

Lung Transplantation in the United States, 1999–2008

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Note on sources: The articles in this report are based on the reference tables in the 2009 OPTN/SRTR Annual Report, which are not included in this publication. Many relevant data appear in the figures and tables included here. All of the tables may be found online at: <http://www.ustransplant.org>.

This article highlights trends and changes in lung and heart–lung transplantation in the United States from 1999 to 2008. While adult lung transplantation grew significantly over the past decade, rates of heart–lung and pediatric lung transplantation have remained low. Since implementation of the lung allocation score (LAS) donor allocation system in 2005, decreases in the number of active waiting list patients, waiting times for lung transplantation and death rates on the waiting list have occurred. However, characteristics of recipients transplanted in the LAS era differed from those transplanted earlier. The proportion of candidates undergoing lung transplantation for chronic obstructive pulmonary disease decreased, while increasing for those with pulmonary fibrosis. In the LAS era, older, sicker and previously transplanted candidates underwent transplantation more frequently compared with the previous era. Despite these changes, when compared with the pre-LAS era, 1-year survival after lung transplantation did not significantly change after LAS inception. The long-term effects of the change in the characteristics of lung transplant recipients on overall outcomes for lung transplantation remain unknown. Continued surveillance and refinements to the LAS system will affect the distribution and types of candidates transplanted and hopefully lead to improved system efficiency and outcomes.

Key words: Deceased donor organs, lung transplantation, living donor transplantation, Scientific Registry

of Transplant Recipients, organ allocation, Organ Procurement and Transplantation Network

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Introduction

This article highlights trends and changes in lung and heart–lung transplantation in the United States from 1999 to 2008. The article builds upon previous Annual Reports (1). In addition to providing an update on generally reported information, this article addresses issues not previously covered in the Scientific Registry of Transplant Recipients' (SRTR) Report on the State of Transplantation. The article uses data from the 2009 Organ Procurement and Transplantation Network (OPTN)/SRTR Annual Report (2) and data from special analyses performed by the SRTR. The reader may view the 2009 OPTN/SRTR Annual Report tables online at: <http://www.ustransplant.org>.

In the United States, transplant programs register acceptable lung transplant candidates with the OPTN. Whereas time on the lung transplant waiting list primarily prioritized donor lung allocation prior to the implementation of the lung allocation score (LAS) system, on May 4, 2005 the LAS system began using medical urgency and expected outcome to prioritize donor lung allocation. The LAS, ABO blood group and distance from the donor hospital determine the order for making donor lung offers to lung transplant candidates ages 12 years and older. Pediatric candidates under age 12 continue to receive lung offers based on the amount of time they have spent waiting for a lung transplant, ABO compatibility and distance from the donor hospital. In addition, the system prioritizes pediatric donor offers to age-matched pediatric age groups (age less than 12 years and age 12–17 years) (3–5).

For each candidate, the LAS algorithm estimates the expected number of days lived during the next year on the waiting list without a transplant (i.e. *waiting list urgency estimate*) and the number of days lived during the first year after transplantation (i.e. *posttransplant survival estimate*). The LAS algorithm calculates the *net transplant benefit* by subtracting the expected days lived on the waiting list without a transplant over the next year from the expected days lived with a transplant over the next year. The *net transplant*

Table 1: Lung allocation score (LAS) primary diagnostic groupings and clinical diagnoses for lung transplant candidates

LAS lung disease primary diagnostic grouping	Clinical diagnosis
<i>Group A</i> (<i>obstructive lung disease</i>)	Allergic bronchopulmonary aspergillosis (ABPA) Bronchopulmonary dysplasia Constrictive bronchiolitis Granulomatous lung disease Kartagener's syndrome Obstructive lung disease Primary ciliary dyskinesia Tuberous sclerosis Wegener's granuloma-bronchiectasis Ehlers-Danlos syndrome Inhalation burns/trauma Sarcoidosis with mean pulmonary artery (PA) pressure \leq 30 mm Hg Alpha-1-antitrypsin deficiency (A1ATD) Chronic obstructive pulmonary disease (COPD)/emphysema Bronchiectasis Lymphangioliomyomatosis (LAM)
<i>Group B</i> (<i>pulmonary vascular disease</i>)	Congenital malformation Portopulmonary hypertension Pulmonary thromboembolic disease Pulmonary veno-occlusive disease Pulmonic stenosis Right hypoplastic lung Thromboembolic pulmonary hypertension CREST-pulmonary hypertension Pulmonary telangiectasia-pulmonary hypertension Scleroderma-pulmonary hypertension Eisenmenger's syndrome: atrial septal defect (ASD) Eisenmenger's syndrome: ventricular septal defect (VSD) Eisenmenger's syndrome: patent ductus arteriosus (PDA) Eisenmenger's syndrome: multiple congenital anomalies Eisenmenger's syndrome: other specific Primary pulmonary hypertension (PPH) Pulmonary vascular disease Secondary pulmonary hypertension
<i>Group C</i> (<i>cystic fibrosis or immunodeficiency disorders</i>)	Common variable immune deficiency (CVID) Fibrocavitary lung disease Hypogammaglobulinemia Schwackman-Diamond syndrome Cystic fibrosis (CF)
<i>Group D</i> (<i>restrictive lung disease</i>)	Wegener's granuloma-restrictive CREST-restrictive Pulmonary telangiectasia-restrictive ANCA positive vasculitis Scleroderma-restrictive Alveolar proteinosis Amyloidosis Acute respiratory distress syndrome (ARDS)/pneumonia Bronchiolitis obliterans and organizing pneumonia (BOOP) Bronchoalveolar carcinoma (BAC) Carcinoid tumorlets Chronic pneumonitis of infancy Eosinophilic granuloma (EG) Fibrosing mediastinitis Graft-versus-host disease (GVHD) Hermansky Pudlak syndrome Hypersensitivity pneumonitis Idiopathic pulmonary hemosiderosis Lymphocytic interstitial pneumonia (LIP)

Continued

Table 1: Continued

LAS lung disease primary diagnostic grouping	Clinical diagnosis
	Lupus
	Mixed connective tissue disease
	Paraneoplastic pemphigus associated Castleman's disease
	Polymyositis
	Pulmonary hyalinizing granuloma
	Sjogren's syndrome
	Silicosis
	Surfactant protein B deficiency
	Teratoma
	Lung retransplant/graft failure: non-specific
	Lung retransplant/graft failure: obliterative bronchiolitis
	Lung retransplant/graft failure: restrictive
	Lung retransplant/graft failure: acute rejection
	Lung retransplant/graft failure: obstructive
	Lung retransplant/graft failure: primary graft failure
	Lung retransplant/graft failure: other specify
	Idiopathic pulmonary fibrosis (IPF)
	Sarcoidosis with mean PA pressure > 30 mm Hg
	Rheumatoid disease
	Occupational lung disease other specify cause
	Obliterative bronchiolitis (non-retransplant)
	Pulmonary fibrosis other specify cause

Source: Revision to policy 3.7.6.1

benefit minus the *transplant urgency* determines the LAS (after normalization of the raw allocation score). The LAS ranges from a low of zero to a high of 100. Patients with the highest LAS have the highest priority for receiving a donor lung offer (3–5).

Transplant center staff members enter clinical data in the OPTN data system for specific variables used in the LAS. Centers may update LAS variable fields at any time, and the OPTN requires centers to update information at least once every 6 months. Data required for registration on the lung transplant waiting list include diagnosis, age, height and weight. The LAS algorithm assigns a score of zero to patients with missing or expired data for functional status or assisted ventilation variables. The system removes candidates with an LAS of zero from the match; they cannot receive donor lung offers. The LAS algorithm replaces remaining missing or expired values with a '*normal*' value for the variables of pulmonary artery systolic pressure, pulmonary artery mean pressure (sarcoidosis diagnoses only), pulmonary capillary wedge mean pressure and PCO₂. The algorithm replaces missing or expired values with the '*least beneficial*' value (i.e. yields the lowest LAS) for the variables of diabetes, supplemental oxygen, 6-min walk distance, forced vital capacity and serum creatinine (5).

A Lung Review Board (LRB) provides peer review of cases when transplant center physicians feel the LAS does not reflect the estimated transplant benefit and urgency of a waiting list candidate. Transplant centers may make requests to the LRB for use of *estimated clinical values* (lab

values or test results) for LAS calculation when they cannot determine real values. If a transplant center feels that the LAS does not accurately represent a patient's net transplant benefit, it may request a specific LAS for that patient from the LRB.

For the LAS calculation, transplant centers give each patient a primary lung diagnosis indication for transplantation that falls into one of four diagnostic categories (Table 1). However, patients with different diseases within the groupings have different characteristics. This article separately describes outcomes for clinical diagnostic groups and LAS diagnostic groups when deemed necessary.

Because the LAS system was implemented in the second quarter of 2005, the 2005 data reflect results from a mixture of the LAS and the pre-LAS systems. Though this article uses data from the past decade, it primarily focuses on what has occurred since implementation of the LAS system. To avoid confusion regarding pre-LAS and current LAS organ allocation system comparisons, some analyses exclude the mixed allocation system data from 2005 (e.g. data from 2006 to 2008 compared with data from 2002 to 2004). Published articles have described the analytical methods used, including adjusted analyses, for this report (6).

LAS Variable Refinements

The OPTN Thoracic Committee receives periodic reports on the performance of the LAS system from

biostatisticians at the SRTR and OPTN. In addition to reviewing and voting on proposed updates to the LAS system, the Thoracic Committee also proposes revisions to the LAS. Proposed revisions that receive a favorable review by the committee undergo a period of public comment. The committee may choose to present certain LAS system revision proposals to the OPTN Board of Directors for approval.

The guidelines for patients with idiopathic pulmonary arterial hypertension (IPAH), issued by the Thoracic Committee on November 21, 2006, stated that candidates with (1) deterioration of optimal therapy, (2) right atrial pressure greater than 15 mmHg and (3) cardiac index less than 1.8 L/min/m² may qualify for an increased LAS. When a transplant center requests an LAS modification for such a candidate, the LRB will consider increasing the candidate's LAS to the 90th percentile of all lung allocation scores at that time.

An OPTN/SRTR analysis of audited PCO₂ data and LAS risk factor and outcomes from patients first listed for lung transplantation between 1998 and 2002 suggested that inclusion of current PCO₂ and PCO₂ change data improved the LAS estimates of patient urgency (7). In March 2007, after undergoing review, public comment, and further discussion, the OPTN Board of Directors approved modifications to Policy 3.7.6.1 that added current and serial changes in PCO₂ to the LAS algorithm for lung transplant candidates age 12 years and older. In December 2007, the OPTN made available an online LAS calculator that allowed input of current and previous PCO₂ variables. Before full implementation of the revised LAS, transplant centers could make an exception request to the LRB based on an LAS increase due to the additional PCO₂ data. The OPTN completed the required programming and testing and implemented the revised LAS in October 2008.

More recent analyses of retrospective OPTN audited data have indicated improved prediction of patient urgency based on current and serial total bilirubin values, particularly for primary lung diagnostic group B (i.e. pulmonary vascular disease) patients with a peak total bilirubin above 1.0 mg/dL who have experienced a 50% increase in total bilirubin within a 6-month period (8). Feedback from two different public comment periods indicated widespread support for this modification of the LAS algorithm. The OPTN Board of Directors approved this revision to policy 3.7.6.1 in July 2009. However, the large anticipated expense of collecting bilirubin data and programming this change into the OPTN computer systems has deferred its implementation. In the interim, the Board of Directors is considering implementing a new version of the online LAS calculator that includes the bilirubin modifications, similar to the procedures used prior to implementation of the PCO₂ modification of the LAS. In specific instances, the revised online LAS calculator would provide transplant centers with the necessary data to make exception requests to the LRB.

