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Original Article

Impact of the lung allocation system score modification by blood type on US lung transplant candidates

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ABSTRACT

The lung continuous distribution system was modified on September 27, 2023, with the goal of increasing transplant access for blood type O candidates after an error was discovered in the simulation used to support the development of the initial allocation policy. This retrospective observational study compares national waitlist outcomes (transplant rate, waitlist mortality) under continuous distribution before (March 10, 2023, through September 26, 2023; premodification) and after (September 27, 2023, through April 14, 2024; postmodification) the blood type score modification. We fit adjusted Poisson regression models of the transplant rate and mortality rate. The transplant rate was lowest for type O candidates in both eras, but significantly increased after the score modification, from a premodification adjusted rate ratio (95% CI) of 0.40 (0.36, 0.45) to postmodification 0.52 (0.45, 0.59), relative to premodification type A candidates. The adjusted mortality incidence (95% CI) decreased in type O candidates from 3.6% (3.0%, 4.3%) premodification to 3.2% (2.6%, 3.8%) postmodification. In an exploratory analysis, we estimated there would have been the same number of waitlist deaths (approximately 105) if the modified score had been adopted

Abbreviations: aRR, adjusted rate ratio; AUC, area under the curve; CAS, composite allocation score; cPRA, calculated panel-reactive antibody; OPTN, Organ Procurement and Transplantation Network; SRTR, Scientific Registry of Transplant Recipients.

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at the start of continuous distribution; however, transplants would have shifted toward type O candidates (57.8 [95% CI: 35.1, 80.9] additional transplants) and deaths would have shifted away from type O candidates (4.6 [95% CI: 2.7, 6.8] fewer deaths).

1. Introduction

Continuous distribution of deceased donor lungs was implemented by the Organ Procurement and Transplantation Network (OPTN) on March 9, 2023.[1] This policy replaced the previous classification-based lung allocation system in the United States, in which lungs were sequentially offered to distinct categories of candidates on the match run. Under continuous distribution, lung candidates are sorted by their composite allocation score (CAS), which includes points for medical urgency, expected posttransplant outcome, candidate biology (ie, blood type, height, and calculated panel-reactive antibody [cPRA] value), patient access (ie, pediatric and prior living donor), and placement efficiency.

The points for blood type were modified in the policy on September 27, 2023, to increase access for candidates with blood type O after the OPTN 3-month monitoring report showed a decreased count of transplants for this group, in contrast to simulation modeling done prior to implementation.[2,3] An error was subsequently discovered in the simulation modeling used to develop continuous distribution of lungs, where the simulation allowed type O candidates to receive transplants from donors of all blood types.[4] Specifically, the monitoring report noted a 10% decrease in transplants to blood type O candidates (from 308 in 3 months pre-CAS to 276 post-CAS) with increased transplants to all other blood types, whereas the 2021 simulation modeling had predicted an increase in transplant rate for blood type O candidates under continuous distribution.[5] The modified blood type score was then developed on an accelerated timeline based on new modeling from the Scientific Registry of Transplant Recipients (SRTR) and the Massachusetts Institute of Technology. This modified score rescaled the blood type points to 5 for type O, 2.2382 for type B, and 0.3032 for type A, from 0.455 for type O, 0.2439 for type B, and 0.0455 for type A, out of 100 total points in the CAS.[3] There were no changes to the 0 points for type AB candidates, who are compatible with all donor blood types, and no changes to the allocation points for other CAS attributes.

The aim of this study was to compare waitlist outcomes in adult lung candidates under continuous distribution before the blood type score modification ("premodification era") with waitlist outcomes after the blood type score modification ("postmodification era"), by candidate blood type. The 2 end points of interest were: (1) transplant rate by blood type, and (2) cumulative incidence of waitlist mortality by blood type. An exploratory analysis also considers how outcomes in the premodification era would have been different if the modified blood type score had been adopted at the start of lung continuous distribution.

2. Materials and methods

2.1. Study population

This study used data from the SRTR. The SRTR system includes data on all donors, waitlisted candidates, and transplant recipients in the United States, submitted by the members of the OPTN, and has been described elsewhere.[6] The Health Resources and Services Administration, US Department of Health and Human Services, provides oversight to the activities of the OPTN and SRTR contractors. Work performed by SRTR is exempt from institutional review board review.

In this retrospective observational study, the premodification cohort included all adult (listed at age 18 years or older) lung candidates waiting on any day from March 10, 2023, through September 26, 2023, and the postmodification cohort included all adult lung candidates waiting on any day from September 27, 2023, through April 14, 2024. We did not include a pre-CAS cohort of candidates, because our specific target of inference was the effect of the blood type score modification, not the broader effects of the transition to CAS. Candidates listed pre-CAS who were still waiting on March 10, 2023, were included. Transplant centers with fewer than 5 candidates in an era were excluded, to enable adjustment for center-level effects ($N = 3$ candidates removed premodification, $N = 7$ postmodification). For patients with multiple listings during an era, the earliest listing was used for analysis.

