Received: 28 January 2021 | Revised: 11 May 2021 | Accepted: 17 May 2021

DOI: 10.1111/ajt.16697

ORIGINAL ARTICLE

AJT

Effects of broader geographic distribution of donor lungs on travel mode and estimated costs of organ procurement

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Funding information
Scientific Registry of Transplant Recipients; Hennepin Healthcare Research Institute, Grant/Award Number: HHSH250201500009C

On November 24, 2017, US lung transplant policy replaced donor service area with 250-nautical-mile radius as the first unit of allocation. Understanding this policy's economic impact is important, because the United States is poised to adopt the broadest feasible geographic organ distribution. All lung transplant recipients from January 1, 2015, to December 31, 2018, in the Scientific Registry of Transplant Recipients, were included. Recipients before and after November 24, 2017 were in the donor service area-first and 250-nautical-mile donor service area-free periods, respectively. Travel time was estimated using a Google application; mode was assigned as flying when driving time was longer than 60 min. Travel costs were estimated by mode and distance. Travel distance and time for organ procurement increased under the policy change. The estimated proportion of organs traveling by air increased from 61% to 76%. Estimated average costs increased by $14 051 if travel mode changed to flying, resulting in an average increase of $1264 for all transplants. Travel costs were highest for candidates <18 years and adults with high lung allocation scores. Broader geographic distribution increased estimated organ procurement costs for a small percentage of lung transplants. Further analysis should elucidate the broad economic impact of such policies.

KEYWORDS
health services and outcomes research, lung transplantation/pulmonology, organ procurement and allocation, organ transplantation in general, organ allocation, organ procurement

1 | INTRODUCTION

The US donor lung allocation system changed on November 24, 2017, to allow broader distribution of donor lungs. The lawsuit that prompted this change challenged the practice of providing primary access to organs for candidates within the boundaries of a donor service area (DSA) without regard to their relative risk of waitlist mortality, compared with nearby candidates who may be sicker. The suit argued that use of DSA was based on historic precedent and did not correlate with organ viability and failed basic principles of distributive justice.[1] The first geographic unit of donor lung allocation was changed from local DSA to a radius of 250 nautical miles (NMs) from the donor hospital as a first policy step toward the goal of adopting the broadest feasible geographic distribution of organs.[2] For most of the United States, this change in allocation policy resulted in broader geographic distribution of organs, allowing sicker

Abbreviations: API, application programming interface; COPD, chronic obstructive pulmonary disease; DCD, donation after cardiac death; DSA, donor service area; LAS, lung allocation score; NM, nautical mile; OPTN, Organ Procurement and Transplantation Network; OPO, organ procurement organizations.

candidates to access organs over a broader geographic area. One year after implementation of this policy, the Organ Procurement and Transplantation Network (OPTN) reported that the median distance traveled for donor lung procurement by US transplant programs increased from 114 to 166 NM.[3]

The transplant community has since voiced concerns over the inefficiencies of broader geographic distribution, including increased procurement costs associated with travel over longer distances; however, the OPTN cannot evaluate the direct economic impact of this policy, because it does not collect data on travel mode or transplant center procurement costs.[4] Understanding the effects of broader geographic distribution on efficiencies of the US transplant system is important, because work is underway toward eliminating geographic boundaries to the extent feasible. In this study, we estimated the financial impact of broader geographic distribution on US lung transplant programs' procurement costs based on distance between donor-recipient pairs in a modern cohort of lung transplant recipients comparing the DSA-first and 250-NM DSA-free eras.

2 | METHODS

2.1 | Study population

This study used data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data submitted by members of the OPTN on all donors, waitlist candidates, and transplant recipients in the United States. The Health Resources and Services Administration, US Department of Health and Human Services, provides oversight of the activities of the OPTN and SRTR contractors.

The study population included all lung transplant recipients from January 1, 2015 to December 31, 2018. Recipients who underwent transplant before November 25, 2017 were classified as prepolicy or "DSA-first," and those who underwent transplant on or after that date were classified as post-policy or "250-NM DSA-free."

2.2 | Travel time calculation

Travel times between donor and recipient hospitals were estimated by geolocation and driving time. We identified active transplant programs and donor hospitals from 2015 to 2018 and reviewed hospital latitude and longitude data for geolocation. To confirm data accuracy, we measured straight-line distances between donor and recipient hospitals using (1) latitude and longitude values for each hospital and (2) ZIP code centroids for each hospital. If these distances differed by more than 5 miles, all data points were examined by hand using Google Map locations, and the most plausible data were used.

We obtained a list of airports from the Federal Aviation Administration, which included latitude and longitude data for each airport. Donor and recipient hospitals were matched to the nearest airport to estimate hospital-to-airport driving times.

A Google application programming interface (API) was used to estimate average driving times from donor to recipient hospitals to the nearest airport and from donor to recipient hospitals for those within 300 straight-line miles. Drive times were averages and did not account for variability due to weather or special-event traffic. Flight times were estimated from airport to airport and did not account for weather or air traffic control delays. For each donor-recipient pair, travel time for driving and flying was estimated. For driving only, travel time was calculated as the total driving time from donor to recipient hospital. For flying, travel time included flight time plus driving time from airports to hospitals. Methods used were similar to those used by Gentry et al.[1]

2.3 | Mode of travel assignment

Based on travel time estimates, travel mode (driving or flying) was assigned using a 60-min cut-point. If a travel time estimate for driving from donor to recipient hospital was 60 min or less, driving was the assigned mode. If the travel time was estimated as longer than 60 min, total time estimates for driving and flying modes were compared. If time for driving was less than that for flying (including driving time to airport), the assigned mode was driving. If travel time for driving was greater than flying, the assigned mode was flying. This algorithm prioritized the shortest trip, even if the drive time exceeded the drive time threshold but remained less than the flying time. Similar steps were taken for analyses using 90- and 120-min cut-points.