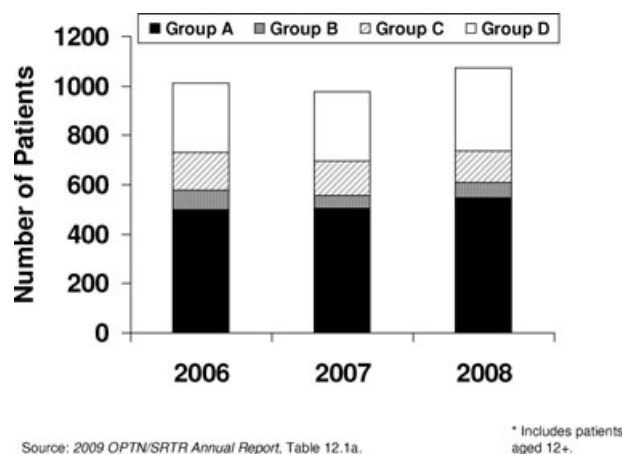


Figure 1: Number of patients active on the lung transplant waiting list by year (2006–2008) and by diagnosis group (A–D).

Overall Waiting List and Transplant Characteristics and Outcomes

Waiting list activity

From 1999 to 2004, over 2000 patients remained on the active lung transplantation waiting list at the end of each year [Table 12.1a], while the total number of candidates registered (active and inactive) progressively increased and peaked at 3859 in 2004 [Table 1.3]. Though all registrants accrue time on the waiting list (most important in young pediatric candidates), only active registrants receive donor offers. In the LAS era of 2006–2008, the number of active wait-listed patients at year-end remained significantly decreased compared with the pre-LAS era (from 2163 in 2004 to 1089 in 2008; a 50% reduction). The number of active wait-listed patients has remained around 1000 since LAS implementation [Table 12.1a] (Figure 1), while the number of inactive wait-listed patients has declined yearly from 2057 in 2005 to 927 in 2008 [Table 12.1b]. In the LAS era, approximately 50% of the active waiting list at year-end consisted of patients with obstructive lung disease (Group A), while about 30% of patients had restrictive lung disease (Group D), 13% of patients had cystic fibrosis or immunodeficiency disorders (Group C) and approximately 6% of patients had pulmonary vascular disease (Group B) (Table 1, Figure 1). The active waiting list typically had fewer than 4% of patients awaiting a repeat lung transplantation (i.e. a subset of Group D). Though the absolute number of patients in each LAS primary disease group on the waiting list decreased over the past decade, the percentage in each group did not undergo significant change [Table 12.1a].

Distribution of waiting list candidate lung allocation scores

The median LAS at listing within the four main lung diagnostic groups remained relatively unchanged in 2006

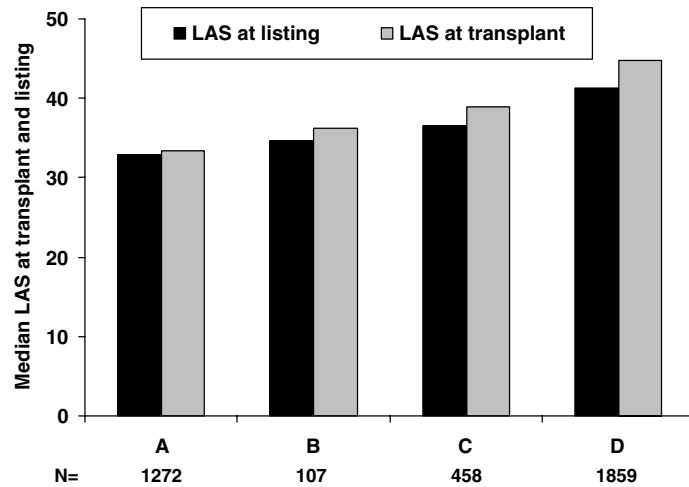


Figure 2: Median LAS at listing and at transplant by diagnosis group (A–D) for patients who received lung transplants between 2006 and 2008*.

Source: SRTR analysis, data as of May 2009

* Includes patients aged 12+ placed on the waiting list on or after 5/4/2005 with non-zero LAS at listing.

to 2008 (SRTR special analysis, June 2009). The average LAS increased when moving from diagnostic group A to D. On average, the LAS at the time of wait-listing slightly increased when last recalculated prior to transplantation (Figure 2). Although the annual total number of waiting candidates held steady since the inception of LAS, the percentage of patients with an LAS of 40 or higher at year-end steadily increased (15.6%, 16.3% and 24.5% in 2006, 2007 and 2008, respectively) after starting at a low in the partial LAS year of 2005 (7.2%) (Table 2) [Table 12.1a].

Time to transplant

For many years prior to LAS implementation, waiting time averaged well over 2 years because of the high ratio of the number of waiting list candidates to the number of available donor lungs. The decade-high median time to transplant (TT) of 2897 days in 1999 dropped to 792 days in 2004, and plummeted to 200 days or less in each year of 2005–2008 [Table 12.2]. The years bracketing the 2005 implementation of the LAS showed a dramatic reduction in median waiting time from 792 days in 2004 (95% CI, 666–965 days) to 134 days in 2006 (95% CI, 114–151 days) [Table 12.2]. In the recent 2008 transplant cohort, one-quarter of wait-listed patients received a transplant within 35 days.

For new lung waiting list registrants, the median TT markedly dropped in the LAS years of 2006–2008 compared with the pre-LAS years of 2002–2004. This drop occurred overall and for primary lung diagnostic groups A, C and D. Group B (i.e. pulmonary vascular disease) had the smallest number of new registrations and did not achieve a median in either era (SRTR special analysis, June 2009).

Median time to transplant by LAS at listing

In general, higher LAS at listing resulted in shorter median time to transplant (SRTR special analysis, June 2009). For patients combined from all diagnostic groups listed for a lung transplant during 2008, those with an LAS of 50 or higher took a median of 38 days to receive a transplant. In comparison, those with an LAS of 40 to less than 50 had a median waiting time of 72 days. The median waiting time increased substantially for those with an LAS lower than 40; those with an LAS of 35 to less than 40 and 30 to less than 35 had median TT of 150 and 324 days, respectively. Fewer than 1% of patients wait-listed had a nonzero LAS below 30. For transplant recipients with an LAS of 30 or higher (i.e. 99% of recipients [Table 12.4]), as the LAS increased within each primary lung diagnostic group,

Table 2: Active lung waiting list patient LAS at end of year

LAS	2006		2007		2008	
	Count	Percentage	Count	Percentage	Count	Percentage
0	138	13.4	35	3.5	21	1.9
20 to <30	31	3.0	18	1.8	10	0.9
30 to <35	485	47.0	573	57.0	459	42.1
35 to <40	216	21.0	216	21.5	332	30.5
40 to <50	106	10.3	116	11.5	196	18.0
50 to <60	28	2.7	26	2.6	40	3.7
60+	27	2.6	22	2.2	31	2.8
Total	1031		1006		1089	

Source: Table 12.1a

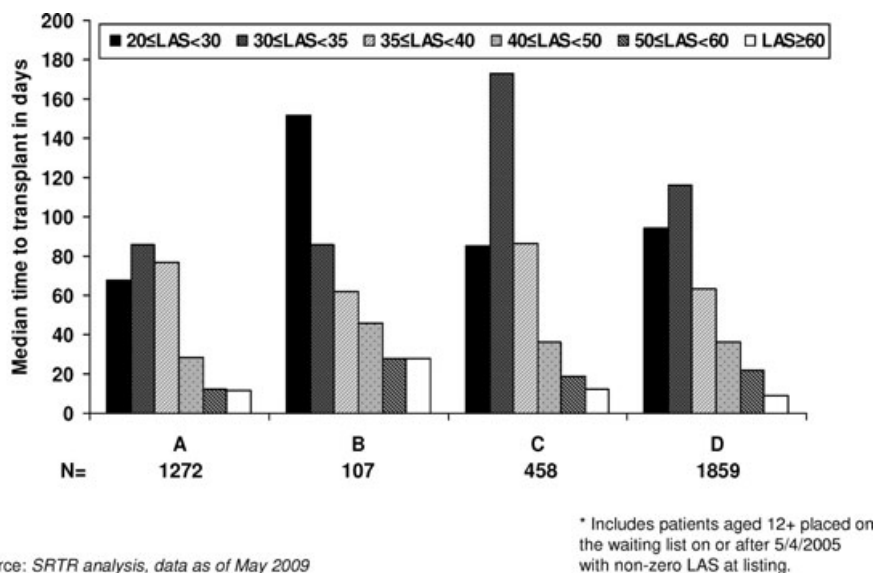


Figure 3: Median time to transplant by diagnosis group (A–D) and LAS group at listing for patients who received lung transplants during 2006–2008.

Source: SRTR analysis, data as of May 2009

the median waiting time for patients who received a transplant decreased (Figure 3). LAS groups that include small numbers of patients make trend analyses less precise (Table A.1).

Greater than 99% of patients that received a single lung transplant fell into LAS diagnostic categories A and D (Table A.1). Most patients in Group A who had a single lung transplant had an LAS in the range of 30 to less than 35; this group had a median waiting time about 2 weeks longer than the bilateral lung transplant group with a similar LAS. In contrast to the low LAS for the majority of patients in Group A, Group D had a greater proportion of patients distributed among the different LAS groups at listing for both single and bilateral lung transplant recipients. Also reversing the trend for Group A, Group D single lung recipients in the most common LAS categories had shorter median waiting times in comparison to Group D bilateral lung recipients (data not shown).

Survival on the lung transplant waiting list

The number of registrants (active and inactive) on the lung transplant waiting list at any point during each year (i.e. the number at risk of dying) hovered around 5000 (high 5650;

low 4868) from 1999 to 2004 [Table 12.3]. Approximately 500 registrants (high 599; low 489) died on the waiting list each year during that same period. The number of annual deaths dropped from 398 in 2005 to 300, 317 and 266 in 2006, 2007 and 2008, respectively. These annual absolute death counts only partially describe waiting list survival trends. Death rates, which account for the number of patient-years at risk, provide better estimates of waiting list survival. Like the death counts, the death rates for patients on the lung transplant waiting list have dropped since 1999. The death rates peaked at 190.5 deaths per 1000 patient-years in 1999, and dropped to a low of 103.5 in 2006 (a 46% decline) [Table 12.3]. Although the waiting list *death rate* dropped following implementation of the LAS system, it did not undergo as dramatic a decline as the *absolute number of deaths* on the waiting list (Table 3) [Table 12.3].

The absolute number of deaths and the death rate decreased in each primary lung diagnostic group in the LAS era of 2006–2008 compared with the pre-LAS era of 2002–2004. Group D had the highest annual number of deaths pre-LAS, and it had the largest decrease in the number of deaths when comparing LAS to pre-LAS eras. However,

Table 3: Lung waiting list reported deaths and annual death rates per 1000 patient-years at risk, 1999–2008

Age this year	Year									
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total										
Patients	4868	5141	5374	5399	5549	5650	5269	4798	4676	4119
Deaths	599	519	532	529	489	512	398	300	317	266
Rate	190.5	152.6	149.1	145.0	131.5	135.0	115.5	103.5	125.9	128.0

Source: OPTN/SRTR Data as of May 4, 2009 [Table 12.3]

Includes patients alive on the waiting list at anytime during the year. Period at risk begins the later of January 1 or waiting list registration and ends on the earlier of December 31, date of death, or date of removal for other reasons. Please see Technical Notes for further details about death rate computation.