2.2. Statistical methods

The analytic approach was chosen to mimic a hypothetical randomized trial of 2 allocation policies.[7] If such a trial were feasible, transplant candidates would be randomized to a policy at the start of the study or on a later listing date, and this randomization would balance candidate characteristics at baseline between the 2 policies. To emulate this target trial with observational data, "baseline" (ie, time 0) was defined as the later of the candidate listing date or era start date, and potential confounders for covariate adjustment were measured at baseline. Proposed confounders were waitlist acuity as measured by the waitlist survival area under the curve (AUC) attribute of the CAS, predicted posttransplant survival as measured by the posttransplant survival AUC attribute of the CAS, blood type, height, cPRA value, and transplant center. The candidate features included in waitlist survival AUC and posttransplant survival AUC are listed in Supplementary Tables S1 and S2, respectively. Missing cPRA values, which indicate no reported unacceptable antigens, were treated as zeros in the modeling.

The transplant end point was defined as waitlist removal for deceased donor transplant at any center, emergency transplant, or patient death during transplant. The waitlist mortality end point was defined as waitlist removal for death or deterioration in condition. Cumulative incidences were estimated by blood type and compared between eras with Fine-Gray tests. Candidates were censored at removal for other reasons and at the era end date.

The premodification and postmodification cohorts were then stacked to create 1 long dataset for adjusted analyses.

We constructed a Poisson survival model for the transplant rate, adjusting for the policy period and all baseline candidate covariates. Continuous covariates were modeled by natural cubic splines with a single interior knot. The initial model included all 2-way interactions between the policy period and the allocation attributes (ie, blood type, height, cPRA, waitlist AUC, and posttransplant AUC), and backward selection by the Akaike information criterion was used to reduce the set of interactions, forcing main effects and the interactions with blood type to remain in the model by design.

We constructed a similar Poisson survival model for the waitlist mortality rate, excluding candidate center from adjustment due to too few events. Again, backward selection by the Akaike information criterion removed terms that did not improve model fit. In theory, the waitlist mortality rate should be quite robust to allocation changes, due to censoring at transplant, but might still vary over time due to external risk factors or because a policy can affect who is censored and when; either possibility would be important to understand for our research question. The transplant rate and waitlist mortality rate can be combined mathematically to calculate a cumulative incidence of waitlist mortality, which is directly affected by allocation policy (through the transplant rate). Using both rate models, we calculated an adjusted cumulative incidence of waitlist mortality over time for each policy period in each blood type group.

Model coefficients were summarized by adjusted rate ratios (aRRs) with 95% CIs. Premodification candidates who were not removed by the postmodification era contributed 2 rows to the stacked dataset. To appropriately handle these correlated data, standard errors and CIs were computed by the cluster bootstrap with 1000 iterations and candidate-level sampling.

To explore waitlist outcomes if the modified blood type score had been adopted at the start of continuous distribution, we calculated predicted transplants and predicted deaths in the premodification era, comparing whether premodification vs postmodification rates were applied. The predicted number of events was calculated as the sum of patient-level predicted probabilities (ie, cumulative incidence by era end date). This analysis was complicated by the fact that donor availability changes over time, affecting the transplant rate. To estimate the effect of the policy alone, not the fluctuating donor pool, we designed the following methodology: we first calculated a scaling factor for the postmodification transplant rate, to ensure no change in the predicted number of transplants when applying postmodification rates to the premodification cohort. In mathematical terms, this scaling factor is a constant that gets multiplied by the transplant rate for each patient, effectively resetting the intercept to meet the desired constraint on total transplants. This approach preserves the relative differences in transplant access by blood type, medical urgency, and other attributes that were observed in the postmodification era while constraining total transplants to the premodification level.

As a sensitivity analysis, we repeated all analyses using only the first 4 months of each policy era, given that behaviors might have changed and exceptions might have been requested for candidates with blood type O after the simulation modeling error was discovered.

3. Results

3.1. Cohort summary

In the premodification era, 2803 adult lung candidates were eligible for analysis, of whom 938 were still waiting in the postmodification era. In the postmodification era, 2759 adult lung candidates were eligible for analysis (Table 1). During the premodification era, 1688 candidates received transplants, and 92 died or were removed for deterioration in condition. Postmodification, 1681 candidates received transplants, and 97 died or were removed for deterioration in condition. For blood type O candidates, the cumulative incidence of transplant was significantly higher after the score modification ($P < .001$ in Fine-Gray test), reaching 0.66 (95% CI: 0.63, 0.69) in the postmodification era, compared with 0.57 (95% CI: 0.54, 0.60) in the premodification era (Fig. 1). There were no significant differences between eras for the other blood types or for the outcome of waitlist mortality for any blood type. About 80% of candidates had missing cPRA values, indicating no reported unacceptable antigens, and there were no other missing data.

3.2. Transplant rate and waitlist mortality rate

During backward selection to build the transplant rate model, the interactions of the policy period with waitlist survival AUC and with posttransplant survival AUC were removed, and the interaction of the policy period with candidate height was retained. In this reduced model, the effect of blood type significantly changed after the score modification (P for interaction $< .001$; Fig. 2). Before the score modification, type O candidates had an aRR (95% CI) of 0.40 (0.36, 0.45) compared with premodification type A candidates, which attenuated to 0.52 (0.45, 0.59) after the score modification, for a candidate of average height. This corresponds to an increase of 29% (95% CI: 13%, 47%) in transplant rate for type O candidates, from premodification to postmodification, with no significant changes in other blood type groups. Type AB candidates had the highest transplant rates in both eras (aRR [95% CI]: 1.40 [1.04, 1.88] premodification, 1.53 [1.06, 2.23] postmodification). The effect of candidate height also significantly changed after the score modification ($P = .03$), with a reduced disparity between the shortest and tallest candidates after the modification (Fig. 3).