2.4 | Time estimates by mode of travel for subgroups

Based on travel time estimates and travel mode assignments, the percentage of donor organs estimated to have been flown and median travel time were calculated by subgroup. Data were stratified by population (DSA-first, DSA-free) and then by each of the following: recipient characteristics (age group, sex, race/ethnicity, height, blood type, lung allocation score [LAS], and primary diagnosis group), transplant program characteristics (OPTN region, US state, annual transplant volume, and US location (east/west of Mississippi River), distance from donor hospital, pediatric vs adult program), donor hospital urbanicity, and ischemic time categories (<3, 3 to <4, 4 to <5, 5–7, ≥7 h).

2.5 | Estimated travel cost calculation

Travel costs were estimated for each lung transplant recipient using the assigned travel mode and straight-line distance between donor and recipient hospitals. Lungs recovered and transplanted at the same facility were assumed to have no travel costs. Lungs delivered by ambulance were assumed to have a fixed round-trip cost of $1219, and lungs transported by airplane were assumed to have a round-trip cost of $8544 + $9.2 × (round-trip miles). These costs were estimated by Gentry et al in 2013,[5] and we converted costs from 2013 to 2019 dollars by using a multiplier of $1.10 in 2019 to $1.00 in 2013.[6]

3 | RESULTS

3.1 | Recipient characteristics by era

The overall cohort included 9300 lung transplant recipients, 6558 (71%) of whom underwent transplant in the DSA-first period and 2742 (29%) in the 250-NM DSA-free period (Table 1). Compared with the DSA-first period, transplant recipients in the 250-NM DSA-free period were older (35.3% vs 30.7% 65 years or older) and sicker, with 23.1% versus 18.9% with an LAS of 60 or higher at transplant. Fewer patients were in diagnosis group A, chronic obstructive pulmonary disease (COPD) and obstructive diseases, with 24.4% in the later, DSA-free era, and 27.4% in the DSA-first era. Donor-to-recipient travel distances increased, as did the proportion of organs with total ischemia time over 5 h.

3.2 | Travel time/mode comparing DSA-first to DSA-free eras

Overall, median straight-line distance between donor and recipient hospitals increased from 125.3 miles in the DSA-first period to 190.9 miles in the 250-NM DSA-free period, while median travel distance increased from 143.1 to 208.2 miles. Travel distance is the over-the-road driving distance for the driving mode, and for the flying mode, it is the flying distance plus the driving distances to and from airports. The proportion of donor organs estimated to have been flown increased from 61.3% to 75.7%, reflecting the broader reach of the first unit of allocation in the 250-NM DSA-free period (Table 2 and Figure 1). Median estimated travel times increased from 1.6 to 1.7 h. Among those assigned the driving mode, median estimated travel distances and times were similar in both eras: 14.7 miles and 0.4 h in the DSA-first period, compared with 17.6 miles and 0.5 h in the 250-NM DSA-free period. Among those assigned the flying mode, median travel distance declined from 344 to 254 miles, reflecting the influence of the new allocation boundary introduced at 250 NM.

3.3 | Travel time/mode by recipient characteristics

The highest estimated percentages of organs flown were for children 0–11 years, reflecting the OPTN policy of prioritizing allocation of pediatric organs to pediatric candidates in that age-group within a 1000-NM radius, followed by candidates aged 12–17 within a 1000-NM radius (Figure 2). For recipients 0–11 years, 93.2% and 92.9% of organs were estimated to have flown in the DSA-first and 250-NM DSA-free era, respectively (Table 2). For recipients 12–17 years, 78.1% of donor organs were estimated to have been flown in the DSA-first era, with 100% in the later, DSA-free era. Median travel times were longer for pediatric candidates than for adults, a finding consistent with pediatric lung allocation and nonuniform distribution of the seven pediatric programs across the United States from 2015 to 2018. For adults, proportions of organs estimated to have been flown in the DSA-first era ranged from 59.5% among recipients 65 years or older to 64.8% among those 35–49 years; in the later, 250-NM DSA-free era, those proportions increased to 73.9% and 80.5%, respectively. The pattern of increased flying in the 250-NM DSA-free era was similar across recipient sex and race/ethnicity groups, as well as blood type.

3.4 | Lung allocation score and travel time/mode

In the DSA-first era, organs for high-LAS recipients were estimated to have been flown more often than those for low-LAS recipients in a dose-response relationship (Table 2 and Figure 3). In the DSA-free era, percentages estimated to have been flown were more similar across LAS groups. This occurred because strong local priority in the DSA-first era allowed low-LAS recipients to access local organs before they were offered to candidates with more urgent conditions outside the DSA. Thus, low-LAS recipients were more likely to get local than nonlocal organs, leading to a lower proportion estimated to have been flown. Once offered outside the local DSA, the highest-LAS patients within a 500-NM radius were prioritized, necessitating flying as the mode of travel. In the 250-NM DSA-free era, all patients within 250 NM were ordered by LAS, and the differences in the proportion estimated to have been flown were attenuated.

