ANNALS OF TRANSPLANTATION

ORIGINAL PAPER

e-ISSN 2329-0358
© Ann Transplant, 2020; 25: e922641
DOI: 10.12659/AOT.922641

Received: 2020.01.06
Accepted: 2020.05.12
Available online: 2020.06.22
Published: 2020.08.18

What Awaits on the Other Side: Post-Lung Transplant Morbidity and Mortality After Pre-Transplant Hospitalization

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ACDEF 1 **Darya Rudym**
ABCDE 1 **Luke Benvenuto**
B 2 **Joseph Costa**
AB 1 **Meghan Aversa**
AB 1 **Hilary Robbins**
AB 1 **Lori Shah**
B 1 **Hanyoung Kim**
AB 2 **Bryan P. Stanifer**
AB 2 **Joshua Sonett**
AB 2 **Frank D'Ovidio**
ABCDEF 1 **Selim M. Arcasoy**

1 Division of Pulmonary, Allergy, and Critical Care Medicine, Columbia University Medical Center, New York, NY, U.S.A.
2 Department of Surgery, Columbia University Medical Center, New York, NY, U.S.A.

Corresponding Author: Selim M. Arcasoy, e-mail: sa2059@cumc.columbia.edu
Source of support: Departmental sources

Background: Morbidity and mortality rates after lung transplantation remain high compared to other solid organ transplants. In the lung allocation score era, patients given the highest priority on the waitlist are those with the greatest severity of illness, who often require preoperative hospitalization.

Material/Methods: To determine the association of pre-transplant hospitalization with post-transplant outcomes, we retrospectively evaluated 448 lung transplant recipients at our center between January 2010 and July 2017 (114 hospitalized; 334 outpatient).

Results: Survival was similar between the groups (hazard ratio 0.93 [95% CI 0.61 to 1.42], p=0.738). However, hospitalized patients had longer hospital and intensive care unit length of stay compared to outpatients – 25 *vs.* 18 days, (p<0.001) and 9.5 *vs.* 6 days, (p<0.001), respectively. Hospitalized patients had higher rates of Grade 3 primary graft dysfunction – 29.8% *vs.* 9.6%, p<0.001 – and remained mechanically ventilated longer – 6 *vs.* 3 days, p<0.001. A greater percentage of hospitalized patients needed a tracheostomy and a re-operation within 30 days – 39.5% *vs.* 15.3% (p<0.001) and 22.8% *vs.* 12.0% (p=0.005) – respectively. After discharge, 28% of hospitalized patients required acute rehabilitation compared with 12% of outpatients (p=0.001).

Conclusions: While pre-transplant hospitalization is not associated with mortality, it is associated with significant morbidity after transplant.

MeSH Keywords: **Hospitalization • Lung Transplantation • Patient Outcome Assessment**

Abbreviations: **6MWT** – six-minute walk test; **CPAP** – continuous positive airway pressure; **ECMO** – extracorporeal membrane oxygenation; **FEV1** – forced expiratory volume during the first second; **FVC** – forced vital capacity; **HR** – hazard ratio; **ICU** – Intensive Care Unit; **IQR** – interquartile range; **LAS** – lung allocation score; **LOS** – length of stay; **MV** – mechanical ventilation; **PA** – pulmonary artery; **PGD** – primary graft dysfunction; **RF** – respiratory failure

Full-text PDF: https://www.annalsoftransplantation.com/abstract/index/idArt/922641

2215 5 2 27

Indexed in: [Science Citation Index Expanded] [Index Medicus/MEDLINE] [Chemical Abstracts] [Scopus]

