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ORIGINAL RESEARCH

Enhancing Air Quality Index Activity Guidelines for Preventing Cardiovascular Events in the General Adult Population

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ABSTRACT

BACKGROUND The public health relevance of daily Air Quality Index (AQI) activity guidelines for the general adult public in the United States to prevent atherosclerotic cardiovascular disease (ASCVD) events is questionable.

OBJECTIVES The purpose of the study was to explore the utility of a policy tailoring activity guidance to calculated ASCVD risk rather than uniform recommendations to the general adult public as currently provided.

METHODS We calculated the number needed to treat (NNT) to prevent one ASCVD event per day by following activity recommendations across 10-year ASCVD risk scores (1% to 20%). Second, we modeled the benefits of tailoring recommendations to ASCVD risk.

RESULTS The NNT decreased as ASCVD risk and/or AQI levels increased. At AQIs up to 151 (68% of days with AQIs above moderate in the United States), the NNTs remained untenably high (>2.7-55.3 million) across ASCVD risk. Under unhealthy conditions (AQIs 151-200), 28% of elevated AQIs, NNTs <1 million could be achieved by current guidance (15% exposure reduction), but only among the highest-risk individuals (ASCVD 18% to 20%) on the most polluted days (AQIs 192-200). Tailoring guidance to ASCVD risk could yield NNTs <1 million at risk thresholds of 7.5% and 10% if activity restrictions were more stringent (35% to 50% exposure reductions) during unhealthy conditions.

CONCLUSIONS ASCVD risk has a major influence on the NNT to prevent cardiovascular events by following AQI guidance. It may be possible for a future policy to improve the utility of AQI activity guidance for the general adult public by tailoring activity recommendations to ASCVD risk. (JACC Adv. 2024;3:101313) © 2024 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

The Environmental Protection Agency issues a daily Air Quality Index (AQI) for locations across the United States to inform the public regarding ambient air pollution levels.[1] Since 1999, AQIs have also provided activity guidance to help reduce acute exposures. Recommendations (eg, avoid outdoor physical activities) are promoted at each AQI stratum and are more aggressive for sensitive

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ABBREVIATIONS AND ACRONYMS

ASCVD = atherosclerotic cardiovascular disease

AQI = Air Quality Index

NNT = number needed to treat

populations (eg, individuals with pre-existing heart disease).[2] Their goal is to reduce air pollution-induced morbidity and mortality, the greatest proportion (>60%) of which are due to cardiovascular diseases (eg, myocardial infarctions, strokes) from short-term exposures to fine particulate matter <2.5 μm ($PM_{2.5}$).[3-7] $PM_{2.5}$ levels are also responsible for driving the most elevated AQI levels in the United States, with some locations also being influenced by ozone during warmer months.

We recently assessed the public health relevance of $PM_{2.5}$ AQI activity restrictions by calculating the number needed to treat (NNT) per day to prevent one atherosclerotic cardiovascular disease (ASCVD) event by following current guidance.[8] While the recommendations might be reasonable for sensitive individuals (eg, patients with heart disease), they were not considered useful for the general adult public due to NNTs exceeding 10 to 18 million people during most (96%) poor air quality days (AQIs 101-200) in the United States.[8-10] This shortcoming principally stems from the simplistic logic employed, which promotes identical recommendations to everyone in the general adult public. This approach fails to account for differential susceptibility to $PM_{2.5}$ due to baseline absolute ASCVD risk, which varies 20-fold related to age and underlying risk factors.[11,12]

We herein sought to examine the importance of ASCVD risk on determining the NNT resulting from the general adult population (ie, individuals without heart or lung disease) following current AQI activity guidance. Second, we aimed to assess if AQI recommendations could be realistically modified to enhance their public health utility by tailoring restrictions to baseline ASCVD risk. This potential strategy would better harmonize with a fundamental principle of modern preventive medicine and clinical practice, which allocates the intensity of interventions according to the underlying absolute health risk.[11,12]

METHODS

This cross-sectional modeling study did not require institutional review board approval at Wayne State University because it did not meet criteria for human participation research as we evaluated publicly available de-identified data. We assessed the impact of baseline ASCVD risk on the utility of the current activity recommendations at each AQI stratum by estimating the NNT per day to prevent one ASCVD event (fatal or nonfatal myocardial infarction or stroke) in the adult public across the spectrum of 10-year ASCVD risk (1%-20%) for individuals without known cardiovascular disease or a risk equivalent.[11,12] "Treatment" was defined as following current $PM_{2.5}$ AQI activity guidance for the general public (Table 1).[2] Second, we estimated the potential benefits of tailoring activity guidance to baseline ASCVD risk by calculating the NNT values resulting from following more tailored activity restrictions for individuals at 7.5% and 10% risk. We focused on these cut points because they are well-established thresholds used in clinical practice and have the potential to impact a large percentage of the general population.[11,12] We also focused on the unhealthy AQI category (151-200) because it is of the greatest public health relevance. AQIs in this range represent 28% of days when air quality is above moderate in the United States, whereas worse conditions are rare (4%) and activity restrictions are not provided for the general adult public at lower levels (≤150).[2,9,10] It is important to note that there is no consensus on what is a goal NNT for following low-risk precautionary public health advice such as the AQI activity guidance. We selected a NNT of 1 million people as a starting point for debate because it is the approximate median population of

