ATS Journals | Annals of the American Thoracic Society

Race-specific Interpretation of Spirometry: Impact on the Lung Allocation Score

Journal:	*Annals of the American Thoracic Society*
Manuscript ID	White-202212-1004OC.R1
Manuscript Type:	OC - Original Research
Date Submitted by the Author:	01-Apr-2023
Complete List of Authors:	Brems, John; Johns Hopkins University School of Medicine, Pulmonary and Critical Care Medicine Balasubramanian, Aparna; Johns Hopkins University, Pulmonary and Critical Care Medicine Psoter, Kevin; Johns Hopkins Bloomberg School of Public Health, Biostatistics Shah, Pali; Johns Hopkins University School of Medicine, Pulmonary/Respiratory Bush, Errol; Johns Hopkins School of Medicine, Department of Surgery, Division of Thoracic Surgery Merlo, Christian; Johns Hopkins University School of Medicine, Pulmonary and Critical Care Medicine McCormack, Meredith; Johns Hopkins University, Pulmonary and Critical Care
Subject Category:	2.09 Racial, Ethnic, or Social Disparities in Lung Disease and Treatment < BEHAVIORAL SCIENCE
Key Words:	Race, Spirometry, Transplant, Lung allocation score, LAS

Race-specific Interpretation of Spirometry: Impact on the Lung Allocation Score

J. Henry Brems[1], MD, MBE, Aparna Balasubramanian[1], MD, MHS, Kevin J. Psoter[2], PhD, Pali Shah[1], MD, Errol L. Bush[3], MD, Christian A Merlo[1], MD, MPH, Meredith C McCormack[1], MD, MHS

1 Johns Hopkins School of Medicine, Division of Pulmonary and Critical Care Medicine, Department of Medicine, Baltimore, MD
2 Johns Hopkins School of Medicine, Department of Pediatrics, Division of General Pediatrics, Baltimore, MD, United States
3 Johns Hopkins School of Medicine, Department of Surgery, Division of Thoracic Surgery, Baltimore, MD

Corresponding Author: J. Henry Brems, M.D., M.B.E.
Email: jbrems2@jh.edu
Mail: 1830 E. Monument St, 5th Floor, Baltimore, MD 21205

Running Title: Race-specific Spirometry and the LAS

Subject Category: 2.9 Racial, Ethnic, or Social Disparities in Lung Disease and Treatment

Word count: 3335

Author contributions: Conception and design of the study: J.H.B., A.B., K.J.P., C.A.M, M.C.M; Data acquisition: J.H.B, P.S., E.L.B., C.A.M, M.C.M; Analysis and data interpretation: J.H.B., A.B., K.J.P., P.S., E.L.B., C.A.M, M.C.M; Drafting and critical revision of the manuscript: J.H.B., A.B., K.J.P., P.S., E.L.B., C.A.M, M.C.M

Sources of Support: Supported by National Institutes of Health grants T32HL007534 (J.H.B)., K23 HL153778 (A.B.) R01HL152419 (MCM), R61HL157845 (MCM), R01HL154860 (MCM), P50ES018176 (MCM), P2CES033415 (MCM). The funders had no role in the study design, data collection, analysis, or interpretation of this study.

Key words: Race, Spirometry, Transplant, Lung allocation score, LAS

This article has an online supplement, which is accessible from this issue's table of contents online at www.atsjournals.org

Abstract

Rationale: Interpretation of spirometry using race-specific reference equations may contribute to health disparities via underestimation of the degree of lung function impairment in Black patients. The use of race-specific equations may differentially impact patients with severe respiratory disease via the use of percent predicted Forced Vital Capacity (FVCpp) when included in the Lung Allocation Score (LAS), the primary determinant of priority for lung transplant.

Objective: To determine the impact of a race-specific versus race-neutral approach to spirometry interpretation on the LAS among adults listed for lung transplant in the U.S.

Methods: We developed a cohort from the United Network for Organ Sharing database including all White and Black adults listed for lung transplant between January 7, 2009 and February 18, 2015. The LAS at listing was calculated for each patient under a race-specific and race-neutral approach, using the FVCpp generated from the GLI equation corresponding to each patient's race (race-specific) or from the GLI 'Other' (race-neutral) equation. Differences in LAS between approaches were compared by race, with positive values indicating a higher LAS under the race-neutral approach.

Results: In this cohort of 8,982 patients, 90.3% were White and 9.7% were Black. The mean FVCpp was 4.4% higher vs 3.8% lower among White versus Black patients ($p<0.001$) under a race-neutral compared to race-specific approach. Compared to White patients, Black patients had a higher mean LAS under both a race-specific (41.9 vs 43.9, $p<0.001$) and race-neutral (41.3 vs 44.3, $p<0.001$) approach. However, the mean difference in LAS under a race-neutral approach was -0.6 vs +0.6 for White vs Black patients ($p<0.001$). Differences in LAS under a race-neutral approach were most pronounced for those in Group B [pulmonary vascular disease] (-0.71 vs +0.70, $p<0.001$) and Group D [restrictive lung disease] (-0.78 vs +0.68, $p<0.001$).

Conclusions: A race-specific approach to spirometry interpretation has potential to adversely impact the care of Black patients with advanced respiratory disease. Compared to a race-neutral approach, a race-specific approach resulted in a lower LAS for Black patients and higher LAS for White patients, which may have contributed to racially biased allocation of lung transplants. The future use of race-specific equations must be carefully considered.

Word count (abstract): 349

Race-specific reference equations are currently recommended for the interpretation of spirometry,(1) but their use has been increasingly called into question. Although average lung function from epidemiologic data of healthy populations has been observed to vary by race,(2) recent studies have suggested that race-specific equations may inappropriately normalize the lower lung function seen among Black and Asian populations.(3–5) This concern has raised questions regarding whether a race-neutral approach to spirometry interpretation, in which the same reference equation would be applied to all patients regardless of their race, is more appropriate.(6–9)

By inflating percent predicted spirometry values for Black and Asian patients, race-specific equations may lead providers to systematically underestimate the degree of lung function impairment for these racial groups. As a result, these equations may contribute to respiratory health disparities. While evidence that race-specific equations inappropriately normalize lower lung function has primarily resulted from healthy populations, racial disparities associated with race-specific reference equations may be exaggerated among more severely diseased individuals, such as those being evaluated for lung transplant.

Priority for lung transplant in the U.S. has primarily relied on the lung allocation score (LAS) since 2005.(10) The LAS is calculated from multiple clinical variables indicative of disease severity, and it has historically included the percent predicted Forced Vital Capacity (FVCpp),(11) which is derived from race-specific reference equations. Although implementation of the LAS improved racial disparities in lung transplant compared to the pre-LAS era in terms of reduced risk of death on the waitlist and increased chance of receiving a lung transplant for Black patients,(12,13) more recent data have shown that Black patients on the waitlist are still less likely to be allocated lungs in the post-LAS era compared to White patients.(14,15)

Although these disparities exist even when controlling for the LAS, the use of race-specific reference equations may have further contributed to the disparate outcomes by estimating a higher FVCpp—and thus a lower LAS and priority for lung transplant among Black patients (compared to a lower FVCpp and higher LAS for White). Given the emphasized need for the equitable distribution of lung transplants as a scarce resource,(10,16–18) and the need for further evidence of the clinical impact of including race in the interpretation of spirometry, understanding if and how a race-specific spirometry interpretation can impact lung transplant allocation is necessary.

Thus, we sought to investigate the effect of race-specific versus race-neutral equations for the interpretation of spirometry on the LAS among Black and White adults listed for lung transplant in the U.S.