Background

Lung transplantation is a potentially lifesaving therapy for patients with end-stage pulmonary disease. While lung transplantation increases survival and improves quality of life, mortality rates after lung transplantation are higher than after other solid organ transplants, with an 85% 1-year survival rate and a nearly 60% 5-year survival rate [1–3]. With the implementation of the lung allocation score (LAS) system in the United States in 2005, the highest priority on the waitlist has been given to patients with the greatest severity of illness [4,5]. As such, these patients often require hospitalization before undergoing lung transplantation for higher oxygen supplementation, mechanical ventilation (MV), or extracorporeal membrane oxygenation (ECMO) support, with a significant increase in the proportion of patients transplanted while supported on MV or ECMO in recent years [6–8]. While these technologies are lifesaving for patients presenting with an acute respiratory decompensation and requiring urgent listing, the hospitalization, in and of itself, is associated with numerous adverse outcomes, including deconditioning, frailty, nosocomial infections, and poor quality of life [9, 10]. The most recent ISHLT Registry report incorporates hospitalization into the multivariable analysis of 1-year and 5-year mortality, with notable adjusted hazard ratios (HRs) of 1.424 and 1.431 for increased mortality, respectively [2]. Outside of this report, the morbidity and mortality associated with inpatient hospitalization prior to lung transplantation have not been rigorously examined.

In this single-center retrospective cohort study, we aimed to investigate morbidity and mortality of lung transplant recipients who required hospitalization prior to lung transplantation. We hypothesized that hospitalized patients would have worse post-transplant survival and an increase in post-transplant complications, compared with outpatient recipients.

Material and Methods

We reviewed all adult patients who underwent lung transplantation at our institution between January 1st, 2010 and July 1st, 2017. Columbia University Medical Center Institutional Review Board approval was obtained for data review and analysis. We excluded patients who underwent re-do transplantation from our analysis. We stratified patients into those who were hospitalized immediately prior to transplant and those who were outpatient. The primary outcome of interest was post-transplant survival in hospitalized lung transplant candidates as compared to outpatient candidates. The secondary outcomes included Intensive Care Unit (ICU) and hospital length of stay (LOS), duration of mechanical ventilation (MV), need for tracheostomy, re-operation within 30 days after transplantation, presence of primary graft dysfunction (PGD) at 72 h after transplant and its grade, and disposition after the index transplant admission, such as to a rehabilitation center versus home. The presence of PGD was independently assessed by 2 pulmonologists using the most recent classification [11].

Categorical data were expressed as frequency and proportion, whereas continuous data were presented as mean and standard deviation or median with interquartile range (IQR). Survival analysis was performed using Kaplan-Meier survival estimates with log-rank test censored at 5 years. Secondary outcomes were assessed using the chi-square test and Wilcoxon signed-rank test. Multivariable logistic regression was used to adjust mortality rate ratios for clinically important covariates, namely, age, LAS, MV or ECMO support, diagnosis group, and the number of days on waitlist, all of which were identified a priori. Six-minute walk test (6MWT) was not included in the final multivariable model due to multicollinearity with the hospitalization status. To address the competing risk of death for secondary outcomes, sensitivity analysis was performed to determine event-free days, using previously described methods [12,13]. Descriptive statistics, regression analysis, and survival estimates were performed using Stata/IC 15.1 statistical software.

Results

The study cohort comprised 448 patients who underwent lung transplantation at our institution during the study period and met the inclusion and exclusion criteria. The cohort was divided into patients who were hospitalized immediately prior to receiving transplant (n=114) and outpatient recipients (n=334). Several baseline demographic characteristics were significantly different between the groups (Table 1). The hospitalized group was on average younger than the outpatient group and differed significantly in race/ethnicity, as well as diagnosis group. Notably, patients with cystic fibrosis, who are on average younger, accounted for 27.2% of the hospitalized group compared to 11.7% of the outpatient group. Not surprisingly, LAS were dramatically different between the groups, with mean LAS of 84.5 in the hospitalized group and 46.5 in the outpatient group. 6MWT, days on waitlist, serum creatinine, mean pulmonary artery pressure (mPAP), and percent requiring MV or ECMO support also differed significantly. Further stratified demographics and clinical variables by hospital location are demonstrated in Table 2.

