other	575 (4%)	315 (4%)	260 (3%)	
No charge	32 (1%)	20 (1%)	12 (1%)	
Median household income by ZIP code (quartiles, n = 14,636)				.97
Quartile 1	2809 (18%)	1392 (18%)	1417 (18%)	
Quartile 2	3633 (23%)	1809 (23%)	1824 (23%)	
Quartile 3	4036 (26%)	2029 (26%)	2007 (26%)	
Quartile 4	4158 (27%)	2106 (27%)	2052 (26%)	

DSA, Donation service area; *IQR*, interquartile range. *Region was defined as 1 of the 9 US Census Bureau Census Divisions.

TABLE E6. Comparisons of in-hospital mortality and complications between quarter 1 and quarter 4 lung transplant recipient hospitalizations

Variables	Quarter 1 (July-September) N = 7838	Quarter 4 (April-June) N = 7809	*P* value
In-hospital mortality	335 (4%)	407 (5%)	.23
In-hospital operator-driven complications			
Pneumothorax	1790 (23%)	1693 (22%)	.11
Vocal cord/diaphragm paralysis	407 (5%)	369 (5%)	.88
Dehiscence	235 (3%)	292 (4%)	.17
In-hospital other major complications			
Myocardial infarction	124 (2%)	98 (1%)	.33
Atrial fibrillation	2381 (30%)	2538 (33%)	1.00
Complete heart block	5 (1%)	25 (1%)	.18
Cardiogenic shock	295 (4%)	295 (4%)	.67
Cardiac arrest	113 (1%)	163 (2%)	**.02**
Pleural effusion	1135 (14%)	1007 (13%)	.53
Pulmonary edema	575 (7%)	571 (7%)	.11
Pulmonary embolism	164 (2%)	281 (4%)	.15
Deep vein thrombosis	493 (6%)	584 (7%)	.08
Acute kidney injury	2793 (36%)	2585 (33%)	.20
Stroke	211 (3%)	250 (3%)	.96
Gastroparesis	313 (4%)	290 (4%)	.65
Cytomegalovirus	200 (3%)	195 (2%)	.35
Length of stay, d (median, IQR)	17 (12-31)	17 (12-31)	.24
Discharge disposition			.62
Routine*	3466 (44%)	3414 (44%)	
Short-term hospital	109 (1%)	102 (1%)	
Care facility	1331 (17%)	1404 (18%)	
Home health care	2597 (33%)	2477 (32%)	
Against medical advice	0 (0%)	5 (1%)	
Died	335 (4%)	407 (5%)	
Total hospitalization charges†, (median, IQR)	$562,721 ($364,423-$958,993)	$550,869 ($354,498-$922,905)	.59
Type of lung transplant			.25
Single	2267 (29%)	2076 (27%)	
Double	5348 (68%)	5461 (70%)	
Heart-lung	34 (1%)	39 (1%)	
Unknown	189 (2%)	233 (3%)	
Procedures			
ECMO	1265 (16%)	1149 (15%)	.25
EVLP	100 (1%)	80 (1%)	.57
Mechanical ventilation	1290 (16%)	1149 (15%)	.13

Statistically significant *P*-values ($P < .05$) are bolded. *DSA*, Donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion; *IQR*, interquartile range. *Routine includes discharge to home/self-care, court/law enforcement, still being a patient, or a planned acute care in-hospital inpatient readmission. †All charges were adjusted for inflation to 2020 dollars.