TABLE 1 Current Air Quality Indices and Estimated $PM_{2.5}$ Exposure Reduction by Following Activity Guidance

Air Quality Index	Frequency[a]	Group	Recommendations	↓Exposure[b]
Unhealthy for sensitive groups AQI 101-150; $PM_{2.5}$ 35.5-55.4 μg/m^3	68%	General public	None	NA
Unhealthy AQI 151-200; $PM_{2.5}$ 55.5-150.4 μg/m^3	28%	General public	Reduce prolonged/heavy exertion outdoors	15%
Very unhealthy AQI 201-300; $PM_{2.5}$ 150.5-250.4 μg/m^3	4%	General public	Avoid prolonged/heavy exertion outdoors	25%
Hazardous AQI 301-500; $PM_{2.5}$ 250.5-500.4 μg/m^3		General public	Avoid all physical activities outdoors	35%

[a]Percentage of the total number of days when an AQI is above "moderate" (>100) in the United States.[9,10] [b]Methods for estimating population mean exposure reductions were described previously.[8]

AQI = Air Quality Index; NNT = number needed to treat; $PM_{2.5}$ = fine particulate matter <2.5 μm in diameter.

TABLE 2 New Air Quality Indices Proposed in February 2024[a]

Air Quality Index	Group	Recommendations	↓Exposure[b]
Unhealthy for sensitive groups AQI 101-150; $PM_{2.5}$ 35.5-55.4 μg/m^3	General public	None	NA
Unhealthy AQI 151-200; $PM_{2.5}$ 55.5-125.4 μg/m^3	General public	Reduce prolonged/heavy exertion outdoors	15%
Very unhealthy AQI 201-300; $PM_{2.5}$ 125.5-225.4 μg/m^3	General public	Avoid prolonged/heavy exertion outdoors	25%
Hazardous AQI 301+; $PM_{2.5}$ 225.5+ μg/m^3	General public	Avoid all physical activities outdoors	35%

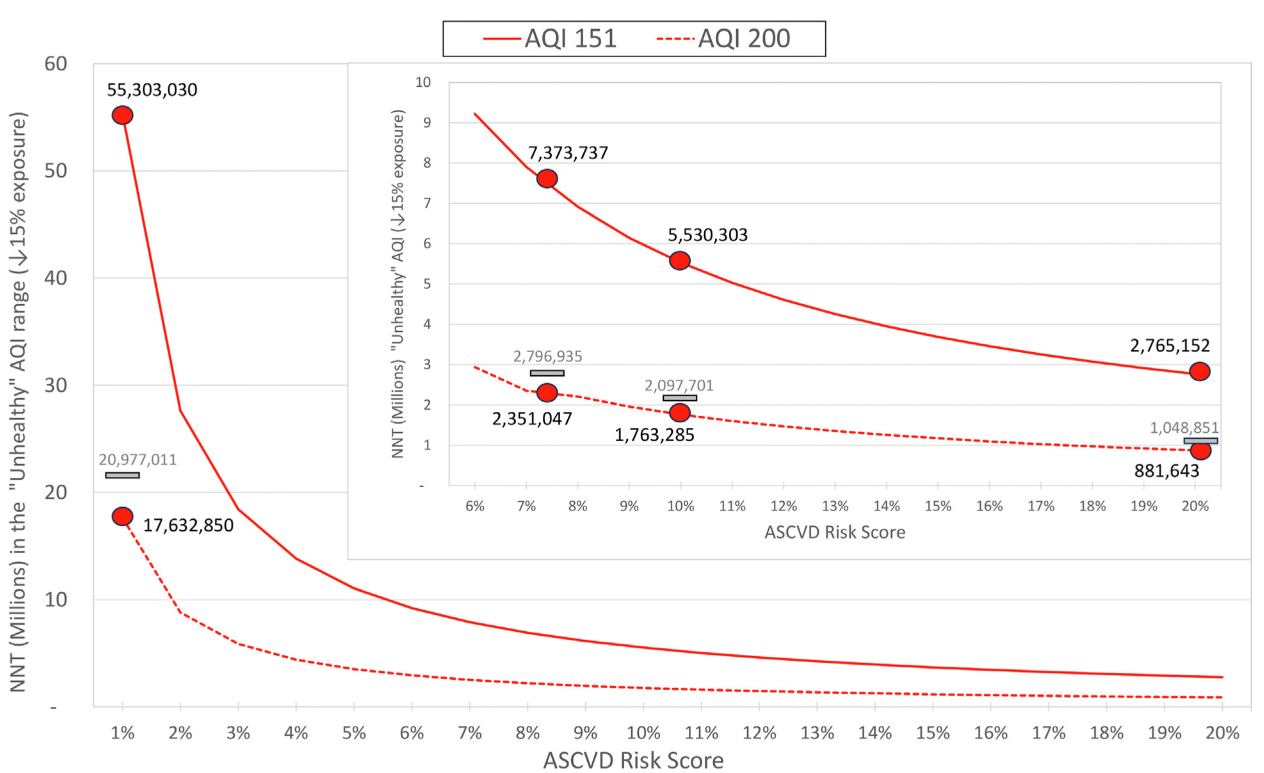
[a]https://www.epa.gov/system/files/documents/2024-02/pm-naaqs-air-quality-index-fact-sheet.pdf; accessed March 15, 2024. [b]Methods for estimating population mean exposure reductions were described previously.[8]

AQI = Air Quality Index; NNT = number needed to treat; $PM_{2.5}$ = fine particulate matter <2.5 μm in diameter.

the largest 143 counties in the United States, which are most impacted by poor air quality and where half the U.S. population lives.[13] All calculations were conducted using Excel, version 2,311 (Microsoft Corp).