3.5 | Diagnosis group and travel time/mode

Percentages of organs estimated to have been flown across diagnosis groups became more similar in the DSA-free era. In the DSA-first era, organs for recipients in diagnosis group A (COPD) were flown less often than other diagnosis groups, which may be explained by the relative low LAS of these candidates.

3.6 | Blood type and height and travel time/mode

Assigned travel mode differed by blood type; organs for recipients with blood type AB were estimated to have been flown the most, and organs for recipients with blood type O the least, in both eras. Recipient height affected the percentages flown, with the highest rates for individuals less than 150 cm tall. This occurs, in part, because the group includes a high proportion of the children in the cohort, and allocation policy for children favors distances that require flying. For individuals more than 150 cm tall, trends mirrored the overall data.

TABLE 1 Patient characteristics by policy era for 60-min cut-point

Subgroup	Level	DSA-first era (January 1, 2015 to November 24, 2017) N (%)	DSA-free era (November 25, 2017 to December 31, 2018) N (%)	*p*-value
All		6558 (100.0)	2742 (100.0)	na
Age	0–11	44 (0.7)	14 (0.5)	0.0003
	12–17	73 (1.1)	25 (0.9)	
	18–34	648 (9.9)	241 (8.8)	
	35–49	739 (11.3)	323 (11.8)	
	50–64	3039 (46.3)	1170 (42.7)	
	≥65	2015 (30.7)	969 (35.3)	
Sex	Female	2710 (41.3)	1115 (40.7)	0.555
	Male	3848 (58.7)	1627 (59.3)	
Race/ethnicity	White	5259 (80.2)	2165 (79.0)	0.166
	Black	616 (9.4)	254 (9.3)	
	Hispanic	497 (7.6)	239 (8.7)	
	Asian	149 (2.3)	60 (2.2)	
	Other/unknown	37 (0.6)	24 (0.9)	
Blood type	A	2674 (40.8)	1027 (37.5)	0.015
	B	734 (11.2)	311 (11.3)	
	AB	246 (3.8)	122 (4.4)	
	O	2904 (44.3)	1282 (46.8)	
Diagnosis group	A	1794 (27.4)	669 (24.4)	0.0002
	B	254 (3.9)	146 (5.3)	
	C	734 (11.2)	280 (10.2)	
	D	3776 (57.6)	1647 (60.1)	
LAS group (age ≥12 years)	<35	1624 (24.9)	600 (22.0)	<0.0001
	30 to <40	1517 (23.3)	587 (21.5)	
	40 to <50	1544 (23.7)	634 (23.2)	
	50 to <60	596 (9.1)	276 (10.1)	
	≥60	1233 (18.9)	631 (23.1)	
Recipient height (cm)	<150	197 (3.0)	79 (2.9)	0.0036
	150 to <160	914 (13.9)	388 (14.2)	
	160 to <170	1978 (30.2)	804 (29.3)	
	170 to <180	2277 (34.7)	942 (34.4)	
	≥180	1189 (18.1)	518 (18.9)	
	Unknown	3 (0.0)	11 (0.4)	
Transplant program OPTN region	1	246 (3.8)	97 (3.5)	<0.0001
	2	1019 (15.5)	488 (17.8)	
	3	652 (9.9)	275 (10.0)	
	4	825 (12.6)	314 (11.5)	
	5	1083 (16.5)	420 (15.3)	
	6	151 (2.3)	55 (2.0)	
	7	546 (8.3)	196 (7.1)	
	8	385 (5.9)	171 (6.2)	
	9	199 (3.0)	144 (5.3)	
	10	856 (13.1)	333 (12.1)	
	11	596 (9.1)	249 (9.1)	

(Continues)

TABLE 1 (Continued)

Subgroup	Level	DSA-first era (January 1, 2015 to November 24, 2017) N (%)	DSA-free era (November 25, 2017 to December 31, 2018) N (%)	p-value
Distance (miles): donor to recipient hospital	<0.5	505 (7.7)	112 (4.1)	<0.0001
	0.5 to <50	1788 (27.3)	474 (17.3)	
	50 to <100	693 (10.6)	268 (9.8)	
	100 to <250	1130 (17.2)	971 (35.4)	
	250 to <500	1516 (23.1)	598 (21.8)	
	500-<1000	747 (11.4)	231 (8.4)	
	≥1000	179 (2.7)	88 (3.2)	
Program location	Eastern US	3828 (58.4)	1708 (62.3)	0.0004
	Western US	2730 (41.6)	1034 (37.7)	
Donor hospital urbanicity	Metro	6444 (98.3)	2688 (98.0)	0.446
	Non-metro	114 (1.7)	54 (2.0)	
Program volume (transplants/year)	<10	173 (2.6)	62 (2.3)	0.020
	10–29	1580 (24.1)	745 (27.2)	
	30–49	1199 (18.3)	484 (17.7)	
	50–99	2423 (36.9)	950 (34.6)	
	≥100	1183 (18.0)	501 (18.3)	
Pediatric program	No	6468 (98.6)	2712 (98.9)	0.278
	Yes	90 (1.4)	30 (1.1)	
Total ischemia time (h)	<3	477 (7.3)	128 (4.7)	<0.0001
	3 to <4	1084 (16.5)	345 (12.6)	
	4 to <5	1489 (22.7)	623 (22.7)	
	5 to <7	2522 (38.5)	1205 (43.9)	
	≥7	941 (14.3)	415 (15.1)	
	Unknown	45 (0.7)	26 (0.9)	

