AMERICAN THORACIC SOCIETY DOCUMENTS

Race and Ethnicity in Pulmonary Function Test Interpretation
An Official American Thoracic Society Statement

Nirav R. Bhakta, Christian Bime, David A. Kaminsky, Meredith C. McCormack, Neeta Thakur, Sanja Stanojevic, Aaron D. Baugh, Lundy Braun, Stephanie Lovinsky-Desir, Rosemary Adamson, Jonathan Witonsky, Robert A. Wise, Sean D. Levy, Robert Brown, Erick Forno, Robyn T. Cohen, Meshell Johnson, John Balmes, Yolanda Mageto, Cathryn T. Lee, Refiloe Masekela, Daniel J. Weiner, Charlie G. Irvin, Erik R. Swenson, Margaret Rosenfeld, Richard M. Schwartzstein, Anurag Agrawal, Enid Neptune, Juan P. Wisnivesky, Victor E. Ortega, and Peter Burney; on behalf of the American Thoracic Society Committees on Pulmonary Function Testing and on Health Equity and Diversity

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Abstract

Current American Thoracic Society (ATS) standards promote the use of race and ethnicity-specific reference equations for pulmonary function test (PFT) interpretation. There is rising concern that the use of race and ethnicity in PFT interpretation contributes to a false view of fixed differences between races and may mask the effects of differential exposures. This use of race and ethnicity may contribute to health disparities by norming differences in pulmonary function. In the United States and globally, race serves as a social construct that is based on appearance and reflects social values, structures, and practices. Classification of people into racial and ethnic groups differs geographically and temporally. These considerations challenge the notion that racial and ethnic categories have biological meaning and question the use of race in PFT interpretation. The ATS convened a diverse group of clinicians and investigators for a workshop in 2021 to evaluate the use of race and ethnicity in PFT interpretation. Review of evidence published since then that challenges current practice and continued discussion concluded with a recommendation to replace race and ethnicity-specific equations with race-neutral average reference equations, which must be accompanied with a broader re-evaluation of how PFTs are used to make clinical, employment, and insurance decisions. There was also a call to engage key stakeholders not represented in this workshop and a statement of caution regarding the uncertain effects and potential harms of this change. Other recommendations include continued research and education to understand the impact of the change, to improve the evidence for the use of PFTs in general, and to identify modifiable risk factors for reduced pulmonary function.

Keywords: race; ethnicity; interpretation; PFT

Overview

Current standards from the American Thoracic Society (ATS) and other professional societies recommend comparing pulmonary function test (PFT) results to expected values calculated from race and ethnicity-specific reference equations (1). These recommendations are based on the observation of cross-sectional, residual differences in measured pulmonary function after adjustment for age, sex, and height between some racial and ethnic groups. The recommendations have been challenged because race and ethnicity do not accurately capture variation in pulmonary function between individuals, there are harms to perpetuating racial views, and continued use

ORCID IDs: 0000-0002-2135-7012 (N.R.B.); 0000-0001-6126-6601 (N.T.); 0000-0003-2272-4387 (S.L.-D.).

Correspondence and requests for reprints should be addressed to Nirav R. Bhakta, M.D., Ph.D., Department of Medicine, University of California, San Francisco, HSE-1355A, 513 Parnassus Avenue, San Francisco, CA 94143-0130. E-mail: nirav.bhakta@ucsf.edu.

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Contents

of race and ethnicity-specific equations may mask the effects of social and environmental factors including structural racism. The ATS convened this workshop panel in 2021 to review the use of race and ethnicity in the interpretation of PFTs; evaluate its clinical implications; and provide guidance so that clinicians, investigators, and patients can make informed decisions. The outcome of the discussion was a lack of consensus and concerns about potential harms. Since the workshop, five research articles presenting strong evidence were published, and discussion continued, leading to the recommendations given in the following text. As the new evidence does not cover all uses of PFTs for individuals in and out of the clinical setting, and we did not undertake the engagement of patients and leaders in affected areas, we are approaching these recommendations with caution. A majority of workshop participants agreed with the recommendations. However, significant concerns regarding changes to practice include an underdeveloped understanding of the potential harms of changing to race-neutral average reference equations and lack of associated education and policies to protect individual patients from these potential harms. The limited evidence with respect to the use of race and ethnicity in the interpretation of diffusing capacity, lung volumes, and other PFTs led the workshop and its recommendations to focus on spirometry.

Key Conclusions and Recommendations

- PFT laboratories should adopt a race-neutral approach to PFT interpretation by reporting and interpreting results using average reference equations. Reasoning includes the following:
  - The superficial appearance of race should not be used to infer biological characteristics. Continued use of race in PFT interpretation risks perpetuating false ideas that race distinguishes people on the basis of innate and immutable features. Beyond the categories' lack of biological meaning, there is significant heterogeneity within these categories and lack of consistency of the definitions across time and geography.
  - Normalization of differences with race-specific equations in PFT interpretation potentially contributes to medical harms from the lack of attention to modifiable risk factors for reduced pulmonary function resulting from racism. Potential medical harms for people of color include delaying or missing disease diagnoses or hindering access to therapies.
  - Emerging evidence from the United States shows that, compared with a race-specific interpretation, use of a single set of reference equations better matches the relationship between pulmonary function and survival and incident chronic lung disease between Black and White persons. A race-neutral average reference equation provides better or equivalent relationships between spirometry and symptoms, airway structure, emphysema, and functional capacity. Although these studies do not show a causal link between differences in pulmonary function and the outcomes, and although they do not address many uses of pulmonary function for individual patients in the clinical setting, they nonetheless challenge current practice.
- The Global Lung Function Initiative (GLI) average equation, published as GLI Global, is a recommended race-neutral average reference equation. There are important limitations and considerations to an implementation of GLI Global that we expect ongoing research to address:
  - GLI Global represents a weighted average of the data included in the original GLI ethnicity-specific equations. The self-identified, or researcher-allocated, racial or ethnic group was used to inform the sample weights, and many of the world's populations are still not included in

this equation. Therefore, the GLI Global equation is a race composite and not truly race agnostic. "Race neutral" refers to the equations not requiring the selection of race for application.
    - As in the construction of other reference equations, the participants contributing data to GLI Global have a variety of exposures throughout life, despite meeting a limited definition of healthy. Therefore, GLI Global is not immune from norming the effects of modifiable risk factors for reduced pulmonary function.
- The recommendation to change to a race-neutral average reference equation does not imply that the reference values represent the pulmonary function for an individual with ideal pulmonary health across the life course. Therefore, a change must also be accompanied with an appreciation of the already existing uncertainty of comparing an individual's PFTs with reference values to differentiate health and disease. Results at or near the lower limit of normal must be interpreted cautiously and augmented by additional history, testing, imaging, and other diagnostics as appropriate. PFTs and, specifically, spirometry are measures of the size and mechanics of the lungs and are not sufficient to differentiate all pulmonary function impairments and diseases.
- The recommendation to change to a race-neutral average reference equation also applies to PFTs beyond spirometry. Adjustment factors for race and ethnicity in the interpretation of lung volumes and D_{LCO} should not be used. Interpretations must recognize that the use of different reference populations for spirometry versus D_{LCO} and lung volume reference equations will lead to some individuals having discordant results that need to be interpreted with extra attention. The major equations available for D_{LCO} and lung volumes are based on data from White persons—reference equation data combined from more diverse populations are needed.
- The aforementioned recommendations are paired with a call for urgent engagement of people living with chronic pulmonary diseases, other professional societies, and agencies external to medicine for continued research and education:
    - Despite limited evidence of clinical utility, many systems external to PFT laboratories have been created to rely on threshold values for decision making. The consequences for the yet-unquantified number of individuals with results near decision-making thresholds, around which results are expected to shift after removing race from reference equations, need to be carefully considered and tracked. Collaborative research is needed to quantify the impacts of changes to interpretation in areas within and outside medicine as well as approaches to mitigate potential harms. Threshold-based decisions that lack evidence of benefit should be reevaluated. Studies examining the potential impact of race-specific equations should continue. Nonetheless, there is a burden of proof of benefit for any continued use of race and ethnicity in PFT interpretation.
    - Laboratories must educate patients and referring clinicians about the rationale for change and the impact on the reported and interpreted values to anticipate consequences and to avoid errors in trending values indexed to reference equations.
- Further research in more diverse populations across the world is needed regarding the social and environmental determinants of lung health and how to measure these factors in a way that could be translated to public policies and the application of pulmonary function testing in the clinic.
- We must improve PFT interpretation by:
    - Taking the patient's medical context and social history into consideration in the clinic. Challenges to this include lack of validated approaches.
    - Emphasizing the value of longitudinal data as trending pulmonary function values over time provides clinical insight.
    - Stressing the use of the ratio of FEV_1 to FVC to identify obstructive ventilatory defects found in chronic obstructive pulmonary disease, asthma, and other diseases affecting the airways, because it varies minimally by race or ethnicity.
    - Aiming to move beyond a simple statistical description of normal pulmonary function by examining the association between pulmonary function and meaningful health outcomes in which we can intervene. Such an approach has the potential to remove the need for reference equations. A larger variety of chronic lung diseases must be included than studied thus far.
- Thoughtfully collecting race and ethnicity data in research remains important to address disparities in lung health; identify modifiable determinants of reduced pulmonary function, including those resulting from structural racism; and increase the diversity of the participants in studies that include pulmonary function.

Introduction

In the context of pulmonary function test (PFT) interpretation, the terms "race" and "ethnicity" have been used interchangeably (1–3). Some reference equations are based on measurements taken from specific racial or ethnic groups, whereas others, such as in administrative policies for the assessment of physiologic impairment for disability rating, use "correction" or "adjustment" factors to calculate expected pulmonary function of persons of color from reference equations derived from White populations. There is growing concern that race and ethnicity-based algorithms in medicine, including PFT interpretation, have the potential to contribute to healthcare disparities and support the false idea that race is a biological variable (4, 5).

In the United States, concerns about race and racism have risen along with attention to its history of slavery and discrimination. Most of the data that challenge the use of race in PFT interpretation come from studies on spirometry in Black and White persons in the United States. The focus of the history and methodology of reference equations reviewed in this report is on the United States. The concerns about race and PFT interpretation, however, are far from limited to the United States. This discussion has global relevance. Furthermore, people who immigrate to the United States are not expected to have the same exposure or

pulmonary function as residents from multiple generations in the United States.

This workshop was convened with the goal of bringing together experts in the field to provide a framework for clinicians, investigators, policy makers, and patients to have informed discussions about the use of race and ethnicity in PFT interpretation. Recommendations were developed after the workshop. Very few articles relate race categories to lung volumes and D_{LCO} (6–8). Because of this insufficient evidence, most laboratories use reference equations derived in White populations for determining predicted values for lung volumes and D_{LCO}, whereas a minority of laboratories apply previously recommended race-adjustment factors (9, 10). Thus, the discussion and recommendations for PFTs other than spirometry are limited in this report.

Methods

Committee Composition and Meetings

The workshop organizers included representatives from the ATS Pulmonary Function Testing Committee and the ATS Health Equity and Diversity Committee. N.R.B., C.B., N.T., M.C.McC., J.P.W., and D.A.K. invited individuals with research and clinical expertise from diverse geographical, gender, race and ethnicity, and career-stage backgrounds. Potential conflicts of interest were managed following ATS policies.

Preworkshop

Through two virtual planning meetings and a survey, participants refined the objectives of the workshop and topics for discussion. This included an agreement for all speakers to prerecord videos of their presentations. The videos were watched by participants before the workshop.