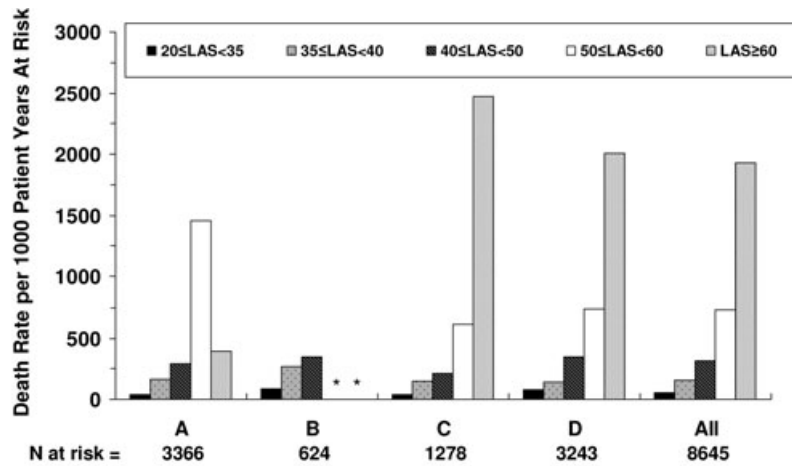


Figure 4: Death rate for patients placed on the lung waiting list from May 4, 2005 to December 31, 2007, stratified by primary diagnostic grouping and LAS at time of listing.

Period at risk begins the later of January 1 or waiting list registration and ends on the earlier of December 31, 2007, date of death, or date of removal for other reasons. Please see Technical Notes for further details about death rate computation.
 Source: SRTR analysis, data as of May 2009

*Rates for groups of <10 patients are not reported.
 ** Includes patients aged 12+ with non-zero LAS at listing.

Group D continued to have the highest annual death rate in both eras, and Group A continued to have the lowest death rate [Table 12.3].

Waiting list death rate by LAS

Despite the LAS prioritization of patients aged 12 and higher for transplant, waiting list death rates increased as the LAS categories increased (Figure 4) [Table 12.3]. Those listed with an LAS 60 or higher in groups C and D had the highest risk of death on the waiting list (2471 and 2006 deaths per thousand patient-years at risk, respectively) (Figure 4). Those listed with an LAS of 50 to less than 60 also had high waiting list death rates (1457, 611 and 739 deaths per thousand patient-years at risk for groups A, C and D, respectively). In 2008, lung transplant candidates had approximately 200 deaths per thousand patient-years at risk for those with LAS of 35 to less than 50, 666 deaths

for those with an LAS of 50 to less than 60 and 1593 deaths for those with LAS of 60 or higher. Patients with an LAS less than 35 had the lowest death rate (184 and 59 deaths per thousand patient-years for those with an LAS of 20 to less than 30, and 30 to less than 35, respectively) [Table 12.3].

Deceased Donor Transplant Activity and Recipient Profiles

The annual volume of deceased donor transplants performed has increased in a stepwise fashion over the past decade (Figure 5) [Table 12.4]. The greatest annual increase occurred from 2004 to 2005, when transplants increased by 21% from 1157 to 1405. Since then, the volume has remained steady. Reversing the trend observed in

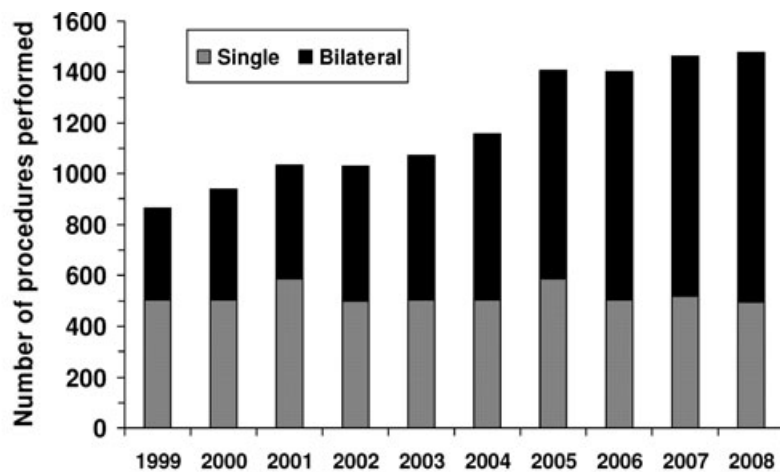


Figure 5: Number of deceased donor lung transplants, 1999–2008.

Source: 2009 OPTN/SRTR Annual Report, Table 12.4

* Includes both pediatric and adult procedures.

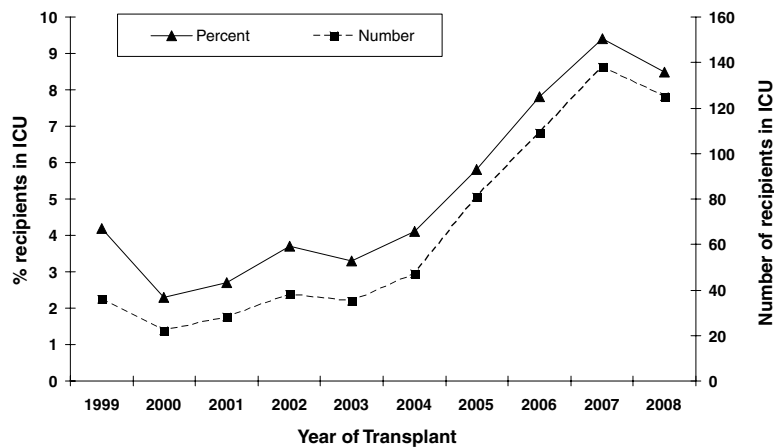


Figure 6: Deceased donor lung transplant recipients in ICU at time of transplantation, 1999–2008.

* Includes both pediatric and adult procedures.

Source: 2009 OPTN/SRTR Annual Report, Table 12.4

the early part of the decade, bilateral lung transplantation became the dominant procedure and accounted for two-thirds of all procedures performed in 2006–2008 (Figure 5) [Table 12.4].

Lung transplant recipient demographics have changed over the past decade [Table 12.4]. The number of recipients 65 years and older steadily increased. Whereas this age group accounted for only 3%–5% of recipients from 1999 to 2002, it accounted for 12%, 15% and 19% of recipients in 2006, 2007 and 2008, respectively. Race and sex demographics also changed. The percentage of white recipients decreased, while the percentage of minority recipients increased. In 1999, 90% of recipients were white; this fell to 83% in 2008. During the same period, the percentage of African American recipients increased from 6% to 9% and Hispanics increased from 3% to 6%. These changes in recipient racial characteristics did not clearly track with changes in primary lung diseases that occur more frequently in certain racial groups. Until 2005, approximately equal percentages of men and women received a lung transplant. Coincident with the introduction of the LAS system, a pattern of slight male predominance emerged. In 2006, 2007 and 2008, males comprised 56%, 58% and 61%, respectively, of all recipients of lungs from deceased donors. This trend occurred in association with an increase in the proportion of recipients that have the male-predominant diagnosis of IPF.

The ability to expeditiously transplant critically ill patients under the LAS system led to a burgeoning pool of recipients who came from the intensive care unit (ICU) at the time of transplant [Table 12.4]. From 2006 to 2008, 7% (323 of 4344) of deceased donor lung recipients required mechanical, ventilated or organ-perfusion support at the time of transplant, compared with 6% (181 of 3256) of recipients from 2002 to 2004. In the past decade, the percentage of recipients on mechanical, ventilated or organ-

perfusion support peaked at 9% in 2008. The percentage of patients in the ICU at transplant showed similar trends (Figure 6); these recipients comprised 8%–9% of the recipient pool from 2006 to 2008 compared with 3%–4% for 2002–2004.

In contrast to the stable proportions of patients with various diagnoses on the waiting list, the distribution of underlying primary diseases among deceased donor transplant recipients changed considerably in the past decade (Figure 7) [Table 12.4]. Notably, these trends began prior to the implementation of the LAS system. The percentage of patients (though not the absolute number) with chronic obstructive pulmonary disease (COPD) (excluding A1ATD) undergoing transplantation declined and reached a nadir in 2008, when patients with COPD accounted for 29% of all recipients compared with approximately 46% in the early part of the decade. Showing a similar trend, the percentage of patients with COPD associated with A1ATD peaked at 8% in 2002 and declined to 3% in 2008. IPAH became an increasingly less common indication for transplantation and accounted for only 2% of transplant procedures in 2008 compared with more than double that in the first half of the decade. In contrast, the number and percentage of patients with idiopathic pulmonary fibrosis (IPF) undergoing transplantation steadily increased; IPF eclipsed COPD as the leading indication for transplantation in 2007. In 2007 and 2008, one-third of transplant recipients had IPF as the primary indication for lung transplantation. The percentage of transplant recipients with cystic fibrosis remained relatively constant, in the range of 14%–18%, throughout the past decade. The distribution of LAS diagnostic groups (Table 1) reflected the trends in specific primary lung diagnoses [Table 12.4]. While the proportion of patients in lung diagnosis Groups A and B undergoing transplantation has declined, the proportion of patients in Group D increased, and the percentage in Group C did not significantly change.

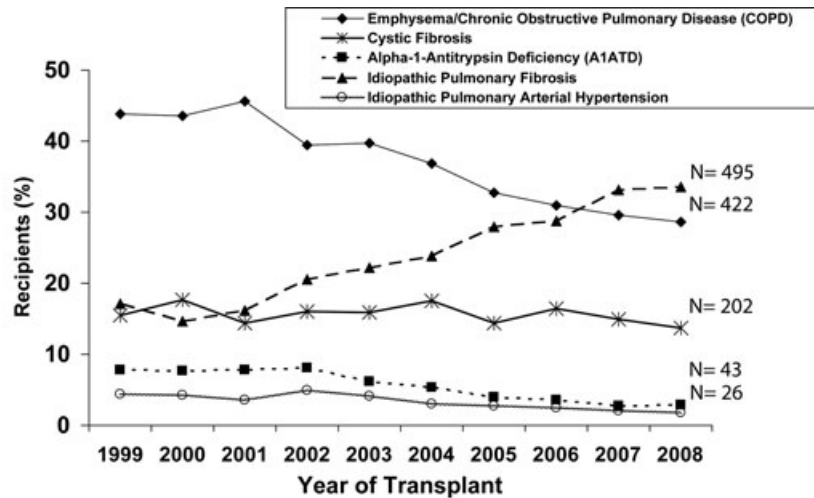


Figure 7: Primary diagnosis of deceased donor lung transplant recipients, 1999–2008.

Source: 2009 OPTN/SRTR Annual Report, Table 12.4

*Includes both pediatric and adult recipients. The COPD groups with and without A1ATD are depicted separately.

Distribution of transplant recipient LAS

Although the lung allocation system favors patients with higher LAS, the distribution of LAS among patients receiving transplants indicates that candidates with scores of at least 30 have had good access to organs [Table 12.4]. In 2008, 220 (15%) of recipients had an LAS of 60 or higher, 138 (9%) had a score of 50 to less than 60, 366 (25%) had an LAS of 40 to less than 50, 353 (24%) had an LAS of 35 to less than 40 and 390 (26%) had an LAS of 30 to less than 35. Only 11 lung recipients (0.7%) had an LAS below 30 at the time of transplant. When broken down by LAS diagnostic group for transplants during 2006–2008, Group D had the highest median LAS at transplant, followed by groups C, B and A (Figure 2).