At 1 year, the crude rate of patient survival was 87.7% in the hospitalized group, compared with 89.2% in the outpatient group, p=0.66. There was no significant survival difference between the groups (HR 0.93 [95% CI 0.61 to 1.42], *p*=0.738), as demonstrated in Figure 1. When adjusted for age, LAS, days on waitlist, MV/ECMO support, and diagnosis group, the finding persisted, with no difference in patient survival (adjusted HR 0.95 [95% CI 0.44–2.05], p=0.901). Further stratified analysis

Indexed in: [Science Citation Index Expanded] [Index Medicus/MEDLINE] [Chemical Abstracts] [Scopus]

Table 1. Baseline characteristics.

	Hospitalized (n=114)	Outpatient (n=334)	*p* Value
Age at transplant, mean (SD), years	47.8 (15.7)	55.8 (12.5)	<0.001
Male, No. (%)	60 (52.6)	182 (54.5)	0.731
Race/Ethnicity, No. (%)			0.018
White	79 (69.3)	258 (77.3)	
African American	12 (10.5)	42 (12.6)	
Hispanic	10 (8.8)	23 (6.9)	
Asian	10 (8.8)	9 (2.7)	
Other	3 (2.6)	2 (0.6)	
Diagnosis group, No. (%)			<0.001
A (obstructive lung disease)	8 (7.0)	59 (17.7)	
B (pulmonary vascular disease)	8 (7.0)	33 (9.9)	
C (cystic fibrosis)	31 (27.2)	39 (11.7)	
D (restrictive lung disease)	67 (58.8)	203 (60.8)	
Body mass index, mean (SD), kg/m^2	23.8 (4.9)	25.0 (4.4)	0.016
LAS, mean (SD)	84.5 (14.0)	46.5 (11.2)	<0.001
6MWT, mean (SD), feet	400 (366)	872 (394)	<0.001
Days on waiting list, mean (SD)	115.3 (165.3)	185.0 (245.0)	0.005
Hospital Location, No (%)			
Intensive Care Unit	84 (73.7)	–	
Step down unit	14 (12.3)	–	
Medicine floors	16 (14.0)	–	
At transplant			
FEV1, mean (SD),% predicted	39.1 (18.9)	36.4 (18.9)	0.189
FVC, mean (SD),% predicted	44.9 (17.8)	44.0 (16.7)	0.638
Serum creatinine, mean (SD), mg/liter	0.68 (0.24)	0.81 (0.23)	<0.001
Mean PA pressure, mean (SD), mmHg	31.5 (15.5)	25.8 (9.8)	<0.001
Chronic hypercapneic RF, No. (%)	38 (33.3)	9 (2.7)*	<0.001
Invasive mechanical ventilation	38	2	
Non-invasive ventilation	–	7	
ECMO Support, No (%)	51 (44.7)	–	

* Two patients receiving nightly MV via tracheostomy at home, seven patients receiving CPAP. Data presented as a percent or mean. SD – standard deviation; LAS – lung allocation score; 6MWT – six-minute walk test; FEV1 – forced expiratory volume in the first second; FVC – forced vital capacity; PA – pulmonary artery; RF – respiratory failure; ECMO – extracorporeal membrane oxygenation; CPAP – continuous positive airway pressure.

of patients admitted to the ICU (n=84) versus all other non-ICU patients (n=364) showed no difference in patient survival (HR 1.07 [95% CI 0.68–1.68], *p*=0.772), as demonstrated in Figure 2. In the hospitalized group, patient survival between ICU and non-ICU patients did not differ significantly (HR 1.65 [95% CI 0.63–4.35, *p*=0.308]).

With regard to secondary end-points, there were multiple significant differences between the groups (Table 3). Median post-transplant hospital LOS was 25 days (IQR 18 to 41 days) in the hospitalized group, compared with 18 days (IQR 13 to 25 days) in the outpatient group (p<0.001). Median post-transplant ICU LOS was 9.5 days (IQR 6 to 19 days) in the hospitalized group,

Indexed in: [Science Citation Index Expanded] [Index Medicus/MEDLINE] [Chemical Abstracts] [Scopus]

Table 2. Baseline characteristics by hospital location.