TABLE E7. Multivariable logistic regression model for adjusted in-hospital mortality of lung transplant recipient hospitalizations in Q1 versus Q4 admissions (2005-2020) with prespecified risk factors

Variables	aOR	SE	Lower 95% CI	Upper 95% CI	*P* value
Quarter 1	0.81	1.19	0.57	1.14	.22
Age	1.01	1.01	0.99	1.02	.45
Female sex	0.82	1.19	0.59	1.15	.25
Race/ethnicity					
White (reference)					
Black	1.20	1.35	0.66	2.20	.54
Hispanic	1.33	1.38	0.71	2.49	.38
Asian or Pacific Islander	1.62	1.86	0.48	5.50	.44
Native American	0.00	1.53	0.00	0.00	**<.001**
Other	1.60	1.58	0.65	3.96	.31
Region*					
East North Central (reference)					
New England	0.99	1.44	0.49	2.03	.99
Middle Atlantic	0.57	1.38	0.31	1.07	.08
West North Central	0.38	1.77	0.12	1.16	.09
South Atlantic	1.12	1.28	0.69	1.83	.65
East South Central	0.45	2.03	0.11	1.80	.26
West South Central	0.79	1.32	0.45	1.36	.39
Mountain	0.43	1.52	0.19	0.96	**.04**
Pacific	0.60	1.46	0.28	1.26	.18
Median household income by ZIP code (quartiles)					
Quartile 1 (reference)					
Quartile 2	1.22	1.31	0.72	2.07	.46
Quartile 3	1.09	1.31	0.63	1.86	.76
Quartile 4	1.11	1.32	0.64	1.91	.71
Type of lung transplant					
Double (reference)					
Single	0.95	1.23	0.63	1.43	.81
Heart-lung	4.92	1.52	2.18	11.14	**<.001**

Statistically significant *P*-values (*P* <.05) are bolded. *aOR*, Adjusted odds ratio; *DSA*, donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion. *Region was defined as 1 of the 9 US Census Bureau Census Divisions.

TABLE E8. Multivariable logistic regression model for adjusted in-hospital operator-driven complications of lung transplant recipient hospitalizations (2005-2020) with prespecified risk factors for quarter 1 versus quarters 2-4

Variables	aOR	SE	Lower 95% CI	Upper 95% CI	*P* value
Quarter 1	1.06	1.07	0.93	1.20	.42
Age	0.99	1.00	0.99	1.00	.05
Female sex	1.08	1.06	0.97	1.21	.15
Race/ethnicity					
White (reference)					
Black	0.88	1.12	0.70	1.09	.24
Hispanic	0.94	1.26	0.60	1.48	.79
Asian or Pacific Islander	1.03	1.70	0.36	2.94	.95
Native American	1.07	1.24	0.70	1.62	.75
Other	0.88	1.12	0.70	1.09	.24
Region*					
East North Central (reference)					
New England	1.20	1.23	0.80	1.79	.38
Middle Atlantic	0.82	1.18	0.59	1.15	.25
West North Central	1.57	1.25	1.02	2.43	**.04**
South Atlantic	1.51	1.19	1.08	2.11	**.02**
East South Central	1.05	1.24	0.69	1.60	.82
West South Central	1.27	1.19	0.91	1.79	.16
Mountain	1.22	1.22	0.83	1.81	.31
Pacific	1.23	1.19	0.88	1.72	.22
Median household income by ZIP code (quartiles)					
Quartile 1 (reference)					
Quartile 2	1.09	1.09	0.92	1.30	.31
Quartile 3	1.10	1.09	0.93	1.31	.27
Quartile 4	1.12	1.10	0.94	1.34	.21
Type of lung transplant					
Double (reference)					
Single	0.72	1.09	0.62	0.85	**<.001**
Heart-lung	0.76	1.56	0.32	1.82	.54

Main complications were defined as a composite outcome for the presence of any of the following operator-driven complications: pneumothorax, dehiscence, vocal cord/diaphragm paralysis. Statistically significant *P*-values ($P < .05$) are bolded. *aOR*, Adjusted odds ratio. *Region was defined as 1 of the 9 US Census Bureau Census Divisions.