3.7 | Location and travel time/mode

In the 250-NM DSA-free era, 76.7% of organs were allocated within a 250-NM radius, but only 24.3% fell within an estimated driving distance of 1 h or less, resulting in increased flying across all regions. The increase in the proportion of organs estimated to have been flown was highest in region 1, from 56.1% in the DSA-first period to 84.5% in the 250-NM DSA-free period (Table 2). Median travel distance in region 1 increased from 107 to 219 miles and median travel time increased from 1.47 to 1.73 h. The increase in the proportion of organs estimated to have been flown was lowest in region 5, from 55.8% in the DSA-first period to 62.1% in the 250-NM DSA-free period. Median travel distance in region 5 increased from 106 to 122 miles, and median travel time increased from 1.45 to 1.55 h.

Generally, the proportion of organs estimated to have been flown, as well as travel times, increased more in the eastern region of the United States than the western region, with the Mississippi River as the dividing line. In the east, the proportion of organs estimated to have been flown increased from 63.1% to 79.6%, compared with 58.6% to 69.3% in the west. Organs originating in nonmetropolitan hospitals were more likely to have been flown in both eras, but the need for organs to be flown increased for both metropolitan and nonmetropolitan hospitals in the DSA-free era (Figure 4).

3.8 | Transplant program characteristics and travel time/mode

Annual transplant program volume was calculated by averaging annual program volume over 3 years. The highest estimated percentage of organs was flown to 13 programs performing fewer than 10 transplants per year in both eras (Table 2). These programs represented less than 3% of all transplants in each era. They included all seven pediatric programs (Table 1) and five programs in metropolitan areas with a larger program(s). Proportions of organs estimated to have been flown increased for all program volume levels but increased most for programs performing 10 to 29 transplants per year, followed by centers performing 30 to 49 transplants per year (Table 2). The largest centers, those performing 100 or more transplants per year, increased minimally, as they were already estimated to have over 70% of their donor organs flown (Figure 5). Pediatric transplant programs (≥80% recipients 0–17 years) had more organs flown than

TABLE 2 Percentage of time donor organs were estimated to have been flown at 60-min cut-point, by era and subgroup

Subgroup	Level	DSA-first era (January 1, 2015 to November 24, 2017) *N* (%)	DSA-free era (November 25, 2017 to December 31, 2018) *N* (%)
All		4023 (61.3)	2077 (75.7)
Age	0–11	41 (93.2)	13 (92.9)
	12–17	57 (78.1)	25 (100.0)
	18–34	411 (63.4)	191 (79.3)
	35–49	479 (64.8)	260 (80.5)
	50–64	1836 (60.4)	872 (74.5)
	≥65	1199 (59.5)	716 (73.9)
Sex	Female	1583 (58.4)	850 (76.2)
	Male	2440 (63.4)	1227 (75.4)
Race/ethnicity	White	3277 (62.3)	1634 (75.5)
	Black	350 (56.8)	200 (78.7)
	Hispanic	282 (56.7)	180 (75.3)
	Asian	89 (59.7)	43 (71.7)
	Other/unknown	25 (67.6)	20 (83.3)
Blood type	A	1655 (61.9)	794 (77.3)
	B	502 (68.4)	248 (79.7)
	AB	179 (72.8)	99 (81.1)
	O	1687 (58.1)	936 (73.0)
Diagnosis group	A	981 (54.7)	503 (75.2)
	B	159 (62.6)	103 (70.5)
	C	465 (63.4)	232 (82.9)
	D	2418 (64.0)	1239 (75.2)
LAS group (age ≥12 years)	<35	866 (53.3)	454 (75.7)
	35 to <40	884 (58.3)	445 (75.8)
	40 to <50	925 (59.9)	493 (77.8)
	50 to <60	406 (68.1)	204 (73.9)
	60+	901 (73.1)	468 (74.2)
Recipient height (cm)	<150 cm	134 (68.0)	66 (83.5)
	150 to <160 cm	528 (57.8)	296 (76.3)
	160 to <170 cm	1179 (59.6)	614 (76.4)
	170 to <180 cm	1423 (62.5)	706 (74.9)
	>=180 cm	757 (63.7)	387 (74.7)
	Unknown	2 (66.7)	8 (72.7)
Transplant program	1	138 (56.1)	82 (84.5)
OPTN region	2	545 (53.5)	363 (74.4)
	3	440 (67.5)	223 (81.1)
	4	509 (61.7)	237 (75.5)
	5	604 (55.8)	261 (62.1)
	6	86 (57.0)	36 (65.5)
	7	337 (61.7)	147 (75.0)
	8	215 (55.8)	135 (78.9)
	9	115 (57.8)	101 (70.1)
	10	572 (66.8)	269 (80.8)
	11	462 (77.5)	223 (89.6)
Distance (miles)	<0.5 (same campus)	0 (0.0)	0 (0.0)
donor to recipient	0.5 to <50	2 (0.1)	0 (0.0)
Hospital	50 to <100	449 (64.8)	189 (70.5)
	>100	3572 (100.0)	1888 (100.0)
Program location	Eastern United States	2424 (63.3)	1360 (79.6)
	Western United States	1599 (58.6)	717 (69.3)
Donor hospital	Metropolitan	3924 (60.9)	2024 (75.3)
urbanicity	Nonmetropolitan	99 (86.8)	53 (98.1)
Program volume (transplants/year)	<10	127 (73.4)	53 (85.5)
	10–29	887 (56.1)	574 (77.0)
	30–49	682 (56.9)	366 (75.6)
	50–99	1491 (61.5)	713 (75.1)
	>=100	836 (70.7)	371 (74.1)
Pediatric program	No	3944 (61.0)	2048 (75.5)
	Yes	79 (87.8)	29 (96.7)
Total ischemia time (h)	<3	77 (16.1)	43 (33.6)
	3–<4	393 (36.3)	191 (55.4)
	4–<5	887 (59.6)	450 (72.2)
	5–<7	1884 (74.7)	1020 (84.6)
	>=7	760 (80.8)	355 (85.5)