Methods

Study Sample

We conducted a retrospective study of all Black or White patients 18 years or older from the United Network for Organ Sharing (UNOS) database who were listed for lung transplant between January 7, 2009 and February 18, 2015. We only included patients of Black or White race as reported in the UNOS database because Black and White patients have the greatest difference in FVCpp with race-specific compared to race-neutral equations.(2) We excluded patients listed after February 18, 2015 as FVCpp was not incorporated for all patients when calculating the LAS after this date.(19) Patients listed prior to January 7, 2009 were excluded as

a revision to the LAS was implemented at that time. We additionally excluded any patients listed for multi-organ transplant to ensure LAS was the primary determinant of priority for transplant.

Patients without a reported FVC were excluded as their FVCpp could not be determined. Lastly, we excluded all patients with missing data for any variable used to calculate the LAS in order to improve validity of our LAS calculation.

LAS calculation

The UNOS LAS calculator that was in effect from January 7, 2009 to February 18, 2015 was used to determine the LAS at listing for each patient.(20) The LAS is calculated by first determining both a waitlist urgency measure (WLi) and posttransplant survival measure (PTi), each of which are derived using independent formulas with a related set of clinical variables, and they denote the expected number of days survived out of the next 365 either without transplant or after transplant. The LAS is then calculated by combining these two measures and normalizing to a scale from 0 to 100. The formulas used to calculate the WLi, PTi, and LAS as well the process used to validate these calculations are found in the Supplement.

Race-specific and Race-neutral approach

We determined the LAS using both a race-specific and race-neutral approach. For the race-specific approach, we calculated the FVCpp using the Global Lung Function Initiative (GLI) equation corresponding to each patient's reported race as recorded in the UNOS database. For the race-neutral approach, we calculated the FVCpp using the GLI 'Other' equation for all

patients regardless of race. The resultant FVCpp was then used to calculate either a race-specific or race-neutral LAS.

For both approaches, all percent predicted values were calculated via the online GLI calculator using each patient's absolute FVC, age, sex, and height from time of initial listing.(21) Although GLI equations were not developed until 2012, we employed them in this study to evaluate the potential impact of currently recommended equations. The GLI 'Other' was selected as our race-neutral approach because the equation does not include a term for race/ethnicity, is averaged from four racial/ethnic groups, and has been previously studied as such an approach.(2–5,22)

Analysis of Difference in LAS between approaches

Demographics and descriptive variables obtained from the UNOS databases were compared across Black and White race using Student's t-test and Mann Whitney U tests for continuous variables and Chi square or Fisher exact tests for categorical variables. Mean differences in spirometry values, LAS, and predicted survival (without transplant and following transplant) were compared between White and Black individuals under both a race-specific and race-neutral approach, as well as the mean differences between the race-specific and race-neutral approaches for White and Black individuals using the previously described approaches. Differences in percent predicted values by race were plotted across the range of observed raw values to assess systematic differences.

To evaluate for varying differences by LAS, we plotted the race-specific LAS (RS-LAS) and race-neutral LAS (RN-LAS) difference against RS-LAS score by race. We also defined bins

by every 10 points of RS-LAS and assessed the average difference between RS-LAS and RN-LAS for each bin across races to better define the range of LAS values across which the greatest difference was observed. Additionally, subgroup analyses by diagnosis groupings (A = Obstructive Lung Disease, B = Pulmonary Vascular Disease, C =Cystic Fibrosis or Immunodeficiency disorder, D = Restrictive Lung Disease) were performed.

To evaluate the potential impact of excluding patients with missing data, we conducted a sensitivity analysis evaluating the difference in LAS between approaches when including patients who were previously excluded due to missing values for the LAS calculations. For these individuals, specified default values were used according to UNOS policy and practice (Tables S1 and S2).(20)

A two-sided P-value < 0.05 was considered statistically significant. All statistical analyses were performed using STATA version 17.0 (StataCorp, College Station, TX).

Results

Demographics

A total of 8,982 patients met inclusion criteria, of which 8,114 (90.3%) were White and 868 (9.7%) were Black (Figure S1). The disease severity of this cohort was demonstrated by a mean reported percent predicted FEV_1 (FEV_1pp) of 38% and FVCpp of 51% among all patients.

Demographics and clinical characteristics of the study population at time of listing are presented in Table 1. The most common diagnosis grouping was Group D (restrictive lung disease) with 4,474 (49.8%) patients. In general, Black patients were younger, more commonly female, less commonly ever smokers, and had a higher average body mass index (BMI) at listing

than White patients. Black patients had multiple indicators of greater disease severity at listing, including a higher median O_2 flow rate (3.0 vs 3.5 L/min), lower median six-minute walk distance (875 vs 770 ft), lower measured FEV_1 (1.2 vs 1.1 L), and lower measured FVC (2.1 vs 1.7 L) compared to White patients ($p<0.001$ for all).

Individuals' medical information used to calculate LAS is summarized in Table S3.

Percent Predicted Spirometry

Spirometry values based on race-specific and race-neutral approaches for White and Black individuals are shown in Table 2. Despite a lower raw FVC among Black patients as compared to White patients, there was no statistically significant difference in FVCpp between White and Black patients using a race-specific approach (51.3% vs 50.4%, $p=0.19$) Moving to a race-neutral approach, however, FVCpp was higher by 4.4%-points on average for White patients and decreased by 3.8%-points for Black patients, resulting in an overall difference of 9%-points (White 55.7% vs Black 46.7%, $p<0.001$).

Similarly, White patients had a 2.6%-points higher mean FEV_1pp under a race-neutral approach compared to race-specific approach (38.0% vs 35.4%, $p<0.001$), whereas Black patients had a 3.0%-point lower mean FEV_1pp under a race-neutral compared to race-specific approach (35.6% vs 38.6%, $p<0.001$). When using a race-specific approach, White individuals had a 3.2%-point lower mean FEV_1pp than Black individuals, whereas when using a race-neutral approach, White individuals had, on average, a 2.4%-point higher FEV_1pp than Black individuals ($p<0.001$).

The difference in FVCpp and FEV_1pp between the race-specific and race-neutral approaches varied over the range of raw FEV_1 and FVC, and this difference appeared to increase as lung volume increased (Figure 1).

Lung Allocation Score

The LAS calculated using race-specific and race-neutral approaches to interpreting spirometry for White and Black patients are shown in Table 2. Compared to White patients, Black patients had a significantly higher LAS at listing under both a race-specific (41.9 vs 43.8, $p<0.001$) and race-neutral (41.3 vs 44.3, $p<0.001$) approach (Table 2).

On average, White patients had a RN-LAS that was 0.6 points lower than the RS-LAS, as compared to Black patients who had a RN-LAS that was 0.6 points higher than their RS-LAS ($p<0.001$). Notably, the difference in LAS between approaches varied according to the RS-LAS and were characterized by a U-shaped (or inverted U-shaped) relationship, with differences in LAS more pronounced among those with a RS-LAS between approximately 40-80 (Figure 2A). When the cohort was divided into bins by 10-point intervals, the average differences between RN-LAS and RS-LAS across the range of 40-80 were approximately 1 LAS point lower or higher, respectively for White and Black patients (Table S4).

In subgroup analyses by diagnosis groupings, the change in LAS was greatest in Group B (-0.71 vs +0.71, $p<0.0001$) and Group D (-0.78 vs +0.68, $p<0.001$). Patients in Group B had the highest change in FVCpp (Table 3). The difference in LAS between approaches had a similar relationship with RS-LAS across all subgroups, and group D appeared to have the greatest

proportion of patients with an LAS between 40-80 (Figure S2). Full results of subgroup analyses by diagnosis grouping are shown in Table 3.

Predicted Survival

Under a race-specific approach, predicted survival on the waiting list was on average higher among White than Black patients by approximately 11 days (294.8 vs 283.9 days, $p<0.001$). The difference in predicted survival under a race-neutral approach was greater among White patients, who had a mean predicted survival that was 3.3 days longer, while Black patients had a 3.3 days shorter ($p<0.001$) predicted survival (Table 2). Similar to the LAS, the difference in predicted survival without transplant between approaches was most pronounced in patients with a race-specific LAS ranging from 40-80 (Figure 2B), with a difference of approximately one week in predicted survival in opposite directions for each race (Table S2).