TABLE E9. Multivariable logistic regression model for in-hospital operator-driven complications of lung transplant recipient hospitalizations (2005-2020) with prespecified risk factors in sensitivity analysis for quarter 1 versus quarter 4

Variables	aOR	SE	Lower 95% CI	Upper 95% CI	*P* value
Quarter 1	1.08	1.08	0.93	1.26	.32
Age	1.00	1.00	0.99	1.00	.25
Female sex	1.10	1.08	0.94	1.29	.23
Race/ethnicity					
White (reference)					
Black	1.30	1.16	0.98	1.72	.07
Hispanic	1.02	1.17	0.75	1.38	.90
Asian or Pacific Islander	0.67	1.42	0.34	1.32	.25
Native American	1.86	2.13	0.42	8.26	.41
Other	1.62	1.31	0.95	2.75	.08
Region*					
East North Central (reference)					
New England	1.06	1.30	0.64	1.77	.82
Middle Atlantic	0.88	1.20	0.62	1.25	.47
West North Central	1.50	1.27	0.93	2.40	.10
South Atlantic	1.74	1.21	1.20	2.54	**<.001**
East South Central	1.01	1.32	0.59	1.76	.96
West South Central	1.25	1.25	0.81	1.92	.32
Mountain	1.27	1.27	0.79	2.02	.32
Pacific	1.25	1.21	0.87	1.81	.23
Median household income by ZIP code (quartiles)					
Quartile 1 (reference)					
Quartile 2	1.23	1.14	0.94	1.60	.13
Quartile 3	1.26	1.14	0.97	1.62	.08
Quartile 4	1.24	1.16	0.92	1.67	.15
Type of lung transplant					
Double (reference)					
Single	0.68	1.13	0.54	0.86	**<.001**
Heart-lung	1.05	1.90	0.30	3.71	.94

Main complications were defined as a composite outcome for the presence of any of the following operator-driven complications: pneumothorax, dehiscence, vocal cord/diaphragm paralysis. Statistically significant *P*-values (*P* <.05) are bolded. *aOR*, Adjusted odds ratio. *Region was defined as 1 of the 9 US Census Bureau Census Divisions.

TABLE E10. Comparisons of in-hospital mortality and complications, and resource use between quarter 1 and quarter 2 lung transplant recipient hospitalizations

Variables	Quarter 1 (July-September) N = 7838	Quarter 2 (October-December) N = 7504	*P* value
In-hospital mortality	335 (4%)	323 (4%)	.97
In-hospital operator-driven complications			
Pneumothorax	1790 (23%)	1660 (22%)	.65
Vocal cord/diaphragm paralysis	407 (5%)	391 (5%)	.98
Dehiscence	236 (3%)	336 (4%)	**.029**
In-hospital other major complications			
Myocardial infarction	124 (2%)	94 (1%)	.43
Atrial fibrillation	2381 (30%)	2394 (32%)	.37
Complete heart block	5 (1%)	25 (1%)	.10
Cardiogenic shock	295 (4%)	315 (4%)	.51
Cardiac arrest	113 (1%)	183 (2%)	**.02**
Pleural effusion	1135 (14%)	1063 (14%)	.78
Pulmonary edema	575 (7%)	578 (8%)	.68
Pulmonary embolism	164 (2%)	211 (3%)	.17
Deep vein thrombosis	493 (6%)	475 (6%)	.97
Acute kidney injury	2793 (36%)	2542 (34%)	.30
Stroke	211 (3%)	151 (2%)	.17
Gastroparesis	311 (4%)	276 (4%)	.65
Cytomegalovirus	200 (3%)	274 (4%)	.13
Length of stay, d (median, IQR)	17 (12-31)	18 (12-34)	.11
Discharge disposition			.89
Routine (n = 15,341)*	3466 (44%)	3403 (45%)	
Short-term hospital	109 (1%)	72 (1%)	
Care facility	1331 (17%)	1248 (17%)	
Home health care	2597 (33%)	2457 (33%)	
Against medical advice	0 (0%)	0 (0%)	
Died	335 (4%)	323 (4%)	
Total hospitalization charges†, (median, IQR)	$562,721 ($364,423-$958,993)	$577,922 ($373,010-$966,285)	.28
Type of lung transplant			.87
Single	2267 (29%)	2179 (29%)	
Double	5348 (68%)	5128 (68%)	
Heart-lung	34 (1%)	43 (1%)	
Unknown	189 (2%)	154 (2%)	
Procedures			
ECMO	1265 (16%)	1285 (17%)	.45
EVLP	100 (1%)	105 (1%)	.77
Mechanical ventilation	1290 (16%)	1365 (18%)	.20