adult programs, at 87.8% in the DSA-first and 96.7% in the 250-NM DSA-free eras (Table 2).

3.9 | Ischemic time and travel time/mode

As expected, ischemia time increased with broader distribution. In the DSA-first period, 24.2% of recipients had ischemia times of less than 4 h, compared with 17.6% in the 250-NM DSA-free period (Table 1). Candidates who received transplants with the lowest ischemic time of <3 h had the lowest percentages of donor organs estimated to have been flown (16.1% in the DSA-first period and 33.6% in the 250-NM DSA-free period). Recipients who had estimated travel time of <1 h had median ischemic times of 4.1 h in the DSA-first era and 4.4 h in the DSA-free era.

3.10 | Cost and travel time/mode

Overall, cost of organ procurement increased with broader geographic distribution by an estimated average of $1264 from the DSA-first to 250-NM DSA-free era overall. Average estimated cost of organ procurement per recipient increased by $1857 per 100 miles.

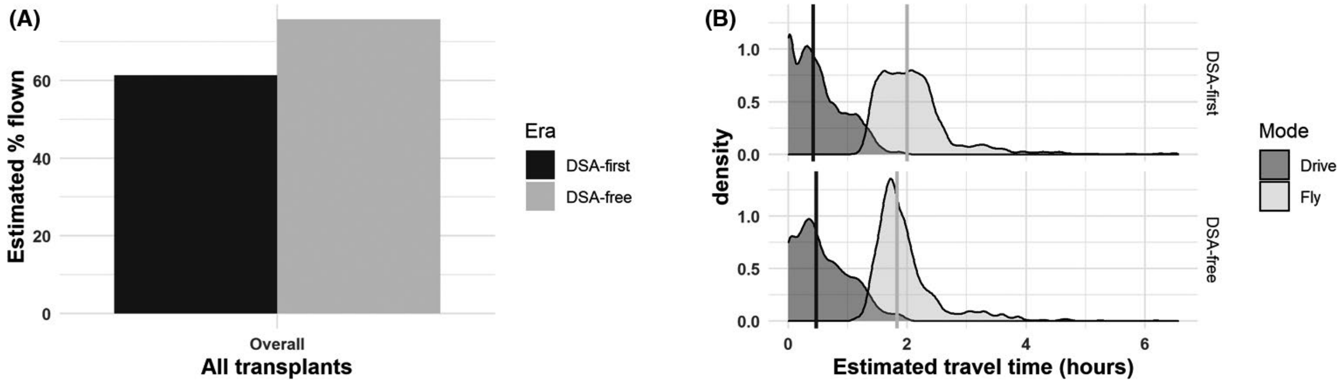


FIGURE 1 Overall estimates of organs flown by era and estimated travel time at a 60-min cut-point. More organs were flown in the donor service area (DSA)-free (250-nautical mile) era than in the DSA-first era. (A) Bar graph displaying estimated percentages of organs flown. (B) Density plot comparing distributions of travel time by estimated travel mode. Vertical line is the median time per mode