Virtual Workshop

During the first day, sessions focused on the history of race in PFT interpretation, history, and methodology of PFT reference equations, and determinants of pulmonary function. The second day was focused on the clinical implications of race-specific reference equations and breakouts into working groups. The format of the virtual meetings was as follows: Session leaders summarized the prerecorded talks and invited the speakers to participate in an active discussion with all participants. For the final session, participants were divided into three working groups: identification of barriers to change, current best practices, and long-term strategies.

Document Development

After the workshop, session leaders provided a summary of the discussions to the workshop co-chairs (N.R.B. and C.B.), who edited the contributions into a single document. Multiple cycles of revision and feedback from all workshop participants followed. The iterative discussion and decision making were informed by evidence published after the workshop.

We did not achieve unanimous consensus with all views and recommendations. Where there was divergence, both the majority and minority perspectives were shared.

Historical Context: Race and Racism in PFTs

Before the 20th Century: Conceptual and Empirical Foundations

In 1785, Thomas Jefferson—Enlightenment philosopher and slave-holding third U.S. president—highlighted differences and deficiencies in the "pulmonary apparatus" of enslaved people in comparison with White people. In the 1840s, British physician John Hutchinson organized lung volume data from a large number of people according to occupational categories, a crude measure of social class (11, 12). When Hutchinson's work reached North America, proslavery Southern plantation physician Samuel Cartwright built a spirometer and quantified differences between groups of people. Rather than occupation, Cartwright organized measurements by race (11, 12). Drawing on Jefferson's theories, Cartwright tied labor needs to oxygen metabolism in ways that are explicitly racist, claiming "the deficiency in the negro was 20 per cent" (12, pp 28–29). Samuel Cartwright provided Jefferson's speculative theories with an empirical foundation.

Writing in the same period as Cartwright, James McCune Smith, the first African American physician in the United States (trained at the University of Glasgow because of exclusion from U.S. medical schools), refuted racial ideologies, offering alternative climatological explanations for claims of Black inferiority (12).

At the end of the Civil War, the U.S. Sanitary Commission charged Boston astronomer Benjamin Apthorp Gould to collect data on Black and White Union soldiers. Unlike Cartwright, Gould did not explicitly link lung capacity to human potential. His work, therefore, appeared race neutral and was cited as a doctrine of difference into the 21st century (12). Gould offered little explanation for observed differences. There was no acknowledgment that formerly enslaved people in the Union Army suffered poorer nutrition, more overcrowding in camps, and higher rates of infectious diseases such as tuberculosis and typhoid fever—from infancy to adulthood—than did White soldiers (12, 13).

Gould's data caught the attention of eminent scholars, including Charles Darwin, who included lung capacity together with craniometry as indicators of innate racial inferiority in his *Descent of Man and Selection in Relation to Sex*, published in 1871. Gould's work was also adopted by Frederick Hoffman, the chief biostatistician of the Prudential Life Insurance Company for 40 years. In 1896, Hoffman published *Race Traits and Tendencies of the American Negro*, recognized as a vicious diatribe that argued that "the smaller lung capacity of the colored race is in itself proof of an inferior physical organism." (12, pp 44–45). According to Hoffman, Black persons were unfit for freedom and, as a race, would die out (14, 15).

Hoffman's argument was refuted as scientific racism by two leading Black intellectuals, W. E. B. DuBois and Kelly Miller. In his monograph, "A Review of Hoffman's Race Traits and Tendencies of the American Negro," Miller emphasized that social conditions affected the lungs of Black persons, especially given the conditions they faced in crowded cities after emancipation (12).

The 20th Century: The Codification of Difference

As spirometry became more widespread, explanations for differences began to expand beyond "a racial factor" to include a wider range of factors such as pulmonary infections, tobacco smoke, pollution, climate, and nutrition. In many clinical and occupational settings, adjustment for race was viewed as a way to avoid disparity and discrimination. The 1978 Occupational Health and Safety Administration cotton dust standard proposed a 15% adjustment

"to provide proper interpretation of spirometry measurements for blacks without inadvertently fostering discrimination in hiring practices," acknowledging that other data suggested an 8% difference (16). However, ideas that differences were innate persisted (17), now framed as representing genetics and given more credibility through improved instrumentation and more complex statistics.

Of particular significance was the 1974 study of asbestos workers in Louisiana by researchers Charles Rossiter and Hans Weill from Wales and the United States, respectively, who developed and published a correction factor of 13.2% to be applied to pulmonary function measurements of Black persons. Arguing that Black and White workers lived and worked in similar conditions and thus ruling out socioeconomic factors, Rossiter and Weill left genetics as the central framework to explain racial difference in average lung capacity measurements (18).

One exception to the general acceptance of innate racial difference was the work of South African researchers, epidemiologist Jonny Myers and pulmonologist Neil White, experts in the monitoring of the health of workers in the mining and manufacturing industries. Amid antiapartheid struggles in the 1980 s, they argued that observed differences were due to social factors, not to biological differences (12). They called for a universal standard, not race-specific values (19, 20). Nonetheless, spirometry continued to be seen through the lens of race, and the notion of innate difference persisted.

The history of race and pulmonary function is troubling. History gives insight into the biases that contributed to race being embedded in PFT interpretation rather than other factors that are known to be associated with pulmonary function such as smoking, body mass index, and early-life events. However, this account neither implies that current interpretation strategies or PFT users are individually prejudiced nor implies that differences between groups solely reflect structural racism. Instead, this history placed a disproportionate emphasis on the role of race and prevented a more robust understanding of the determinants of pulmonary function. A search for new data that account for the multitude of factors that affect pulmonary function is important to combat structural racism in medicine and achieve the best scientific understanding of pulmonary health.

History and Methodology of Race-Specific Reference Equations

People who smoked tobacco, workers with toxic exposures, and measures taken from substandard spirometers were often included in early reference populations. Without the standardization of inclusion criteria, measurement protocols, and equipment, comparisons between different populations were limited by measurement error and selection bias until the 1970s. Recognizing these limitations, organizations began to develop systematic protocols for lung function measurement to improve data collection from reference populations.

In 1999, standardized data collected from non–tobacco-smoking individuals without known pulmonary disease from the population-based cross-sectional National Health and Nutrition Examination Survey III (NHANES III) led to reference equations for the U.S. population aged 8–80 years (21). Consistent with the design of NHANES and historical practice, race and ethnicity were used in the analysis of the pulmonary function data. Residual differences in measured pulmonary function after adjustment for age, sex, and height remained between racial and ethnic groups. Therefore, separate equations were made for White ($n = 2,281$), African American ($n = 2,508$), and Mexican American ($n = 2,639$) individuals; a later analysis found that a single equation with an African American coefficient would have been sufficient (22). For populations not included in these three groups (e.g., for Asian American individuals), a "correction factor" was recommended (10, 23). In 2012, the Global Lung Function Initiative (GLI) Network was organized to develop reference equations from data collated from cross-sectional studies (3). As with NHANES III, differences in pulmonary function across racial and ethnic groups were observed. GLI included data from many countries, but sufficient data were only available to derive reference values for four groups ages 3–95 years: White (labeled "Caucasian"; $n = 57,395$), African American ($n = 3,545$), Northeast Asian ($n = 4,992$), and Southeast Asian ($n = 8,255$). Analysis of more contemporary data found that the Southeast Asian equation was appropriate for the whole Chinese population (24). The numbers of African Americans and Asian Americans were small relative to the number of White persons included. White populations include Mexican Americans because no significant difference in pulmonary function was observed between these groups. It is important to note that the data for Black persons were derived from African Americans and are probably not applicable to Black persons from Africa and other parts of the world (25). Continental Africa is very genetically diverse and represents people with very heterogeneous exposures. Although there were data for people of other backgrounds, none was determined to be statistically robust enough to develop into GLI equations, so a fifth category of "Other" was created that used the average of the coefficients from the four groups. In a subsequent publication, equations labeled as GLI Global were developed by weighting observations to reflect differing proportions of the four racial and ethnic groups. Compared with GLI Other, GLI Global yields similar mean predicted values but with wider limits of normal (26).

Within the context of reference equations for pulmonary function, it is important to differentiate a "normal" population from a "reference" population. The purpose of a reference population is to describe the observed values for pulmonary function on the basis of the distribution of values measured in a cross-sectional sample of healthy people. Reference equations do not adjust for individuals' unique exposure histories or environmental changes across generations that affect how pulmonary function changes with time (27). Defining "normal" in medicine is complex and varies depending on whether the definition is based on statistics, commonality, fitness, or ideal health (28). For pulmonary function, non–tobacco-smoking people without a history of pulmonary symptoms or physician diagnosis of pulmonary disease are identified as "healthy." As with many clinical laboratory tests in medicine, a statistical definition is used for PFTs where the lower limit of normal (LLN) is conventionally, if arbitrarily, defined as the fifth percentile. This approach contrasts with some other areas in medicine, such as hypertension, in which the benefit of treating patients in randomized controlled trials influences the threshold chosen to define "abnormal" (29). The LLN is defined from reference populations and, therefore, depends on the choice of reference equation, whether race specific or not. The aim is to determine

whether an individual's result would be unusual (e.g., less than 5% occurrence) in the reference population with the same age, sex, and height as the patient. Where the reference set comprises people without any known disease, this definition assigns 5% of the apparently healthy reference population to below the LLN. Results less than the LLN are labeled "abnormal" but do not necessarily reflect the presence of a disease (30). Similarly, results close to the predicted value from a reference equation do not exclude pulmonary pathology. An important aspect to this determination is whether the population used as the reference is truly healthy. The current definition of "normal" does not capture manifestations of reduced lung growth, development from prematurity, or other perinatal conditions and early-life exposures.

Until recently, reference equations incorporating race and ethnicity were mostly justified by presumed biological differences in pulmonary function between populations (10). One argument that has cited Allen's rule about homeothermic species (31, 32) was that differences in leg length and chest wall dimension between people of the same standing height but different races explain why Black persons have lower pulmonary function than White persons (33). However, the focus on reference values being intrinsic to different populations on the basis of race or ethnicity may mask the influence of important socioeconomic and environmental factors that likely contribute to these differences (34, 35). Moreover, socioeconomic status (SES) has been overlooked in most studies that examine differences in pulmonary function among people of different racial and ethnic backgrounds (17). Fully capturing SES is challenging. Income and education are often used but are limited, potentially contributing to the persistence of differences in pulmonary function between racial and ethnic groups after adjustment for these factors (36, 37).

Determinants of Pulmonary Function

There is a strong body of evidence that *in utero* and early-life factors affect lung growth trajectories and may increase the risk of chronic obstructive pulmonary disease (COPD) and other pulmonary diseases later in life (Figure 1) (38–41). Genetic determinants and genomic interactions with the environment contribute to interindividual variability in pulmonary function.

In Utero and Early-Life Exposures that Influence Pulmonary Function

Prematurity and its consequences (e.g., perinatal hypoxia, bronchopulmonary dysplasia, and failure to thrive) can affect lung development such that structure and function are impacted (42, 43) (Figure 1). Maternal smoking during pregnancy, a recognized risk factor for poor lung growth, is more prevalent in some racial and ethnic groups and individuals of lower SES (44). Multiple social determinants of health have been associated with higher risk of preterm labor, including discriminatory policies, SES, immigration status, and living in neighborhoods with higher police contact rates (45, 46). Harmful early-life exposures affect lung growth health throughout life, including secondhand smoke, poor air quality, and infections (47). Undernutrition, as well as obesity, is associated with social determinants of health and reduced pulmonary function (47, 48).

Lower respiratory tract infections in early life are associated with lower pulmonary function in childhood, as well as respiratory morbidity later in life (49). Respiratory syncytial virus infection and severe bronchiolitis are more frequent in those of lower SES, owing perhaps to crowding, smoke exposure, higher risk of prematurity, and other factors (50).