Outcomes following deceased donor transplantation

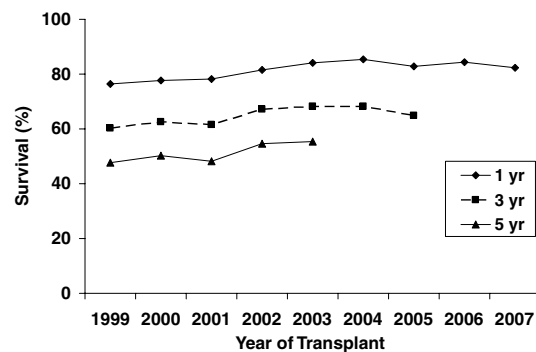
During the past decade, the most recent cohorts of deceased donor lung transplantation recipients had 1-, 5-, and 10-year unadjusted survival rates of 83%, 54% and 29%, respectively [Table 12.14]. Survival rates at 1, 3 and 5 years posttransplant showed subtle improvement over the past 10 years [Table 12.15] (Figure 8). Since implementation of the LAS system, 1-year posttransplant survival rates have not significantly changed. Long-term survival data for recipients in the LAS system do not yet exist.

Survival outcomes for lung recipients remain inferior to those achieved following other solid organ transplant procedures [Table 1.13]. Heart transplant recipients have survival rates at 1, 5 and 10 years of 88%, 75% and 56%. Deceased donor liver transplant recipients have corresponding survival rates of 88%, 74% and 60%.

Subgroups of patients had different unadjusted survival rates after lung transplantation. However, adjustment for other factors could have significantly affected the results. Different primary lung diagnosis populations demonstrated

modest differences in survival, with a trend toward better long-term unadjusted survival among patients with cystic fibrosis, IPAH and COPD associated with A1ATD, compared with COPD not associated with A1ATD and IPF (Figure 9) [Table 12.14]. Compared with most other primary lung diagnostic groups, patients with COPD not associated with A1ATD had relatively good short-term survival and relatively poor long-term survival. Alternatively, patients with IPAH had relatively poor short-term survival and relatively good long-term survival.

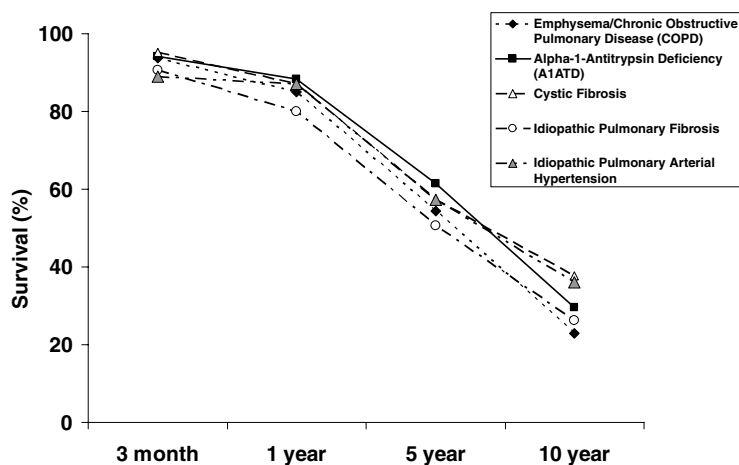
Age did not have a major impact on 1- and 5-year unadjusted survival rates for adult recipients below the age of 65, but recipients 65 years and older had lower survival rates than younger groups at these time points (Figure 10) [Table 12.14]. At 10 years posttransplant, adult recipients in age cohorts of less than 50 years old, 50 to less than 65



Source: 2009 OPTN/SRTR Annual Report, Table 12.15

* Includes both pediatric and adult procedures.

Figure 8: Unadjusted patient survival for recipients of deceased donor lung transplants, by year of transplant, 1999–2007.



* Includes both pediatric and adult recipients. Transplants 2006-2007 used to calculate 3 month and 1 year survival, 2002-2007 for 5 year survival, and 1997-2007 for 10 year survival. The COPD groups with and without A1ATD are depicted separately.

Source: 2009 OPTN/SRTR Annual Report, Table 12.14

Figure 9: Unadjusted patient survival for recipients of deceased donor lung transplants, by primary diagnosis.

years old and 65 years old and above had survival rates of 38%, 23% and 13%, respectively.

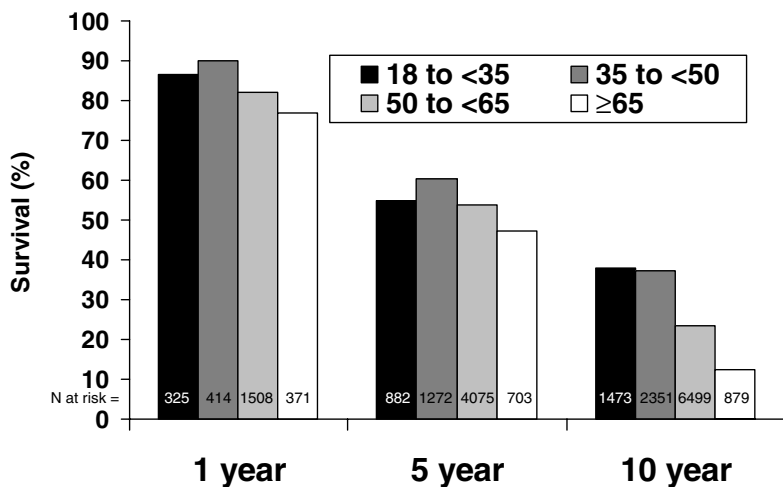
Patients who received single or bilateral lung transplants had the same 1-year unadjusted survival of 83% [Table 12.14]. By 5 years, however, patients undergoing bilateral transplantation had higher unadjusted survival compared with those undergoing single lung transplantation (57% vs. 51%; p-value < 0.001); this trend became more pronounced at 10 years (37% vs. 21%; p-value < 0.001).

Patients hospitalized in the ICU at the time of transplant had a lower unadjusted 1-year survival (57%) than hospitalized non-ICU patients (84%) and nonhospitalized patients (86%) (Figure 11) [Table 12.14]. Using the metric of deaths per thousand patient-years at risk, these recipient groups

demonstrated similar trends for the initial posttransplant year [Table 12.7]. For patients transplanted in 2007, for example, death rates were 699 deaths per thousand patient-years at risk for ICU patients, 237 deaths for hospitalized, non-ICU patients and 172 deaths for nonhospitalized patients. The survival differential between the ICU and non-ICU groups became far less pronounced at 5 and 10 years (Figure 11).

Posttransplant Survival by LAS at Transplant

By itself, the last recorded LAS prior to transplant did not clearly predict 1-year posttransplant survival in any of the primary LAS diagnostic groups (Figure 12). As suggested



*Transplants 2006-2007 used to calculate 1 year survival, 2002-2007 for 5 year survival, and 1997-2007 for 10 year survival.

Source: 2009 OPTN/SRTR Annual Report, Table 12.14

Figure 10: Unadjusted patient survival for recipients of deceased donor lung transplants, by recipient age (in years).

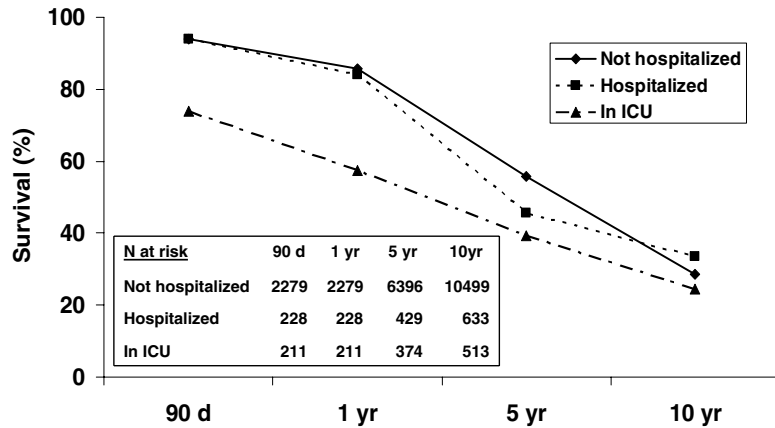


Figure 11: Unadjusted patient survival for recipients of deceased donor lung transplants, by care setting at time of transplantation.

Source: 2009 OPTN/SRTR Annual Report, Table 12.14

*Includes both pediatric and adult recipients. Transplants 2006-2007 used to calculate 90-day and 1-year survival, 2002-2007 for 5-year survival, and 1997-2007 for 10-year survival. ICU – intensive care unit.

earlier, other factors may have significantly affected post-transplant survival.

Comparison of posttransplant death rates [Table 12.7] to waiting list death rates [Table 12.3] for different patients with similar last-recorded LAS provides an estimate of the survival effects of transplantation compared with continued waiting. However, this methodology does not adjust for factors other than LAS. Such a comparison demonstrated a survival advantage (transplantation favored over continued waiting) for patients with an LAS of 50 or higher (Figure 13). Candidates on the waiting list during 2008 with a last-reported LAS of 60 or greater had the highest waiting list death rate of all LAS groups (1593 deaths per thousand patient-years at risk). Even though recipients with an LAS of 60 or greater at transplant had the

highest posttransplant death rate for patients transplanted in 2007 (330 deaths per thousand patient-years at risk), this subgroup showed the biggest reduction in death rates (1263 deaths) when compared with those on the waiting list in the corresponding LAS group. The subgroup with last-recorded LAS of 50 to less than 60 prior to transplant in 2007 had 182 deaths per thousand patient-years at risk posttransplant, whereas the corresponding LAS group on the waiting list in 2008 had 666 deaths (484 fewer deaths compared with those on the waiting list). The cohorts with an LAS of 40 to less than 50 had a posttransplant death rate of 263 per thousand patient-years at risk and a waiting list death rate of 215 (48 more deaths posttransplant compared with deaths on the waiting list per thousand patient-years at risk). A comparison of the posttransplant death rate of this LAS cohort against a similarly calculated

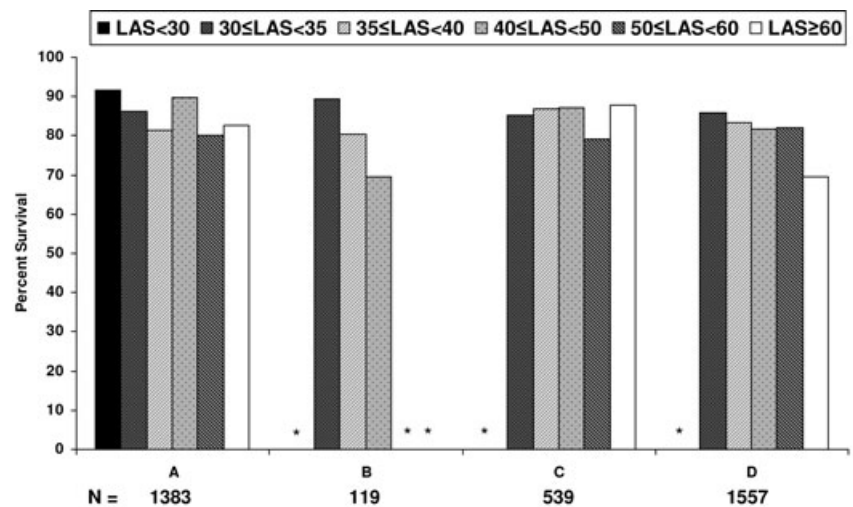
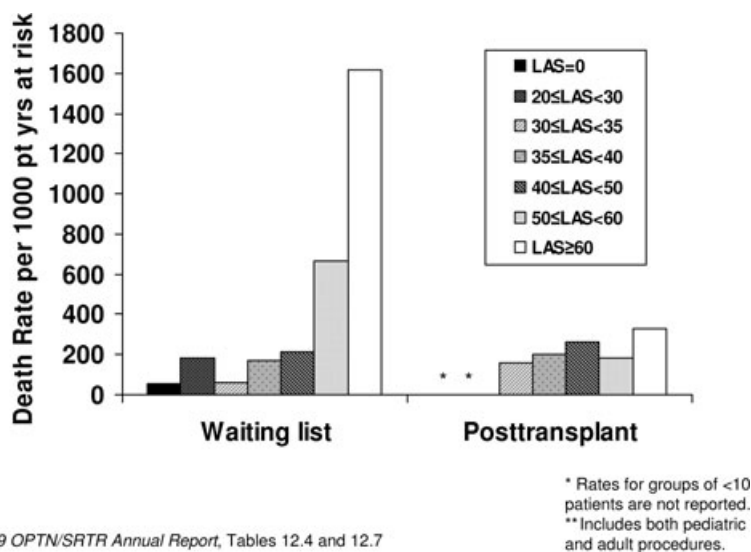


Figure 12: One-year posttransplant survival by diagnosis group and LAS group at transplant for patients who received lung transplants from May 4, 2005 to December 31, 2007.