During backward selection to build the waitlist mortality rate model, all 2-way interactions with the policy period were removed

Table 1
Baseline characteristics of adult lung candidates pre vs post the OPTN blood type score modification.

Characteristic	Premodification (N = 2803)	Postmodification (N = 2759)	Overall (N = 5562)
Blood type			
A	1023 (36.5%)	922 (33.4%)	1945 (35.0%)
AB	90 (3.2%)	68 (2.5%)	158 (2.8%)
B	319 (11.4%)	277 (10.0%)	596 (10.7%)
O	1371 (48.9%)	1492 (54.1%)	2863 (51.5%)
Height (cm)			
Mean (SD)	168 (10.3)	168 (10.3)	168 (10.3)
Median (minimum, maximum)	168 (140, 201)	168 (128, 201)	168 (128, 201)
cPRA			
Mean (SD)	0.355 (0.292)	0.328 (0.283)	0.341 (0.287)
Median (minimum, maximum)	0.280 (0.0000460, 0.999)	0.266 (0.0000460, 1.00)	0.277 (0.0000460, 1.00)
Missing	2268 (80.9%)	2195 (79.6%)	4463 (80.2%)
Waitlist AUC			
Mean (SD)	299 (83.5)	296 (84.0)	297 (83.8)
Median (minimum, maximum)	329 (3.48, 365)	327 (2.86, 365)	328 (2.86, 365)
Posttransplant AUC			
Mean (SD)	1420 (99.0)	1410 (103)	1420 (101)
Median (minimum, maximum)	1430 (859, 1740)	1430 (689, 1670)	1430 (689, 1740)
Primary diagnosis group			
A	675 (24.1%)	626 (22.7%)	1301 (23.4%)
B	213 (7.6%)	183 (6.6%)	396 (7.1%)
C	60 (2.1%)	44 (1.6%)	104 (1.9%)
D	1855 (66.2%)	1906 (69.1%)	3761 (67.6%)
Age at listing (y)			
Mean (SD)	58.5 (11.5)	59.5 (11.3)	59.0 (11.4)
Median (minimum, maximum)	62.0 (18.0, 79.0)	62.0 (18.0, 78.0)	62.0 (18.0, 79.0)
Birth sex			
Female	1348 (48.1%)	1301 (47.2%)	2649 (47.6%)
Male	1455 (51.9%)	1458 (52.8%)	2913 (52.4%)
OPTN region			
1	121 (4.3%)	117 (4.2%)	238 (4.3%)
2	357 (12.7%)	339 (12.3%)	696 (12.5%)
3	267 (9.5%)	273 (9.9%)	540 (9.7%)
4	338 (12.1%)	337 (12.2%)	675 (12.1%)
5	438 (15.6%)	428 (15.5%)	866 (15.6%)
6	79 (2.8%)	80 (2.9%)	159 (2.9%)
7	300 (10.7%)	299 (10.8%)	599 (10.8%)
8	129 (4.6%)	112 (4.1%)	241 (4.3%)
9	218 (7.8%)	248 (9.0%)	466 (8.4%)

(*continued on next page*)

Table 1 (*continued*)

Characteristic	Premodification (N = 2803)	Postmodification (N = 2759)	Overall (N = 5562)
10	332 (11.8%)	338 (12.3%)	670 (12.0%)
11	224 (8.0%)	188 (6.8%)	412 (7.4%)
Duration of follow-up (d)			
Mean (SD)	69.5 (68.2)	67.2 (68.1)	68.3 (68.2)
Median (minimum, maximum)	41.0 (1.00, 201)	38.0 (1.00, 201)	40.0 (1.00, 201)

AUC, area under the curve; cPRA, calculated panel-reactive antibody; OPTN, Organ Procurement and Transplantation Network.