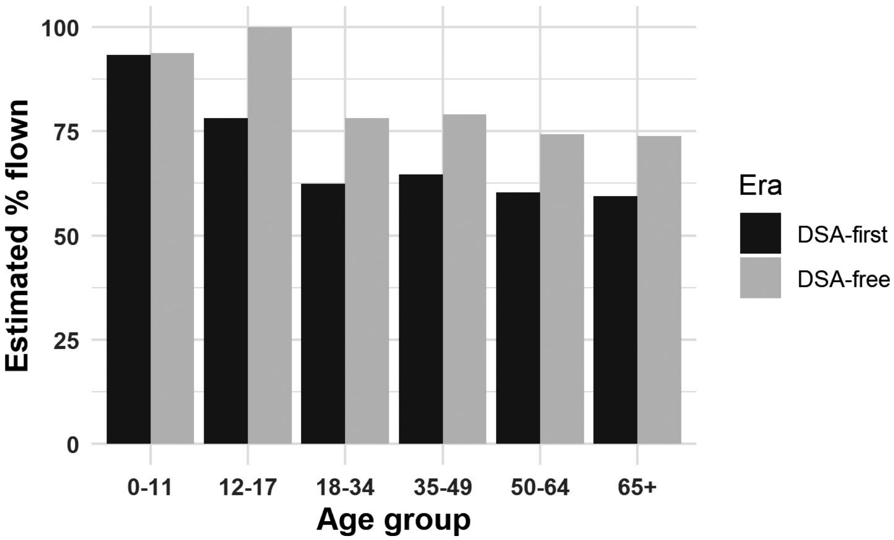


FIGURE 2 Estimated percentages of organs flown by recipient age and era

Ninety-seven percent of donor organs were procured from within 1000 miles of the recipient. Mean cost for driving was less than for flying, with an estimated fixed ambulance cost of $1219, compared with a mean cost for flying of $15 076. The average estimated costs among organs projected to have been flown, however, declined slightly, from $15 444 in the DSA-first period to $14 363 in the 250-NM DSA-free period. This is likely because in the DSA-first era, nonlocal offers were made over a 500-NM radius; however, in the 250-NM era, more flying occurred but over a shorter distance. Costs of organ procurement were highest for recipients younger than 12 years, at an estimated median cost of $20 546, compared with $11 264 for adults. Estimated mean travel costs increased slightly with increasing LAS (Table 3).

4 | DISCUSSION

4.1 | Principal findings

Moving from DSA-first to 250-NM radius as the first unit of allocation led to an increase in estimated travel distance and time required for organ procurement and increased costs of procurement for a small percentage of US lung transplants. As the travel distance increased, greater costs were incurred when the mode of travel changed from driving to flying. Given that many lung transplant programs already used flying to procure organs before the policy change, changing to the 250-NM DSA-free allocation led to an increase in likelihood of flying for only 14% of transplants. Estimated overall costs of organ procurement increased by $1264 during this period.

4.2 | Broader geographic distribution and efficiency

Our goal was to study the potential impact of broader geographic distribution of donor lungs on the efficiencies of the US organ procurement system as the OPTN moves toward its legal obligation under the Final Rule to "distribute organs over as broad a geographic area as feasible". We analyzed how the interim policy step of moving from DSA to 250 NM as the first unit of allocation affected the efficiency metrics of travel distance, mode, and associated costs. The OPTN does not collect data on travel mode or

FIGURE 3 Estimated percentages of organs flown by lung allocation score (LAS) and era

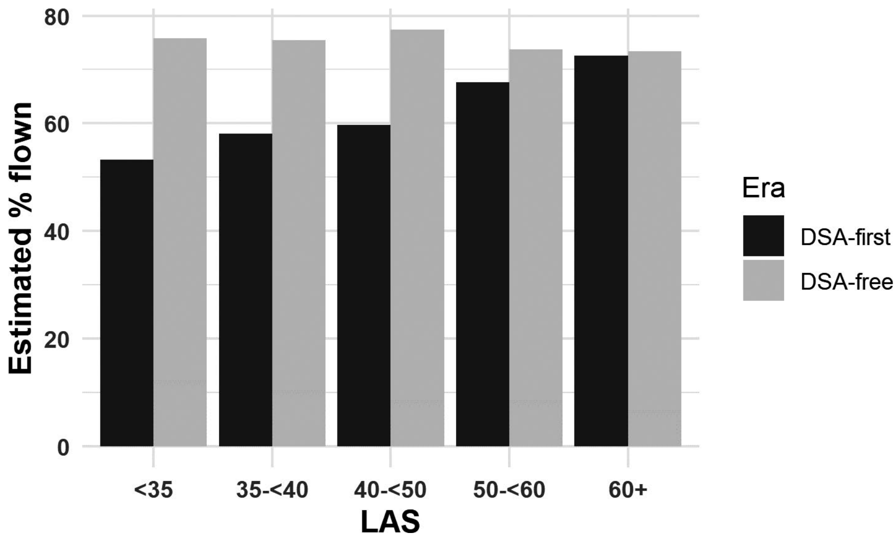
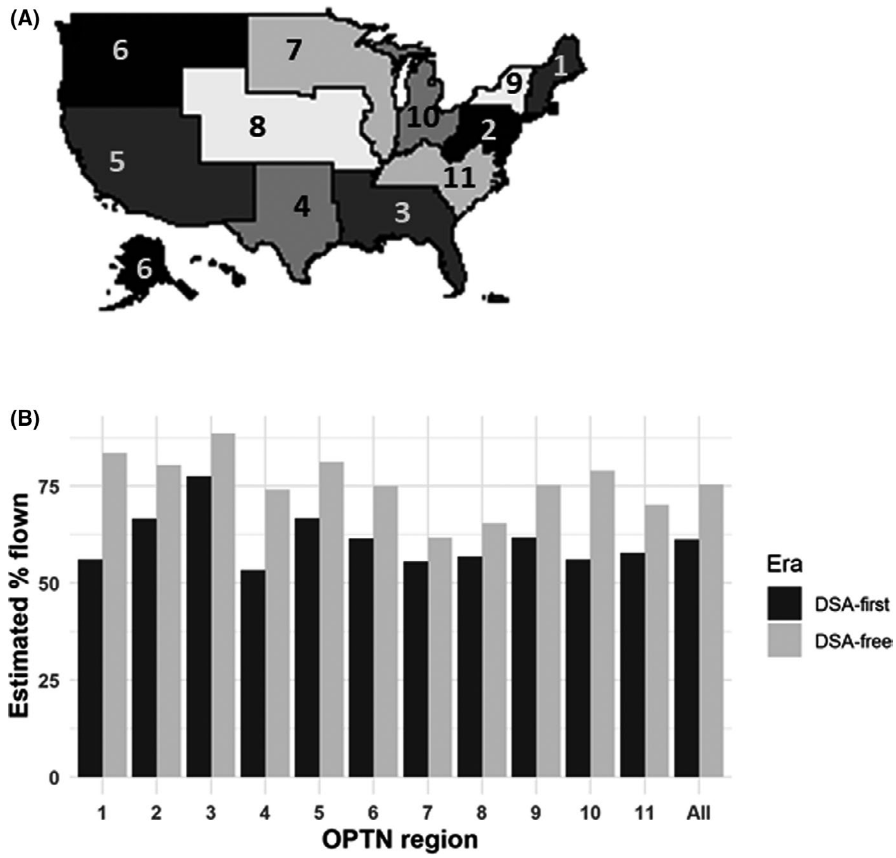