Statistically significant *P*-values ($P < .05$) are bolded. *ECMO*, Extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion; *IQR*, interquartile range. *Routine includes discharge to home/self-care, court/law. †All charges were adjusted for inflation to 2020 dollars.

TABLE E11. Comparisons of in-hospital mortality and complications between quarter 1 and quarter 3 lung transplant recipient hospitalizations

Variables	Quarter 1 (July-September) N = 7838	Quarter 3 (January-March) N = 7637	*P* value
In-hospital mortality	335 (4%)	422 (6%)	.22
In-hospital operator-driven complications			
Pneumothorax	1790 (23%)	1565 (20%)	.11
Vocal cord/diaphragm paralysis	407 (5%)	387 (5%)	.88
Dehiscence	236 (3%)	294 (4%)	.17
In-hospital other major complications			
Myocardial infarction	124 (2%)	88 (1%)	.33
Atrial fibrillation	2381 (30%)	2320 (30%)	1.00
Complete heart block	5 (1%)	20 (1%)	.18
Cardiogenic shock	295 (4%)	265 (3%)	.67
Cardiac arrest	113 (1%)	187 (2%)	**.02**
Pleural effusion	1135 (14%)	1049 (14%)	.53
Pulmonary edema	575 (7%)	458 (6%)	.11
Pulmonary embolism	164 (2%)	221 (3%)	.15
Deep vein thrombosis	493 (6%)	600 (8%)	.08
Acute kidney injury	2793 (36%)	2549 (33%)	.20
Stroke	211 (3%)	208 (3%)	.96
Gastroparesis	313 (4%)	291 (4%)	.67
Cytomegalovirus	200 (3%)	155 (2%)	.35
Length of stay, d (median, IQR)	17 (12-31)	18 (12-33)	.99
Discharge disposition			.62
Routine*	3466 (44%)	3479 (46%)	
Short-term hospital	109 (1%)	120 (2%)	
Care facility	1331 (17%)	1296 (17%)	
Home health care	2597 (33%)	2315 (30%)	
Against medical advice	0 (0%)	5 (1%)	
Died	335 (4%)	422 (6%)	
Total hospitalization charges†, (median, IQR)	$562,721 ($364,423-$958,993)	$547,515 ($355,197-$929,351)	.34
Type of lung transplant			.25
Single	2267 (29%)	2284 (30%)	
Double	5348 (68%)	5082 (67%)	
Heart-lung	34 (1%)	48 (1%)	
Unknown	189 (2%)	223 (3%)	
Procedures			
ECMO	1265 (16%)	1166 (15%)	.25
EVLP	100 (1%)	75 (1%)	.57
Mechanical ventilation	1290 (16%)	1290 (17%)	.13

Statistically significant *P*-values ($P < .05$) are bolded. *DSA*, Donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion; *IQR*, interquartile range. *Routine includes discharge to home/self-care, court/law enforcement, still being a patient, or a planned acute care in-hospital inpatient readmission. †All charges were adjusted for inflation to 2020 dollars.