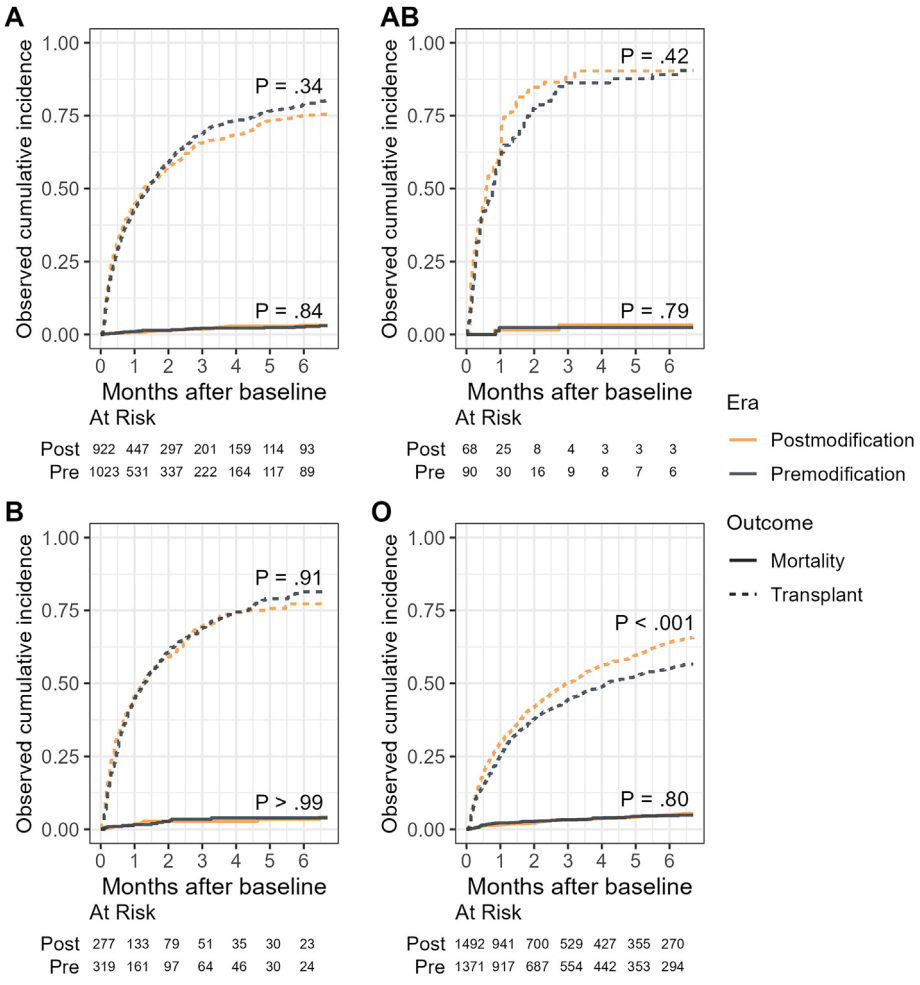

Figure 1. Observed (unadjusted) cumulative incidence of transplant and waitlist mortality, by blood type and policy era. *P* values are from Fine-Gray tests comparing policy eras.

to improve model fit, including the interaction of policy period with blood type. In this reduced model, there was no evidence of a significant change in waitlist mortality rate after the blood type score modification (ie, no main effect of policy period) ($P = .62$) and no significant differences by blood type ($P = .60$). Concordance, calibration plots, and coefficients for the reduced transplant rate and waitlist mortality models are available in Supplementary Tables S3-S5 and Supplementary Figs. S1 and S2.

Using both rate models, we calculated an adjusted cumulative incidence of waitlist mortality for each policy period and blood type. For this predictive analysis, we considered the Akaike information criterion of more parsimonious mortality models and ultimately selected a mortality rate model including only waitlist survival AUC and posttransplant survival AUC, meaning any differences in the cumulative incidence of mortality by era and blood type are attributable to differences in the model-predicted transplant rate. In both eras, mortality incidence was highest for type O candidates, although type O candidates had the largest reduction in mortality after the score modification (maximum incidence of 3.6% [95% CI: 3.0%, 4.3%] premodification, 3.2% [95% CI: 2.6%, 3.8%] postmodification). There was also a slight decrease in mortality incidence for type AB candidates, a slight

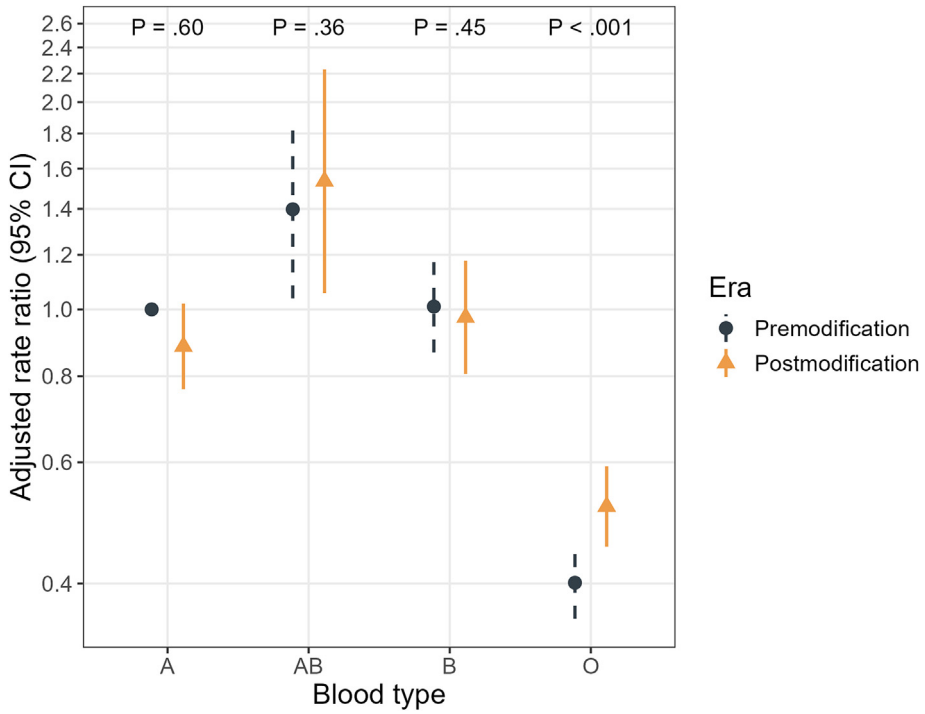

Figure 2. Transplant rate ratios for blood type by policy era, adjusted for height, calculated panel-reactive antibody value, waitlist survival area under the curve, posttransplant survival area under the curve, and transplant center, for a candidate of average height (168 cm). Premodification type A candidates are the reference group. *P* values are for the interaction between each blood type and policy era.