For predicted survival after transplant, White patients had a mean predicted survival of 318.1 days compared to 316.9 days for Black patients ($p<0.001$, Table 2). There was a small but statistically significant difference in predicted survival after transplant between approaches (+0.3 vs -0.3 days, $p <0.001$).

Sensitivity Analyses

In the sensitivity analysis, an additional 3,510 patients were included, and characteristics are shown in Table S5. Similar to the primary analysis, White patients had an RN-LAS that was 0.6 points lower than the RS-LAS, and Black patients had an RN-LAS that was 0.6 points higher. (Table S6).

Discussion

Our findings raise concern that a race-specific approach to spirometry interpretation may contribute to racial bias in respiratory disease through an impact on priority for lung transplant. These results are particularly significant in the context of interest in an evidence-based understanding of how a race-specific approach influences patient care. Overall, in this population-based study of individuals listed for lung transplant between 2009-2015, we demonstrated that a race-neutral approach, in which a single reference equation was applied to all patients regardless of race, would have resulted in a higher average LAS for Black patients and a lower average LAS for White patients compared to a race-specific approach.

Importantly, our results demonstrate how the use of race-specific equations may impact patients with severe respiratory disease. Recent data have suggested that race-specific equations may underestimate disease prevalence, severity, or outcomes among Black patients; however, these studies have generally assessed healthier cohorts that are not defined by the presence of respiratory disease and that consist of research participants.(3–5,22) In contrast, our cohort consisted of data from real-world patients with severe respiratory disease. This study fills a previously identified research gap by demonstrating that race-specific equations may have biased the care of those awaiting lung transplant. More broadly, our finding reflects wider concerns in pulmonology that race-specific equations contribute to under-treatment of respiratory disease among Black patients.(3–5,22)

In addition, our results demonstrated that inclusion of race in estimating lung function had a clear impact on the LAS. Our findings align with previous suggestions that race-specific equations may reduce access to lung transplant for Black compared to White patients.(8,9,23)

While we did not investigate measures of access to transplant such as time to transplant or probability of transplantation, the LAS is the primary determinant of priority for lung transplant in the U.S., and fairness of the LAS has been identified as a key theme in considering equity of lung transplant allocation.(10,24,25) Thus, by generating a lower LAS for Black patients, race-specific equations may have contributed to previously reported racial disparities in access to lung transplant.(14,15) Additionally, because Black and White patients have the greatest magnitude of difference in FVCpp (and thus likely in LAS) between a race-specific and race-neutral approach, the average difference in LAS for Asian patients would likely be somewhere in between -0.6 and +0.6—the differences found for White and Black patients, respectively.(2) Regardless of the exact effect size, Asian patients would have been disadvantaged relative to White patients in terms of the LAS under a race-specific system compared to a race-neutral one.

Notably, we found that the difference in LAS between a race-specific and race-neutral approach was most pronounced across the range of values wherein a change in LAS may have pronounced impact on waitlist time. A slight change in LAS among patients with a very high or very low LAS will be of minimal impact on their time on the waitlist. However, we found the greatest magnitude of difference in LAS between approaches in patients with an LAS between 40-80, which is in the middle of the LAS range. The importance of the LAS in this range is emphasized by Organ Procurement and Transplantation Network data that reports an increasing proportion of waitlisted patients have an LAS > 50 and that the median LAS at transplant is consistently greater than 40.(26)

To provide additional context for our findings, the coefficients for the LAS (Table S5) indicate that a change in arterial PCO_2 of 15 mmHg would produce a roughly equivalent change in the LAS as found in our study between a race-specific and race-neutral approach. This

analogy reflects that the difference in LAS between approaches in our study could be indicative of meaningful underlying clinical changes.

Further, we found that the choice of a race-specific or race-neutral approach had the greatest impact on patients with a Group D diagnosis, the most common grouping. This is likely due to the fact that Group D had a higher proportion of patients listed with an LAS in the 40-80 range as shown in Figure S2. Interestingly, there was a similarly high difference between approaches in Group B despite comparatively few patients listed with an LAS of 40-80. As shown in Table 3, this is likely because patients in Group B had the greatest change in FVCpp, which itself is likely a result of their greater underlying lung function (Figure 1).

Our results are also novel in demonstrating the impact of race-specific equations on percent predicted spirometry values in patients with advanced respiratory disease, and these data suggest that race-specific equations have a greater impact on respiratory health disparities earlier in the course of disease progression. The differences in percent predicted values between race-specific and race-neutral approaches were observed to be larger at higher absolute lung functions. This explains why we found on average a 4% difference in FVCpp between approaches, compared to prior studies in healthier populations that found a difference closer to 7%.(3–5) The differing impact of race-specific versus race-neutral approaches across lung function severity suggests a race-specific approach is most likely to bias care at earlier stages of disease. This upstream impact is particularly relevant to lung transplant because differences in FVCpp can affect whether a patient is listed for transplant, and the subsequent clinical and psychological effects of not being listed may be substantial.

In interpreting our findings, it must be noted that the FVCpp was only included for patients in Group D after February 18, 2015, and it was recently removed altogether from the

LAS in September 2021.(11,27) Although patients listed after February 18, 2015 were not included in our study, it is likely that race-specific equations would have had a very similar impact on the LAS for those in Group D (who would have had FVCpp incorporated into their LAS until September 2021) as those in our cohort based on the similarity in FVCpp coefficient values in the LAS equation before and after that date.(28) In addition, the lung transplant allocation system is currently pending further change from the LAS to the Continuous Allocation System (CAS),(29) which will still include current components of the LAS but also incorporate biological factors (e.g. donor compatibility), patient access, and placement efficiency. These changes demonstrate that U.S. lung allocation system is continually evolving and iteratively updated. Spirometry metrics (FVCpp or otherwise) are highly likely to be considered for inclusion in future updates given their broad importance in assessing respiratory disease severity. Thus, our results provide strong rationale to carefully consider which spirometry metrics should be evaluated for inclusion in the future.

Our study has a few limitations. First, our results do not demonstrate whether a race-specific or race-neutral approach is a more accurate measure of lung disease, but they do provide novel evidence on how race-specific equations may contribute to racial disparities in lung transplant. Second, we relied on race as reported electronically, which may be mis-reported in the electronic health record (EHR) particularly among minorities.(30) However, race as listed in the EHR is probably what is used by the embedded algorithms that produce FVCpp. This practice means our results are likely indicative of clinical practice but also underscores inherent problems with using race in clinical algorithms such as spirometry equations. Lastly, our study cannot conclude how a race-specific versus race-neutral approach impact outcomes such as probability of transplantation or time to transplantation. Multiple other factors beyond LAS

impact this such as size, blood type, preformed antibodies, and listing center.(31,32) However, because of the primary importance of LAS in determining allocation, use of a race-specific versus race-neutral interpretation of spirometry has the potential to have some effect on access to transplantation.

Conclusion

Compared to a race-neutral approach to spirometry interpretation, a race-specific approach results in a lower LAS for Black patients and higher LAS for White patients. As such, a race-specific approach may have contributed to decreased access to lung transplant among Black compared to White patients on the waitlist. Race-specific equations may promote inequitable care, and their future use must be carefully considered.

References

1. Graham BL, Steenbruggen I, Miller MR, Barjaktarevic IZ, Cooper BG, Hall GL, et al. Standardization of Spirometry 2019 Update. An Official American Thoracic Society and European Respiratory Society Technical Statement. Am J Respir Crit Care Med. 2019 Oct 15;200(8):e70–88.

2. Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, et al. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. Eur Respir J. 2012 Dec;40(6):1324–43.