FIGURE 4 Estimated percentages of organs flown by Organ Procurement and Transplantation Network (OPTN) region and era. (A) OPTN regions are outlined on the US map and (B) percentages of organs flown are displayed in the bar graph by region and across all regions



cost of organ procurement; therefore, travel mode was assigned as driving or flying based on estimated travel time between actual donor and recipient pairs before and after the change in policy.

Distances and travel time to procure organs increased overall and across programs of all sizes. In the DSA-first era, 61.3% of donor lungs were estimated to have been flown at a 60-min cut-point, compared with 75.7% in the 250-NM DSA-free period. Percentages flown increased in the DSA-free era by 14% across all cut-points. This interval increase in the frequency of flying was relatively small because the vast majority of donor lungs were already being procured by teams by flying to the donor hospital. While it is true that this policy increased the estimated proportion of organs flown to programs of all sizes, increases were largest in programs with volumes of 10–49 transplants per year. The impact on small- to medium-sized programs may be different, depending on their available resources and personnel. The relative inefficiency of longer travel may go from a minor inconvenience for programs that are large with different teams for organ recovery and transplant to a significant one where teams are less available to perform transplants in smaller programs that may have fewer resources.

OPTN regions were differentially impacted by this policy. Notably, region 1 had the lowest flying rate of any region before the policy

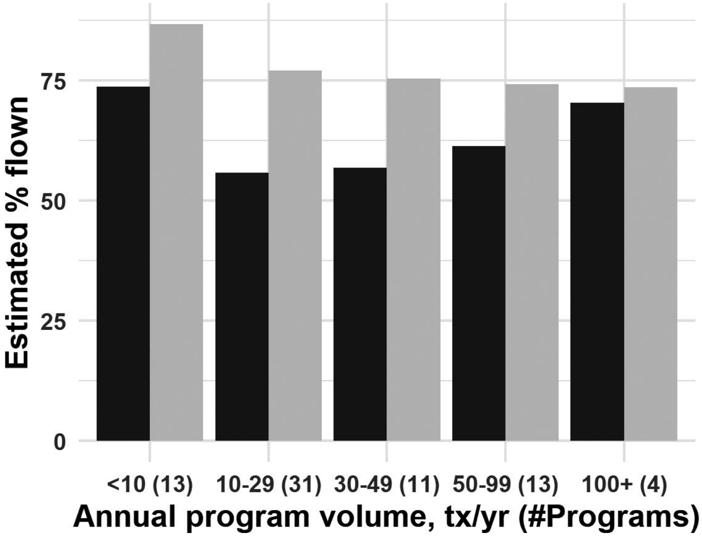


FIGURE 5 Estimated percentages of organs flown by annual program volume and era

TABLE 3 Estimated travel costs by subgroup (age, LAS, diagnosis, and mode)

	Subgroup	*N*	Mean	Median	95th percentile	Mean relative to category reference	Mean relative to overall mean cost ($10 241)
Age (years)	<12	58	$19 553	$20 546	$29 818	$9420	$9311
	12–17	98	$14 830	$15 370	$27 077	$4697	$4589
	≥18	9144	$10 133	$11 264	$22 383	$0	−$108
LAS	<35	2224	$9312	$10 579	$22 744	−$776	−$929
	35 to <40	2104	$9878	$11 059	$23 731	−$210	−$363
	40 to <50	2178	$10 088	$11 248	$22 832	$0	−$153
	50 to <60	872	$10 974	$11 890	$23 981	$885	$732
	≥60	1864	$11 307	$12 510	$20 183	$1219	$1065
	No LAS (age <12)	58	$19 553	$20 546	$29 818	$9465	$9311
Diagnosis	Group A	2463	$9464	$10 754	$22 965	−$1028	−$778
	Group B	400	$10 219	$11 269	$23 946	−$272	−$22
	Group C	1014	$10 802	$11 774	$24 684	$310	$560
	Group D	5423	$10 492	$11 753	$22 705	$0	$250
Mode	Drive	3200	$1025	$1219	$1219	−$14 051	−$9216
	Fly	6100	$15 076	$13 502	$26 240	$0	$4835
Overall	All	9300	$10 241	$11 379	$23 000		

Note: Subgroups are shown with mean, median, and 95th percentile of cost in US dollars, as well as the cost relative to the reference category in the subgroup and the overall average cost for lung acquisition.

change, but in the postpolicy DSA-free era, these programs flew as often as other regions. Region 11 had the highest flying rate of any region and remained so after the policy change. The Final Rule requirement to promote patient access to transplant was interpreted by the OPTN Ad Hoc Committee on Geography to require the reduction of regional differences in donor supply and transplant demand. Therefore, the significance of regional convergence in the frequency of flying to recover organs needs to be understood in the context of the ratio of donor supply and demand, an analysis beyond the scope of this work.