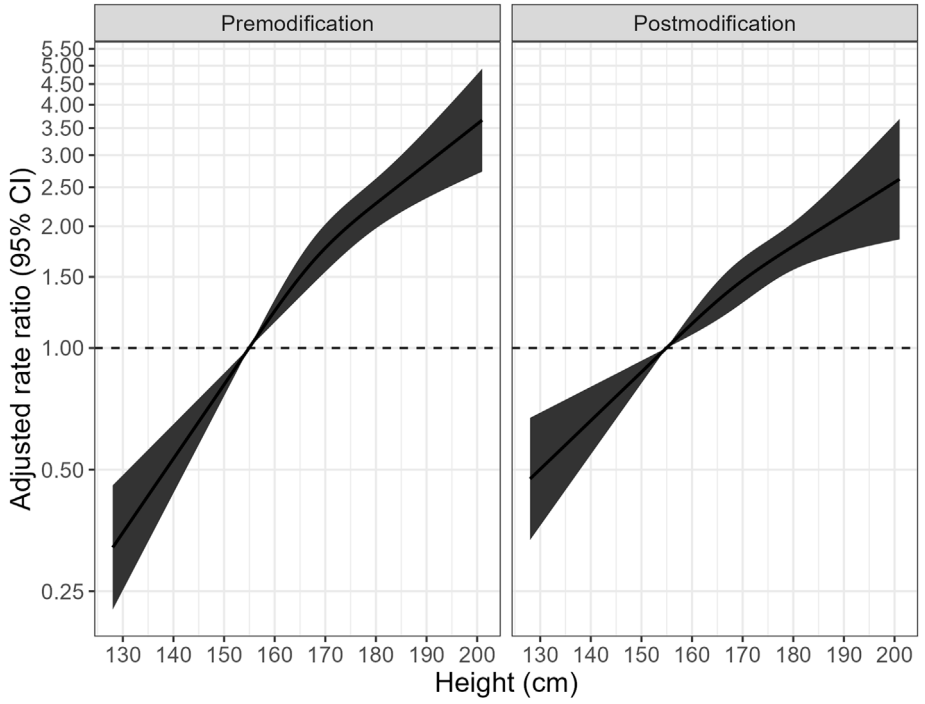

Figure 3. Transplant rate ratios for candidate height by policy era, adjusted for blood type, calculated panel-reactive antibody value, waitlist survival area under the curve, posttransplant survival area under the curve, and transplant center. The interaction between height and policy era was statistically significant ($P = .03$).

increase for type A candidates, and effectively no change for type B candidates (Fig. 4).

When we refit these models using only the first 4 months of each era, there were no major differences in the results (Fig. 5).

3.3. Counterfactual analysis

A counterfactual analysis was performed to predict waitlist outcomes under premodification vs postmodification rates, in the