TABLE E12. Comparisons of in-hospital mortality and complications between quarter 2 and quarter 3 lung transplant recipient hospitalizations

Variables	Quarter 2 (October-December) N = 7504	Quarter 3 (January-March) N = 7637	*P* value
In-hospital mortality	323 (4%)	422 (6%)	.14
In-hospital operator-driven complications			
Pneumothorax	1660 (22%)	1565 (20%)	.23
Vocal cord/diaphragm paralysis	391 (5%)	387 (5%)	.85
Dehiscence	336 (4%)	294 (4%)	.43
In-hospital other major complications			
Myocardial infarction	94 (1%)	88 (1%)	.80
Atrial fibrillation	2394 (32%)	2320 (30%)	.37
Complete heart block	25 (1%)	20 (1%)	.72
Cardiogenic shock	315 (4%)	265 (3%)	.28
Cardiac arrest	183 (2%)	187 (2%)	1.00
Pleural effusion	1063 (14%)	1049 (14%)	.73
Pulmonary edema	578 (8%)	458 (6%)	.05
Pulmonary embolism	211 (3%)	221 (3%)	.88
Deep vein thrombosis	475 (6%)	600 (8%)	.08
Acute kidney injury	2542 (34%)	2549 (33%)	.74
Stroke	151 (2%)	208 (3%)	.19
Gastroparesis	276 (4%)	291 (4%)	.86
Cytomegalovirus	274 (4%)	155 (2%)	**.009**
Length of stay, d (median, IQR)	18 (12-34)	18 (12-33)	.37
Discharge disposition			.22
Routine (n = 15,140)*	3403 (45%)	3479 (46%)	
Short-term hospital	72 (1%)	120 (2%)	
Care facility	1248 (17%)	1296 (17%)	
Home health care	2457 (33%)	2315 (30%)	
Against medical advice	0 (0%)	5 (1%)	
Died	323 (4%)	422 (6%)	
Total hospitalization charges†, (median, IQR)	$577,922 ($373,010-$966,285)	$547,515 ($355,197-$929,351)	.09
Type of lung transplant			.74
Single	2179 (29%)	2284 (30%)	
Double	5128 (68%)	5082 (67%)	
Heart-lung	43 (1%)	48 (1%)	
Unknown	154 (2%)	223 (3%)	
Procedures			
ECMO	1285 (17%)	1166 (15%)	.17
EVLP	105 (1%)	75 (1%)	.36
Mechanical ventilation	1365 (18%)	1290 (17%)	.36

Statistically significant *P*-values ($P < .05$) are bolded. *DSA*, Donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion; *IQR*, interquartile range. *Routine includes discharge to home/self-care, court/law enforcement, still being a patient, or a planned acute care in-hospital inpatient readmission. †All charges were adjusted for inflation to 2020 dollars.

TABLE E13. Comparisons of in-hospital mortality and complications between quarter 2 and quarter 4 lung transplant recipient hospitalizations

Variables	Quarter 2 (October-December) N = 7504	Quarter 4 (April-June) N = 7809	*P* value
In-hospital mortality	323 (4%)	407 (5%)	.25
In-hospital operator-driven complications			
Pneumothorax	1660 (22%)	1693 (22%)	.78
Vocal cord/diaphragm paralysis	391 (5%)	369 (5%)	.57
Dehiscence	336 (4%)	292 (4%)	.34
In-hospital other major complications			
Myocardial infarction	94 (1%)	98 (1%)	.98
Atrial fibrillation	2394 (32%)	2538 (33%)	.73
Complete heart block	25 (1%)	25 (1%)	.95
Cardiogenic shock	315 (4%)	295 (4%)	.66
Cardiac arrest	183 (2%)	163 (2%)	.48
Pleural effusion	1063 (14%)	1007 (13%)	.30
Pulmonary edema	578 (8%)	571 (7%)	.67
Pulmonary embolism	211 (3%)	281 (4%)	.18
Deep vein thrombosis	475 (6%)	584 (7%)	.11
Acute kidney injury	2542 (34%)	2585 (33%)	.63
Stroke	151 (2%)	250 (3%)	**.02**
Gastroparesis	276 (4%)	290 (4%)	.96
Cytomegalovirus	274 (4%)	195 (2%)	.06
Length of stay, d (median, IQR)	18 (12-34)	17 (12-31)	.12
Discharge disposition			.46
Routine (n = 15,312)*	3403 (45%)	3414 (44%)	
Short-term hospital	72 (1%)	102 (1%)	
Care facility	1248 (17%)	1404 (18%)	
Home health care	2457 (33%)	2477 (32%)	
Against medical advice	0 (0%)	5 (1%)	
Died	323 (4%)	407 (5%)	
Total hospitalization charges†, (median, IQR)	$577,922 ($373,010-$966,285)	$550,869 ($354,498-$922,905)	.06
Type of lung transplant			.35
Single	2179 (29%)	2076 (27%)	
Double	5128 (68%)	5461 (70%)	
Heart-lung	43 (1%)	39 (1%)	
Unknown	154 (2%)	233 (3%)	
Procedures			
ECMO	1285 (17%)	1149 (15%)	.06
EVLP	105 (1%)	80 (1%)	.43
Mechanical ventilation	1365 (18%)	1149 (15%)	.006