Socioenvironmental Determinants of Lung Function

Deeply connected to systemic discrimination, people who live in lower SES neighborhoods are at increased risk of exposure to poor indoor and outdoor air quality (51–53). Air quality is an independent, and modifiable, factor for reduced pulmonary function (54). Reducing pollution exposure leads to improvement in lung growth (55) and attenuates pulmonary function decline (56). In the United States, people of color are more likely to live in neighborhoods with poor outdoor air quality (57). People who live in poverty are more likely to live in areas with poor indoor air quality and be exposed to secondhand tobacco smoke (58, 59). Globally, indoor air quality and use of biomass fuels for heat and cooking may be important contributors to poor lung growth and development.

A meta-analysis reported that youths from "disadvantaged socioeconomic circumstances" have lower FEV_1, regardless of how such a disadvantage was measured (60). There is increased attention to the potential interaction between environmental exposures and psychosocial stress that likely plays a role in how social determinants impact health (61–63). Stressors including prenatal intimate partner violence, community violence and parental verbal conflict, and exposure to hostility in young adults are associated with worse pulmonary function and may increase susceptibility to the pulmonary effects of air pollution (63–67).

The variability in results, definitions, and measurement instruments makes it challenging to quantify the environmental effects on pulmonary function. Meta-analyses and systematic reviews in White populations give quantitative estimates for the effects of broad measures of social status. A meta-analysis by Steinberg and Becklake in 1986 and one performed by Rocha and colleagues in 2019 suggest a socioeconomic effect on FEV_1 of about 400 ml for children and young adults (60, 68). A multicohort study found an SES effect equivalent to aging in terms of pulmonary function decline of about 4 years in older adults (69). A review by Hegewald and Crapo in 2007 of 14 studies estimated an SES effect on FEV_1 at $>$300 ml. A smaller number of studies have attempted to quantify the environmental contributions to average differences in pulmonary function between racial and ethnic categories. In 1996, Goldin and colleagues found, in a study of White and Black bank workers in South Africa, that a measure of adult social status (income + rank + number of dependents + home fuel type + home ownership) explained as much variability in pulmonary function as race (35). In contrast, studies of NHANES data by Harik-Khan and colleagues in 2001 and 2004 found that poverty index and education accounted for about 10% of the racial differences in pulmonary function between Black and White persons (36, 70). A systematic review reported that the proportion of differences in pulmonary function between Black and White persons attributable to SES factors ranged from 2% to 43% for FEV_1 and from 4% to 42% for FVC (33).

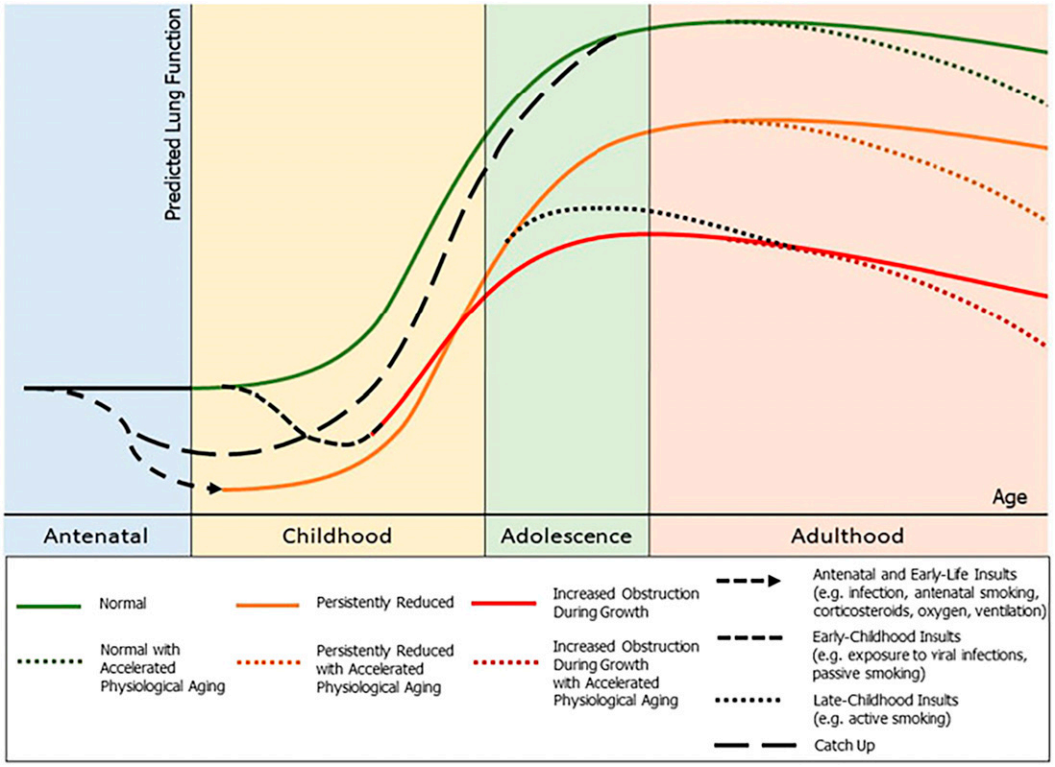

Figure 1. Influence of environmental exposures on lung growth and aging depending on the time of life when exposure occurred. Examples of early-life events affecting lung growth are prematurity and its consequences, as well as exposure to secondhand smoke, poor air quality, and infections. Discrimination is associated with differential risk of prematurity and exposures. Reprinted by permission from reference (42).

Genetic Determinants of Pulmonary Function

Across the genome, single nucleotide polymorphism heritability of pulmonary function is estimated to be 20.7% (SE = 1.5%) for FEV_1, 19.9% (SE = 1.4%) for FVC, and 17.5% (SE = 1.4%) for FEV_1/FVC (71). Limiting single nucleotide polymorphisms to those with genomewide significance in genomewide association studies has identified more than 250 independent loci that together contribute to as much as 9% of the observed variability in FEV_1 (72). Ancestry-specific or multiethnic meta-analyses that included minority populations have identified over 50 additional loci that have not shown significance in European White descent populations, which have been the focus of most studies thus far (71). Continental genetic ancestry, the cumulative measure of population or individual differences in allele frequencies for variants across the genome, is associated with pulmonary function variation (73–75). However, continental genetic ancestry is based on limited reference populations and does not specifically include genetic variants linked to pulmonary function or disease (76). Genetic ancestry also aligns with historic, geographic, cultural, and experiential factors that might influence epigenetic and other alterations to then impact pulmonary function. An example of such a relationship not concerning pulmonary function is the finding that the association between higher African ancestry among children and increased risk of readmission for asthma was mediated by family hardship (77).

Genetic associations with pulmonary function do not provide evidence for the use of race or ethnicity in PFT interpretation. The description of genetic variation among Africans and the African diaspora is suboptimal when considering the immense variation in these populations, thereby limiting conclusions about genetic determinants of pulmonary function within and between populations. A gradient of genetic variation and genetic overlap exists between people categorized on the basis of race (78). Genetic variation within a race or ethnicity category exceeds the genetic variation found between these categories. Genetic associations are confounded by shared environments. Nonetheless, further investigation of genetic contributions to pulmonary function overall will improve our understanding of health and disease. For example, the study of people adapted to high altitudes could show a genetic selection toward higher lung volumes. It is important to note that the burden of proof has not been met for a biological meaning to the sociopolitical constructs of race or ethnicity labels.

Challenging Questions Raised during the Workshop

Workshop discussion led to the unveiling of critical research questions that are necessary to improve our understanding of the determinants of pulmonary function. These included the following: What is the full, healthy pulmonary function potential at a given age, body size, and sex in the absence of exposure to any early-life risk factors? In the research setting, do White-specific equations have value as an unadjusted benchmark that we expect someone who does not experience the myriad effects linked to racism to achieve? Is there a measure of body size that best captures

expected, healthy lung volume and that is minimally affected by adverse early-life exposures so as not to normalize modifiable differences in pulmonary function? How do genetic and environmental determinants influence lung volumes, whether through alveolarization, chest wall development and thoracic size (31, 32), distensibility of these tissues, or muscle strength (79)? How does the environment influence gene expression through epigenetic modifications (80)? Might further insight into genetic and environmental contributors to pulmonary function come from the study of the Inuit and indigenous populations living at high altitudes who, because they have shorter legs in relation to standing height than White individuals, appear to have supranormal lung function, despite some markers of low SES (81–83)?

Clinical Implications of Race-Specific Pulmonary Function Prediction Equations

There are many areas within and outside medicine in which pulmonary function results above or below a threshold trigger important decisions. Regardless of the reference equation used, patients with results close to these thresholds require careful consideration. Examples of patients whose results cross decision-making thresholds with a switch in reference equation are shown in Table 1. Race-specific reference equations yield predicted values that are lower for most groups of color compared with White populations. For example, consider a 40-year-old man who is 6 feet tall and whose predicted FEV_1 is 4.50 L (fifth percentile, 3.56 L) by GLI White and 3.84 L (fifth percentile, 2.95 L) by GLI African American. If this individual's measured FEV_1 is 3.50 L, it is 91% of predicted and above the fifth percentile by GLI African American but 78% of predicted and below the fifth percentile by GLI White. The differences between reference equations vary depending on age, sex, and height. An average reference equation formed by combining populations, such as GLI Global, is expected to yield predicted values for FEV_1 and FVC that are lower compared with White and higher compared with Black and Asian reference equations. The ratio of FEV_1 to FVC is similar across race and ethnicity in both children and adults (3).

Concerns with Not Using Race in PFT Interpretation

Changing from race-specific equations to GLI Global for PFT interpretation may increase the proportion of persons of color deemed to be unfit for certain occupations, including firefighting or commercial diving, working around coal mine and cotton dust, and serving in the military; it may also increase the proportion of persons of color charged higher premiums for life and health insurance. Given the lower mean values for spirometry in Black persons versus White persons (17), a Black person may be at disproportionate risk for these consequences in a system that did not consider race in its predicted values. One recommendation that reduces the concern about more persons of color being deemed unfit for employment if race-specific equations are not used is to use other means of assessing risk in individuals with results near a threshold. Another counterpoint to the concern about shifting results of persons of color from above to below the safety threshold is that policies can change to allow employment coupled with increased monitoring and protective measures. It is uncertain whether the lower mean spirometry values in Black persons are associated with more occupational risk. Data are not available to answer these questions. Attention to obtaining baseline preexposure PFTs would avoid potential harm from interpreting subsequent results during employment for those at risk for a decline in lung function caused by occupational hazards.

There is also concern that a switch to an average reference equation will lead to more difficulty for persons of color with results near thresholds to meet criteria for surgical resection of lung cancer. Notably, although a change to GLI Global is expected to influence this concern through FEV_1, the current lack of use of race-specific values for D_{LCO} means that this key parameter for assessing eligibility is based on data from White persons and at risk of biasing against persons of color. Patients who do not meet eligibility criteria by FEV_1 or D_{LCO} are recommended to undergo further evaluation with other tests to determine safety for resection. Data are unavailable to inform whether patients with results near thresholds would have equivalent, worse, or better outcomes from lung cancer with a change to an average reference equation.

A change to an average reference equation will increase the number of persons of color with values below the LLN and decrease the number of White persons below the LLN. Thus, there is a concern that persons of color might undergo further testing to work up a restrictive ventilatory defect suggested by an FVC less than the LLN and an FEV_1/FVC within the range of normal. In balance with the concerns for making this group of patients potentially undergo unnecessary testing and experience anxiety is the potential for a reduced chance of delayed or missed diagnoses. Among White persons, fewer might undergo a further workup after a change to an average reference equation because of a shift in results close to the LLN from below to above this threshold. In balance with this concern is the need to appreciate the uncertainty in making decisions on the basis of a threshold, to include the broader clinical context, and to consider trending against future results to calibrate suspicion for disease.