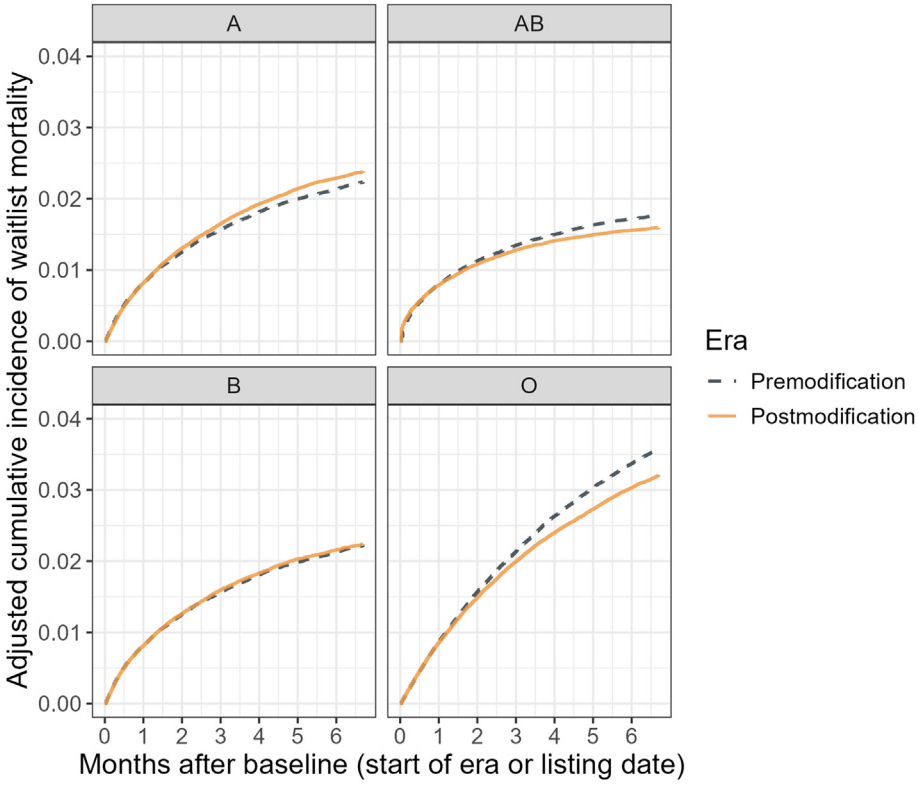

Figure 4. Cumulative incidence of waitlist mortality by blood type and policy era, adjusted for height, calculated panel-reactive antibody value, waitlist survival area under the curve, posttransplant survival area under the curve, and transplant center. The adjusted cumulative incidence is calculated as the median model-predicted cumulative incidence across all premodification patients, if those patients had had the specified blood type in the specified era.

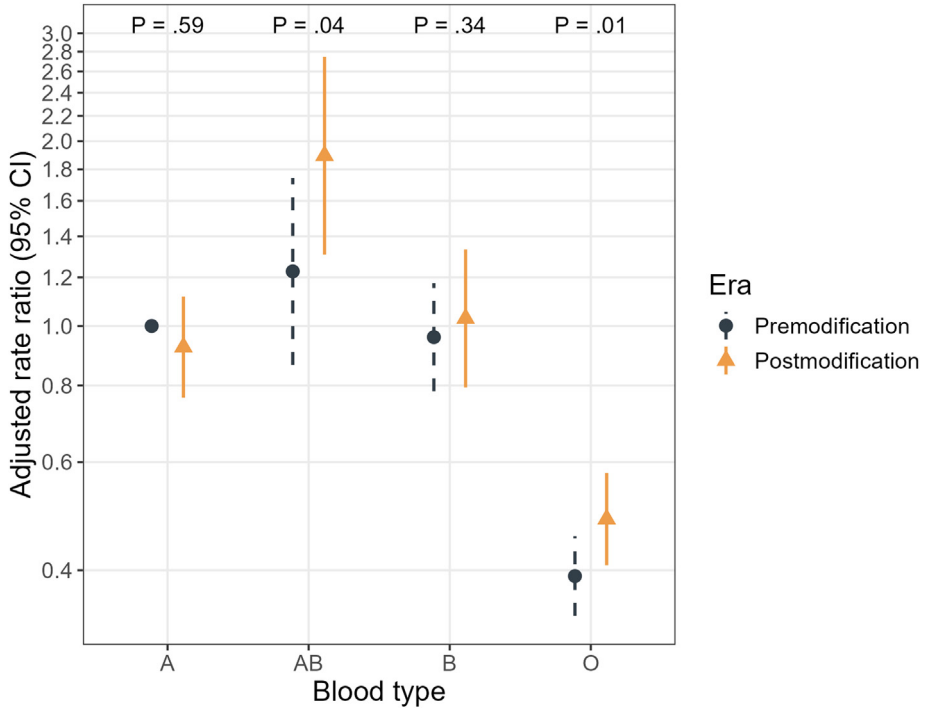

Figure 5. Transplant rate ratios for blood type by policy era in the 4-month sensitivity analysis, adjusted for height, calculated panel-reactive antibody value, waitlist survival area under the curve, posttransplant survival area under the curve, and transplant center, for a candidate of average height (168 cm). Premodification type A candidates are the reference group. *P* values are for the interaction between each blood type and policy era.

premodification cohort of adult lung candidates, using the final version of the 2 rate models. This exploratory analysis aimed to estimate how many transplants and deaths would have occurred, by blood type, if the modified blood type score had been adopted at the start of continuous distribution. Applying premodification rates to the premodification cohort (N = 2803), we predicted a total of 1724.7 (95% CI: 1663.1, 1789.8) transplants, mostly in type A (727.6 [95% CI: 682.1, 773.5] transplants) and type O candidates (696.3 [95% CI: 651.1, 740.1] transplants) (Table 2). When postmodification rates were applied to the same cohort with a constraint on total transplants, there were 57.8 (95% CI: 35.1, 80.9) additional predicted type O transplants, 48.5 (95% CI: 25.8, 72.6) fewer type A transplants, 9.5 fewer (95% CI: 22.0 fewer, 3.9 additional) type B transplants, and about the same number of type AB transplants. Notably, the premodification and postmodification rates yielded roughly the same number of total predicted deaths (104.5 [95% CI: 90.3, 119.3] and 104.6 [95% CI: 90.2, 119.1], respectively), despite our methodology not requiring these 2 totals to be equal (as it did for predicted transplants). Under the postmodification rates, there were 4.6 (95% CI: 2.7, 6.8) fewer predicted type O deaths in the premodification cohort, 4.1 (95% CI: 2.1, 6.1) additional type A deaths, 0.7 additional (95% CI: 0.3 fewer, 1.6 additional) type B deaths, and the same number of deaths in type AB candidates.