The change from DSA-first to 250-NM DSA-free allocation resulted in an increase in LAS from 41.97 to 44.20 in the 2 years after the policy change.[3] Both national deceased donor utilization and discard rates, excluding ex vivo lung perfusion and donation after cardiac death (DCD) donors, did not meaningfully change, but variation occurred among OPTN regions.[3] With the policy change, this study found that more organs would likely be flown for candidates with higher LAS values, diagnosis of cystic fibrosis and pediatric candidates. The frequency of organs flown for pediatric candidates is explained by existing pediatric allocation policy, which has broader geographic distribution of organs for this population due to scarcity of pediatric organs.[7] One impetus for this policy change was to allow sicker candidates to have broader access to organs and so by that measure, the policy meets its intended goal. However, scenarios must be avoided in which organs are allocated to candidates farther away for minimal and clinically insignificant differences in LAS. This potential unintended consequence requires consideration with further proposed policy changes as ways to optimize efficiency are considered so that organs are allocated to candidates at increasing distances for clinically meaningful differences.

4.3 | Broader geographic distribution and cost

Concerns have also been raised that as travel distances increase, costs for organ procurement may rise, which could impede transplant centers' financial viability, ultimately affecting their ability to offer transplants to their patients. In the publication of a single center's experience after the 2017 change in allocation policy, the authors reported a decline in transplants from donors in the local DSA and a doubling of their median organ recovery cost.[4] Another single-center study demonstrated both increased travel costs ($8626 pre vs $14 482 post) and total procurement costs ($60 852 pre vs $69 052 post) in the 2 years pre-policy and post-policy change.[8] A recent analysis on the impact of policy change on two organ procurement organizations (OPOs) revealed an average increased OPO organ acquisition cost of $12 424 per transplant.[9] These findings are similar to the mean approximation of increase in cost of organ recovery in our analysis. Centers may differ in the time cut-point at which they choose to fly rather than drive to procure an organ, but it is likely that as travel distances lengthen, so will the travel cost of procurement if the lung organ procurement system remains the same. Some experts have proposed that formation of a network of local recovery teams would make the US lung procurement system more efficient by minimizing travel for transplant teams and, theoretically, lower travel costs as well.[10] Currently, the OPTN does not collect data on travel mode or procurement costs. As allocation policy continues to change, national collection of this data would permit granular economic analyses. Until that data are available, continued use of simulation algorithms can help predict potential economic outcomes as well as assess economic consequences of implemented policy.

We showed that moving from DSA-first to 250-NM DSA-free allocation resulted in an increase in LAS of transplant recipients. Indeed, a goal of this policy was to make more organs available to sicker transplant candidates. Implementation of the urgency-based LAS system in the United States increased cost of total transplants by 40% in the first 6 years of its implementation, and transplant costs have been shown to incrementally increase with rising LAS values.[11,12] Greater increases in transplant of more high-urgency/LAS candidates would be expected if geographic boundaries were further expanded to allow transplant of candidates at highest risk for waitlist mortality. If such allocation changes were implemented without constraints that considered other elements (eg, likelihood of posttransplant morbidity and mortality), it would likely affect transplant costs in a more significant way than efficiency metrics such as longer travel or change in travel mode for organ recovery.

4.4 | Limitations

Travel time and mode are not directly available through registry data but were estimated though a Google application and determined algorithmically. In this analysis, assumptions are the same for every transplant program, though individual programs might behave differently in ways that could increase or decrease travel time and alter travel mode. It is possible that our overall results may reflect varied positive or negative financial impacts on individual programs that cannot be seen in this aggregate analysis. Some OPOs manage donors at a central facility that is neither the donor hospital nor the recipient center. We did not have access to information about who those donors were and where those facilities were located, so their travel time and mode predictions could be incorrect. Cost data were estimated using an algorithm described in liver transplant that used a cohort from 2010; however, our values are updated to the 2019 equivalent.

5 | CONCLUSION

Broader geographic distribution of donor lungs has and will likely continue to increase organ procurement costs, although for a small proportion of transplants. Direct rises in the cost of organ procurement are relatively small and likely represent a small fraction of the overall economic costs introduced by broader geographic distribution of donors. These findings are important considerations in work to minimize geographic disparities in access to lung transplant for US patients.

ACKNOWLEDGMENTS

The authors thank SRTR colleagues Mary Van Beusekom, MS, ELS, for manuscript editing and Yoon Son Ahn for assistance in developing figures and graphs. This work was conducted under the auspices of the Hennepin Healthcare Research Institute, contractor for the SRTR, as a deliverable under contract number HHSH250201500009C (US Department of Health and Human Services, Health Resources and Services Administration, Healthcare Systems Bureau, Division of Transplantation). As a US Government sponsored work, there are no restrictions on its use. The views expressed herein are those of the authors and not necessarily those of the US Government.

DISCLOSURE

The authors of this manuscript have no conflicts of interest to disclose as described by the *American Journal of Transplantation*.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Lehr CJ, Skeans MA, Lease ED, Valapour M. Effects of broader geographic distribution of donor lungs on travel mode and estimated costs of organ procurement. *Am J Transplant*. 2021;21:4012–4022. https://doi.org/10.1111/ajt.16697