3. Baugh AD, Shiboski S, Hansel NN, Ortega V, Barjakteravic I, Barr RG, et al. Reconsidering the Utility of Race-Specific Lung Function Prediction Equations. Am J Respir Crit Care Med. 2022 Apr;205(7):819–29.

4. Elmaleh-Sachs A, Balte P, Oelsner EC, Allen NB, Baugh A, Bertoni AG, et al. Race/Ethnicity, Spirometry Reference Equations, and Prediction of Incident Clinical Events: The Multi-Ethnic Study of Atherosclerosis (MESA) Lung Study. Am J Respir Crit Care Med. 2022 Mar 15;205(6):700–10.

5. McCormack MC, Balasubramanian A, Matsui EC, Peng R, Wise RA, Keet CA. Race, Lung Function and Long-term Mortality in the National Health and Examination Survey III. Am J Respir Crit Care Med [Internet]. 2021 Oct 1 [cited 2021 Oct 4]; Available from: https://www.atsjournals.org/doi/10.1164/rccm.202104-0822LE

6. Anderson MA, Malhotra A, Non AL. Could routine race-adjustment of spirometers exacerbate racial disparities in COVID-19 recovery? The Lancet Respiratory Medicine. 2021 Feb 1;9(2):124–5.

7. Schluger NW. The Vanishing Rationale for the Race Adjustment in Pulmonary Function Test Interpretation. Am J Respir Crit Care Med. 2022 Mar 15;205(6):612–4.

8. Kaminsky DA. Is There a Role for Using Race-Specific Reference Equations? Yes and No. Am J Respir Crit Care Med. 2022 Apr;205(7):746–8.

9. Bhakta NR, Balmes JR. A Good Fit versus One Size for All: Alternatives to Race in the Interpretation of Pulmonary Function Tests. Am J Respir Crit Care Med. 2022 Mar 15;205(6):616–8.

10. Egan TM, Murray S, Bustami RT, Shearon TH, McCullough KP, Edwards LB, et al. Development of the new lung allocation system in the United States. Am J Transplant. 2006;6(5 Pt 2):1212–27.

11. Updated Cohort for Calculation of the Lung Allocation Score (LAS) [Internet]. 2020. Available from: https://optn.transplant.hrsa.gov/media/4206/bp_202012_updated-cohort-for-calculation-of-the-lung-allocation-score.pdf

12. Wille KM, Harrington KF, deAndrade JA, Vishin S, Oster RA, Kaslow RA. Disparities in lung transplantation before and after introduction of the lung allocation score. The Journal of Heart and Lung Transplantation. 2013 Jul 1;32(7):684–92.

13. Lederer DJ, Benn EKT, Barr RG, Wilt JS, Reilly G, Sonett JR, et al. Racial Differences in Waiting List Outcomes in Chronic Obstructive Pulmonary Disease. Am J Respir Crit Care Med. 2008 Feb 15;177(4):450–4.

14. Mooney JJ, Hedlin H, Mohabir P, Bhattacharya J, Dhillon GS. Racial and ethnic disparities in lung transplant listing and waitlist outcomes. The Journal of Heart and Lung Transplantation. 2018 Mar 1;37(3):394–400.

15. Riley LE, Lascano J. Gender and racial disparities in lung transplantation in the United States. J Heart Lung Transplant. 2021 Sep;40(9):963–9.

16. OPTN/UNOS Ad Hoc Geography Committee. Frameworks for Organ Distribution [Internet]. OPTN. [cited 2023 Feb 26]. Available from: https://optn.transplant.hrsa.gov/media/2565/geography_publiccomment_201808.pdf

17. Egan TM. Ethical issues in thoracic organ distribution for transplant. Am J Transplant. 2003 Apr;3(4):366–72.

18. Federal Register, Volume 64 Issue 202 (Wednesday, October 20, 1999) [Internet]. [cited 2022 Aug 11]. Available from: https://www.govinfo.gov/content/pkg/FR-1999-10-20/html/99-27456.htm

19. OPTN. OPTN Lung Allocation Policy Update, Effective Feb 19, 2015 [Internet]. [cited 2022 Aug 12]. Available from: https://optn.transplant.hrsa.gov/media/1576/policynotice_20150201.pdf

20. A Guide to Calculating the Lung Allocation Score [Internet]. UNOS. 2020 [cited 2020 Dec 3]. Available from: https://unos.org/wp-content/uploads/Lung_Calculation.pdf

21. GLI Lung Function Calculator [Internet]. [cited 2022 Aug 9]. Available from: http://gli-calculator.ersnet.org/

22. Liu GY, Khan SS, Colangelo LA, Meza D, Washko GR, Sporn PHS, et al. Comparing Racial Differences in Emphysema Prevalence Among Adults With Normal Spirometry: A Secondary Data Analysis of the CARDIA Lung Study. Ann Intern Med [Internet]. 2022 Jul 19 [cited 2022 Aug 14]; Available from: https://www.acpjournals.org/doi/10.7326/M22-0205

23. Bhakta NR, Kaminsky DA, Bime C, Thakur N, Hall GL, McCormack MC, et al. Addressing Race in Pulmonary Function Testing by Aligning Intent and Evidence With Practice and Perception. Chest. 2021 Aug 24;S0012-3692(21)03692-8.

24. Merlo CA, Weiss ES, Orens JB, Borja MC, Diener-West M, Conte JV, et al. Impact of U.S. Lung Allocation Score on survival after lung transplantation. J Heart Lung Transplant. 2009 Aug;28(8):769–75.

25. Schnellinger EM, Cantu E, Kimmel SE, Szymczak JE. A Conceptual Model for Sources of Differential Selection in Lung Transplant Allocation. Annals ATS [Internet]. 2022 Aug 31 [cited 2022 Sep 5]; Available from: https://www.atsjournals.org/doi/abs/10.1513/AnnalsATS.202202-105OC

26. Valapour M, Lehr CJ, Skeans MA, Smith JM, Uccellini K, Lehman R, et al. OPTN/SRTR 2017 Annual Data Report: Lung. American Journal of Transplantation. 2019;19(S2):404–84.

27. Changes to the Updated Cohort for Calculation of the Lung Allocation Score (LAS) are now in effect [Internet]. UNOS. 2021 [cited 2022 Sep 1]. Available from: https://unos.org/news/changes-to-the-updated-cohort-for-calculation-of-the-lung-allocation-score-las-are-now-in-effect/

28. A Guide to Calculating the Lung Allocation Score [Internet]. UNOS. 2020 [cited 2023 Mar 10]. Available from: https://unos.org/wp-content/uploads/unos/lung-allocation-score.pdf

29. Lung continuous distribution policy - OPTN [Internet]. [cited 2022 Nov 30]. Available from: https://optn.transplant.hrsa.gov/professionals/by-organ/heart-lung/lung-continuous-distribution-policy/?j=628641&sfmc_sub=84493098&l=14_HTML&u=27931812&mid=100001876&jb=4#TK_Policy

30. Samalik JM, Goldberg CS, Modi ZJ, Fredericks EM, Gadepalli SK, Eder SJ, et al. Discrepancies in Race and Ethnicity in the Electronic Health Record Compared to Self-report. J Racial Ethn Health Disparities. 2022 Nov 23;

31. Benvenuto LJ, Arcasoy SM. The new allocation era and policy. Journal of Thoracic Disease [Internet]. 2021 Nov [cited 2022 Aug 16];13(11). Available from: https://jtd.amegroups.com/article/view/53502

32. Benvenuto LJ, Anderson DR, Kim HP, Hook JL, Shah L, Robbins HY, et al. Geographic disparities in donor lung supply and lung transplant waitlist outcomes: A cohort study. Am J Transplant. 2018 Jun;18(6):1471–80.