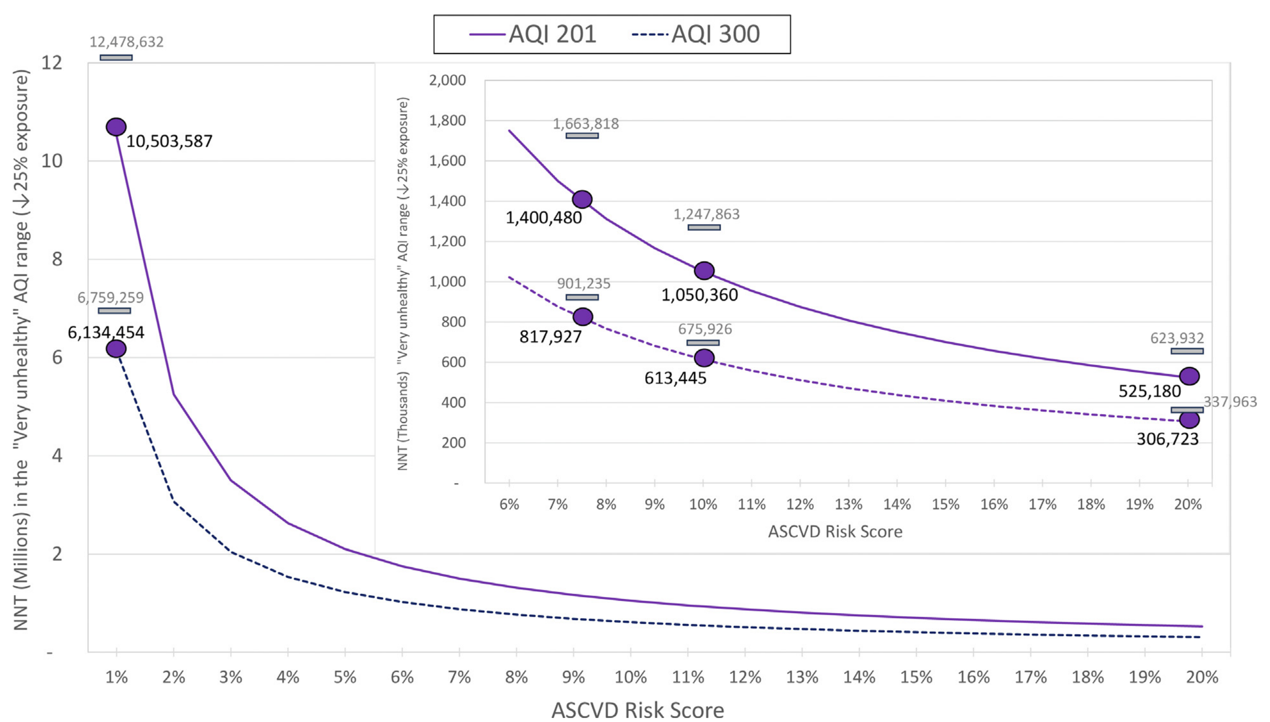
We first estimated the baseline absolute ASCVD event rate per day per million people across 10-year ASCVD risk scores of 1% to 20%. For example, the calculation for a score of 10% was: ([0.1/10]/365) × 1,000,000 = 27.4 events per day per million people. Next, the excess absolute ASCVD event rates per day per million people were calculated by multiplying baseline event rates by the increases in risks from elevations in $PM_{2.5}$ at each AQI level. A monotonic 1% increase in risk per day for every 10 μg/m^3 elevation

FIGURE 1 NNT to Prevent One ASCVD Event in the "Unhealthy" AQI Range



Curves represent the NNT across ASCVD risk scores at the low and high AQI thresholds. Gray bars represent the NNT following new 2024 AQI guidance. AQI = Air Quality Index; ASCVD = atherosclerotic cardiovascular disease; NNT = number needed to treat.

FIGURE 2 NNT to Prevent One ASCVD Event in the "Very Unhealthy" AQI Range



Curves represent the NNT across ASCVD risk scores at the low and high AQI thresholds. Gray bars represent the NNT following new 2024 AQI guidance. Abbreviations as in Figure 1.