Data and Concerns that Challenge the Use of Race-Specific Equations

Multiple studies of people in the United States show improvements or noninferiority of a single reference equation compared with race-specific equations for associations of pulmonary function with clinical outcomes in both cross-sectional population and cohort studies. Mortality is more similar between Black and White persons at every percent predicted value if a single reference equation is used rather than race-specific equations (Figure 2) (84–87). Two of these studies on mortality compared race-specific equations with a White reference equation, and the other two used a race-neutral average reference equation. These studies have argued that, because using a single reference equation leads to matched survival at similar pulmonary function in mixed populations, the single reference equation approach is superior to using race-specific equations. However, because lung disease is not a significant cause of the difference in mortality between Black and White persons and the use of a single reference equation will improve the lung function results for White persons relative to Black persons, the observed improved fit for survival may be coincidental and not causal. Similarly, a race-neutral average reference equation performed as well as race-specific equations to predict incident chronic pulmonary disease in a population-based cohort (87). These studies suggest that, for making a prognosis, a single reference equation is superior to race-specific equations. A cross-sectional analysis of people with a history of

Table 1 Examples of Results Close to Thresholds for Which Decisions Change Depending on the Choice of Pulmonary Function Reference Equations

Clinical Context	Black Reference Equation		White Reference Equation		"Other" Average Reference Equation	
	FEV_1	FVC	FEV_1	FVC	FEV_1	FVC
Life insurance evaluation (female: age, 54 yr; height, 166 cm; $FEV_1 = 1.44$ L)*	60%		52%		56%	
Evaluation for interstitial disease (male: age, 54 yr; height, 190 cm; FVC = 3.90 L)†		81%		68%		74%
Determining need for noninvasive ventilatory support for neuromuscular weakness (male: age, 60 yr; height, 176 cm; FVC = 2.2 L)‡		57%		49%		53%
Threshold for lung transplantation evaluation for ILD (male: age, 60 yr; height, 176 cm; FVC = 1.6 L)§		42%		35%		38%
Fitness for surgical lung cancer resection (male: age, 60 yr; height, 176 cm; $FEV_1 = 1.1$ L; planned RUL)‖	31% (ppo)		26% (ppo)		28% (ppo)	

Definition of abbreviations: ILD = interstitial lung disease; RUL = right upper lobectomy.
The hypothetical patients need not be assigned to, or self-identify with, a race or ethnicity. Measurements are shown as percentages of predicted pulmonary function. Values indicated in green meet the threshold for policy or clinical action; those indicated in red do not. Values are reported as percentages of predicted from Global Lung Function Initiative reference equations. The examples show currently used thresholds of percentage of predicted pulmonary function based on reference values. However, the examples are not intended to endorse the use of percentage of predicted, given the associated age, sex, and height biases addressed by using percentiles (or *z*-scores) (1, 3). Threshold determines the status given in each footnote.
*Patient is in the "mild pulmonary disease" risk pool ($FEV_1 = 60$–80%), paying a lower premium than in "moderate pulmonary disease" risk pool ($FEV_1 = 50$–60%); https://www.quotacy.com/.
†Patient is marked for further evaluation.
‡Patient meets American Academy of Neurology criteria for ventilator support (FVC < 50%) (115).
§Patient should be referred to evaluation by transplant team (FVC < 40%) (93).
‖Patient requires cardiopulmonary exercise test before surgery (predicted postoperative FEV_1 percentage of predicted <30%) (112).

smoking tobacco showed that a race-neutral average reference equation improved the fit between pulmonary function and symptoms (Figure 3), airway structure, and functional capacity compared with a race-specific equation (88). In a COPD cohort, pulmonary function measurements that are not indexed to age, sex, or race performed as well as values indexed to race-specific reference equations for predicting symptoms, functional capacity, and emphysema (89). A population-based cohort study found that the prevalence of emphysema in specific ranges of percent predicted FEV_1 was better matched between Black and White persons with use of a race-neutral average rather than race-specific reference equations (90). These studies suggest that race-specific equations mask differential exposures and risk for lung disease. However, the studies do not prove a causal link between pulmonary function and the outcomes. The results show improved fit of associations that remain weak with significant variability of the data and are difficult to apply to individual patients. Except for two studies (86, 89), the results are biased by the use of the percentage of predicted pulmonary function rather than *z*-scores or percentiles. Although this bias is not expected to change the conclusions, the magnitude of the results should be interpreted with caution.

People of color currently face decreased odds of receiving a lung transplant (91). Although there are multiple reasons for this, the choice of PFT prediction equation influences referral rates for transplantation consideration, as percent predicted threshold values are commonly used. Although pulmonary function is not used in the lung allocation score, the timing and listing for lung transplantation depends on—although it is not exclusively dependent on—FEV_1 (for COPD, cystic fibrosis, and lymphangioleiomyomatosis) and FVC (for interstitial lung disease) as a percentage of the predicted value (92). The timing of lung transplantation represents a balance of risks and benefits of the current disease process versus those of transplantation. The use of an average reference equation would make the percent predicted pulmonary function of Black persons lower (93) and more likely to trigger a referral compared with race-specific equations (Table 1). We do not know whether increasing access to transplantation for Black persons in all cases will lead to better survival, nor has the potential for delayed referral and listing for White persons been considered.

The decision to use race-specific equations to rate impairment for disability evaluations occurs outside of clinical practice. We recognize that ATS statements can heavily influence these organizations and legal proceedings. PFT interpretation in claims against employers for lack of proper protections may aim to optimally predict a person's pulmonary function in the absence of occupational exposures, whereas assessment of impairment for disability rating may not be concerned about why the pulmonary function is reduced. State disability offices are known to use race-specific equations or adjustments in PFT interpretation. Many workers' compensation insurers use the American Medical Association Guide scales, which

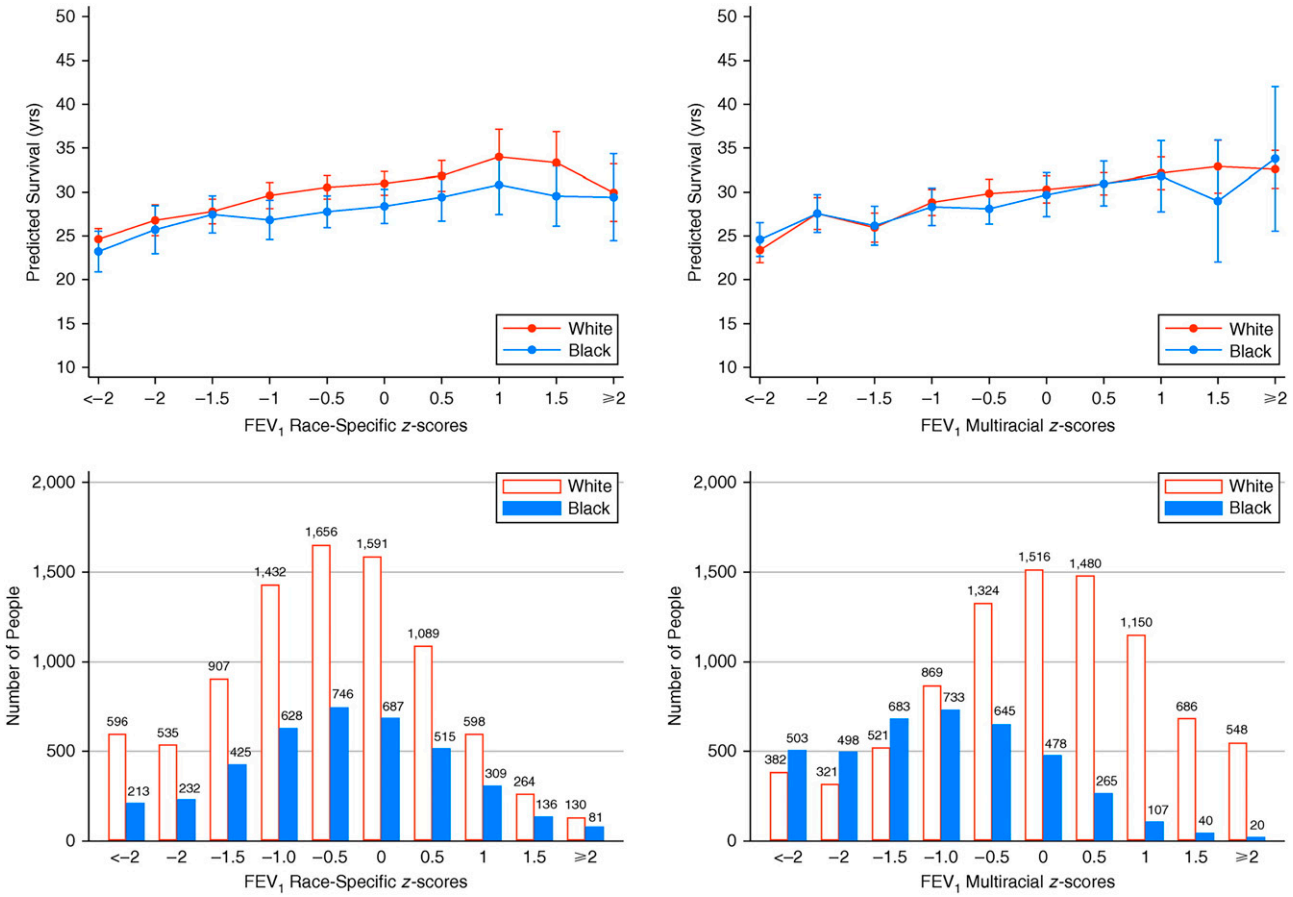

Figure 2. Influence of race-specific equations compared with a single reference equation in the interpretation of pulmonary function and the association with survival. The predicted survival for a 55-year-old, non–tobacco-smoking woman living at two times the federal income-poverty ratio is displayed for Black and White participants using each approach (top). Histograms demonstrate the distribution of FEV_1 *z*-scores applying race-specific equations compared with a single reference equation (Global Lung Function Initiative reference equations) (bottom). Reprinted from reference (86).

recommend the NHANES III race-specific equations (94). In contrast, for the rating of impairment for assessment of overall disability, the Social Security Administration uses a single standard (95). The assumptions underlying the current system of race-specific equations can prevent or delay determinations of disability (94). For 7 years, an administrative ruling required that worker's compensation claims related to asbestos exposure use race adjustment in pulmonary function tests, until it was overturned (96). The subsequent use of a single reference equation is expected to lead to more persons of color being eligible for compensation in disability cases.

Working Groups

Clarifying the Problems

The purposes of spirometry must be considered when evaluating potential strategies to address the use of race and ethnicity in PFT interpretation. Discussion took place on whether a model using race-specific values may be preferable to avoid unnecessary exclusion of some groups from occupations as noted above. For epidemiological studies of population health disparities and disease prognosis, a different set of reference values may be more appropriate than those used to care for individual patients. Although one approach is to allow use of different reference equations for each particular context, many workshop participants expressed concern that complexity and susceptibility to bias are barriers for real-world application.

Some workshop participants noted that the already common use of reference equations for $D_{L_{CO}}$ on the basis of data collected only from White persons, and variability in whether laboratories adjust for hemoglobin when reporting and interpreting $D_{L_{CO}}$, are accepted uncertainties that can make the perception of increased uncertainty with regard to changing to an average reference equation for spirometry more acceptable.