Table 1. Demographics and Clinical Characteristics at Time of Lung Transplantation Listing

	White (N = 8,114)	**Black (N = 868)**	**P value***
Age at listing (years), mean (SD)	55.8 (13.1)	52.6 (10.7)	<0.001
Gender, n (%)			<0.001
Female	3,395 (41.8%)	520 (59.9%)	
Male	4,719 (58.2%)	348 (40.1%)	
Height (cm), mean (SD)	170.0 (9.9)	168.4 (9.9)	<0.001
BMI (kg/m^2), mean (SD)	25.4 (4.7)	26.2 (4.7)	<0.001
History of Cigarette Use, n (%)			<0.001
No	2,982 (36.8%)	394 (45.4%)	
Yes	5,130 (63.2%)	473 (54.6%)	
Diagnosis Group, n (%)			<0.001
A (Obstructive lung disease)	2,797 (34.5%)	273 (31.5%)	
B (Pulmonary vascular disease)	355 (4.4%)	69 (7.9%)	
C (Cystic Fibrosis)	1,000 (12.3%)	14 (1.6%)	
D (Restrictive lung disease)	3,962 (48.8%)	512 (59.0%)	
Supplemental O_2 Use (L/min), median (25,75th percentiles)	3.0 (2.0-5.0)	3.5 (2.0-6.0)	<0.001
Six Minute Walk Distance (ft), median (25,75th percentiles)	875 (578-1143)	770 (450-1011)	<0.001
Continuous Mechanical Ventilation, n (%)	202 (2.5%)	18 (2.1%)	0.45
ECMO, n (%)	57 (0.7%)	10 (1.2%)	0.14
FEV_1 (L), median (25,75th percentiles)	0.99 (0.63-1.63)	0.98 (0.65 – 1.41)	0.02
FVC (L), median (25,75th percentiles)	1.92 (1.48-2.5)	1.58 (1.18-2.03)	<0.001
LAS at listing, reported, median (25,75th percentiles)	36.7 (33.5-43.6)	38.1 (34.3-47.3)	<0.001

*P values based on Student t or Mann Whitney U tests for continuous variables and Chi square or Fisher exact tests for categorical variables

Table 2 – Primary and Secondary Outcomes, compared by approach and stratified by race

	Race-Specific	Race-Neutral	Difference by approach*	P value†
FEV_1 %-predicted, mean (SD)				
White	35.4 (21.8)	38.0 (23.4)	+2.6	<0.001
Black	38.6 (21.3)	35.6 (19.6)	-3.0	<0.001
Difference by race‡	-3.2	+2.4		
FVC %-predicted, mean (SD)				
White	51.3 (18.0)	55.7 (19.5)	+4.4	<0.001
Black	50.4 (18.3)	46.7 (16.9)	-3.8	<0.001
Difference by race‡	+0.9	+9.0		
LAS				
White	41.9 (14.2)	41.3 (14.1)	-0.6	<0.001
Black	43.8 (15.4)	44.3 (15.5)	+0.6	<0.001
Difference by race‡	-1.9	-3.0		
Predicted survival without transplant (days), mean (SD)				
White	294.8 (81.2)	298.1 (80.4)	+3.3	<0.001
Black	283.9 (87.3)	280.6 (87.9)	-3.3	<0.001
Difference by race‡	+10.9	+17.5		
Predicted survival after transplant (days), mean (SD)				
White	318.1 (12.3)	318.4 (12.1)	+0.3	<0.001
Black	316.9 (11.9)	316.6 (12.1)	-0.3	<0.001
Difference by race‡	+1.2	+1.8		

*Positive values indicate a greater value with race-neutral approach

† P values based on Student t tests

‡ Positive values indicate a greater value among White patients

Table 3. Difference in LAS and FVC percent predicted between approaches among diagnosis groups and stratified by race

	Difference in LAS*†		Difference in %-predicted FVC*†	
	White	**Black**	**White**	**Black**
Diagnosis Group				
A (Obstructive lung disease)	-0.30 (0.21)	+0.33 (0.22)	+4.8 (1.5)	-3.9 (1.3)
B (Pulmonary vascular disease)	-0.71 (0.32)	+0.70 (0.40)	+5.9 (1.8)	-4.6 (1.8)
C (Cystic Fibrosis)	-0.50 (0.25)	+0.44 (0.27)	+3.5 (1.0)	-3.2 (1.1)
D (Restrictive lung disease)	-0.78 (0.45)	+0.68 (0.44)	+4.3 (1.5)	-3.6 (1.3)

*Positive values indicate a greater value with race-neutral approach. All values are presented as mean(SD)

†$p<0.0001$ for all comparisons between White and Black patients. P values based on Student t tests

Figure 1. Difference in percent predicted spirometry between race-specific (RS) and race-neutral (RN) approaches as a function of measured spirometry. The difference in percent predicted spirometry measures when using a RN compared to RS approach is shown over the range of actual (measured) spirometry values (L) for White and Black individuals. Positive values indicate a higher %-predicted spirometry under a RN approach. Each point represents an individual at time of listing. Best fit linear lines with 95% confidence interval are presented. Differences in percent predicted spirometry measures increase as measured lung volumes increase

Figure 2. Difference in LAS and WLi between race-specific (RS) and race-neutral (RN) approaches as a function of RS-LAS at listing. Differences in (A) LAS and (B) predicted survival without transplant between RS and RN approaches are shown over the range of the RS-LAS at listing. The RS-LAS on x-axis was calculated using FVCpp from RS reference equations. Each point represents an individual at time of listing. Best fitting quadratic lines with 95% confidence interval are displayed for White and Black individuals. Positive values indicate (A) higher LAS or (B) greater number of predicted days survived under a RN approach

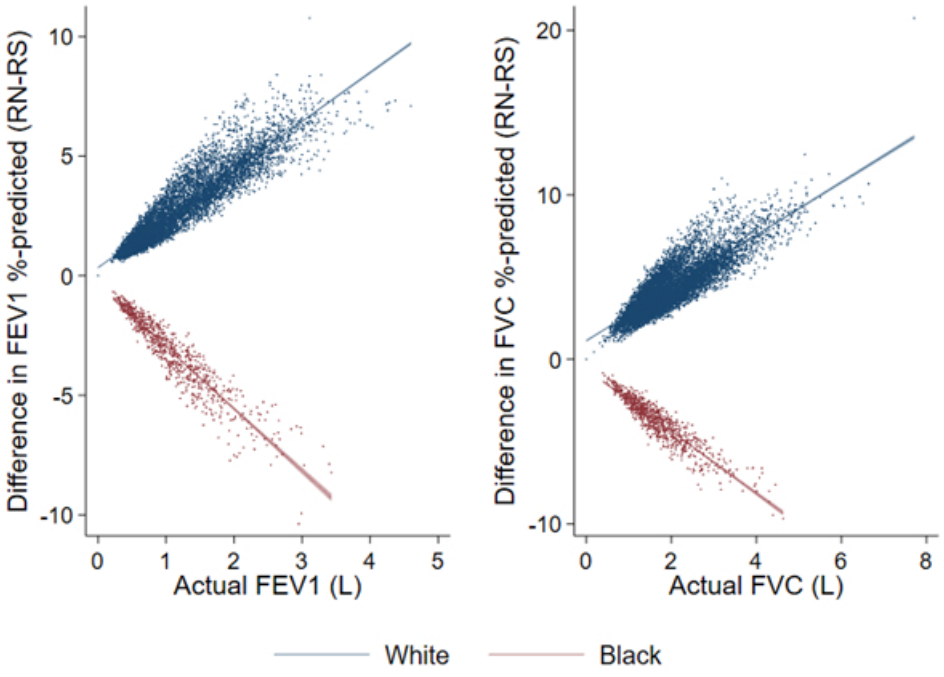

Figure 1. Difference in percent predicted spirometry between race-specific (RS) and race-neutral (RN) approaches as a function of measured spirometry. The difference in percent predicted spirometry measures when using a RN compared to RS approach is shown over the range of actual (measured) spirometry values (L) for White and Black individuals. Positive values indicate a higher %-predicted spirometry under a RN approach. Each point represents an individual at time of listing. Best fit linear lines with 95% confidence interval are presented. Differences in percent predicted spirometry measures increase as measured lung volumes increase