	ICU (n = 84)		Non-ICU (n = 30)		*p* Value
Age at transplant, mean (SD), years	45.7	(16.3)	53.6	(12.4)	0.017
Male, No. (%)	42	(50.0)	18	(60.0)	0.346
Race/Ethnicity, No. (%)					0.874
White	58	(69.0)	21	(70.0)	
African American	9	(10.7)	3	(10.0)	
Hispanic	7	(8.3)	3	(10.0)	
Asian	7	(8.3)	3	(10.0)	
Other	3	(3.6)	0		
Diagnosis group, No. (%)					0.039
A (obstructive lung disease)	7	(8.3)	1	(3.3)	
B (pulmonary vascular disease)	6	(7.1)	2	(6.7)	
C (cystic fibrosis)	28	(33.3)	3	(10.0)	
D (restrictive lung disease)	43	(51.2)	24	(80.0)	
Body mass index, mean (SD), kg/m^2	23.6	(5.2)	24.4	(4.3)	0.436
LAS, mean (SD)	87.8	(9.73)	75.2	(19.2)	<0.001
6MWT, mean (SD), feet	359	(362)	517	(358)	0.042
Days on waiting list, mean (SD)	109	(154)	133	(193)	0.504
At transplant	27.5	(26.5)	27.6	(17.6)	0.983
FEV1, mean (SD), % predicted	37.7	(18.2)	42.2	(20.7)	
FVC, mean (SD), % predicted	45.1	(18.0)	44.2	(17.5)	0.176
Serum creatinine, mean (SD), mg/liter	0.67	(0.24)	0.72	(0.23)	0.827
Mean PA pressure, mean (SD), mmHg	31.9	(14.3)	30.2	(18.3)	0.310
Chronic hypercapneic RF, No. (%)					0.603
Invasive mechanical ventilation	37	(44.0)	–		
Non-invasive ventilation	–		1	(3.3)	
ECMO Support, No (%)	51	(60.7)	–		

Data presented as a percent or mean. SD – standard deviation; LAS – lung allocation score; 6MWT – six-minute walk test; LOS – length of stay; FEV1 – forced expiratory volume in the first second; FVC – forced vital capacity; PA – pulmonary artery; RF – respiratory failure; ECMO – extracorporeal membrane oxygenation; CPAP – continuous positive airway pressure.

compared to 6 days (IQR 4 to 10 days) in the outpatient group (p<0.001). In the hospitalized group, 34 patients (29.8%) had Grade 3 PGD at 72 h, compared to 32 patients (9.6%) in the outpatient group (p<0.001). Hospitalized patients remained mechanically ventilated a median of 6 days after transplantation (IQR 3 to 15 days), whereas outpatient recipients required mechanical ventilation for a median of 3 days (IQR 2 to 6 days) (p<0.001). Twenty-six hospitalized patients (22.8%) required a re-operation within 30 days of transplantation, compared to 40 patients (12.0%) in the outpatient group (p=0.005). Of the hospitalized recipients, 45 patients (39.5%) required a tracheostomy as compared to 51 patients (15.3%) in the outpatient group (p<0.001). Lastly, in the hospitalized group, 32 patients (28%) required acute rehabilitation after discharge, compared to 40 (12%) in the outpatient group (p=0.001).

Specific to the hospitalized group, secondary outcomes in the ICU versus non-ICU patients are reported in Table 4. Notably, patients hospitalized in the ICU had significantly longer hospital and ICU LOS compared to non-ICU hospitalized patients. The ICU subgroup also remained mechanically ventilated longer, had higher rates of tracheostomy, and was less likely to return directly home after hospitalization.

Indexed in: [Science Citation Index Expanded] [Index Medicus/MEDLINE] [Chemical Abstracts] [Scopus]

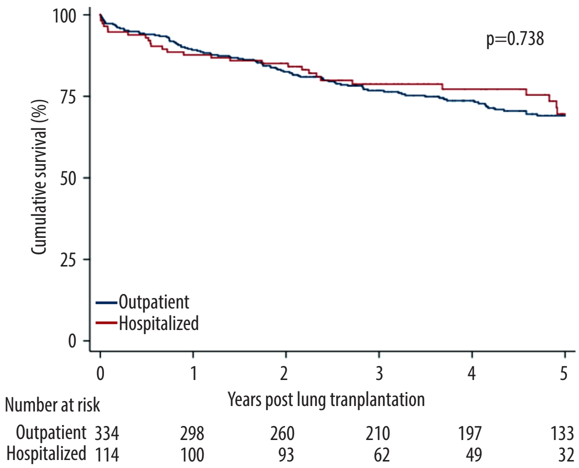

Figure 1. Kaplan-Meier curve illustrating survival based on hospitalization status.