It is uncertain how to counsel a patient with pulmonary function near thresholds, switching from normal to abnormal on the basis of the choice of reference equations. Without further diagnostic evaluation, it is unclear whether such a finding reflects lung disease and what clinical action should be taken. The strong relationship between FEV_1 and survival is well described (97, 98), but the interventions that the clinician should take in the absence of a pulmonary diagnosis are unclear (99, 100). Many of the determinants of pulmonary function, such as early-life exposures and genetics, are unable to be intervened upon by clinicians caring for adults.

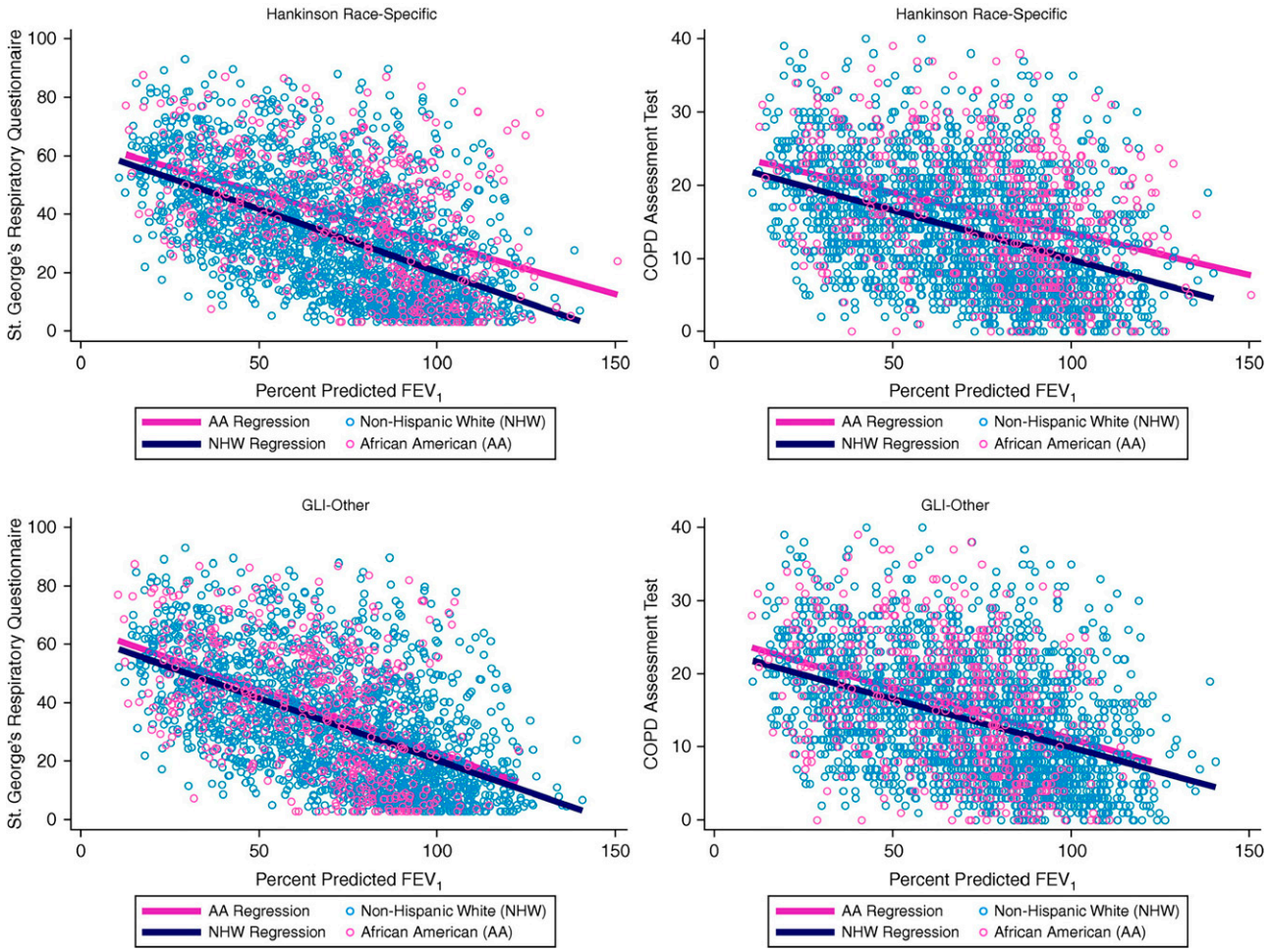

Figure 3. Pulmonary function versus symptoms in the Sub-Populations and InteRmediate Outcome Measures In Chronic Obstructive Pulmonary Disease (COPD) Study. For each patient-reported outcome (St. George's Respiratory Questionnaire and COPD Assessment Test), participants' scores are plotted against percent predicted FEV_1. Separate univariable linear regressions for each self-identified racial group are superimposed. The relationships between symptoms and pulmonary function are more consistent with a universally applied single reference equation (GLI Other). AA = African American; GLI = Global Lung Function Initiative; NHW = non-Hispanic White. Reprinted from reference (88).

Recommendation for PFT Reporting and Interpretation

A majority (30/33) of workshop participants recommend using a race-neutral average reference equation instead of race-specific equations in PFT laboratories and clinical practice. The majority cited limitations and problems with classifying individuals by race, the lack of evidence for benefit of race-specific equations, and the growing scientific evidence that supports both the use of a single reference equation and the concerns about norming social and environmental risk factors for reduced pulmonary function. Among the three who disagreed, one cited the harms in not comparing a person's results to those of other people who self-identify with the same race or ethnicity, as well as the recommendation's conflict with their view of heritable differences in body proportions between people that were set by different ancestral climates. Another participant did not approve of the use of race and ethnicity in the construction of GLI Global but agreed with not using race-specific equations. One participant was concerned about lack of precision by not using race-specific equations.

Other Potential Approaches to Improve PFT Reporting and Interpretation

Table 2 summarizes short-term and long-term approaches to report and interpret PFTs. Many options have the potential to reduce potential harms of using an average reference equation, and some better reflect the underlying uncertainty in the clinical application of PFTs. For example, if spirometry around the age of maximal lung size were available, results obtained when there is concern for disease can be compared with the patient's own baseline, with adjustment for the known effects of baseline function, aging, and height on trends (3). Another possible option in the short term is the reporting of multiple predicted values to give more choice to clinicians on how to apply the patient's results, especially where current practice is to compare with a prespecified threshold for decision making.

Other approaches give hope for substantial improvements to interpretation pending additional investigation. Standardizing FEV_1 to powers of standing height yielded values that perform as well or better than the percentage of predicted or

Table 2. Approaches and Concerns Discussed in Working Groups

Approach	Potential Benefits	Concerns and Barriers
Short-term changes		
Continue with race-specific equations but report strengths and limitations of incorporating race and ethnicity alongside PFT results to aid interpretation	Recognizes that race and ethnicity are not biological variables, are variably defined, and are not stable over time	Stops short of acting on the recognition of the limitations and evidence against race; risks medical harms
Change to reporting and interpreting PFTs with an average reference equation	– Consistent with scientific evidence supporting an average reference standard for mortality, incident lower pulmonary disease, and symptoms and lung structure in COPD – Potential for reduced medical harms; more persons of color with results near thresholds would be: – Further evaluated for pulmonary disease – Eligible for: – Pulmonary rehabilitation – Noninvasive ventilatory support – Earlier referral and listing for lung transplantation – Lung volume reduction surgery	– Uncertain effects and potential harms for persons of color with results near decision-making thresholds: – Persons of color with results near thresholds may have: – Reduced employment opportunity – More evaluation to be considered for surgical resection of lung cancer – Higher life insurance premiums in setting of chronic lung disease – Unknown if expected increased access to lung transplantation would increase harm for some patients – Uncertain effects and potential harms for White persons with results near decision-making thresholds: – Potential for underdiagnosis – Decreased eligibility for: – Pulmonary rehabilitation – Noninvasive ventilation – More easily meet eligibility criteria for lung cancer resection, employment, and lower life insurance premiums – Limitations of the proposed average reference equations, GLI Global – The number of potentially affected persons is unknown.
Report multiple predicted values Report multiple LLNs (e.g., 2.5th, 5th, and 10th percentiles)	– Emphasizes the uncertainty inherent in applying reference equations – Allows choice of sensitivity and specificity for the clinical question – Option to report values from locally applicable race-specific equations, e.g., without race labels	– More burden on physicians – Challenging to make a choice without an adequate evidence base – Challenging to communicate results to ordering physicians and patients – Local predicted values may mask the impact of modifiable social and environmental factors on reduced pulmonary function
Measure pulmonary function in everyone between ages 20 and 25	– Baseline value for comparison if concern for pulmonary disease develops – Less dependence on choice of reference equation	– Cost – Conflict of interest, as laboratories and clinicians can make more money from more testing
Obtain more longitudinal data	– Detect a change within the expected range, detect disease sooner	
Long-term changes		
Develop a gray zone of uncertainty around the LLN	– Values lower than the lower bound of the gray zone more likely to be associated with disease – Values within the gray zone will be marked for the need to interpret with more caution and context	– No validated placement of the bounds of the gray zone – Values above the upper limit of the bound may still be found in disease if maximal attained pulmonary function in life is very high – An additional boundary to navigate is created

(*Continued*)

Table 2. (*Continued*)

Approach	Potential Benefits	Concerns and Barriers
Use absolute FEV_1, absolute FEV_1 standardized to a power of height, or FEV_1Q instead of reference equations	– Absolute FEV_1 and FEV_1 standardized to height equivalently classified ventilatory impairment in COPD without using race or age, compared with using predicted values (89) – Better prediction of survival (102–104) and COPD exacerbations (101) – Similar to the Social Security Administration's use of PFTs for assessment of disability (95)	– Need data on performance beyond predicting mortality and in COPD, ventilatory impairment, and exacerbations – Limited diversity of populations studied – Clinicians do not have experience using these – Not applicable to pediatrics – FEV_1Q derived from European Coal and Steel Community reference equations and should be validated in GLI
Use of sitting height, trunk:limb ratio (Cormic index), or other measures of chest size and limb length	– More precise expected values: sitting height explained up to 40% of the residual variation in lung size in one study (36) – May perform better in some applications such as detecting pathology arising after lung development	– Sensitive to socioenvironmental exposures (116–118) – Might normalize the effects of experiencing a harmful environment during lung growth – Variable results from studies with some finding body proportions are much less explanatory of racial differences in pulmonary function (33, 99, 105) – Larger and more diverse datasets with multiple measures of chest size have yet to be collected to determine whether they can be used to improve precision
Cessation of labeling individual results as "normal" or "abnormal" to convey the personalized approach necessary in PFT interpretation	– Use of individual *z*-scores within a continuous distribution of pulmonary function may be more helpful than binary "normal" and "abnormal" labels – Encourage development of models that combine PFTs and other data to predict specific outcomes – May remove need for reference equations	– Data and models to guide a personalized approach are lacking – Complex models built with machine learning algorithms risk perpetuating biases
Reference equations informed by genetic variants found to influence pulmonary function	– More precision for calculating expected pulmonary function	– Privacy, cost, blood collection – Increased precision has potential to lessen focus on clinical context in interpretation – Based on correlation and may not be causative
Adjust expected values on the basis of social and environmental factors	– More precision for calculating expected pulmonary function – Understanding of potentially modifiable risk factors in the population	– Demographic and socioeconomic characteristics need to be collected in a standardized way on a global level – Even when such data are available, their impact on pulmonary function and interactions with genetics need to be determined – If pulmonary function were adjusted for SES, this has the potential to obscure drivers of health disparities and could inappropriately normalize pulmonary function among those with adverse exposures

Definition of abbreviations: COPD = chronic obstructive pulmonary disease; FEV_1Q = FEV_1 in increments of a sex-specific absolute lung volume defined by the first percentile value found in people and patients with abnormal lung function; GLI = Global Lung Function Initiative; LLN = lower limit of normal; PFT = pulmonary function test; SES = socioeconomic status.

z-scores derived from reference equations to predict all-cause mortality and features of COPD (89, 101–104). Expressing FEV_1 in increments of a sex-specific absolute lung volume defined by the first percentile value found in people and patients with abnormal lung function, termed FEV_1Q, led to an age- and height-independent measure that outperformed all of the aforementioned measures to predict COPD exacerbations and all-cause mortality (101, 102, 104). These new concepts for interpreting FEV_1 need further study in multiple pulmonary conditions and in more diverse populations. FEV_1Q does not give a determination of whether a result is unusual for a particular individual. Data on the effect of including sitting height to understand differences in pulmonary function between Black and White persons is inconsistent (33, 99, 105). More study of chest dimensions in larger and more diverse datasets is needed to inform use. A move from standing height to measures of chest size requires

careful consideration because of the risk of normalizing the effects of adverse exposures during lung growth. Chest size and environmental factors are not exclusive determinants of pulmonary function. Instead, variation in chest size is one consequence of the effects of the environment on lung development and is related to pulmonary function. Using data-driven approaches to compute and report the likelihood of specific patient-relevant outcomes by considering determinants of maximal lung growth, exposures, and the broader clinical context is aspirational.