Source: SRTR analysis, data as of May 2009.

* Rates for groups of <10 patients are not reported.
** Includes patients aged 12+.



Source: 2009 OPTN/SRTR Annual Report, Tables 12.4 and 12.7

Figure 13: Death rates for lung patients on the waiting list in 2008 and lung transplant recipients in 2007, stratified by LAS.

waiting list death rate for 2007 (not 2008) showed 103 fewer deaths per thousand patient-years at risk for lung transplantation compared with continued waiting. However, for this LAS cohort, the posttransplant death rate substantially increased from that observed in patients transplanted in 2005 and 2006 (approximately 180–190 deaths per thousand patient-years at risk in those years). Patient cohorts with LAS of 30 to less than 35, and 35 to less than 40, had low posttransplant death rates in 2007 (157 and 199 deaths per thousand patient-years at risk, respectively). However, similar LAS cohorts of patients on the waiting list in 2008 also had low death rates (59 and 172 deaths per thousand patient-years at risk for those with an LAS of 30 to less than 35, and 35 to less than 40, respectively).

Observed versus expected days lived during first year after lung transplant based on LAS modeling

Because the LAS is based in part on each patient's estimated number of days lived during the first year after transplant, an important integrity check involves the comparison of LAS projections against prospectively observed days lived among patients transplanted since LAS implementation. Since transplanted patients are removed from the waiting list, we cannot measure observed days lived without a transplant in these same patients. Thus, we cannot perform a similar observed versus expected comparison for waiting list survival.

On average, the LAS posttransplant model predicted 317 days of life in the first posttransplant year for those receiving transplants from May 4, 2005 to December 31, 2007 (*SRTR special analysis, June 2009*). In actuality, patients lived an average of 324 days during their first posttransplant year; that is an average underestimate by the LAS of 7 days. Although the observed and the expected num-

ber of days lived had similar average values for the group, the LAS did not consistently make accurate predictions for each transplanted recipient. Ten percent of transplanted patients had an overestimate of their first year of survival by 180 days or more and 10% had an underestimate of their survival of 60 days or more.

Various age subgroups had small differences in their average observed versus expected days lived in the first year posttransplant. On average, the LAS underestimated survival by 24 days for those aged 12–17 years, and it overestimated survival by 4 days for those aged 65 years or older. Other age groups had average underestimates of survival in the 7–10 day range. For recipients aged 12–17, 90% of predictions showed expected survival within 3 months of observed survival, and expected survival typically underestimated the observed survival. Older age groups showed much greater variability in observed versus expected survival. For recipients aged 65 years and older, the middle 80% of differences showed overestimates in days lived as high as 222 days and underestimates as much as 61 days.

LAS diagnostic subgroups showed small average underestimates (expected value less than observed value) by LAS for days lived during the first year posttransplant; 10 days for Groups B and C, 8 days for Group A and 5 days for Group D. In terms of variability in prediction accuracy, LAS had the lowest variability for Group C patients and had the highest variability for Group B patients. For Group C, 10% of transplanted patients had an overestimate of their first year of survival by 96 days or more and 10% of patients had an underestimate of 54 days or more. For Group B, 10% of patients had an overestimate of their first year of survival by 257 days or more and 10% had an underestimate of 81 days or more. Groups A and D had variability in observed minus expected days lived similar to that seen in the overall population of recipients.

Retransplantation

Parallel with the overall decline in active candidates on the waiting list since LAS introduction, the number of candidates listed for retransplantation also declined, falling from a range of 56–67 patients at the end of each year prior to 2005 to 45, 34 and 35 candidates for 2006, 2007 and 2008, respectively [Table 12.1a]. Retransplant candidates accounted for 3%–4% of the total waiting list population during 2006–2008, compared with 2%–3% in the pre-LAS era of 1999–2004.

Though death rates on the waiting list declined for all major disease groups awaiting primary transplantation since implementation of the LAS system, the opposite trend has occurred for patients awaiting retransplantation. The death rate for those awaiting retransplantation increased earlier in the decade, stabilized in the year and a half prior to and after LAS implementation, and then increased again in the next 2 years. The roughly 370 deaths per one thousand patient-years at risk recorded in 2007 and 2008 for retransplantation candidates represented a 68%–200% increase compared with rates from 1999 to 2004 [Table 12.3].

The indications for retransplantation have remained relatively consistent over the past decade (*SRTR special analysis, June 2009*). Primary lung transplant recipients have bronchiolitis obliterans syndrome (BOS) and primary graft failure as the two most common diagnoses leading to relisting. In 2008, 61% of primary recipients listed for retransplantation had BOS as the relisting diagnosis while 15% had primary graft failure as the diagnosis. Diagnostic misclassification inherent in the data collection system likely resulted in underestimation of the number of patients in these categories, since numerous patients had their diagnosis classified under alternative nonspecific diagnostic categories such as ‘graft failure—other’ and ‘graft failure—obstructive’ or under the initial primary diagnosis (e.g. COPD/emphysema). Patients listed for retransplantation in 2006, 2007 and 2008 had a mean LAS of 47, 45 and 52 (median 39, 40 and 42), respectively. These scores occurred within the upper quintile for all patients on the active waiting list during those years [Table 12.1a].

The interval from the primary transplant to retransplantation has remained relatively constant over the past decade, with a mean of 1478 (median 1154) days during the pre-LAS era of 1999–2004 and 1433 (median 1038) days for the LAS era of 2005–2008 (*SRTR special analysis, June 2009*). In contrast, waiting times from relisting to retransplantation have fallen considerably since implementation of the LAS system. The mean waiting time of 336 (median 146) days for the pre-LAS era of January 1, 2003 to May 3, 2005 declined to 190 (median 45) days for the LAS era of May 4, 2005 to December 31, 2007 (*SRTR special analysis, June 2009*).

A significant and sustained increase in the number of patients undergoing retransplantation occurred after the introduction of the LAS system. From 2006 to 2008, 211 patients underwent retransplantation (99 single, 112 bilateral), compared with only 94 recipients for the period from 2002 to 2004 (46 single, 48 bilateral) [Table 12.4]. The annual number of retransplantation recipients peaked in 2007 at 84, declining slightly in 2008 to 73 recipients. Retransplantation accounted for 5.7% of all recipients in 2007 and 4.9% in 2008, compared with 1.9%–3.3% of transplant volume in the pre-LAS years of 1999–2004.

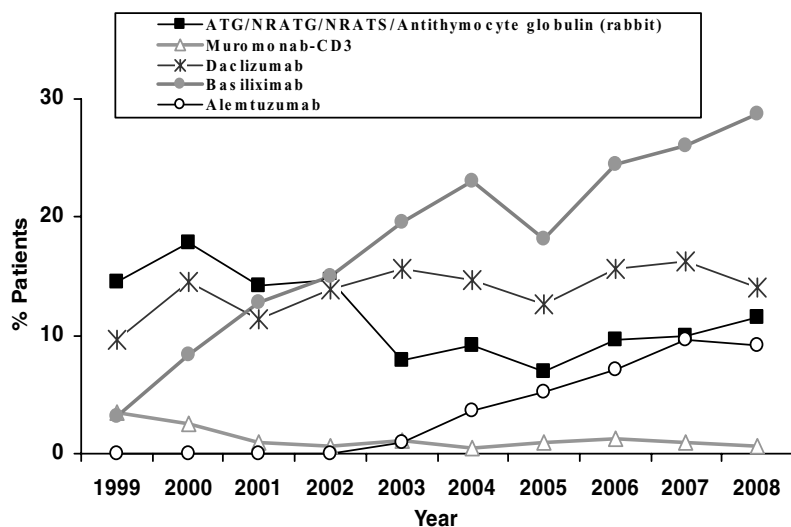
Unadjusted 1-year survival rates associated with retransplantation improved slightly over the past decade; increasing from 63% for the 1999–2004 era to 70% for the 2005–2007 era (*SRTR special analysis, June 2009*). Nonetheless, the 1-year unadjusted survival rate following retransplantation remained inferior to the 83% rate achieved with primary transplantation in the LAS era [Table 12.14]. Similarly, between 2005 and 2007, death rates for primary transplant recipients ranged from 174.7 to 198.5 deaths per thousand patient-years at risk [Table 12.7] compared with 231.5–551.4 deaths per thousand patient-years at risk for retransplant recipients [Table 12.7]. Patients with different indications for retransplantation had different survival rates. Lung recipients retransplanted for BOS, by definition diagnosed more than 3 months after the primary transplant, had superior unadjusted 1-year posttransplant survival compared with patients undergoing early and urgent retransplantation (within 90 days of initial transplantation) for primary graft failure: 71% (95% CI, 61.1%–78.1%) for 112 patients retransplanted for BOS between May 2005 and December 2007 compared with 54% (95% CI, 24.8%–76.0%) for 13 patients urgently retransplanted for primary graft failure during that time (*SRTR special analysis, June 2009*).

Previous lung transplantation does not specifically affect LAS. However, diagnoses commonly used for retransplant candidates (e.g. primary graft failure, BOS) place these patients in LAS diagnostic Group D. The LAS overestimated days lived in the year after retransplantation by an average of 6 days. Ten percent of retransplantation recipients had projections overestimated by 231 days or more and 10% had projections underestimated by 83 days or more (*SRTR special analysis, June 2009*).

Recipient Immunosuppression

Induction immunosuppression for lung transplantation

The use and types of an induction regimen for lung transplant recipients have evolved over the last decade (Figure 14) [Table 12.6a]. Induction therapy use more than doubled from 31% in 1999 to 63% in 2008. Polyclonal antilymphocyte antibody induction therapy declined over



Source: 2009 OPTN/SRTR Annual Report, Table 12.6a.