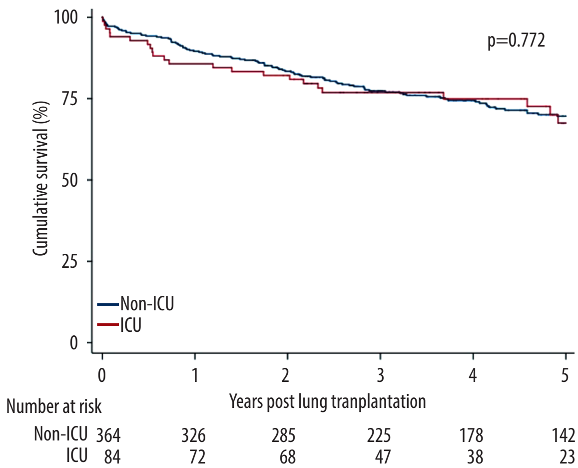

Figure 2. Kaplan-Meier curve illustrating survival based on ICU status.

Table 3. Morbidity in hospitalized versus outpatient lung transplant recipients.

	Hospitalized (n=114)		Outpatient (n=334)		*p* Value
Hospital LOS, median [IQR], days	25	[18;41]	18	[13;25]	<0.001
ICU LOS, median [IQR] days	9.5	[6;19]	6	[4;10]	<0.001
Grade 3 PGD at 72 hours, No. (%)*	34	(29.8)	32	(9.6)	<0.001
Length of MV, median [IQR], days	6	[3;15]	3	[2;6]	<0.001
Need for re-operation, No. (%)	26	(22.8)	40	(12.0)	0.005
Need for tracheostomy, No. (%)	45	(39.5)	51	(15.3)	<0.001
Disposition, No. (%)					0.001
Home	73	(64.0)	276	(82.6)	
Acute rehab	32	(28.1)	40	(12.0)	
Long-term acute care hospital	9	(7.9)	18	(5.4)	

* Missing data on 41 patients, analysis performed on a cohort of 407 patients. Data presented as a percent or median with an interquartile range. LOS – length of stay; IQR – interquartile range; ICU – Intensive Care Unit; PGD – primary graft dysfunction; MV – mechanical ventilation.

To account for the competing risk of death, event-free days through day 28 were compared between the groups (Table 5). The median hospital-free days was 1 day (IQR 0 to 9 days) in the hospitalized group, compared with 10 days (IQR 1 to 14 days) in the outpatient group (p<0.001). The median ICU-free days was 18 days (IQR 8 to 22 days) in the hospitalized group, compared with 22 days (IQR 17 to 24 days) in the outpatient group (p<0.001). Finally, there were less ventilator-free days in the hospitalized group, with a median of 22 days (IQR 12 to 55 days), compared to the outpatient group with a median of 25 days (IQR 22 to 26 days) (p<0.001).

Discussion

In this single-center study, we retrospectively evaluated the effect of preoperative hospitalization on morbidity and mortality in lung transplant recipients. We demonstrated that although hospitalized lung transplant candidates are much sicker, with higher LAS compared with outpatient candidates, there was no significant difference in post-transplant survival between the groups. Notably, however, pre-transplant hospitalization portended significant morbidity. In our study, patients hospitalized prior to lung transplantation required longer post-transplant hospital and ICU stays, longer duration of MV,

Indexed in: [Science Citation Index Expanded] [Index Medicus/MEDLINE] [Chemical Abstracts] [Scopus]

Table 4. Morbidity in hospitalized patients by hospital location.