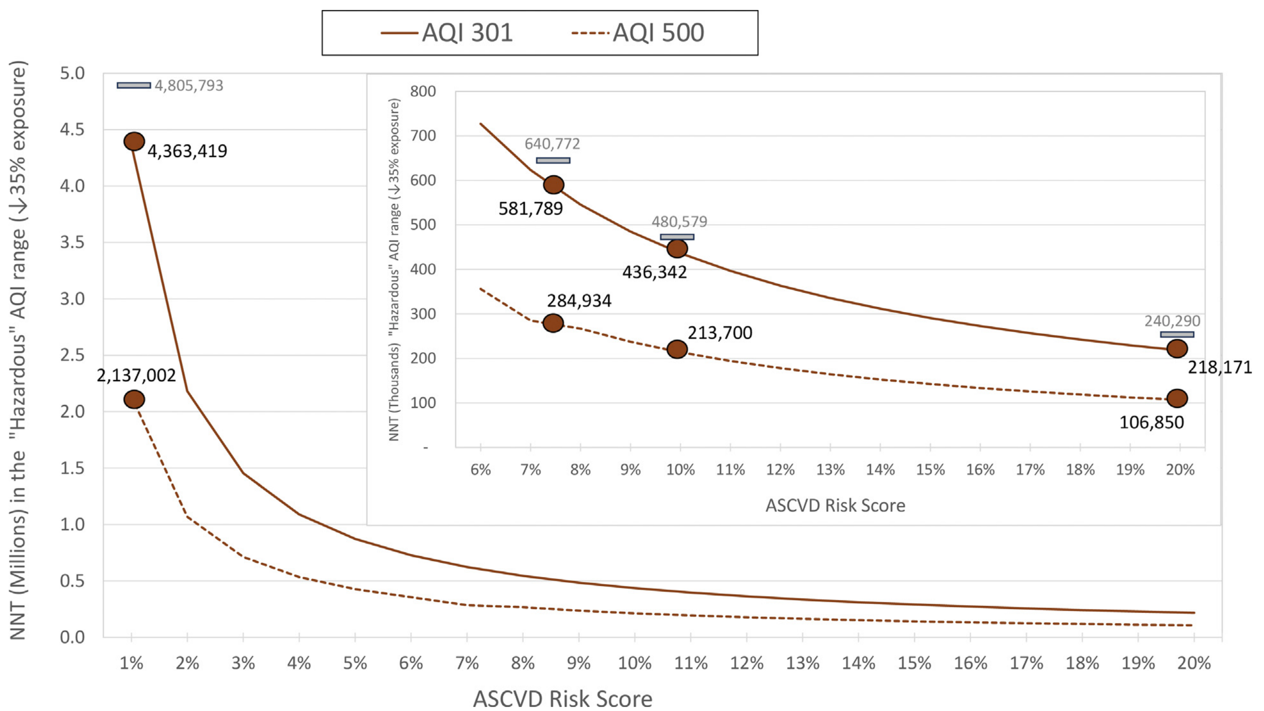
above an AQI of good ($PM_{2.5}$ = 12 μg/m^3) was used in the modeling.[14-17] The rates were calculated for each AQI range at the lower and upper cut-off values. For example, at the lower threshold of "unhealthy" conditions, the AQI is 151 ($PM_{2.5}$ = 56 μg/m^3).[18] We subtracted 12 from 56 to yield an increase in exposure of 44 μg/m^3, which corresponds to a 4.4% increase in ASCVD events per day. For patients with a 10% ASCVD risk at this exposure, the calculation is: 27.4 × 0.044 = 1.21 excess events per day per million people. Third, 24-hour exposure reductions incurred by following the activity guidance were estimated as previously described (Table 1).[2,8] We acknowledged that there is no scientific consensus on this topic. As such, the specific values we modeled were purposely optimistic in nature (eg, assuming rather effective consequences from the activity restrictions) to provide best-case scenarios as a basis to begin exploring the public health implications. At each AQI, the absolute excess event rate per day per million people was multiplied by the percentage in exposure reduction to provide the number of events prevented per day per million people. Using the prior example, the calculation is: 1.21 × 0.15 (ie, 15% exposure reduction by activity guidance at an AQI of 151) = 0.18 events prevented per million people per day. The NNT per day was calculated as the reciprocal of the number of events prevented per day per million people multiplied by 1 million: (1/0.18) x 1,000,000 = 5,530,303 people.

In February 2024, the U.S. Environmental Protection Agency proposed new AQI criteria for $PM_{2.5}$ (Table 2). This ensued from a recent change in National Ambient Air Quality Standards that lowered the annual goal $PM_{2.5}$ average to 9 μg/m^3. The new AQIs utilize more stringent upper threshold concentrations of $PM_{2.5}$ for several of the AQI strata. All calculations of the NNT results were repeated as previously described following the new AQI criteria and a lower $PM_{2.5}$ goal of 9 μg/m^3.

RESULTS

The NNT results to prevent one ASCVD event per day for unhealthy, very unhealthy, and hazardous AQI strata are shown in Figures 1, 2, and 3, respectively. Overall, the NNTs decreased in direct proportion to increases in baseline ASCVD risk. Accordingly, the

FIGURE 3 **NNT to Prevent One ASCVD Event in the "Hazardous" AQI Range**



Curves represent the NNT across ASCVD risk scores at the low and high AQI thresholds. Gray bars represent the NNT following new 2024 AQI guidance. Abbreviations as in Figure 1.