ATG – antithymocyte globulin (equine),
NRATG/NRATS – Nashville rabbit
antithymocyte globulin/serum

Figure 14: Trends in induction immunosuppression for lung transplantation, 1999–2008.

the past decade. Use of a non-rabbit antithymocyte globulin (i.e. equine ATG/NRATG/NRATS), the most commonly prescribed type of perioperative induction agent in 1999, trended downward from 13% in 1999 to 7% in 2008. Rabbit derived antithymocyte globulin (i.e. thymoglobulin) has shown fluctuation and a slight downward trend from a high of 8% in 2002 to 5% in 2008. Overall, monoclonal antilymphocyte antibody induction therapy has increased over the past decade. Use of the interleukin-2 (IL-2) receptor antagonists, basiliximab or daclizumab, has almost quadrupled over the past decade to account for 43% of all induction therapy used in 2008. Basiliximab became the most commonly used induction agent in lung transplantation in 2002. Alemtuzumab had a marked increase in use in the last half of the past decade, increasing tenfold from 0.9% of recipients in 2003 to 9% in 2008. Muromonab-CD3 (i.e. OK-T3) had limited use over the past decade (0.7% in 2008), and the manufacturer discontinued its production in 2009.

Maintenance immunosuppression before hospital discharge, after lung transplantation

The use of the two main calcineurin inhibitors before the first hospitalization discharge showed divergent trends over the past decade. The use of cyclosporine (CyA) for maintenance therapy decreased steadily from 67% in 1999 to 8% in 2008. Conversely, use of tacrolimus (Tac) increased over the same period, from 30% in 1999 to 89% in 2008 (Figure 15) [Table 12.6e]. Use of the two main classes of antimetabolite cell cycle inhibitors before lung transplant hospitalization discharge also showed divergent trends over the past decade. Azathioprine (Aza) use declined steadily from 64% in 1999 to 28% in 2008, while mycophenolate agent (mycophenolate mofetil [MMF] and, much less commonly, mycophenolate sodium [MPA]) administration increased from 28% in 1999 to 63% in 2008.

The use of sirolimus, a mammalian target of rapamycin (MTOR) kinase inhibitor, peaked at 4% in 2001, and then decreased to only 0.4% in 2008. The vast majority of patients (98% in 2008) continued to receive glucocorticoids prior to discharge from the hospital.

At the time of the first hospital discharge after transplantation, 58% of recipients received Tac/MMF or Tac/MPA (the fastest growing regimen over the past decade), and 23% received Tac/Aza [Table 12.6d]. CyA/Aza, the most common regimen from the 1980s to the early 2000s, accounted for only 4% of regimens in 2008. CyA/MMF, which peaked at 18% in 2001, accounted for only 3%.

Maintenance regimen change and discontinuation for lung transplantation

Almost all patients used glucocorticoids throughout follow-up after transplantation. Regarding use of immunosuppressive agents other than glucocorticoids over time (Figure 16) [Table 12.6h], the greatest changes generally occurred in the first year after transplantation. For recipients in the 2006 cohort that used Tac/MMF or Tac/MPA as the original discharge regimen, 61% of them still used it at 3 years after transplantation (the highest for all of the regimens). For recipients initially treated with the Tac/Aza regimen, only 28% continued its use. For the CyA/MMF or CyA/MPA group, only 18% continued its use. The highest rate of regimen attrition occurred in patients initially treated with CyA/Aza, of which only 16% continued its use.

Acute lung transplant rejection treatment

Over the past decade, antirejection therapy use fluctuated during the first posttransplant year. In patients transplanted in 2007, treatment for acute rejection in the first posttransplant year in 380 patients out of a total cohort of 1471

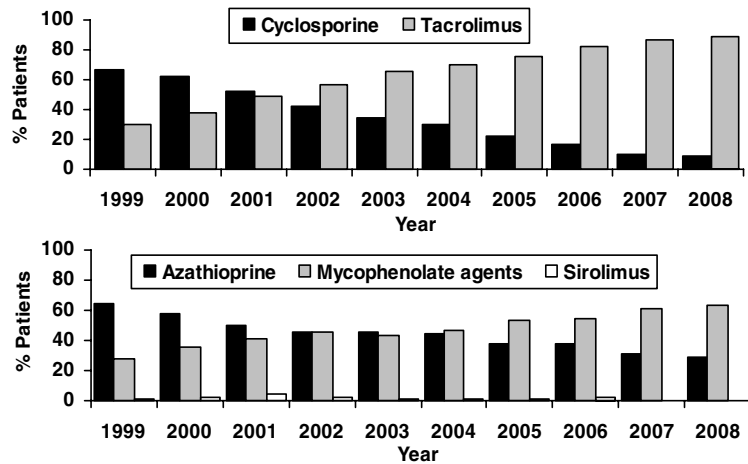


Figure 15: Trends in maintenance immunosuppression during lung transplantation hospitalization, 1999–2008.

Source: 2009 OPTN/SRTR Annual Report, Table 12.6e.

*Includes both pediatric and adult procedures. Mycophenolate agents includes mycophenolate mofetil and mycophenolate sodium

(26%) decreased compared with the 10-year high of 46% in 2001 [Table 12.6i]. Of those in the 2007 transplant cohort who received treatment, the great majority of patients (93%) received acute augmented glucocorticoid therapy. Of those treated, only 14% received an antilymphocyte antibody preparation, and most received a polyclonal antilymphocyte antibody; 6% received rabbit antithymocyte globulin and 5% received non-rabbit antithymocyte globulin (Figure 17) [Table 12.6j].

Donor Characteristics

Deceased lung donors have shown a relatively stable age distribution over the past decade [Table 2.7]. Donors in the 18–34 year-old cohort have provided the most lungs (46% in 2008), while the second most common donors came from the 35–49 year-old cohort (25% in 2008). De-

ceased lung donors have also had relatively stable ethnicity, race and sex distribution, with the 2008 cohort 62% white, 19% African American and 16% Hispanic. Male donors made up 61% of the 2008 cohort. Donor blood type distribution remained constant over the past decade, with 52% type O, 35% type A, 11% type B and 2% type AB. In 2008, donors most commonly died from head trauma (48%), cerebrovascular injury (36%) or anoxia (12%), while the specific mechanisms that led to donor death most commonly consisted of intracranial hemorrhage/stroke (38%), blunt injury (26%) and gunshot/stab wounds (20%).

Of all deceased donors, donation after brain death (DBD) donors provided the most lungs for recipients, while donation after cardiac death (DCD) donors have provided few. Kidney and liver transplantation have seen much higher rates of DCD compared with lung transplantation.

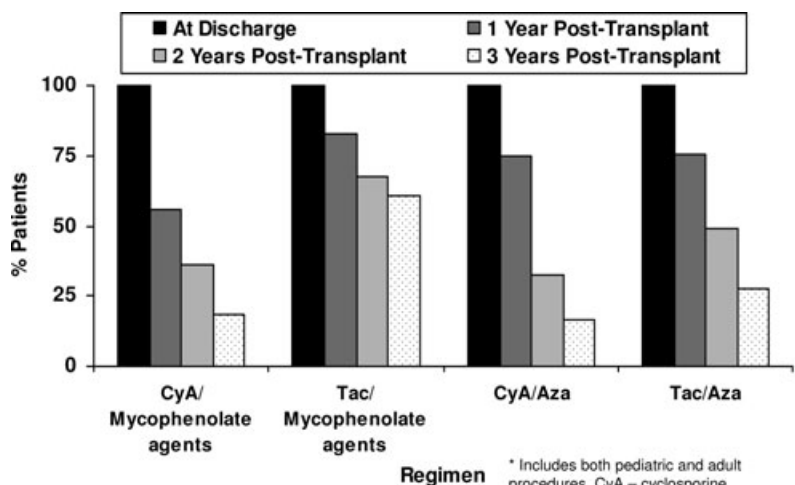
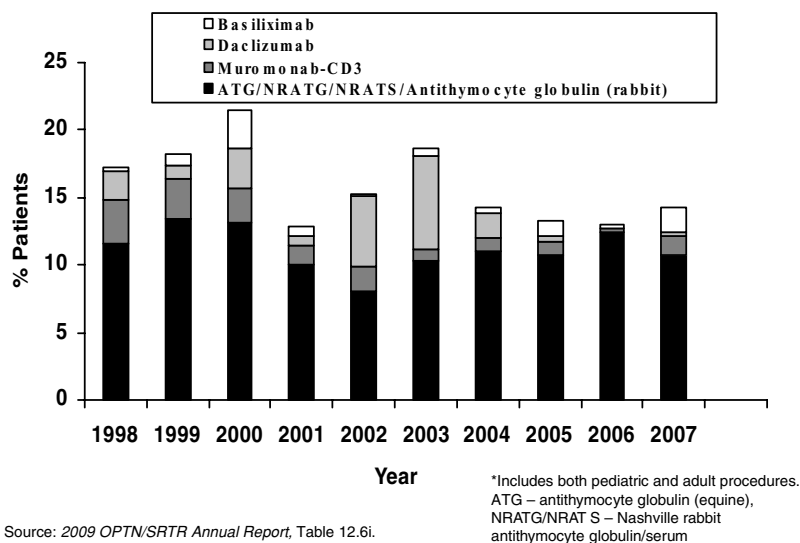


Figure 16: Percentage of lung transplant recipients continuing initial maintenance immunosuppression at 1, 2 and 3 years posttransplant, for four most common regimens 2006.

Source: 2009 OPTN/SRTR Annual Report, Table 12.6h.

* Includes both pediatric and adult procedures. CyA – cyclosporine, mycophenolate agents includes mycophenolate mofetil and mycophenolate sodium, Tac – tacrolimus, Aza - azathioprine



Source: 2009 OPTN/SRTR Annual Report, Table 12.6i.

Figure 17: Antilymphocyte antibody therapy for rejection episodes in first year following lung transplantation, 1998–2007.

Centers first reported use of lungs from DCD donors in 2001. Though the highest number of DCD lung transplants (19 total cases) occurred in 2008, it only represented 1% of the total number of recipients of deceased donor lung transplants that year [Table 2.7].

Lobar lung transplantation from living donors decreased steadily over the past decade. The number of living donors peaked at 58 (representing 7% of all lung donors) in 1999, and decreased to six cases in 2007 and zero cases in 2008 [Table 2.11]. The greatest decline occurred between the 2004 and 2005 cohorts.

Some interesting and important trends have occurred in deceased donor organ use over the past 10 years [Table 2.18]. The total number of deceased donor lungs used for transplantation on a yearly basis continued a decade-long increase to a high of 2534 lungs from a high of 1388 donors in 2008. This represents a 91% increase in transplanted lungs and a 79% increase in total lung donors since 1999. For the metric of organs transplanted per donor (OTPD), the lung-specific OTPD counts each lung separately, whereas the percentage donating a lung(s) methodology counts single or double lung donation only once for each donor. The lung-specific OTPD peak of 0.32 in 2008 represented a 39% increase compared with 1999. Specifically looking at DBD, the OTPD for lungs in 2008 was 0.35 compared with 0.23 in 1999 (a 52% increase). Not surprisingly, in view of the limited experience and relatively slow adoption of DCD lungs by the lung transplant community, the lung OTPD for DCD donors was only 0.04 (representing a total of only 34 transplanted lungs in 2008). For all deceased donors of any organ, the percentage donating a lung(s) increased from 13% in 1999 to a decade high of 17% in 2008. The largest 1-year interval increase in the number of lung donors and lung donor conversion rates occurred in the 2004–2005 interval (a 21% lung donor increase and a 13% conversion rate increase).