	ICU (n=84)		Non-ICU (n=30)		*p* Value
Hospital LOS, median [IQR], days	29	[19;43]	20	[14;26]	0.009
ICU LOS, median [IQR] days	11	[7;20]	7	[4;10]	0.009
Grade 3 PGD at 72 hours, No. (%)*	30	(35.7)	4	(13.3)	0.062
Length of MV, median [IQR], days	7	[4;17]	3	[2;6]	<0.001
Need for re-operation, No. (%)	20	(23.8)	6	(20.0)	0.669
Need for tracheostomy, No. (%)	40	(47.6)	5	(16.7)	0.003
Disposition, No. (%)					0.028
Home	47	(60.0)	26	(86.7)	
Acute rehab	29	(34.5)	3	(10.0)	
Long-term acute care hospital	6	(7.1)	3	(10.0)	

* Missing data on 8 patients, analysis performed on a cohort of 106 patients. Data presented as a percent or median with an interquartile range. LOS – length of stay; IQR – interquartile range;ICU – Intensive Care Unit; PGD – primary graft dysfunction; MV – mechanical ventilation.

Table 5. Event-free days through day 28 in hospitalized versus outpatient lung transplant recipients.

	Hospitalized (n=114)		Outpatient (n=334)		*p* Value
Hospital-free days, median [IQR]	1	[0;9]	10	[1;14]	<0.001
ICU-free days, median [IQR]	18	[8;22]	22	[17;24]	<0.001
Ventilator-free days, median [IQR]	22	[12;55]	25	[22;26]	<0.001

Data presented as a median with an interquartile range. IQR – interquartile range; ICU – Intensive Care Unit.

higher rates of Grade 3 PGD, greater need for tracheostomy and re-operation, and higher likelihood of inpatient rehabilitation upon hospital discharge. Subgroup analysis of hospitalized patients in the ICU compared to non-ICU hospitalized patients revealed similar results, with the exception of similar rates of PGD and re-operation.

Our main finding of comparable survival between hospitalized and outpatient groups was unexpected and has a number of plausible explanations reflective of center-specific practice. First, our hospitalized cohort was overly representative of cystic fibrosis patients and had fewer patients with obstructive lung disease, thus representing a younger and more likely to survive population. Second, the comparable survival may be reflective of the kind of hospitalized patients in our center who survive until transplantation. While we do not have data on deactivation rates of hospitalized versus outpatient candidates, our waitlist mortality rate is 21.0 per 100 person-years, compared to national average of 17.7 per 100 person-years [14]. This may in turn suggest that those patients who become deactivated, as determined by end-organ failure, presence of systemic infection, or severe muscular deconditioning, might be sicker, and thus the hospitalized group that goes through to transplant might be healthier. Additionally, nearly half of our hospitalized patients require preoperative ECMO support as bridge to transplantation, which our center has extensive experience in and has previously reported successful bridging to transplant rates of 59% in nearly the exact same cohort as in the present study [15]. Lastly, higher survival in the hospitalized group could potentially be explained by a trend toward accepting less marginal organs for this population, although this is unlikely as we and others have reported similar post-transplant survival following transplantation using marginal lungs [16].

The implementation of LAS in 2005 has led to successful reduction in waitlist mortality and allocation of organs to candidates in greatest need [4]. Prioritization of the most severely ill patients in the post-LAS era, however, has fueled an emergence of literature addressing the subject of resource utilization and cost. Our findings are in line with those of Mooney and colleagues, who reported an increasing number of patients requiring preoperative ICU admission, mechanical ventilation, or ECMO support [17]. In recent years, the utilization of ECMO for bridging to transplantation has become more widespread with an increasing number of centers reporting greater use, which

Indexed in: [Science Citation Index Expanded] [Index Medicus/MEDLINE] [Chemical Abstracts] [Scopus]

is reflective of our findings as well, and underscores the trend for sicker patients being transplanted [18–20]. Furthermore, Keller et al. reported that patients with the highest LAS have substantially greater healthcare utilization, noting an increasing trend in the percent of patients requiring preoperative hospitalization – up to 15% of all recipients in the 2012 through 2015 study period [21]. Our study builds on this finding by reporting an even greater percentage (one-quarter of all recipients) requiring hospitalization prior to lung transplantation, suggesting this trend might be on the rise. Corollary to these findings are the reports of progressively increasing lung transplant costs [22,23]. While we could not ascertain the exact costs of hospitalization in our study, we highlight a number of morbid outcomes in hospitalized patients when compared to outpatient recipients, all of which inarguably and dramatically increase healthcare utilization and associated costs.