Education

There needs to be greater education within the medical community that race is based on appearance and, because of its imbued sociopolitical meanings, should not be taken as an unbiased reflection of genetic difference (106–109). The history of how race was embedded into PFT interpretation should be taught to avoid similar biases as PFT interpretation evolves. More education is needed about how nongenetic determinants of pulmonary function, particularly disadvantaged socioeconomic environments, can contribute to racial differences in lung growth and functional decline. We must use the correct terminology: *1*) "race-specific" (or "from a similar population") is distinct from "race-adjusted" or "race-corrected," and *2*) reference equations provide predicted (or expected) values, not a diagnostic threshold to identify disease. Some workshop participants noted that the methodological distinction between race-specific and "race-adjusted" or "race-corrected" is not important because the clinical implications are the same.

We must stress the uncertainty around making clinical diagnoses on the basis of comparison to predicted values. The use of thresholds of pulmonary function on the basis of reference values does not take account of the low correlation between PFTs and pulmonary symptoms and outcomes (110, 111).

Working with Nonpulmonary Groups on Changing PFT Interpretation

Changing the approach to PFT interpretation will affect decisions about eligibility for work and medical disability. This can financially impact institutions and their individual members in opposing directions, and they may resist change if the impact is likely to be negative. For rule-making bodies such as insurance companies and organizations that recommend standards for safety and hiring, strict thresholds for PFT values should not be used without offering an alternative means of assessment. The use of exercise testing in thoracic surgery guidelines is one example of assessing risk through additional examinations to resolve uncertainty (112). Performance of the thresholds in ensuring safety from occupational hazards, and with use of respirators, should be studied. We must invite broad collaboration.

Best Practices

This panel recommends the inclusion of standardized scripts on PFT reports, with results in the electronic health record, and on laboratory websites to communicate a change to an average reference equation and its anticipated consequences. Example text is provided in an online supplement. Patients should be informed that a change in their results may trigger important thresholds for evaluation or treatment. Patients should be informed that PFTs are incomplete measures of lung health, need to be interpreted in the clinical context, and are not surrogates for fitness.

Prior and future testing should be obtained and examined for trends that may correlate with the clinical concern. Comparing results within an individual over time is an ATS/European Respiratory Society standard and represents one way to sidestep the challenges of selecting and using reference values (1). Interpretation can stress the use of the ratio of FEV_1 to FVC, which is used to identify obstructive ventilatory defects found in COPD, asthma, and other diseases affecting the airways, and it varies minimally by race or ethnicity in the NHANES III and GLI reference equations.

Collecting race and ethnicity data in research is important to identify modifiable determinants of reduced pulmonary function, including those resulting from structural racism (113). Race and ethnicity data are often characterized by absence of information, inconsistent methods of ascertainment, and internal disagreement within a single patient's records (114). There is a mismatch between self-identified race and phenotypic appearance. We need to increase the diversity of the participants in studies that include pulmonary function (2). Our current understanding of pulmonary function, health, and disease is based on studies in which the world's diversity is underrepresented. Attention to race and ethnicity in research studies is one way to ensure equity in the development of precision medicine (113). One workshop participant did not agree that categorizing people by race or ethnicity was necessary to make research results broadly applicable and equitable.

Conclusions

This workshop was conducted in May 2021 after meetings in 2020–2021 programmed sessions on the history of race and ethnicity in PFT interpretation, a review of the known determinants of pulmonary function, and the clinical implications of using or not using race and ethnicity in PFT interpretation. The workshop ended with a discussion of potential changes to current practice through working groups on barriers to change, best practices, and long-term strategies. Despite the lack of consensus to give recommendations at the end of the workshop, many participants continued to engage together on this topic. This ongoing discussion, along with the publication of new evidence, gave this report an opportunity to make recommendations paired with cautions and countering views. The recommendation to use an average reference equation instead of race-specific equations in PFT laboratories and clinical practice represents an evolution in thought since the most recent technical standards were published. There is an urgent need to collaborate with leaders outside of the expertise of this workshop panel such as in thoracic surgery, occupational medicine, disability and insurance programs, medical insurance coverage, and lung transplantation. Further study on the consequences of adopting the recommendations is imperative. This panel recognizes the need for research studies to increase population diversity, the variety of pulmonary diseases, and PFTs beyond spirometry. In the United States, Native Americans and Asian Americans are examples of groups who are underrepresented in studies. The engagement of investigators in many parts of Africa is required to improve on the limited representation of heterogeneity among Black persons in existing data that are dominated by African Americans primarily of West African ancestry. The field should continue to study the determinants of pulmonary function and generate evidence-based approaches to using PFTs. ■

This official statement was prepared by *ad hoc* subcommittees of the ATS Committees on Pulmonary Function Testing and on Health Equity and Diversity.

Members of the subcommittees are as follows:

Nirav R. Bhakta, M.D., Ph.D. (*Co-Chair*)[1,5]
Christian Bime, M.D. (*Co-Chair*)[2]
David A. Kaminsky, M.D.[3*]
Meredith C. McCormack, M.D., M.H.S.[4*]
Neeta Thakur, M.D., M.P.H.[5,6*‡]
Sanja Stanojevic, Ph.D.[7‡]
Aaron D. Baugh, M.D.[1‡]
Lundy Braun, Ph.D.[8,9,10‡]
Stephanie Lovinsky-Desir, M.D., M.S.[11*]
Rosemary Adamson, M.B. B.S.[12,13*]
Jonathan Witonsky, M.D., M.A.S.[14§]
Robert A. Wise, M.D.[4‡]
Sean D. Levy, M.D.[15‡]
Robert Brown, M.D.[16*]
Esteban G. Burchard, M.D., M.P.H.[33*||]
Erick Forno, M.D., M.P.H., A.T.S.F.[17‡]
Robyn T. Cohen, M.D., M.P.H.[18*]
Meshell Johnson, M.D.[5,19*]
John Balmes, M.D.[5,20§]
Yolanda Mageto, M.D., M.P.H.[21‡]
Cathryn T. Lee, M.D.[22*]
Refiloe Masekela, M.D., Ph.D.[23‡]
Martin R. Miller, B.Sc., M.D.[34*||]
Daniel J. Weiner, M.D.[17§]
Charlie G. Irvin, Ph.D.[3*]
Erik R. Swenson, M.D.[12,13*]
Margaret Rosenfeld, M.D., M.P.H.[24,25,26*]
Richard M. Schwartzstein, M.D.[15§]
Anurag Agrawal, M.B. B.S., Ph.D.[27*]
Enid Neptune, M.D.[4§]
Juan P. Wisnivesky, M.D., Dr.P.H.[28,29§]
Victor E. Ortega, M.D., Ph.D.[30,31‡]
Peter Burney, M.A., M.D.[32§]

[1]Division of Pulmonary, Critical Care, Allergy, and Sleep Medicine, [5]Department of Medicine, [14]Department of Pediatrics, and [33]School of Pharmacy, University of California, San Francisco, San Francisco, California; [2]The College of Medicine, The University of Arizona Health Science, Tucson, Arizona; [3]The University of Vermont, Burlington, Vermont; [4]Department of Medicine, Johns Hopkins University School of Medicine, Baltimore, Maryland; [6]Zuckerberg San Francisco General Hospital, San Francisco, California; [7]Department of Community Health and Epidemiology, Dalhousie University, Halifax, Nova Scotia, Canada; [8]Department of Africana Studies, [9]Department of Pathology and Laboratory Medicine, and [10]Science and Technology Program, Brown University, Providence, Rhode Island; [11]Division of Pediatric Pulmonary Medicine, Department of Pediatrics, Columbia University Vagelos College of Physicians and Surgeons, New York, New York; [12]Division of Pulmonary, Critical Care and Sleep Medicine, [24]Department of Pediatrics, and [25]Department of Epidemiology, University of Washington, Seattle, Washington; [13]Section of Pulmonary, Critical Care and Sleep Medicine, Veterans Affairs Puget Sound Healthcare System, Seattle, Washington; [15]Division of Pulmonary, Critical Care, and Sleep Medicine, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, Massachusetts; [16]Pulmonary and Critical Care Unit, Massachusetts General Hospital, Boston, Massachusetts; [17]Division of Pediatric Pulmonary Medicine, University of Pittsburgh Medical Center, Children's Hospital of Pittsburgh, Pittsburgh, Pennsylvania; [18]Division of Pediatric Pulmonary and Allergy, Boston Medical Center and Boston University School of Medicine, Boston, Massachusetts; [19]Veterans Affairs San Francisco, San Francisco, California; [20]School of Public Health, University of California Berkeley, Berkeley, California; [21]Baylor Scott and White Health University Medical Center, Dallas, Texas; [22]Section of Pulmonary & Critical Care Medicine, Department of Medicine, University of Chicago, Chicago, Illinois; [23]Department of Pediatrics and Child Health, University of KwaZulu Natal, Durban, South Africa; [26]Seattle Children's Research Institute, Seattle, Washington; [27]Bioscience and Health Research, Trivedi School of Biosciences, Ashoka University, Haryana, India; [28]Division of General Internal Medicine and [29]Division of Pulmonary and Critical Care Medicine, Icahn School of Medicine at Mount Sinai, New York, New York; [30]Division of Pulmonary Medicine, Department of Internal Medicine, and [31]Division of Epidemiology, Department of Quantitative Health Sciences, Center for Individualized Medicine, Mayo Clinic, Phoenix, Arizona; and [32]National Heart and Lung Institute, Imperial College, London, United Kingdom; [34]University of Birmingham, Birmingham, United Kingdom

*Group leader.
‡Speaker.
§Participant.
||Member of the subcommittee who was not part of the writing committee.

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References

1. Stanojevic S, Kaminsky DA, Miller MR, Thompson B, Aliverti A, Barjaktarevic I, *et al.* ERS/ATS technical standard on interpretive strategies for routine lung function tests. *Eur Respir J* 2022;60: 2101499.
2. Caulfield T, Fullerton SM, Ali-Khan SE, Arbour L, Burchard EG, Cooper RS, *et al.* Race and ancestry in biomedical research: exploring the challenges. *Genome Med* 2009;1:8.
3. 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;40:1324–1343.
4. Cerdena JP, Plaisime MV, Tsai J. From race-based to race-conscious medicine: how anti-racist uprisings call us to act. *Lancet* 2020;396: 1125–1128.
5. Vyas DA, Eisenstein LG, Jones DS. Hidden in plain sight—reconsidering the use of race correction in clinical algorithms. *N Engl J Med* 2020;383: 874–882.