417x298mm (38 x 38 DPI)

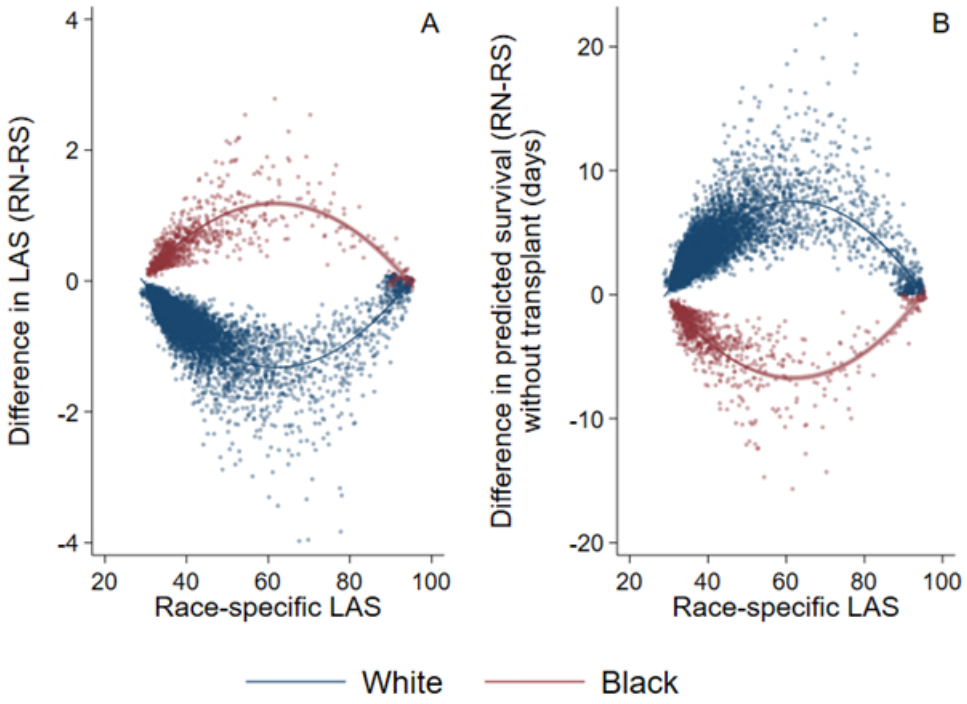

Figure 2. Difference in LAS and WLi between race-specific (RS) and race-neutral (RN) approaches as a function of RS-LAS at listing. Differences in (A) LAS and (B) predicted survival without transplant between RS and RN approaches are shown over the range of the RS-LAS at listing. The RS-LAS on x-axis was calculated using FVCpp from RS reference equations. Each point represents an individual at time of listing. Best fitting quadratic lines with 95% confidence interval are displayed for White and Black individuals. Positive values indicate (A) higher LAS or (B) greater number of predicted days survived under a RN approach

417x303mm (38 x 38 DPI)

Online Supplement

Race-specific Interpretation of Spirometry: Impact on the Lung Allocation Score

J. Henry Brems[1], MD, MBE, Aparna Balasubramanian[1], MD, MHS, Kevin J. Psoter[2], PhD, Pali Shah[1], MD, Errol L. Bush[3], MD, Christian A Merlo[1], MD, MPH, Meredith C McCormack[1], MD, MHS

Supplemental Methods

Calculations of WLi, PTi, LAS

We first calculated the WLi and PTi for all patients according to the UNOS policy.[16] Both the WLi and PTi are first calculated by summing parameter estimates, which are calculated as the product of a patient characteristic value (x) and a coefficient (β), as outlined in Tables S1 and S2. The sum of these products is then exponentiated, multiplied by the survival probability at each of the 365 days in the next year, and then summed. This full process, including the survival probabilities, is outlined in UNOS documentation.[16]

Once calculated, the WLi and PTI are combined to generate the LAS according to the formula:

$$LAS = \frac{100 * [(PTi - 2 * WLi) + 730]}{1095}$$

LAS calculator validation

To validate our calculator, we initially compared our calculated LAS to the reported LAS at listing among all patients in the main study cohort in addition to patients who had missing values for any variable used to calculate the LAS. For patients with missing values, we used imputed values according the UNOS policy.[20] For the purpose of validating our equation, we used the FVCpp as reported in the UNOS database.

Subsequently, we compared our calculated LAS to the reported LAS at listing after excluding all patients who had missing variables or who had a reported LAS that was missing or zero. Due to improved performance of our calculator among this cohort, we excluded patients with missing values for variables to calculate the LAS from the main study cohort. Characteristics of those patients with at least one missing variable are shown in Table S4.

Table S1. Patient Characteristics and coefficients used to generate WLi per UNOS policy

Characteristic (x)	**Coefficient (β)**	**Default value***
Age at offer (Groups A,B,C), years	0.015097	0
Age at offer (Group D), years	0.021223	0
BMI, kg/m^2	-0.051781	0
Diabetes (regardless or insulin dependency)	0.158821	No diabetes
Requires some assistance to perform activities of daily living	0.182250	No assistance required to perform activities of daily living
Requires total assistance to perform activities of daily living	0.115024	No assistance required to perform activities of daily living
FVC percent predicted	-0.019675	0
PA systolic pressure (Groups A,C,D), mmHg	0.015889	0
O_2 requirement at rest (Groups A,D), L/min	0.187599	0
O_2 requirement at rest (Group B), L/min	0.040766	0
O_2 requirement at rest (Group C), L/min	0.125568	0
Six-minute walk distance < 150ft	0.330752	Distance ≥ 150ft
Continuous mechanical ventilation	1.213804	Not on continuous mechanical ventilation
PCO_2 (arterial or capillary) – 40, mmHg	0.005448	40
Increase in PCO_2 of 15% or greater in 6 month period*	0.076370	No change or change < 15%
Group B	2.376700	Group A
Group C	0.943377	Group A
Group D	0.996936	Group A
Diagnosis - Bronchiectasis	0.157212	Not diagnosis
Diagnosis – Eisenmenger's Syndrome	-0.627866	Not diagnosis
Diagnosis - Lymphangioleiomyomatosis	-0.197434	Not diagnosis
Diagnosis - Obliterative bronchiolitis (non-retransplant)	-0.256480	Not diagnosis
Diagnosis - Pulmonary Fibrosis other	-0.265233	Not diagnosis
Diagnosis - Sarcoidosis and PA mean > 30 mm Hg	-0.707346	Not diagnosis
Diagnosis - Sarcoidosis and PA mean < 30 mm Hg	0.455348	Not diagnosis

*Default values as specified by UNOS policy for those with missing value for corresponding variable[20]

Table S2. Patient Characteristics and coefficients used to generate PTi per UNOS policy

Characteristic (x)	**Coefficient (β)**	**Default value***
Age, years	0.003510	0
Creatinine, mg/dl	0.061986	0
Requires no or some assistance to perform activities of daily living	-0.488525	Requires total assistance to perform activities of daily living
FVC percent predicted (Groups B and D)	0.002751	0
Mean pulmonary capillary wedge pressure ≥ 20 mmHg (Group D)	0.033046	<2 mmHg
Continuous mechanical ventilation	0.312846	Not on continuous mechanical ventilation
Group B	0.623207	Group A
Group C	0.008514	Group A
Group D	0.413173	Group A
Diagnosis - Bronchiectasis	0.056116	Not diagnosis
Diagnosis – Eisenmenger's Syndrome	0.393526	Not diagnosis
Diagnosis - Lymphangioleiomyomatosis	-0.624209	Not diagnosis
Diagnosis - Obliterative bronchiolitis (non-retransplant)	-0.443786	Not diagnosis
Diagnosis - Pulmonary Fibrosis other	-0.172243	Not diagnosis
Diagnosis - Sarcoidosis and PA mean > 30 mm Hg	-0.122351	Not diagnosis
Diagnosis - Sarcoidosis and PA mean < 30 mm Hg	-0.016505	Not diagnosis