Our findings also corroborate those reported by Crawford and colleagues, supporting the claim that sicker, and in our case hospitalized, patients are not necessarily at a survival disadvantage as they once might have been [24]. Nevertheless, the sickest and most functionally limited patients are often the ones to become hospitalized prior to lung transplantation and remain hospitalized until transplant or death, with very low likelihood of sufficient recovery to go home. Considerable efforts are undertaken to keep hospitalized patients physically active, infection-free, and high-spirited in an attempt to preserve their candidacy. Our study results suggest that during that time, we should also be setting realistic expectations about post-transplant morbidity. Our data provide valuable anticipatory guidance to patients and their families considering lung transplantation and would enrich discussions during the consenting process.

This study has a number of important limitations. First, we had no objective measure of patient frailty, which is an emerging predictor of post-transplant outcomes and is likely directly affected by hospitalization, thereby potentially driving the effect of hospitalization [25]. Second, inpatient transplant recipients were significantly sicker, as demonstrated by high LAS, suggesting that potentially LAS, and not hospitalized status, could be driving the morbidity seen in our cohort, although we could not ascertain the extent of the effect of LAS on morbid outcomes [26,27]. Third, we lack data on the quality of life after transplant. Although mortality rate is similar, it is possible that the quality of life differs considerably between the 2 groups. Similarly, we lack accessible data on lung function and rates of rejection after transplant, both of which would be of interest in this population and may be influenced by the pre-transplant clinical trajectory. Lastly, as this was a single-center study reflecting the practices of Columbia University Medical Center only, our findings might not be generalizable to other centers.

Conclusions

In conclusion, we demonstrated that patients hospitalized immediately prior to lung transplantation have a rate of survival similar to that of outpatient recipients, yet pre-transplant hospitalization portends significant post-transplant morbidity.

Acknowledgements

We would like to thank all members of our transplant team for their tireless work, without whom this study would not have been possible. We would also like to acknowledge the Boomer Eisiason Foundation for their support of our research.

References:

1. Lung Kaplan-Meier Graft Survival Rates for Transplants Performed: 2008–2015. 2019; *https://optn.transplant.hrsa.gov/data/view-data-reports/nationaldata/#*
2. Chambers D, Cherikh W, Goldfarb S et al: The International Thoracic Organ Transplant Registry of the International Society for Heart and Lung Transplantation: Thirty-fifth adult lung and heart-lung transplant report – 2018; Focus theme: Multiorgan Transplantation. J Heart Lung Transplant, 2018; 37(10): 1169–83
3. Thabut G, Mal H: Outcomes after lung transplantation. J Thorac Dis, 2017; 9(8): 2684–91
4. Egan T, Murray S, Bustami R et al: Development of the new lung allocation system in the United States. Am J Transplant, 2006; 6 (Part 2): 1212–27
5. Vock D, Durheim M, Tsuang W et al: Survival benefit of lung transplantation in the modern era of lung allocation. Ann Am Thorac Soc, 2017; 14(2): 172–81
6. Bermudez C, Rocha R, Zaldonis D et al: Extracorporeal membrane oxygenation as a bridge to lung transplant: Midterm outcomes. Ann Thorac Surg, 2011; 92: 1226–32
7. Fuehner T, Kuehn C, Hadem J et al: Extracorporeal membrane oxygenation in awake patients as bridge to lung transplantation. Am J Respir Crit Care Med, 2012; 185(7): 763–68
8. Gulack B, Hirji S, Hartwig M: Bridge to lung transplantation and rescue post-transplant: The expanding role of extracorporeal membrane oxygenation. J Thorac Dis, 2014; 6(8): 1070–79
9. Charlson M, Sax F, Mackenzie C et al: Morbidity during hospitalization: Can we predict it? J Chronic Dis, 1987; 40(7): 705–12
10. Wickerson L, Rozenberg D, Janaudis-Ferreira T et al: Physical rehabilitation for lung trasnplant candidates and recipients: An evidence-informed clinical approach. World J Transplant, 2016; 6(3): 517–31
11. Snell G, Yusen R, Weill D et al: Report of the ISHLT Working Group on Primary Lung Graft Dysfunction, part I: Definition and grading – A 2016 Consensus Group statement of the International Society for Heart and Lung Transplantation. J Heart Lung Transplant, 2017; 36(10): 1097–103
12. Schloenfeld D, Bernard G: Statistical evaluation of ventilator-free days as an efficacy measure in clinical trials of treatments for acute respiratory distress syndrome. Crit Care Med, 2002; 30(8): 1772–77
13. Beitler J, Ghafouri T, Jinadasa S et al: Favorable neurocognitive outcome with low tidal volume ventilation after cardiac arrest. Am J Respir Crit Care Med, 2017; 195(9): 1198–206
14. NY Presbyterian Hospital/Columbia University Medical Center Report. Scientific Registry of Transplant Recipients; 2019. *https://www.srtr.org/PDFs/072019_release/pdfPSR/NYCPTX1LU201905PNEW.pdf*