Statistically significant *P*-values ($P < .05$) are bolded. *DSA*, Donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion; *IQR*, interquartile range. *Routine includes discharge to home/self-care, court/law enforcement, still being a patient, or a planned acute care in-hospital inpatient readmission. †All charges were adjusted for inflation to 2020 dollars.

TABLE E14. Comparisons of in-hospital mortality and complications, and resource utilization between quarter 3 and quarter 4 lung transplant recipient hospitalizations

Variables	Quarter 3 (July-September) N = 7637	Quarter 4 (October-December) N = 7809	*P* value
In-hospital mortality	422 (6%)	407 (5%)	.69
In-hospital operator-driven complications			
Pneumothorax	1565 (20%)	1693 (22%)	.42
Vocal cord/diaphragm paralysis	387 (5%)	369 (5%)	.69
Dehiscence	294 (4%)	292 (4%)	.86
In-hospital other major complications			
Myocardial infarction	88 (1%)	98 (1%)	.78
Atrial fibrillation	2320 (30%)	2538 (33%)	.20
Complete heart block	20 (1%)	25 (1%)	.73
Cardiogenic shock	265 (3%)	295 (4%)	.66
Cardiac arrest	187 (2%)	163 (2%)	.48
Pleural effusion	1049 (14%)	1007 (13%)	.50
Pulmonary edema	458 (6%)	571 (7%)	.16
Pulmonary embolism	221 (3%)	281 (4%)	.25
Deep vein thrombosis	600 (8%)	584 (7%)	.66
Acute kidney injury	2549 (33%)	2585 (33%)	.87
Stroke	208 (3%)	250 (3%)	.44
Gastroparesis	291 (4%)	290 (4%)	.88
Cytomegalovirus	155 (2%)	195 (2%)	.31
Length of stay, d (median, IQR)	18 (12-33)	17 (12-31)	.33
Discharge disposition			.82
Routine*	3479 (46%)	3414 (44%)	
Short-term hospital	120 (2%)	102 (1%)	
Care facility	1296 (17%)	1404 (18%)	
Home health care	2315 (30%)	2477 (32%)	
Against medical advice	5 (1%)	5 (1%)	
Died	422 (6%)	407 (5%)	
Total hospitalization charges†, (median, IQR)	$547,515 ($355,197-$929,351)	$550,869 ($354,498-$922,905)	.86
Type of lung transplant			.14
Single	2284 (30%)	2076 (27%)	
Double	5082 (67%)	5461 (70%)	
Heart-lung	48 (1%)	39 (1%)	
Unknown	223 (3%)	233 (3%)	
Procedures			
ECMO	1166 (15%)	1149 (15%)	.65
EVLP	75 (1%)	80 (1%)	.91
Mechanical ventilation	1290 (17%)	1149 (15%)	.07

DSA, Donor service area; *ECMO*, extracorporeal membrane oxygenation; *EVLP*, ex vivo lung perfusion; *IQR*, interquartile range. *Routine includes discharge to home/self-care, court/law enforcement, still being a patient, or a planned acute care in-hospital inpatient readmission. †All charges were adjusted for inflation to 2020 dollars.