The SRTR recently conducted new analyses (*SRTR special analysis, June 2009*) to assess the distribution of donor lungs to the respective recipient age groups in the pre-LAS and LAS eras (e.g. 1 year before and all years after LAS implementation). Since advanced age accompanies the LAS diagnostic group with highest average LAS (i.e. Group D), and LAS prioritizes lung transplantation, the distribution of donor lungs has shifted from younger to older recipients. For lungs from donors aged 18–34, only 6% went to recipients aged 65+ years before the implementation of the LAS system. However, in the 3.5 years since implementation of the LAS system, a shift in the donor–recipient age distribution occurred. In the last half of 2008, 21% of lungs from donors aged 18 to less than 35 years went to recipients aged 65 years or older, compared with 6% in the recent pre-LAS era (a 250% increase). Similarly, 19% of lungs from donors aged 35 to less than 50 years went to recipients aged 65 years or older in the last half of 2008, compared with 6% in the recent pre-LAS era (a 217% increase).

Pediatric Lung Transplantation

Trends in pediatric lung transplantation during the past decade, particularly since LAS inception, continued to reflect limited growth. Pediatric lung allocation had important interactions with adult lung allocation based on issues, such as LAS allocation for older pediatric candidates, preferential allocation of pediatric lungs to pediatric candidates and size matching.

Indications for pediatric lung transplant

In 2008, cystic fibrosis, with its associated bronchiectasis and obstructive lung disease, remained the most common indication for lung transplantation in children (age less than 18 years) and accounted for nearly 70% of pediatric lung transplants (*SRTR special analysis, June 2009*). More than

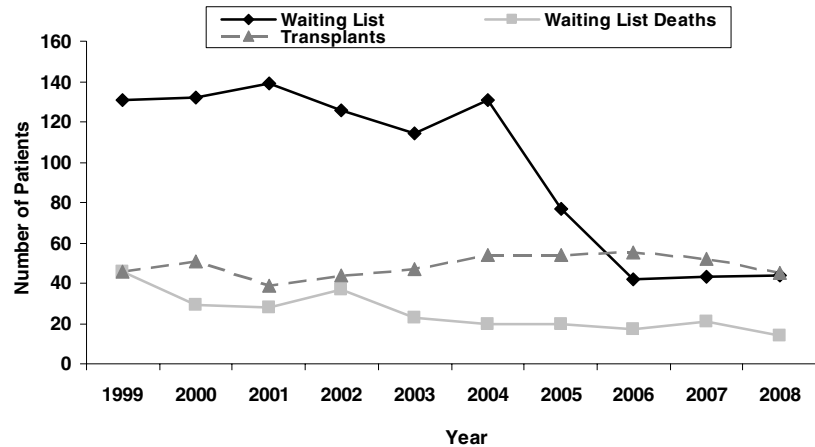


Figure 18: Pediatric patients listed for lung transplant, deaths on the waiting list and transplanted, 1999–2008.

Source: 2009 OPTN/SRTR Annual Report, Tables 12.1a, 12.3 - 12.4.

90% of pediatric lung transplants for cystic fibrosis occurred in adolescents (age 12 to less than 18 years) in 2008. Transplantation for cystic fibrosis rarely occurred before age 6. The percentage of pediatric lung transplants for pulmonary hypertension, either primary or associated with congenital heart disease, decreased steadily through the decade and accounted for less than 10% of transplants in 2008. Recently, pulmonary parenchymal disease, mainly related to surfactant abnormalities, became the most common (80%) indication for lung transplantation for children younger than 6.

Pediatric waiting list and transplant activity

The number of pediatric candidates active on the lung transplant waiting list at the end of 2008 remained essentially unchanged since LAS inception. However, this represented a significant decline from a pre-LAS average of 130 (Figure 18) [Table 12.1a]. From 2007 to 2008, the number of adolescents active on the lung transplant waiting list doubled from 15 to 31, while the number of pediatric candidates aged 0 to less than 12 years dropped from 28 in 2007 to 13 in 2008. The 45 to 54 deceased donor pediatric lung transplants performed annually did not appreciably change over the past half decade [Table 12.4]. Centers did not report any pediatric living donor lung transplants in 2008 [Table 2.11].

Only 14 deaths occurred on the pediatric lung transplant waiting list (active and inactive) during 2008, compared with 21 in 2007 (Figure 18) [Table 12.3]. A reduction in overall adolescent deaths accounted for most of this decrease; an annual average of 13 adolescent candidate deaths occurred in 2005–2007, while only four adolescent candidate deaths occurred in 2008. During 2008, the 1 to less than 6 year-old age group and the 6 to less than 12 year-old age group had waiting list death rates (candidate deaths per one thousand patient-years at risk) of 416.2 and 151.1, respectively, well above the average rates observed during the past 5 years and the highest rates observed since LAS inception. In contrast, adolescents on the active

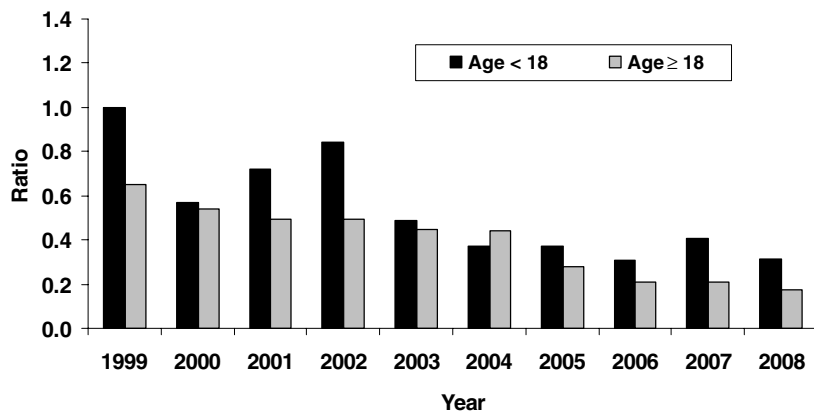
waiting list had a death rate of only 53.5, the lowest during the decade and the lowest for any age group in 2008. During the last 5 years, candidates less than a year old had only one waiting list death reported.

The ratio of the percentage of patients on the waiting list (active and inactive) who died to the percentage of patients who received a transplant (i.e. waiting list death to transplant ratio) provides another metric for assessing lung allocation effectiveness. The ratio decreased for both pediatric and adult lung transplant candidates over the past decade. Since LAS inception, the ratio remained relatively stable for children while it continued to decline for adults (Figure 19).

Adult wait-listing and transplantation numbers have increasingly overshadowed those of children. In 1999, children represented 5% of the lung transplant active waiting list [Table 12.1a] and 4% of the transplants [Table 12.4]; in 2008, children made up 4% of the active waiting list [Table 12.1a] and 3% of the transplants [Table 12.4]. Of new pediatric registrants on the active lung waiting list, only adolescents have median time to transplant data available for each year since LAS inception. The TT metric for adolescent candidates declined steadily since implementation of the LAS, from 521 days in 2005 to 117 days in 2008. Adolescent pediatric candidates had a median TT shorter than adult age subgroups, except for those 65 years and older [Table 12.2].

Pediatric lung allocation

OPTN policy adopted in conjunction with implementation of the LAS directs lungs from pediatric donors first to pediatric candidates ages 0 to less than 12 years and then to those 12 to less than 18 years. This policy led to a modest increase in the percentage of age 0 to less than 12 years old donor lungs transplanted into children; from 70% in the year preceding LAS implementation to between 80% and 89% in the first 3 years after. Within the 0 to less than 12 years group, the relatively small number of donors or the



Source: 2009 OPTN/SRTR Annual Report, Tables 12.3-12.4.

* Includes active and inactive patients

Figure 19: Ratio of lung waiting list deaths to transplants, pediatric and adult, 1999–2008.

decrease in the number of actively listed children may have caused an anomalous drop (to 50% in the most recent [partial year] cohort) in same age group donor–recipient matching. The percentage of lungs from adolescent donors transplanted into children (predominantly adolescents) fluctuated and had a modest increase since LAS implementation, from 8% the year before implementation to as high as 14% in the most recent cohort (*SRTR special analysis, June 2009*).

Pediatric lung transplantation outcomes

In the 2006 and 2007 cohorts, pediatric deceased donor lung transplant recipients had adjusted 1-year survival (83%–97%) comparable to adult lung transplant recipients. Of the four pediatric age groups (<1 year, 1 year to <6 years, 6 years to <12 years, and 12 years to <18 years), children aged 6 to less than 12 years had the highest 1-year adjusted survival (97%) and adolescents had the next highest (95%). In a cohort of mostly pre-LAS recipients, children 6 to less than 12 years of age still had the highest adjusted 5-year survival (66%) out of all pediatric recipients. In contrast, adolescent recipients from a similar era had the worst 5-year survival (38%) of any pediatric or adult age group [*Table 12.12*].

Heart–Lung Transplantation

The 91 heart–lung transplant candidates (active and inactive) on the waiting list at the end of 2008 had a broad spectrum of baseline primary cardiopulmonary disorders that included the Eisenmenger syndrome spectrum of diseases (55%) and IPAH (15%). Mixed diseases, such as combinations of coronary artery disease and IPF, or valvular heart disease and COPD, occurred in 14% of candidates. Patients with sarcoidosis represented 4% of candidates and combined organ congenital diseases represented 9% [*Tables 13.1a and 13.1b, SRTR Special Analysis*].

At the end of 2008, the heart–lung transplant active waiting list consisted of only 33 (36%) of the 91 heart–lung

candidates [*Table 13.1a*]. Ten of the 33 active candidates (30%) and 48 of the 58 inactive candidates (83%) had been on the list for more than 2 years [*Tables 13.1a and 13.1b*].

The death rate for candidates (active and inactive) on the heart–lung transplant waiting list fluctuated widely over the past decade, although the rate showed a gradual decline [*Table 13.3*]. Candidates on the heart–lung transplant waiting list during 2008 had a death rate (155 per thousand patient-years at risk; 95% CI 112.6–143.4) lower than that of patients on the heart-only transplant waiting list (170 per thousand patient-years; 95% CI 154.0–185.6) and higher than that of patients on the lung-only transplant waiting list (128 per thousand patient-years; 95% CI 76.5–233.1) [*Tables 11.3, 12.3, and 13.3*].

The number of heart–lung transplant recipients declined from 51 in 1999 to 27 in 2008 [*Table 13.4*]. Over the past 5 years, only two transplant centers performed an average of two or more heart–lung transplants per year [*Table 13.17*]. Recipients of heart–lung transplants rarely underwent heart–lung retransplantation. The 58 heart–lung transplant recipients in 2007–2008 consisted of nine pediatric patients (16%), 27 hospitalized patients (47%) and 17 patients using some form of mechanical, ventilated or organ-perfusion support (29%) [*Table 13.4*]. Of the 58 recipients of heart–lung transplants in 2007–2008, 33% had a diagnosis of Eisenmenger syndrome, 24% had IPAH, 9% had sarcoidosis and 7% had combined-organ congenital diseases. Patients with primary cardiac lesions with secondary pulmonary hypertension represented 7% of cases. Mixed diseases, such as combinations of valvular heart disease and IPF or dilated cardiomyopathy and cystic fibrosis represented 12% of candidates. Patients with dual organ consequences of cancer-related therapy accounted for 7% of cases (*SRTR special analysis, June 2009*).

Recipients of heart–lung transplantation in the past decade had adjusted posttransplant survival rates of 86% at 3 months, 81% at 1 year, 45% at 5 years and 29% at 10 years

[Table 13.12]. Though these rates more closely approximated the survival rates of lung-only transplant recipients than heart-only recipients, heart–lung transplant recipients had lower survival than patients undergoing other types of solid organ transplantation [Tables 5.12c, 6.12, 7.12, 8.12, 9.12, 10.12, 11.12, 12.12 and 13.12].