*Default values as specified by UNOS policy for those with missing value for corresponding variable[20]

Table S3. Medical information used to calculate the lung allocation score, by race

	White (N = 8,114)	Black (N = 868)	P value†
Age at listing (years), mean (SD)	55.8 (13.1)	52.6 (10.7)	<0.001
BMI (kg/m^2), mean (SD)	25.4 (4.7)	26.2 (4.7)	<0.001
Diabetes, n (%)	1,575 (19.4%)	159 (18.3%)	0.44
Functional Status (Assistance needed to perform ADLs), n (%)			0.006
No Assistance	813 (10.0%)	58 (6.7%)	
Some Assistance	6,876 (84.7%)	766 (88.2%)	
Total Assistance	425 (5.2%)	44 (5.1%)	
Pulmonary Artery Systolic Pressure (mmHg), mean (SD)	41.7 (15.5)	51.3 (19.6)	<0.001
Supplemental O_2 Use (L/min), median (25,75th percentiles)	3.0 (2.0-5.0)	3.5 (2.0-6.0)	<0.001
Six Minute Walk Distance (ft), median (25,75th percentiles)	875 (578-1143)	770 (450-1011)	<0.001
Continuous Mechanical Ventilation, n (%)	202 (2.5%)	18 (2.1%)	0.45
PCO_2 (mmHg), mean (SD)	46.2 (12.2)	47.5 (13.2)	0.003
Serum Creatinine (mg/dL), mean (SD)	0.8 (0.5)	0.9 (0.4)	<0.001
Pulmonary Capillary Wedge Pressure (mmHg), mean (SD)	0.8 (0.5)	0.9 (0.4)	<0.001
Diagnosis Group, n (%)			<0.001
A (Obstructive lung disease)	2,797 (34.5%)	273 (31.5%)	
B (Pulmonary vascular disease)	355 (4.4%)	69 (7.9%)	
C (Cystic Fibrosis)	1,000 (12.3%)	14 (1.6%)	
D (Restrictive lung disease)	3,962 (48.8%)	512 (59.0%)	
Diagnosis*			<0.001
Bronchiectasis	126 (1.6%)	10 (1.2%)	
Eisenmenger Syndrome	6 (0.1%)	0 (0.0%)	
Lymphangioleiomyomatosis	41 (0.5%)	4 (0.5%)	
Obliterative Bronchiolitis (re transplant)	48 (0.6%)	0 (0.0%)	
Pulmonary Fibrosis, Other	652 (8.0%)	101 (11.6%)	
Sarcoidosis (mean PA Pressure > 30mmHg)	46 (0.6%)	117 (13.5%)	
Sarcoidosis (mean PA Pressure < 30mmHg)	39 (0.5%)	60 (6.9%)	
Race-specific FVC %-predicted, mean (SD)	51.3 (18.0)	50.4 (18.3)	0.19
Race-neutral FVC %-predicted, mean (SD)	55.7 (19.5)	46.7 (16.9)	<0.001

* Includes only the diagnoses that are incorporated in calculation of the LAS when present

† P values based on Student t or Mann Whitney U tests for continuous variables and Chi square or Fisher exact tests for categorical variables

Table S4: Difference in outcomes and percent of patients transplanted among 10-point bins of race-specific LAS for White and Black patients.

Race-specific LAS	N	Difference in LAS*†	Difference in WLi*†
White			
20-30	17	-0.19 (0.07) [-0.36, -0.02]	1.1 (0.4) [0.1, 2.0]
30-40	5272	-0.40 (0.20) [-1.50, -0.06]	2.3 (1.2) [0.3, 9.1]
40-50	1600	-0.87 (0.31) [-2.88, -0.22]	5.0 (1.8) [1.3, 16.7]
50-60	474	-1.22 (0.43) [-2.99, -0.36]	6.9 (2.4) [2.0, 16.8]
60-70	202	-1.42 (0.59) [-3.98, -0.66]	8.0 (3.3) [3.7, 22.2]
70-80	135	-1.33 (0.61) [-3.8, -0.26]	7.5 (3.4) [2.1, 21.0]
80-90	145	-0.63 (0.47) [-2.18, -0.08]	3.7 (2.6) [0, 12.5]
90-100	269	-0.08 (0.15) [-0.72, -0.10]	0.7 (0.8) [0, 4.4]
Black			
20-30	0	--	--
30-40	518	0.39 (0.19) [0.07, 1.27]	-2.3 (1.1) [-7.3, -0.4]
40-50	174	0.80 (0.32) [0.24, 2.14]	-4.6 (1.8) [-12.1, -1.4]
50-60	73	1.09 (0.50) [0.33, 2.54]	-6.2 (2.8) [-14.7, -1.9]
60-70	26	1.36 (0.51) [0.64, 2.79]	-7.7 (2.9) [-15.7, -3.6]
70-80	25	1.06 (0.47) [0.24, 2.54]	-6.0 (2.6) [-14.3, -1.5]
80-90	13	0.52 (0.28) [-0.05, 1.13]	-3.1 (1.5) [-6.5, -0.6]
90-100	39	0.07 (0.13) [-0.09, 0.65]	-0.6 (0.7) [-3.9, -0.2]

*Positive values indicate a greater value with race-neutral approach
† Values are presented as mean (SD) over [range]

Table S5. Demographics and clinical characteristics at time of listing among those with no missing data versus those partially missing data.

	No missing data (N = 8,982)	**Partially missing data (N = 3,510)**	**P value†**
Age at listing (years), mean (SD)	55.5 (12.9)	53.6 (14.4)	<0.001
Gender, n (%)			0.54
Female	3,915 (43.6%)	1,551 (44.2%)	
Male	5,067 (56.4%)	1,959 (55.8%)	
Race, n (%)			0.012
Black	868 (9.7%)	392 (11.2%)	
White	8,114 (90.3%)	3,118 (88.8%)	
Height (cm), mean (SD)	169.8 (9.9)	169.5 (9.9)	0.16
BMI (kg/m^2), mean (SD)	25.5 (4.7)	24.9 (4.9)	<0.001
History of Cigarette Use, n (%)†			<0.001
No	3,376 (37.6%)	1,590 (45.3%)	
Yes	5,603 (62.4%)	1,918 (54.7%)	
Diagnosis Group, n (%)			<0.001
A (Obstructive lung disease)	3,070 (34.2%)	833 (23.7%)	
B (Pulmonary vascular disease)	424 (4.7%)	130 (3.7%)	
C (Cystic Fibrosis)	1,014 (11.3%)	461 (13.1%)	
D (Restrictive lung disease)	4,474 (49.8%)	2,086 (59.4%)	
Supplemental O_2 Use (L/min), median (25,75th percentiles)	3.0 (2.0-5.0)	3.5 (2.0-6.0)	<0.001
Six Minute Walk Distance (ft), median (25,75th percentiles)†	861.5 (561.0-1128.0)	822.5 (500.0-1115.0)	<0.001
Continuous Mechanical Ventilation, n (%)	220 (2.4%)	224 (6.4%)	<0.001
ECMO, n (%)	57 (0.7%)	10 (1.2%)	<0.001
FEV_1 (L), median (25,75th percentiles)†	1.0 (0.6-1.6)	1.1 (0.7-1.6)	<0.001
FVC (L), median (25,75th percentiles)	1.9 (1.4-2.5)	1.8 (1.4-2.4)	<0.001
LAS at listing, reported, median (25,75th percentiles)	36.9 (33.6-43.8)	38.0 (33.7-47.1)	<0.001