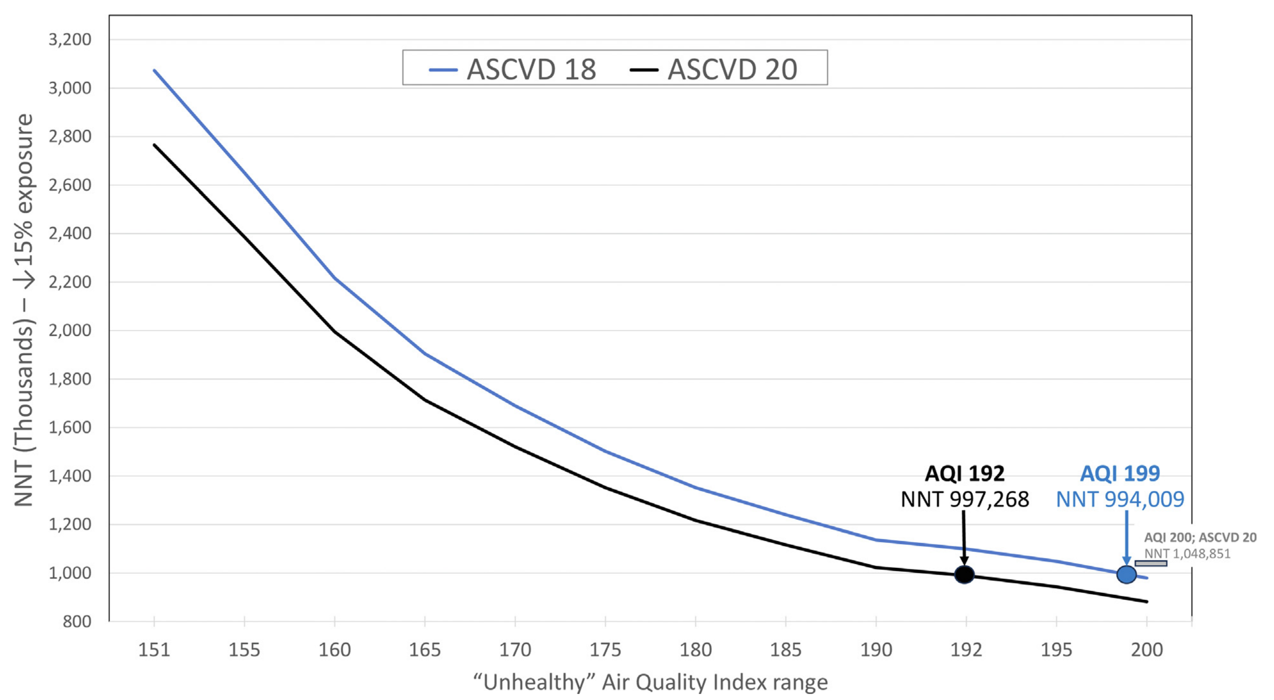
results varied within each AQI stratum by 20-fold across the spectrum of 10-year ASCVD risk (1% to 20%), with larger absolute variations in the NNT values at lower AQI ranges. The NNTs approached or fell below 1 million people per day at 7.5% to 10% ASCVD risk by following current guidelines under very unhealthy and hazardous AQIs. However, for unhealthy conditions, which are far more relevant, NNTs below 1 million could only be achieved for those at very high ASCVD risk (18% to 20%) and under the most severe conditions (AQIs 192-200) (Figure 4). Further modeling found that it would be feasible to reach NNT values near or below 1 million people at ASCVD risk thresholds used in clinical practice of 7.5% and 10% during unhealthy AQI conditions if the activity restrictions were more aggressive than currently recommended (ie, lowering exposures by 35% to 50% instead of 15%) (Figure 5). Lastly, all NNT results were similar, indeed slightly higher (Figures 1 to 5), based upon calculations utilizing the new AQI thresholds proposed in February 2024 (Table 2).

Finally, we created an online calculator that provides NNT results across a range of plausible scenarios using the updated 2024 AQI criteria. The calculator requires the input of $PM_{2.5}$ concentration, baseline ASCVD risk, the risk for an event per 10 μg/m^3 of $PM_{2.5}$ exposure, and the estimated exposure reduction provided by the intervention. Plausible ranges of values for each of the 4 factors are provided. The calculator is publicly available on the PHOENIX website of Wayne State University (https://phoenix.wayne.edu/learning-lab).

DISCUSSION

Reducing prevailing $PM_{2.5}$ levels over the long term saves lives and decreases cardiovascular morbidity and mortality.[5-7] Decreasing acute exposures to residual day-long elevations in $PM_{2.5}$ should also help improve public health. Personal actions, such as following daily AQI activity guidance, can reduce exposures and could in theory help prevent acute ASCVD events. Nevertheless, this does not automatically mean that the national policy recommendations as they currently stand are optimally effective. We herein demonstrated for the first time the major

FIGURE 4 AQI and ASCVD Risk Score in the "Unhealthy" Range Where the NNT Is Below One Million