4. Discussion

The OPTN modified the allocation points given for blood type in lung continuous distribution on September 27, 2023, to increase transplant access for blood type O candidates.[3] This analysis confirms that the score modification was effective in reducing the disparity in transplant rate by blood type under continuous distribution. The transplant rate for blood type O candidates significantly increased by 29% from premodification to postmodification—the largest change in transplant rate between the eras for any blood type (Fig. 2). In contrast, there were no significant changes in waitlist mortality rate from premodification to postmodification, controlling for candidate characteristics in each era, and there were no significant differences in waitlist mortality rate between blood types. Therefore, the higher transplant rate for type O candidates was solely responsible for reducing the adjusted cumulative incidence of waitlist mortality in type O candidates from 3.6% premodification to 3.2% postmodification, which was the largest change in mortality incidence between the eras for any blood type (Fig. 4). Our exploratory counterfactual analysis estimated that, if adopted at the start of lung continuous distribution, the modified blood type score might have resulted in 57.8 additional transplants to type O candidates instead of candidates of other blood types and 4.6 fewer type O deaths; however, note that this counterfactual analysis also estimated there would have been 4.8 additional deaths in type A and type B candidates (Table 2).

Our results are consistent with unadjusted results from the OPTN 1-year monitoring report on lung continuous distribution, which compared premodification with postmodification CAS and also examined a 5.5-month period prior to CAS implementation. Transitioning from the pre-CAS period to the premodification CAS period, in type O candidates, the unadjusted waitlist mortality rate decreased by about 32% and the unadjusted transplant rate decreased by about 15%. From premodification to postmodification, in type O candidates, the unadjusted waitlist mortality rate stayed the same, and the unadjusted transplant rate increased by about 20%.[8]

This analysis focused on waitlist outcomes by blood type after the score modification; however, a characteristic of a composite score is that changing the contribution of one attribute affects the prioritization of all other attributes in the final score. In evaluating the impact of the blood type score modification, we observed a reduction in the relative differences in transplant rate by candidate height (Fig. 3). For example, in the premodification era, a candidate at the 75th percentile of height (175 cm) had an aRR (95% CI) of 1.65 (1.51, 1.80) relative to a candidate at the 25th percentile (160 cm), which attenuated to 1.42 (1.31, 1.54) for the same interquartile comparison in the postmodification era. This interaction of height with the policy period was most pronounced at the extremes of height. It is not surprising that the blood type score modification might have had this effect on another attribute. Again, changing the rating scale or weight of any one attribute in a composite score affects the prioritization of other attributes, and the scale and direction of change might be counterintuitive.

Table 2
Predicted transplants and predicted deaths by blood type for the premodification cohort of adult lung candidates waiting on any day from March 10, 2023, through September 26, 2023, under premodification rates vs postmodification rates. The postmodification transplant rate was scaled to ensure no change in the total predicted transplants. Predicted deaths include removals for deterioration in condition. The total number of predicted events might not equal the sum across blood types due to rounding.

	Predicted no. of events (95% bootstrap CI)				
	A (N = 1023)	AB (N = 90)	B (N = 319)	O (N = 1371)	Total (N = 2803)
Predicted transplants					
Under premodification rates	727.6 (682.1, 773.5)	73.2 (57.1, 90.5)	227.6 (200.9, 253.3)	696.3 (651.1, 740.1)	1724.7 (1663.1, 1789.8)
Under postmodification rates	679.1 (633.3, 725.1)	73.4 (57.5, 91.3)	218.1 (190.9, 244.4)	754.1 (710.0, 796.5)	1724.7 (1663.2, 1789.9)
Predicted deaths					
Under premodification rates	30.8 (25.8, 36.1)	2.0 (1.3, 3.0)	9.0 (7.1, 10.9)	62.7 (53.2, 72.1)	104.5 (90.3, 119.3)
Under postmodification rates	34.9 (29.4, 41.1)	2.0 (1.2, 2.9)	9.7 (7.5, 11.8)	58.1 (49.2, 66.7)	104.6 (90.2, 119.1)

Building continuous distribution policies will require monitoring these interactions and expecting secondary impacts of policy changes. Research on the impact of candidate height on access to lung transplant is ongoing.

Although the blood type score modification significantly improved transplant access by blood type, disparities remain. The pattern of increasing lung transplant rate with increasing candidate height was present in both policy eras (Fig. 3), and the general pattern of access by blood type was the same across eras, with the most access for type AB candidates and the least access for type O candidates at the same level of acuity and allocation priority (Fig. 2). Our analysis did not adjust for candidates who received exceptions to their calculated score after review by the national Lung Review Board. The blood type disparity may be even more pronounced in the absence of the disproportionate use of "exceptions" for type O candidates, especially premodification.[8] The CAS was designed to weigh all attributes considered in the allocation of donor lungs simultaneously. Blood type was weighted at a maximum of 5 out of 100 total points, with waitlist acuity and predicted posttransplant survival making up a maximum of 50 points.[1] Therefore, the composite score was not designed (nor would it be predicted) to achieve equal transplant rates by blood type. Rather, the composite score was designed to provide a boost for candidates with harder-to-match biological characteristics including blood type, allowing other candidate attributes to be prioritized above candidate blood type during lung allocation. In our analysis, we did not compare with the previous classification-based lung allocation system, because our target of inference was the effect of the blood type score modification of CAS, not the effect of transitioning to CAS. Future research could include pre-CAS data to better determine how access has changed over time and quantify trade-offs between equity in access by blood type and other system goals.