*P values based on Student t or Mann Whitney U tests for continuous variables and Chi square or Fisher exact tests for categorical variables

†Incomplete data were available for these variables. For history of cigarette use, six minute walk distance, and FEV_1, data were available 3508, 3274, 3086 patients out 3,510, respectively

Table S6. Difference in outcomes between approaches among main study cohort in addition to those excluded from primary analysis due to missing variables

	White (N = 11,232)	**Black (N = 12,60)**	**P value†**
LAS			
Race-specific	42.8 (15.2)	44.2 (15.7)	0.002
Race-neutral	42.2 (15.1)	44.7 (15.8)	<0.001
Difference*	-0.6 (0.4)	0.6 (0.4)	<0.001
Predicted survival without transplant (days)			
Race-specific	289.5 (87.0)	281.3 (88.9)	0.002
Race-neutral	292.8 (86.4)	278.0 (89.4)	<0.001
Difference*	3.3 (2.4)	-3.3 (2.2)	<0.001
Predicted survival after transplant (days)			
Race-specific	317.4 (13.0)	316.4 (11.9)	0.009
Race-neutral	317.7 (12.8)	316.0 (12.1)	<0.001
Difference*	0.3 (0.3)	-0.3 (0.3)	<0.001

*Positive values indicate a greater value with race-neutral approach

† P values based on Student t tests

Figure S1. Development of Cohort

Figure S2. Difference in LAS between race-specific (RS) and race-neutral (RN) approaches as a function of RS-LAS at listing among each diagnosis group. Differences in LAS between RS and RN approaches are shown over the range of RS-LAS at listing for patients among diagnosis group A (A), group B (B), group C (C), and group D (D). The RS-LAS on x-axis was calculated using FVCpp from RS reference equations. Each point represents an individual at time of listing. Best fitting quadratic lines with 95% confidence interval are displayed for White and Black individuals. Positive values indicate higher LAS under a race-neutral approach

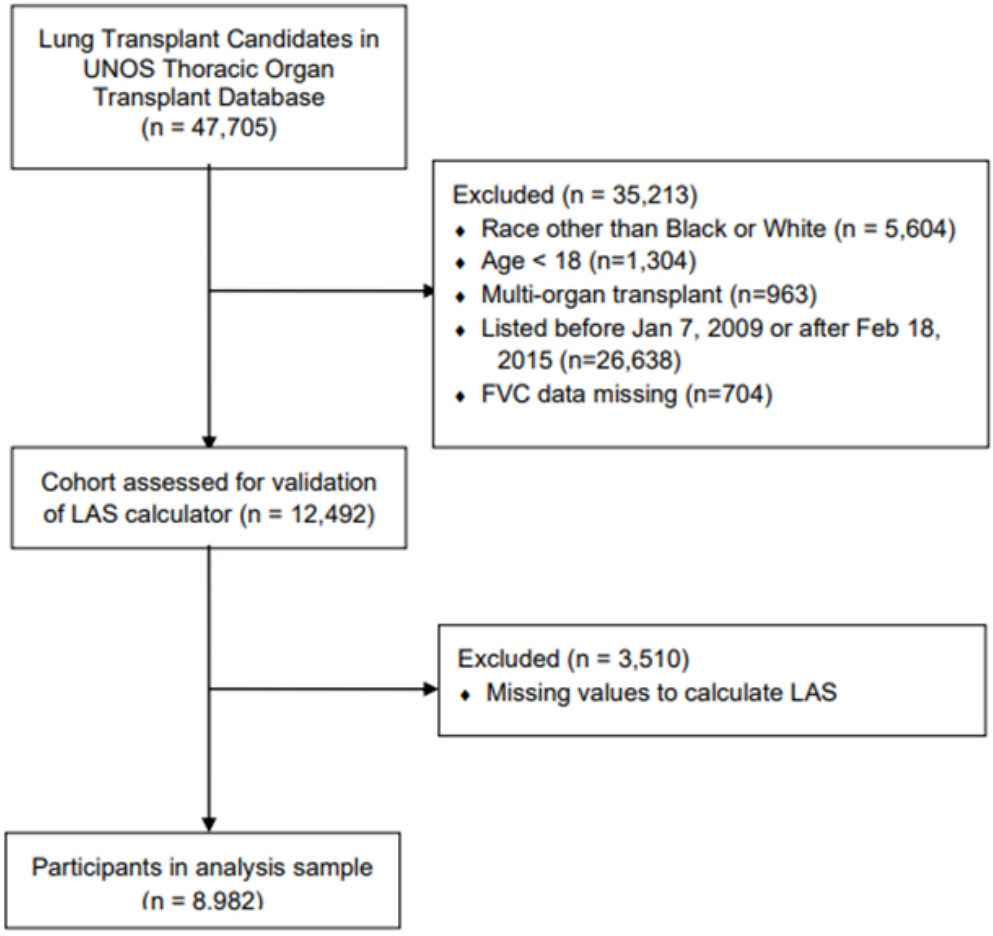

Figure S1. Development of Cohort

409x385mm (38 x 38 DPI)

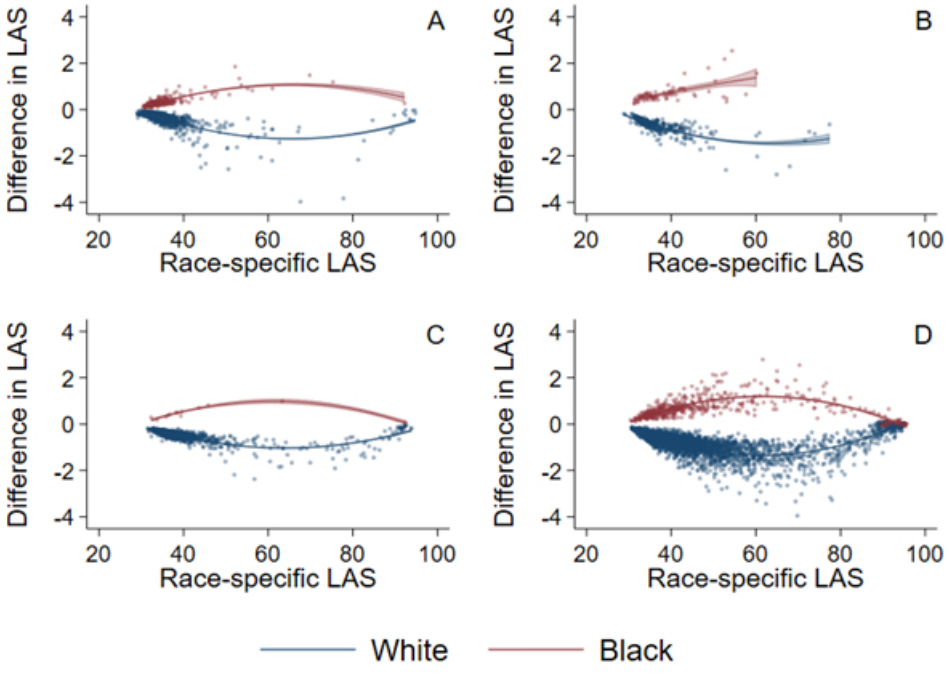

Figure S2. Difference in LAS between race-specific (RS) and race-neutral (RN) approaches as a function of RS-LAS at listing among each diagnosis group. Differences in LAS between RS and RN approaches are shown over the range of RS-LAS at listing for patients among diagnosis group A (A), group B (B), group C (C), and group D (D). The RS-LAS on x-axis was calculated using FVCpp from RS reference equations. Each point represents an individual at time of listing. Best fitting quadratic lines with 95% confidence interval are displayed for White and Black individuals. Positive values indicate higher LAS under a race-neutral approach

417x294mm (38 x 38 DPI)