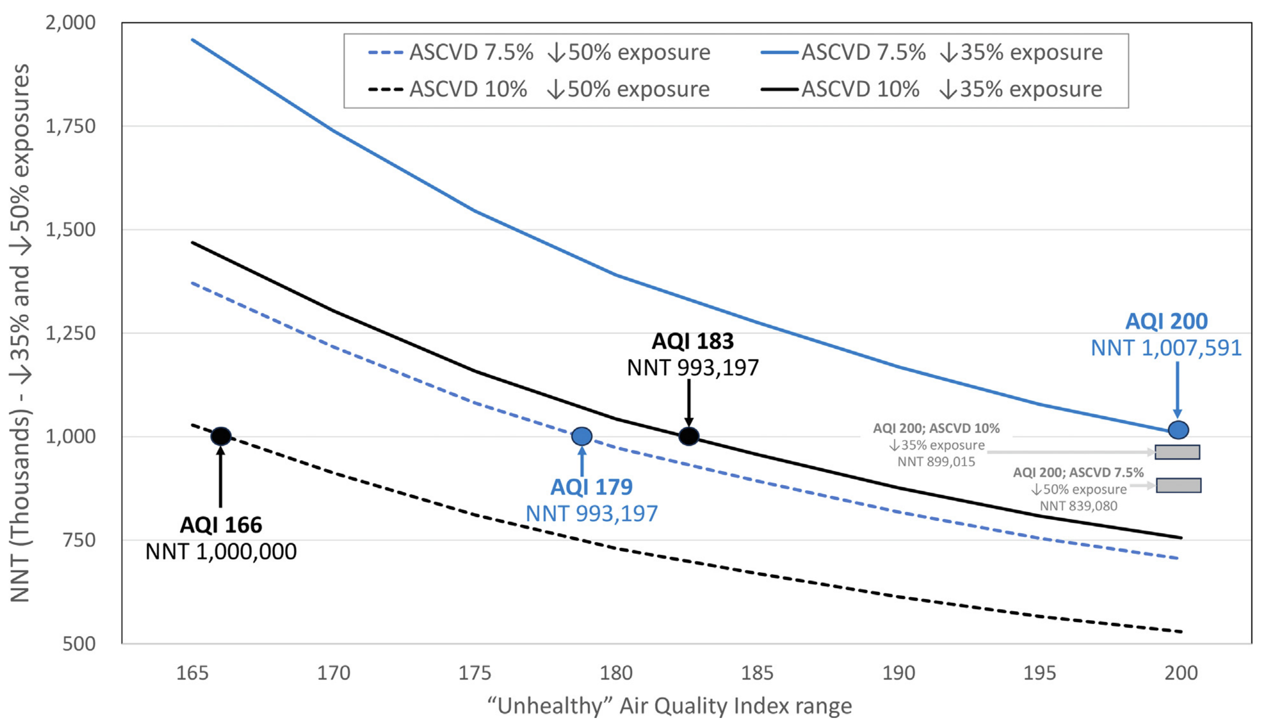
Curves represent the NNT at ASCVD risk scores of 18% and 20%. Gray bars represent the NNT following new 2024 AQI guidance. Abbreviations as in **Figure 1**.

influence that underlying ASCVD risk has on determining the utility of AQI activity recommendations for the general adult public. The NNTs to prevent 1 ASCVD event per day varied 20-fold in relation to baseline ASCVD risk within each AQI stratum. Overall, following current uniform AQI recommendations yields potentially untenable NNTs equal to many millions of people under most AQI conditions in the United States. Using the new AQI criteria does not substantively change the results. The main implication of our findings is that one way to plausibly improve the relevance and public health benefits from AQI guidance might be to tailor recommendations to ASCVD risk (or categories of 10-year risk scores) rather than providing uniform guidance for the general adult public (**Central Illustration**).[11,12] Our online calculator could be helpful in developing this process in the future (https://phoenix.wayne.edu/learning-lab).

We confirmed this reasoning using additional modeling. Under unhealthy air quality conditions (AQI 151-200), tens of millions of people who are at population-level average 10-year ASCVD risk (3% to 5%) would need to follow current guidance to prevent a single adverse event. This suggests that providing uniform activity guidance that applies equally to the population, including lower-risk individuals (ASCVD risk scores <5%), is not likely a tenable public health strategy. However, adopting a more personalized approach could dramatically reduce the NNT. For example, calculated intermediate ASCVD risk scores of 7.5% and 10% are commonly used in clinical practice to trigger the initiation of preventive therapies.[11,12] More reasonable NNTs of <1 million people could be achieved among these intermediate-risk individuals if more stringent (yet feasible) activity restrictions were advised. It is important to note that this specific scenario is of significant public health relevance because it pertains to many millions of people. A sizeable proportion of the general adult public is at intermediate (7.5% to 10%), or higher, cardiovascular risk, plus roughly 28% of days with an elevated AQI are in the unhealthy range.[9-12] This proposed strategy better follows the core principles of preventive medicine and clinical practice, which allocate the intensity of interventions according to underling absolute health risks.[11,12]

The main study limitation is that no consensus exists on what is an acceptable NNT to prevent one ASCVD event for a realistic public health policy. As far as we are aware, there has never been scientific debate in this regard. Nonetheless, the many millions

FIGURE 5 **AQI in the "Unhealthy" Range Where the NNT Is Below One Million for Individuals With ASCVD Risk Scores of 7.5% and 10%**