6. Neas LM, Schwartz J. The determinants of pulmonary diffusing capacity in a national sample of US adults. *Am J Respir Crit Care Med* 1996;153: 656–664.
7. Pesola GR, Huggins G, Sherpa TY. Abnormal predicted diffusion capacities in healthy Asians: an inequality with a solution. *Respiration* 2006;73:799–807.
8. Pesola GR, Sunmonu Y, Huggins G, Ford JG. Measured diffusion capacity versus prediction equation estimates in blacks without lung disease. *Respiration* 2004;71:484–492.
9. Lung function testing: selection of reference values and interpretative strategies. American Thoracic Society. *Am Rev Respir Dis* 1991;144: 1202–1218.
10. Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, *et al.* Interpretative strategies for lung function tests. *Eur Respir J* 2005; 26:948–968.
11. Braun L. Spirometry, measurement, and race in the nineteenth century. *J Hist Med Allied Sci* 2005;60:135–169.
12. Braun L. Breathing race into the machine: the surprising career of the spirometer from plantation to genetics. Minneapolis, MN: University of Minnesota Press; 2014.
13. Humphreys M. Intensely human: the health of the Black soldier in the American Civil War. Baltimore, MD: Johns Hopkins University Press; 2008.
14. Bay M. The White image in the Black mind: African American ideas about White people, 1830–1925. New York, NY: Oxford University Press; 2000.
15. Fredrickson GM. The Black image in the White mind; the debate on Afro-American character and destiny, 1817–1914, 1st ed. New York, NY: Harper & Row; 1971.
16. Occupational Exposure to Cotton Dust: Final Mandatory Occupational Safety and Health Standards. Federal Register no. 43:27418-63, Standard Number: 1910.1046, 1978 [accessed 2021 Nov 12]. Available from: https://www.osha.gov/laws-regs/federalregister/1978-06-23.
17. Braun L, Wolfgang M, Dickersin K. Defining race/ethnicity and explaining difference in research studies on lung function. *Eur Respir J* 2013;41: 1362–1370.
18. Rossiter CE, Weill H. Ethnic differences in lung function: evidence for proportional differences. *Int J Epidemiol* 1974;3:55–61.
19. Myers JE. Differential ethnic standards for lung functions, or one standard for all? *S Afr Med J* 1984;65:768–772.
20. White NW. 'Ethic discounting' and spirometry. *Respir Med* 1995;89: 312–313.
21. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general US population. *Am J Respir Crit Care Med* 1999;159:179–187.
22. Kiefer EM, Hankinson JL, Barr RG. Similar relation of age and height to lung function among Whites, African Americans, and Hispanics. *Am J Epidemiol* 2011;173:376–387.
23. Hankinson JL, Kawut SM, Shahar E, Smith LJ, Stukovsky KH, Barr RG. Performance of American Thoracic Society–recommended spirometry reference values in a multiethnic sample of adults: the Multi-Ethnic Study of Atherosclerosis (MESA) lung study. *Chest* 2010;137:138–145.
24. Wang F, Wang K, Bowerman C, Ulla H, Sun J, Topalovic M, *et al.* Evaluation of the Global Lung Function Initiative 2012 reference values for spirometry in China: a national cross-sectional study. *Eur Respir J* 2022;60:2200490.
25. Smith SJ, Gray DM, MacGinty RP, Hall GL, Stanojevic S, Mphahlele R, *et al.* Choosing the Better Global Lung Initiative 2012 equation in South African population groups. *Am J Respir Crit Care Med* 2020;202: 1724–1727.
26. Bowerman C, Bhakta NR, Brazzale D, Cooper BR, Cooper J, Gochicoa-Rangel L, *et al.* A race-neutral approach to the interpretation of lung function measurements. *Am J Respir Crit Care Med* 2023;207: 768–774.
27. Allinson JP, Afzal S, Colak Y, Jarvis D, Backman H, van den Berge M, *et al.* Changes in lung function in European adults born between 1884 and 1996 and implications for the diagnosis of lung disease: a cross-sectional analysis of ten population-based studies. *Lancet Respir Med* 2022;10:83–94.
28. Whyte MB, Kelly P. The normal range: it is not normal and it is not a range. *Postgrad Med J.* 2018;94:613–616.
29. Group SR, Wright JT Jr, Williamson JD, Whelton PK, Snyder JK, Sink KM, *et al.* A randomized trial of intensive versus standard blood-pressure control. *N Engl J Med* 2015;373:2103–2116.
30. Haynes JM, Kaminsky DA, Stanojevic S, Ruppel GL. Pulmonary function reference equations: a brief history to explain all the confusion. *Respir Care* 2020;65:1030–1038.
31. Allen JA. The influence of physical conditions in the genesis of species. *Radical Review* 1877;1:108–140.
32. Pomeroy E, Stock JT, Wells JCK. Population history and ecology, in addition to climate, influence human stature and body proportions. *Sci Rep* 2021;11:274.
33. Holland R, Bowerman C, Stanojevic S. The contribution of anthropometry and socioeconomic status to racial differences in measures of lung function: a systematic review. *Chest* 2022;162:635–646.
34. 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* 2022;161:288–297.
35. Goldin JG, Louw SJ, Joubert G. Spirometry of healthy adult South African men. Part II. Interrelationship between socio-environmental factors and 'race' as determinants of spirometry. *S Afr Med J* 1996;86:820–826.
36. Harik-Khan RI, Muller DC, Wise RA. Racial difference in lung function in African American and White children: effect of anthropometric, socioeconomic, nutritional, and environmental factors. *Am J Epidemiol* 2004;160:893–900.
37. Lum S, Bountziouka V, Sonnappa S, Wade A, Cole TJ, Harding S, *et al.* Lung function in children in relation to ethnicity, physique and socioeconomic factors. *Eur Respir J* 2015;46:1662–1671.
38. Bui DS, Lodge CJ, Burgess JA, Lowe AJ, Perret J, Bui MQ, *et al.* Childhood predictors of lung function trajectories and future COPD risk: a prospective cohort study from the first to the sixth decade of life. *Lancet Respir Med* 2018;6:535–544.
39. Bui DS, Lodge CJ, Perret JL, Lowe A, Hamilton GS, Thompson B, *et al.* Trajectories of asthma and allergies from 7 years to 53 years and associations with lung function and extrapulmonary comorbidity profiles: a prospective cohort study. *Lancet Respir Med* 2021;9:387–396.
40. Lange P, Celli B, Agusti A, Boje Jensen G, Divo M, Faner R, *et al.* Lung-function trajectories leading to chronic obstructive pulmonary disease. *N Engl J Med* 2015;373:111–122.
41. Stern DA, Morgan WJ, Wright AL, Guerra S, Martinez FD. Poor airway function in early infancy and lung function by age 22 years: a non-selective longitudinal cohort study. *Lancet* 2007;370:758–764.
42. Gibbons JTD, Wilson AC, Simpson SJ. Predicting lung health trajectories for survivors of preterm birth. *Front Pediatr* 2020;8:318.
43. Kotecha SJ, Edwards MO, Watkins WJ, Henderson AJ, Paranjothy S, Dunstan FD, *et al.* Effect of preterm birth on later FEV_1: a systematic review and meta-analysis. *Thorax* 2013;68:760–766.
44. Ooka T, Akiyama Y, Shinohara R, Yokomichi H, Yamagata Z. Individual and regional characteristics associated with maternal smoking during pregnancy in Japan: healthy parents and children 21. *Int J Environ Res Public Health* 2019;17:173.
45. Hardeman RR, Chantarat T, Smith ML, Karbeah J, Van Riper DC, Mendez DD. Association of residence in high-police contact neighborhoods with preterm birth among Black and White individuals in Minneapolis. *JAMA Netw Open* 2021;4:e2130290.
46. Sudhinaraset M, Woofter R, Young MT, Landrian A, Vilda D, Wallace SP. Analysis of state-level immigrant policies and preterm births by race/ethnicity among women born in the US and women born outside the US. *JAMA Netw Open* 2021;4:e214482.
47. Mocelin HT, Fischer GB, Bush A. Adverse early-life environmental exposures and their repercussions on adult respiratory health. *J Pediatr (Rio J)* 2022;98:S86–S95.
48. Forno E, Han YY, Mullen J, Celedon JC. Overweight, obesity, and lung function in children and adults—a meta-analysis. *J Allergy Clin Immunol Pract* 2018;6:570–581.e10.
49. Fauroux B, Simoes EAF, Checchia PA, Paes B, Figueras-Aloy J, Manzoni P, *et al.* The burden and long-term respiratory morbidity associated with respiratory syncytial virus infection in early childhood. *Infect Dis Ther* 2017;6:173–197.
50. Bont L, Checchia PA, Fauroux B, Figueras-Aloy J, Manzoni P, Paes B, *et al.* Defining the epidemiology and burden of severe respiratory syncytial virus infection among infants and children in western countries. *Infect Dis Ther* 2016;5:271–298.
51. Gauderman WJ, Avol E, Gilliland F, Vora H, Thomas D, Berhane K, *et al.* The effect of air pollution on lung development from 10 to 18 years of age. *N Engl J Med* 2004;351:1057–1067.