15. Tipograf Y, Salna M, Minko E et al: Outcomes of extracorporeal membrane oxygenation as a bridge to lung transplantation. Ann Thorac Surg, 2019; 107: 1456–63
16. Kawut S, Reyentovich A, Wilt J et al: Outcomes of extended donor lung recipients after lung transplantation. Transplantation, 2005; 79(3): 310–16
17. Mooney J, Weill D, Boyd J et al: Effect of transplant center volume on cost and readmissions in medicare lung transplant recipients. Ann Am Thorac Soc, 2016; 13(7): 1034–41
18. Hayanga A, Aboagye J, Esper S et al: Extracorporeal membrane oxygenation as a bridge to lung transplantation in the United States: An evolving strategy in the management of rapidly advancing pulmonary disease. J Thorac Cardiovasc Surg, 2015; 149: 291–96
19. Hoetzenecker K, Donahoe L, Yeung J et al: Extracorporeal life support as a bridge to lung transplantation – experience of a high-volume transplant center. J Thorac Cardiovasc Surg, 2018; 155(3): 1316–28
20. Inci I, Klinzing S, Schneiter D et al: Outcome of extracorporeal membrane oxygenation as a bridge to lung transplantation: An institutional experience and literature review. Transplantation, 2015; 99(8): 1667–71
21. Keller C, Gonwa T, White L et al: Utilization and cost analysis of lung transplantation and survival after 10 years of adapting the lung allocation score. Transplantation, 2019; 103(3): 638–46
22. Arnaoutakis G, Allen J, Merlo C et al: Impact of the lung allocation score on resource utilization after lung transplantation in the United States. J Heart Lung Transplant, 2011; 30: 14–21
23. Maxwell B, Mooney J, Lee P et al: Increased resource use in lung transplant admissions in the lung allocation score era. Am J Respir Crit Care Med, 2015; 191(3): 302–8
24. Crawford T, Grimm J, Magruder J et al: Lung transplant mortality is improving in recipients with a lung allocation score in the upper quartile. Ann Thorac Surg, 2017; 103: 1607–13
25. Singer J, Diamond J, Gries C et al: Fraily phenotypes, disability, and outcomes in adult candidates for lung transplantation. Am J Respir Crit Care Med, 2015; 192(11): 1325–34
26. Liu V, Zamora M, Dhillon G, Weill D: Increasing Lung Allocation Scores predict worsened survival among lung transplant recipients. Am J Transplant, 2010; 10(4): 915–20
27. Russo M, Iribarne A, Hong K et al: High lung allocation score is associated with increased morbidity and mortality following transplantation. Chest, 2010; 137(3): 651–57

Indexed in: [Science Citation Index Expanded] [Index Medicus/MEDLINE] [Chemical Abstracts] [Scopus]