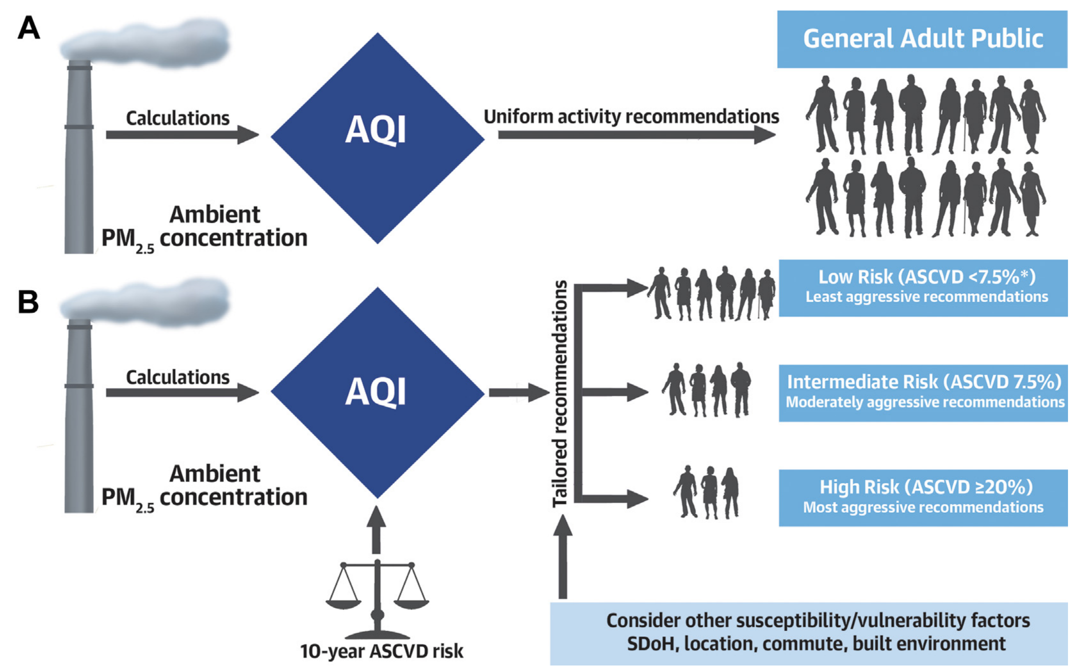


Curves represent the NNT at ASCVD risk scores of 7.5% and 10%, modeling 35% and 50% exposure reductions. Gray bars represent the NNT following new 2024 AQI guidance. Abbreviations as in Figure 1.

of people needed to follow guidance under unhealthy air quality levels (by far the most relevant AQI category), especially for individuals at lower and intermediate risk (ASCVD score <5 to 10%), raises concerns over the real-world relevance or potential effectiveness of the current policy in the present-day United States. In the largest 143 counties across the United States, the median total population is ~822,000 people.[13] Activity guidance that requires more people to follow the promulgated advice to prevent one ASCVD event than in fact reside in the relevant location is of questionable logic. Even under very unhealthy conditions, which account for <4% of elevated AQIs in the United States, the NNT does not approach 1 million people unless the ASCVD score is >5% (Figure 2). While the most relevant NNT could be debated, we believe our findings demonstrate that AQI guidance might benefit from tailoring them to ASCVD risk under the 96% of conditions (AQI 101-200) occurring in the present-day United States.

A limitation of AQI guidance is that public awareness and adherence are suboptimal.[19-21] Our modeling and figures illustrate best-case scenarios. If the real-world following of AQI guidance is less than ideal (eg, 50%), then the NNT values will increase accordingly. Even though the proposed more aggressive activity restrictions we herein proposed are feasible, it remains unclear if the AQI advice would be undertaken at a population-level necessary to achieve 1 million people following guidance. However, this shortcoming applies equally to the AQI guidelines as they currently exist. It is also uncertain if enough of the public could be made aware of (or would be willing to calculate) their own ASCVD risk score that would be required to successfully implement the recommendations at a national level. We do believe, however, that the widescale availability and ease of calculating 10-year ASCVD risk scores make it at least a plausible supposition. Even for individuals who do not know their actual blood pressure or cholesterol values, useful predictions of general ASCVD risk categories (eg, low, intermediate, high) can be calculated by assessing a few simple factors such as age, sex, smoking, and underlying conditions (ie, hypertension).[11,12,22] The details of any future policy are not intended to be finalized herein. We acknowledge that

CENTRAL ILLUSTRATION Tailored AQI Activity Recommendations



Brook RD, et al. JACC Adv. 2024;3(11):101313.

(A) Current approach. Uniform activity recommendations for the entire general adult public based solely upon AQI level calculated from ambient $PM_{2.5}$ concentration. (B) Proposed approach. Tailored activity recommendations for subsets of the general adult public based upon the combined information of AQI level plus calculated ASCVD risk score (as well as potentially considering other factors). The specific tailored activity guidance for the subgroups could be based upon achieving a reasonable NNT (eg, below 1 million). Achieving an appropriate balance between significantly enhancing the public health utility of the AQI recommendations versus promoting overly complicated guidance is crucial. Among low-risk people (eg, <7.5% risk), the NNT may never fall below 1 million. The recommendations may therefore need to emphasize education regarding the adverse health effects of $PM_{2.5}$ and preventing lifetime risks rather than averting acute illness due to day-long exposures, except perhaps under hazardous conditions. *Specific thresholds of ASCVD risk (eg, 7.5% vs 10%) are debatable. SDoH, social drivers of health; other abbreviations as in Figure 1.

the development of future AQI guidance that potentially accounts for baseline ASCVD risk (as well as other possible modifying factors) will require much debate among experts, stakeholders, and governmental agencies. However, we aim to illustrate the merits as a general concept of considering underlying ASCVD risk for developing future AQI activity guidance.