52. Rice MB, Rifas-Shiman SL, Litonjua AA, Gillman MW, Liebman N, Kloog I, *et al.* Lifetime air pollution exposure and asthma in a pediatric birth cohort. *J Allergy Clin Immunol* 2018;141:1932–1934.e7.
53. State of the air. American Lung Association; 2021 [accessed 2022 Aug 27]. Available from: https://www.lung.org/getmedia/17c6cb6c-8a38-42a7-a3b0-6744011da370/sota-2021.pdf.
54. Rylance S, Masekela R, Banda NPK, Mortimer K. Determinants of lung health across the life course in sub-Saharan Africa. *Int J Tuberc Lung Dis* 2020;24:892–901.
55. Gauderman WJ, Urman R, Avol E, Berhane K, McConnell R, Rappaport E, *et al.* Association of improved air quality with lung development in children. *N Engl J Med* 2015;372:905–913.
56. Downs SH, Schindler C, Liu LJ, Keidel D, Bayer-Oglesby L, Brutsche MH, *et al.* Reduced exposure to PM10 and attenuated age-related decline in lung function. *N Engl J Med* 2007;357:2338–2347.
57. Tessum CW, Paolella DA, Chambliss SE, Apte JS, Hill JD, Marshall JD. $PM_{2.5}$ polluters disproportionately and systemically affect people of color in the United States. *Sci Adv* 2021;7:eabf4491.
58. QuickStats: trends in secondhand smoke exposure* among nonsmoking adults, by race† and Hispanic origin—National Health and Nutrition Examination Survey, United States, 2009–2018. *MMWR Morb Mortal Wkly Rep.* 2021;70:224.
59. Tsai J, Homa DM, Gentzke AS, Mahoney M, Sharapova SR, Sosnoff CS, *et al.* Exposure to secondhand smoke among nonsmokers—United States, 1988–2014. *MMWR Morb Mortal Wkly Rep*. 2018;67: 1342–1346.
60. Rocha V, Soares S, Stringhini S, Fraga S. Socioeconomic circumstances and respiratory function from childhood to early adulthood: a systematic review and meta-analysis. *BMJ Open* 2019;9:e027528.
61. Padula AM, Rivera-Nunez Z, Barrett ES. Combined impacts of prenatal environmental exposures and psychosocial stress on offspring health: air pollution and metals. *Curr Environ Health Rep* 2020;7:89–100.
62. Rosa MJ, Lee AG, Wright RJ. Evidence establishing a link between prenatal and early-life stress and asthma development. *Curr Opin Allergy Clin Immunol* 2018;18:148–158.
63. Wright RJ. Perinatal stress and early life programming of lung structure and function. *Biol Psychol* 2010;84:46–56.
64. Clougherty JE, Kubzansky LD. A framework for examining social stress and susceptibility to air pollution in respiratory health. *Environ Health Perspect* 2009;117:1351–1358.
65. Jackson B, Kubzansky LD, Cohen S, Jacobs DR Jr, Wright RJ; CARDIA study investigators. Does harboring hostility hurt? Associations between hostility and pulmonary function in the Coronary Artery Risk Development in (Young) Adults (CARDIA) study. *Health Psychol* 2007; 26:333–340.
66. Kariuki SM, Gray DM, Newton C, Vanker A, MacGinty RP, Koen N, *et al.* Association between maternal psychological adversity and lung function in South African infants: a birth cohort study. *Pediatr Pulmonol* 2020;55: 236–244.
67. Suglia SF, Wright RO, Schwartz J, Wright RJ. Association between lung function and cognition among children in a prospective birth cohort study. *Psychosom Med* 2008;70:356–362.
68. Steinberg M, Becklake MR. Socio-environmental factors and lung function. *S Afr Med J* 1986;70:270–274.
69. Rocha V, Fraga S, Moreira C, Carmeli C, Lenoir A, Steptoe A, *et al.* Life-course socioeconomic disadvantage and lung function: a multicohort study of 70 496 individuals. *Eur Respir J* 2021;57:2001600.
70. Harik-Khan RI, Fleg JL, Muller DC, Wise RA. The effect of anthropometric and socioeconomic factors on the racial difference in lung function. *Am J Respir Crit Care Med* 2001;164:1647–1654.
71. Wyss AB, Sofer T, Lee MK, Terzikhan N, Nguyen JN, Lahousse L, *et al.* Multiethnic meta-analysis identifies ancestry-specific and cross-ancestry loci for pulmonary function. *Nat Commun* 2018;9:2976.
72. Shrine N, Guyatt AL, Erzurumluoglu AM, Jackson VE, Hobbs BD, Melbourne CA, *et al.* New genetic signals for lung function highlight pathways and chronic obstructive pulmonary disease associations across multiple ancestries. *Nat Genet* 2019;51:481–493.
73. Kumar R, Seibold MA, Aldrich MC, Williams LK, Reiner AP, Colangelo L, *et al.* Genetic ancestry in lung-function predictions. *N Engl J Med* 2010; 363:321–330.
74. Ortega VE, Meyers DA. Pharmacogenetics: implications of race and ethnicity on defining genetic profiles for personalized medicine. *J Allergy Clin Immunol* 2014;133:16–26.
75. Pino-Yanes M, Thakur N, Gignoux CR, Galanter JM, Roth LA, Eng C, *et al.* Genetic ancestry influences asthma susceptibility and lung function among Latinos. *J Allergy Clin Immunol* 2015;135:228–235.
76. Cerdeña JP, Grubbs V, Non AL. Genomic supremacy: the harm of conflating genetic ancestry and race. *Hum Genomics* 2022;16:18.
77. Mersha TB, Qin K, Beck AF, Ding L, Huang B, Kahn RS. Genetic ancestry differences in pediatric asthma readmission are mediated by socioenvironmental factors. *J Allergy Clin Immunol* 2021;148: 1210–1218.e4.
78. ASHG denounces attempts to link genetics and racial supremacy. *Am J Hum Genet* 2018;103:636.
79. Donnelly PM, Yang TS, Peat JK, Woolcock AJ. What factors explain racial differences in lung volumes? *Eur Respir J* 1991;4:829–838.
80. de Vries M, Nedeljkovic I, van der Plaat DA, Zhernakova A, Lahousse L, Brusselle GG, *et al.* DNA methylation is associated with lung function in never smokers. *Respir Res* 2019;20:268.
81. Krause TG, Pedersen BV, Thomsen SF, Koch A, Wohlfahrt J, Backer V, *et al.* Lung function in Greenlandic and Danish children and adolescents. *Respir Med* 2005;99:363–371.
82. Duhaime G, Édouard R. Monetary poverty in Inuit Nunangat. *Artic* 2015; 68:223–232.
83. Brutsaert TD, Soria R, Caceres E, Spielvogel H, Haas JD. Effect of developmental and ancestral high altitude exposure on chest morphology and pulmonary function in Andean and European/North American natives. *Am J Hum Biol* 1999;11:383–395.
84. Burney PG, Hooper RL. The use of ethnically specific norms for ventilatory function in African American and white populations. *Int J Epidemiol* 2012;41:782–790.
85. Gaffney AW, McCormick D, Woolhandler S, Christiani DC, Himmelstein DU. Prognostic implications of differences in forced vital capacity in Black and White U.S. adults: findings from NHANES III with long-term mortality follow-up. *EClinicalMedicine* 2021;39: 101073.
86. McCormack MC, Balasubramanian A, Matsui EC, Peng RD, Wise RA, Keet CA. Race, lung function, and long-term mortality in the National Health and Nutrition Examination Survey III. *Am J Respir Crit Care Med* 2022;205:723–724.
87. 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;205:700–710.
88. Baugh AD, Shiboski S, Hansel NN, Ortega V, Barjaktarevic I, Barr RG, *et al.* Reconsidering the utility of race-specific lung function prediction equations. *Am J Respir Crit Care Med* 2022;205:819–829.
89. Checkley W, Foreman MG, Bhatt SP, Dransfield MT, Han M, Hanania NA, *et al.* Differences between absolute and predicted values of forced expiratory volumes to classify ventilatory impairment in chronic obstructive pulmonary disease. *Respir Med* 2016;111:30–38.
90. 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* 2022;175:1118–1125.
91. Mooney JJ, Hedlin H, Mohabir P, Bhattacharya J, Dhillon GS. Racial and ethnic disparities in lung transplant listing and waitlist outcomes. *J Heart Lung Transplant* 2018;37:394–400.
92. Leard LE, Holm AM, Valapour M, Glanville AR, Attawar S, Aversa M, *et al.* Consensus document for the selection of lung transplant candidates: an update from the International Society for Heart and Lung Transplantation. *J Heart Lung Transplant* 2021;40:1349–1379.
93. Shweish O, Dronavalli G. Indications for lung transplant referral and listing. *J Thorac Dis* 2019;11:S1708–S1720.
94. Sood A. Performing a lung disability evaluation: how, when, and why? *J Occup Environ Med* 2014;56:S23–S29.
95. Social Security Disability SSI. Disability evaluation under social security. Washington, DC: Social Security Administration, n.d. [accessed 2021 Feb 26] Available from: https://www.ssa.gov/disability/professionals/bluebook/3.00-Respiratory-Adult.htm.

96. ACandS Inc. v Godwin, 340 Md. 344, 667 A.2d 116 (1995).
97. Duong M, Islam S, Rangarajan S, Leong D, Kurmi O, Teo K, *et al.* Mortality and cardiovascular and respiratory morbidity in individuals with impaired FEV_1 (PURE): an international, community-based cohort study. *Lancet Glob Health* 2019;7:e613–e623.
98. Schunemann HJ, Dorn J, Grant BJ, Winkelstein W Jr, Trevisan M. Pulmonary function is a long-term predictor of mortality in the general population: 29-year follow-up of the Buffalo Health Study. *Chest* 2000; 118:656–664.
99. Agrawal A, Aggarwal M, Sonnappa S, Bush A. Ethnicity and spirometric indices: hostage to tunnel vision? *Lancet Respir Med* 2019; 7:743–744.
100. Doubeni CA, Simon M, Krist AH. Addressing systemic racism through clinical preventive service recommendations from the US Preventive Services Task Force. *JAMA* 2021;325:627–628.
101. Huang TH, Hsiue TR, Lin SH, Liao XM, Su PL, Chen CZ. Comparison of different staging methods for COPD in predicting outcomes. *Eur Respir J* 2018;51:1700577.
102. Miller MR, Pedersen OF. New concepts for expressing forced expiratory volume in 1 s arising from survival analysis. *Eur Respir J* 2010;35: 873–882.
103. Miller MR, Pedersen OF, Lange P, Vestbo J. Improved survival prediction from lung function data in a large population sample. *Respir Med* 2009;103:442–448.
104. Pedone C, Scarlata S, Scichilone N, Forastiere F, Bellia V, Antonelli-Incalzi R. Alternative ways of expressing FEV_1 and mortality in elderly people with and without COPD. *Eur Respir J* 2013;41: 800–805.
105. Whittaker AL, Sutton AJ, Beardsmore CS. Are ethnic differences in lung function explained by chest size? *Arch Dis Child Fetal Neonatal Ed* 2005;90:F423–F428.
106. Gravlee CC. How race becomes biology: embodiment of social inequality. *Am J Phys Anthropol* 2009;139:47–57.
107. Manly JJ. Deconstructing race and ethnicity: implications for measurement of health outcomes. *Med Care* 2006;44: S10–S16.
108. Witzig R. The medicalization of race: scientific legitimization of a flawed social construct. *Ann Intern Med* 1996;125:675–679.
109. Krainc T, Fuentes A. Genetic ancestry in precision medicine is reshaping the race debate. *Proc Natl Acad Sci USA* 2022;119:e2203033119.
110. Carranza Rosenzweig JR, Edwards L, Lincourt W, Dorinsky P, ZuWallack RL. The relationship between health-related quality of life, lung function and daily symptoms in patients with persistent asthma. *Respir Med* 2004;98:1157–1165.
111. Han MK, Muellerova H, Curran-Everett D, Dransfield MT, Washko GR, Regan EA, *et al.* GOLD 2011 disease severity classification in COPDGene: a prospective cohort study. *Lancet Respir Med* 2013;1: 43–50.
112. Brunelli A, Kim AW, Berger KI, Addrizzo-Harris DJ. Physiologic evaluation of the patient with lung cancer being considered for resectional surgery. diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. *Chest* 2013;143: e166S–e190S.
113. Borrell LN, Elhawary JR, Fuentes-Afflick E, Witonsky J, Bhakta N, Wu AHB, *et al.* Race and genetic ancestry in medicine—a time for reckoning with racism. *N Engl J Med* 2021;384:474–480.
114. Lee SJ, Grobe JE, Tiro JA. Assessing race and ethnicity data quality across cancer registries and EMRs in two hospitals. *J Am Med Inform Assoc* 2016;23:627–634.
115. Miller RG, Jackson CE, Kasarskis EJ, England JD, Forshew D, Johnston W, *et al.* Practice parameter update: the care of the patient with amyotrophic lateral sclerosis: drug, nutritional, and respiratory therapies (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. *Neurology* 2009;73:1218–1226.
116. van de Wal BW, Erasmus LD, Hechter R. Stem and standing heights in Bantu and white South Africans: their significance in relation to pulmonary function values. *S Afr Med J* 1971;45:568–570.
117. Wadsworth ME, Hardy RJ, Paul AA, Marshall SF, Cole TJ. Leg and trunk length at 43 years in relation to childhood health, diet and family circumstances; evidence from the 1946 national birth cohort. *Int J Epidemiol* 2002;31:383–390.
118. Quanjer PH, Kubota M, Kobayashi H, Omori H, Tatsumi K, Kanazawa M, *et al.* Secular changes in relative leg length confound height-based spirometric reference values. *Chest* 2015;147:792–797.