Discussion

The number of adult lung transplants significantly increased over the past decade, while the number of pediatric lung transplants and heart–lung transplants remained low. Significant changes in listing practices, characteristics of recipients transplanted and treatment approaches have occurred in the LAS era compared with before. Associated with implementation of the LAS system, the number of active waiting list patients, the waiting times for lung transplantation and the death rates on the waiting list decreased. One-year survival after lung transplantation did not significantly change in the recent pre-LAS and the LAS eras. The LAS system has produced intended and unintended consequences, and the long-term effects remain unknown.

Though the LAS system had overall positive effects in comparison to the pre-LAS system, it demonstrated differential effects upon common diagnostic subgroups that included COPD (non-A1ATD and A1ATD), cystic fibrosis, IPF and IPAH. Waiting time for transplantation decreased for all major diagnostic subgroups in conjunction with a reduced number of patients on the waiting list and a presumed decrease in the practice of early listing. The increase in transplant priority for patients with IPF and the decrease for patients with COPD led to increased transplants in patients with IPF and decreased transplants in patients with COPD. Patients with IPAH on the lung transplant waiting list, on average, had a lower priority than patients with cystic fibrosis or IPF. Some small single center studies (9,10), a multi-center study (11), and some studies of SRTR data (12–14) supported our findings that the distribution of diagnoses of patients undergoing lung transplant changed in association with implementation of the LAS system. One study of SRTR data did not show statistically significant changes in the distribution of diagnoses, but the trends remained apparent, especially for an increase in the proportion of patients undergoing transplant for IPF and a decrease in those undergoing transplant for COPD (15).

This SRTR article showed that the number and proportion of patients with IPAH wait-listed and undergoing transplant remains dwarfed by the other primary lung diagnoses. Compared with other LAS diagnostic groups, Group B (including the IPAH patients) had the highest variability in observed versus predicted posttransplant survival. A recent investigator-initiated study of data from the SRTR for adults wait-listed for lung transplantation between 2002 and 2008

suggested that patients with IPAH had a lower likelihood of undergoing transplant compared with those with IPF; a greater risk of death on the waiting list than patients with COPD; and a posttransplant mortality not significantly different from patients with the other primary lung diseases (14). Though a guideline for modifying the LAS for patients with IPAH exists, refinements of the system for distributing donor lungs will require additional data collection and analyses. However, the ability to generate reliable and accurate models for patients with IPAH remains limited by the small number of patients.

Another study that only included 1 year of post-LAS data found that posttransplant hospital length of stay shortened after implementation of LAS (12), while a multicenter study found that ICU length of stay increased (11). The multicenter study also found that rates of primary graft dysfunction (PGD) increased after implementation of the LAS system (11), while another single center study did not see such an increase (10).

Since the LAS system facilitated the ability to perform expedited transplantation, the number of critically ill patients transplanted increased. These patients typically had high LAS because of high supplemental oxygen requirements and/or need for mechanical ventilation; they, therefore, had preferential access to donor lungs. However, critical illness may have resulted in profound deconditioning, malnutrition or other significant complications that increased the risk of poor early outcomes after transplant. Accordingly, patients who came from the ICU had lower short-term posttransplant survival in comparison with less acutely ill populations. Nonetheless, waiting list death rates compared with posttransplant death rates for patients with the highest LAS suggested that this group of patients had the largest short-term transplant benefit.

Advanced age became less of a barrier to transplantation over the past decade, and almost 20% of recipients in 2008 were at least 65 years old. Such recipients had a higher first-year posttransplant mortality than any other age group, and longer-term follow-up also showed a higher mortality rate.

The annual number of patients undergoing retransplantation roughly doubled since the introduction of the LAS system. Both acute (e.g. PGD) and chronic (e.g., BOS) forms of graft failure placed retransplant candidates into LAS diagnostic Group D. Compared with the pre-LAS era in which long waiting times often precluded retransplantation, retransplant candidates in the LAS era often had short waiting times because of very high LAS. In the pre-LAS and LAS eras, patient survival after retransplantation remained lower than the survival of patients after primary lung transplantation, and retransplantation for PGD had even lower survival rates than retransplantation for BOS. The increased use of retransplantation in the setting of ongoing organ shortages raises ethical

issues. The Thoracic Committee may assess the appropriateness of adding factors to the posttransplant portion of the LAS model to correct for the worse outcomes associated with retransplantation compared with primary transplantation, once they obtain sufficient data. In addition, the committee could consider separately grouping retransplant candidates from other Group D candidates. However, similar to the scenario with IPAH candidates, the ability to generate reliable and accurate models for retransplant candidates remains limited by the small number of patients.

Overall, patients undergoing lung transplantation experienced modest improvements in both short- and long-term survival over the past decade, though barely half of recipients reached the 5-year milestone and less than a third achieved 10-year survival. Multiple studies corroborate this article's finding that overall posttransplant mortality did not increase after implementation of LAS (10–14). Lung transplantation has consistently demonstrated inferior intermediate and long-term survival compared with renal, heart and liver transplantation. Pre-LAS and LAS data suggest that the increasing number of critically ill, elderly, and previously transplanted candidates undergoing lung transplantation may drive down the overall survival of recipients. Optimizing outcomes in these higher risk groups may require more careful selection of candidates (16–17).

The limited growth in pediatric lung transplantation compared with that seen in adults during the LAS era illustrates one of the most notable pediatric lung transplant trends identified in this report. Historically, children underwent lung transplantation primarily for cystic fibrosis-related lung disease. However, children with cystic fibrosis have had a significantly increased median survival over the decade. The upward shift of the average age at transplant for children with cystic fibrosis provides the most likely explanation for a lack of growth in transplantation for children.

Divergent trends in waiting list outcomes occurred in children and adolescents in the LAS era. In contrast to pediatric candidates less than 12 years of age (donor lung allocation prioritized by time on the waiting list), adolescent candidates (donor lung allocation prioritized by LAS) had a reduction in waiting list mortality. Compared with younger candidates, adolescents also had a shorter waiting time to transplant, likely because of a combination of reduction in active candidates (i.e. adolescents are no longer listed solely to gain time on the waiting list) and improved access to transplant as a result of the LAS system. In spite of excellent 1-year survival, long-term outcomes in adolescents remained poor in comparison with other age groups, and the reasons for this disparity remain unclear.

The ratio of the percentage of patients on the waiting list who died to the percentage who underwent transplant did not decrease in children after implementation of the LAS

system. However, this metric for assessing lung allocation effectiveness decreased in adults. These trends imply that the current LAS system may have greater effectiveness in adults than children. Recently, the OPTN Board of Directors approved modifications of the lung allocation policy to create a simple status system and provide broader geographic sharing of lungs from donors aged 0 to less than 12 years to all children (18). Implementation of this policy should improve access to transplantation and lead to decreased waiting time and death rates on the waiting list for young children.

The Thoracic Committee originally intended that the donor lung allocation algorithm and model (i.e. LAS) remain a work in progress, and it planned to update the model based on prospective data collection. After originally creating the LAS model based on data from almost a decade ago, the SRTR and the OPTN Thoracic Committee have begun addressing several topics related to updating the LAS based on more recent data. Because the LAS moved patients with higher waiting list mortality from the candidate pool to the lung transplant recipient pool, the projections of unobserved waiting list deaths based on data from patients remaining on the waiting list has raised some statistical modeling challenges. New models based on an LAS cohort address this issue by placing higher weight on follow-up information from nontransplanted candidates who have characteristics similar to patients who have gone on to receive a transplant (19). The committee also expected that the algorithm would change risk factors and adjust hazard ratios or variable weights when appropriate. The SRTR and the Thoracic Committee continue to explore alternative ways to characterize risk based on existing LAS variables. For example, during initial LAS development, the model did not have serial changes in predictor data available. Based on more recently available serial change data, the first substantive change in the LAS consisted of the inclusion of PCO₂ and PCO₂ change data in the model. Recent analyses showed that the addition of bilirubin and bilirubin change variables to the model improved its predictive ability. However, questions exist about appropriate funding choices for programming new policy; the LAS model has not yet incorporated the bilirubin variables.

Although the need for organs continues to outstrip demand, donor lung transplant volume significantly increased in the early portion of the past decade and then stabilized more recently. The decade's largest 1-year interval increase in the number of lung donors and lung donor conversion rates occurred in 2004–2005, around the time of LAS system implementation. The increase in lung transplant volume occurred despite preferential use of bilateral transplantation, a trend that had the potential to rapidly consume the limited donor pool. Multiple events contributed to the increase in the OTPD, and lungs had the greatest increase of any organ in the last half of this decade. Though the improved efficiency of lung placement at a lower position on the match run (i.e. fewer phone calls needed to

place the organ and less time elapsed) with the LAS system may have increased the OTPD, at least three other factors likely played an equal or greater role: (1) the Department of Health and Human Services sponsored Organ Donation Breakthrough Collaborative (first initiated in 2003) increased donor identification and consent rates (20–21); (2) Organ Procurement Organizations (OPOs) standardized and improved the management of potential donors; and (3) transplant centers increasingly use expanded criteria donors (ECD).

The quality of this report depends on the quality of the data in the SRTR. The SRTR database contains robust information that covers a broad range of areas. However, inherent limitations in prospective registries exist. Misclassification of diagnoses occurs based on the limited clinical information available, data entry errors, and the requirements of the classification system. Long-term data do not exist yet for the LAS system. Small sample sizes for uncommon conditions limit the ability to do some subgroup analyses. Though the SRTR has relatively high-quality survival data, the system does not collect quality of life data and therefore does not have the ability to address quality-adjusted survival. The predictive models that use the SRTR data also have inherent limitations, and the models require ongoing validation and refinement.

Changes to the LAS system and to geographic sharing of donor lungs will continue to affect the distribution and types of candidates undergoing transplantation and their outcomes. Continued surveillance and refinement of the transplant system will hopefully lead to improved system efficiency and patient outcomes.

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Conflict of Interest Statement

The authors declare no conflicts of interest.

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Table A.1: Sample size for median time to transplant by LAS diagnostic group and LAS group at listing in years 2006–2008

LAS primary diagnostic group	LAS group at listing	All lung transplant patients*	Single lung transplant patients	Bilateral lung transplant patients
		N	N	N
A	20–<30	33	12	21
	30–<35	996	422	574
	35–<40	184	62	122
	40–<50	44	9	35
	50–<60	5	0	5
	60+	10	2	8
	ALL	1272	507	765
B	20–<30	6	1	5
	30–<35	53	1	52
	35–<40	29	2	27
	40–<50	17	3	14
	50–<60	2	0	2
	60+	0	0	0
	ALL	107	7	100
C	20–<30	3	0	3
	30–<35	131	1	130
	35–<40	208	2	206
	40–<50	83	1	82
	50–<60	17	0	17
	60+	16	0	16
	ALL	458	4	454
D	20–<30	8	4	4
	30–<35	287	136	151
	35–<40	510	268	242
	40–<50	655	283	372
	50–<60	187	71	114
	60+	212	73	139
	ALL	1859	835	1022

*See Figure 3.

Includes patients aged 12+ placed on the waiting list on or after May 4, 2005 with nonzero LAS at listing.

Two patients in group D did not have single/bilateral transplant type specified, so they are excluded from the single/bilateral transplant column data.