We deliberately limited the focus of this paper to preventing ASCVD events in the general population. This is logical because myocardial infarctions and strokes do indeed occur at a known rate (ie, the 10-year ASCVD risk score) in the general adult population who are otherwise seemingly healthy (ie, no prior diagnosis of heart disease). Conversely, pulmonary disease events (eg, hospitalization for asthma or chronic obstructive pulmonary disease) are likely rare and occur at an unknown rate among adults without a prior diagnosis of lung disease. It is highly unlikely that a single-day $PM_{2,5}$ exposure in the range that occurs under most conditions in the present-day United States will trigger a pulmonary event among the general adult population—specifically, individuals without prior asthma or chronic obstructive lung disease. Focusing AQI in the general adult population on preventing ASCVD events (which do occur) is thus logical. However, we acknowledge a limitation of our analysis that there may be a 25% to 50% underdiagnosis of lung conditions in the population. There is potentially a risk among such individuals with lung disease who are not properly diagnosed. Cardiovascular events also comprise the majority (>60%) of the public health threat posed by $PM_{2.5}$[3]. However, our online calculator does provide NNT calculations for pulmonary events based upon certain factors (baseline number of pulmonary events per year), and interested readers are referred to the website (https://phoenix.wayne.edu/learning-lab). Future studies will evaluate in more detail the benefit of better tailoring activity recommendations for individuals with pre-existing pulmonary diseases. We also focused the paper on $PM_{2.5}$ levels. The ASCVD risk associated with $PM_{2.5}$ is far more robust and established than for other pollutants including ozone, which also only has a major influence on health during warm seasons. Future analyses could consider the complex question of how to improve AQI guidance related to other pollutants.

STUDY LIMITATION. Limitations regarding the methods for calculating NNT were discussed in detail in our prior publication.[8] We acknowledge that some degree of uncertainty will always be present in the estimated calculations. There could be modest changes in the NNT results depending upon estimations of the exposure-risk associations and the degree to which activity changes lower exposures. The range of NNT results involving a degree of uncertainty in the calculations was previously reported.[8] However, the general sizes of the NNT results are not highly sensitive to these factors and remain within similar magnitudes regardless of a reasonable range of values estimated in this regard. Most importantly, our overarching conclusion that underlying ASCVD risk has a substantial impact upon the NNT in the general adult public does not change at all even if a range of potential NNT values is provided. For the sake of clarity, we chose to provide what we believe is the best estimate of the NNT based upon the scientific literature.[8] Finaly, a range of plausible NNT values could be available by using our online calculator and considering variations in the estimations used in the formula (https://phoenix.wayne.edu/learning-lab).

It is possible that other or complementary approaches than the methods we used in this analysis focusing on the NNT could provide a more complete understanding of the public health relevance of current AQI guidance.[23] We must highlight that our overarching intent was not to resolve this complex issue herein but to spark robust and fair debate necessary to improve AQI guidance moving forward. We presented one potential approach to update the AQI recommendations in the future. This does not exclude other possible considerations.

Finally, we acknowledge that other socioeconomic factors and environmental exposures (eg, greenspaces) modulate the ASCVD risk due to $PM_{2.5}$ and are independent risk factors for heart disease.[24,25] Further assessment along these lines was beyond the scope of this study; however, we will plan to evaluate the intersection of these factors and the potential benefits of AQI guidance among subgroups of populations in the future.

CONCLUSIONS

Underlying ASCVD risk has a major influence on the theoretical utility of AQI guidance for the general adult public. Tailoring activity recommendations to ASCVD risk could help improve their overall public health benefits in the future.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: By providing uniform activity recommendations to the entire general adult public, current AQI activity guidance fails to account for the importance of baseline ASCVD risk in determining the public health effectiveness of the policy. Our proposed modifications to AQI activity guidelines would adopt a core principle of preventive medicine (ie, the intensity of intervention should be tailored to absolute health risk) to future AQI activity guidelines. This could theoretically make them more effective for preventing ASCVD events and protecting the public health. Our results apply to clinicians as well as policy officials specifically in relation to the competency domains of medical knowledge and interpersonal and communication skills.

TRANSLATIONAL OUTLOOK: Our study is positioned at the intersection of clinical science evidence and the development and implementation of national public health policy. Future studies will need to compare various approaches to identify an optimal balance of improving the effectiveness of the recommendations (eg, lowering the NNT, providing more personalized guidance) vs providing overly complex recommendations. More knowledge is required to determine the capacity for the general adult public to implement risk-based guidelines that call for determining ASCVD risk scores and following the germane recommendation. A better understanding of how to overcome knowledge gaps and barriers to uptake of the AQI guidance as well as how to optimally communicate the necessary messaging to the public is required.

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