Our counterfactual analysis to estimate waitlist outcomes if the modified score had been adopted at the start of continuous distribution makes 2 noteworthy assumptions: (1) any change in the number of transplants between policy eras is due to donor availability and not the impact of the modified blood type score on lung utilization; and (2) the model-estimated policy interaction effects are due to the policy change itself, not changes in lung donor characteristics over time. We believe these assumptions may be reasonable, given the limited nature of the policy change and the short time span of this analysis. To further evaluate the second assumption, we examined national distributions of blood type and height in lung donors over time (Supplementary Figs. S3 and S4). In both policy periods, the trends were nonlinear but displayed an uptick in recovered lungs from type A and particularly type O donors starting in February 2024, as well as an increase over time in lung donors 170 cm or taller. Importantly, when we reran our analyses on the first 4 months of each policy period, we found essentially the same effect of blood type on transplant rate in the postmodification compared with the premodification era (Fig. 5); this 4-month sensitivity analysis censored postmodification candidates on January 27, 2024, so the more-recent uptick in type O donors cannot fully explain our findings. Likewise, we would not expect to observe a reduced disparity in transplant access by candidate height as a result of more tall donors having lungs recovered, because taller lung candidates had faster transplant rates to begin with, in the premodification period of continuous distribution. Although these sensitivity analyses lend robustness to our results, we emphasize that the counterfactual analysis should still be viewed as exploratory.

Limitations of our observational analysis include the potential for unmeasured confounding that was not captured in the OPTN database or in our modeling. Although our models included all candidate attributes in the lung CAS, there may be confounders that contribute to the transplant rate through offer acceptance behaviors only, not allocation policy, and have shifted in the candidate population over time. Donor characteristics and availability can also vary over time, as discussed above, and policy effects are not separable from time effects in this analysis. Misclassification is also possible in registry analyses. In our study, for example, sensitization is likely to be underreported, with both sensitized and unsensitized candidates reporting no unacceptable antigens (ie, cPRA of 0). However, cPRA was a control covariate in this analysis, not a primary exposure, and therefore a proportion of misclassification is unlikely to dramatically affect our main findings.

In conclusion, the OPTN blood type score modification for lung continuous distribution significantly increased the transplant rate for adult blood type O lung candidates. Our analyses suggest the modification led to reduced disparities in transplant access by blood type in the postmodification period, compared with an equal period under continuous distribution premodification. Continued monitoring of outcomes by blood type will be essential to inform whether further adjustments to the CAS are needed to better meet the goals and uphold the values of stakeholders in the lung transplant community.

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Declaration of competing interest

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Data availability

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajt.2025.01.034.

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References

1. Organ Procurement and Transplantation Network. Notice of OPTN policy, guidance, and guideline changes. *Establish continuous distribution of lungs*; 2023. https://optn.transplant.hrsa.gov/media/b13dlep2/policy-notice_lung_continuous-distribution.pdf. Accessed May 19, 2024.
2. Weiss S, Weibel C, Mupfudze T. OPTN Lung Transplantation Committee. Lung continuous distribution three month monitoring report. https://optn.transplant.hrsa.gov/media/fzhh1e5r/data_report_lung_committee_cd_07_13_2023.pdf; 2023. Accessed May 19, 2024.
3. Organ Procurement and Transplantation Network. Notice of OPTN policy change. Modify lung allocation by blood type. https://optn.transplant.hrsa.gov/media/rrkeagop/policy-notice_lung-blood-type_sep-2023.pdf; 2023. Accessed May 19, 2024.
4. Valapour M, Lehr CJ, Wey A, Skeans MA, Miller J, Lease ED. Corrigendum 'Expected effect of the lung Composite Allocation Score system on US lung transplantation' [American Journal of Transplantation. Volume 22, Issue 12 (December 2022) Pages 2971-2980]. *Am J Transplant*. 2024;24(8):1520. https://doi.org/10.1016/j.ajt.2024.04.019.
5. Wey A, Miller J, Skeans M, Weaver T, Audette K, Valapour M. Continuous distribution simulations for lung transplant: Round 2. https://optn.transplant.hrsa.gov/media/4646/lu2021_01_cont_distn_report_final.pdf; 2021. Accessed May 19, 2024.
6. Leppke S, Leighton T, Zaun D, et al. Scientific Registry of Transplant Recipients: collecting, analyzing, and reporting data on transplantation in the United States. *Transplant Rev (Orlando)*. 2013;27(2):50–56. https://doi.org/10.1016/j.trre.2013.01.002.
7. Hernán MA, Robins JM. Using big data to emulate a target trial when a randomized trial is not available. *Am J Epidemiol*. 2016;183(8):758–764. https://doi.org/10.1093/aje/kwv254.
8. Weiss S, Hawkins C. OPTN Lung Transplantation Committee. *Lung continuous distribution one year monitoring report*; 2024. https://optn.transplant.hrsa.gov/media/srino34s/data_report_lung_cd_1year_20240509.pdf. Accessed May 28, 2024.