Interventions to Reduce Personal Exposures to Air Pollution

A Primer for Health Care Providers

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Epidemiological studies during the past few decades have associated numerous ailments with both acute and chronic exposures to air pollutants (Fig. 1). Fine particulate matter, defined as particles ≤2.5 μm in diameter ($PM_{2.5}$), is the leading pollutant associated with increased morbidity and mortality [1]. $PM_{2.5}$ can be emitted from the natural environment (e.g., forest fires), but most $PM_{2.5}$ is derived from man-made sources (e.g., power generation, industrial processes) due to the global reliance on fossil fuels (e.g., coal, oil). Traffic-related air pollution (TRAP) from gas and diesel automobiles is one of the largest contributors to exposure worldwide. In addition, household air pollution can also be an important source, especially in developing nations that burn biomass or solid fuels for heating and cooking [2,3].

More than one-half of the excess morbidity and mortality risk is due to cardiovascular diseases (myocardial infarctions, strokes, heart failure) [1,3] despite the multitude of other associated illnesses. Some examples include allergic rhinitis, eczema, cancers, lung diseases (asthma and chronic obstructive pulmonary disease), pre-eclampsia, low birthweight, preterm birth, diabetes mellitus, hypertension, obesity, autism, neurocognitive disorders (Parkinson's disease, Alzheimer's disease, dementia, multiple sclerosis), autoimmune and rheumatic diseases, lower respiratory tract infections, and kidney diseases [2–4] (Fig. 1). $PM_{2.5}$ exposures from TRAP may compromise the cardiopulmonary benefits of walking [5], which can complicate health care recommendations and may amplify the public health burden if physical activity is limited in attempts to avoid air pollution.

In 2015, air pollution was identified as the fifth-ranked cause of global disease burden behind high systolic blood pressure, smoking, elevated glucose, and cholesterol and just ahead of diets high in sodium, high body mass index, and diets low in whole grains [3]. The most recent Global Burden of Disease data support that over 4.2 million premature deaths in 2015 were attributable to long-term ambient $PM_{2.5}$ exposure [2]. All forms of air pollution were responsible for 268 million disability-adjusted life-years: 254 million years of life lost and 14 million years lived with disability [2]. Household air pollution contributes an additional 2.8 million deaths with the highest burden occurring in India [3]. Developing and populous nations such as China and India are among the most heavily polluted (population-weighted mean $PM_{2.5}$ exposures of 58.4 and 74.3 $\mu g/m^3$, respectively) and thus suffer from the greatest disease burdens (over 50% of global total) attributable to $PM_{2.5}$ [3]. On the other hand, regulations have successfully reduced $PM_{2.5}$ concentrations across the United States during the past few decades. Most Americans now enjoy air quality within or near annual World Health Organization Air Quality Guidelines of <10 $\mu g/m^3$, which has increased life expectancy by several months since the 1980s [4]. Unfortunately, large-scale epidemiological studies now show that even low $PM_{2.5}$ concentrations within current World Health Organization Air Quality Guidelines still increase all-cause mortality [5]. No lower "safe" threshold of exposure has yet been shown to exist [3]; therefore, $PM_{2.5}$ remains a threat to public health on a worldwide scale.

Despite the staggering global health threat posed by air pollution, there have been few studies informing health care providers or patients on risk-reducing actions. In 2010, the American Heart Association scientific statement [1] addressed the risks but provided few specific recommendations because of the lack of applicable clinical trials [6]. The evidence has since been reviewed [4,7] and the first clinically oriented guidance for health care providers was published in 2018 [8].

Air pollution and the related public health burden are expected to worsen across many developing nations. We provide an evidentiary review that concludes with a practical algorithm for health care professionals to mitigate the adverse health effects of air pollution.

PRACTICAL RECOMMENDATIONS TO LIMIT EXPOSURES

Table 1 provides background information, options, and suggestions to decrease personal level exposures to air pollutants that include lifestyle changes and personal protection interventions [1,4]. Figures 2A and 2B display specific recommendations for those who live in developed or underdeveloped areas. Recommendations are to be used with the health care provider's best judgment, taking the patient's lifestyle and financial situation into account. The supporting, published reports follows.

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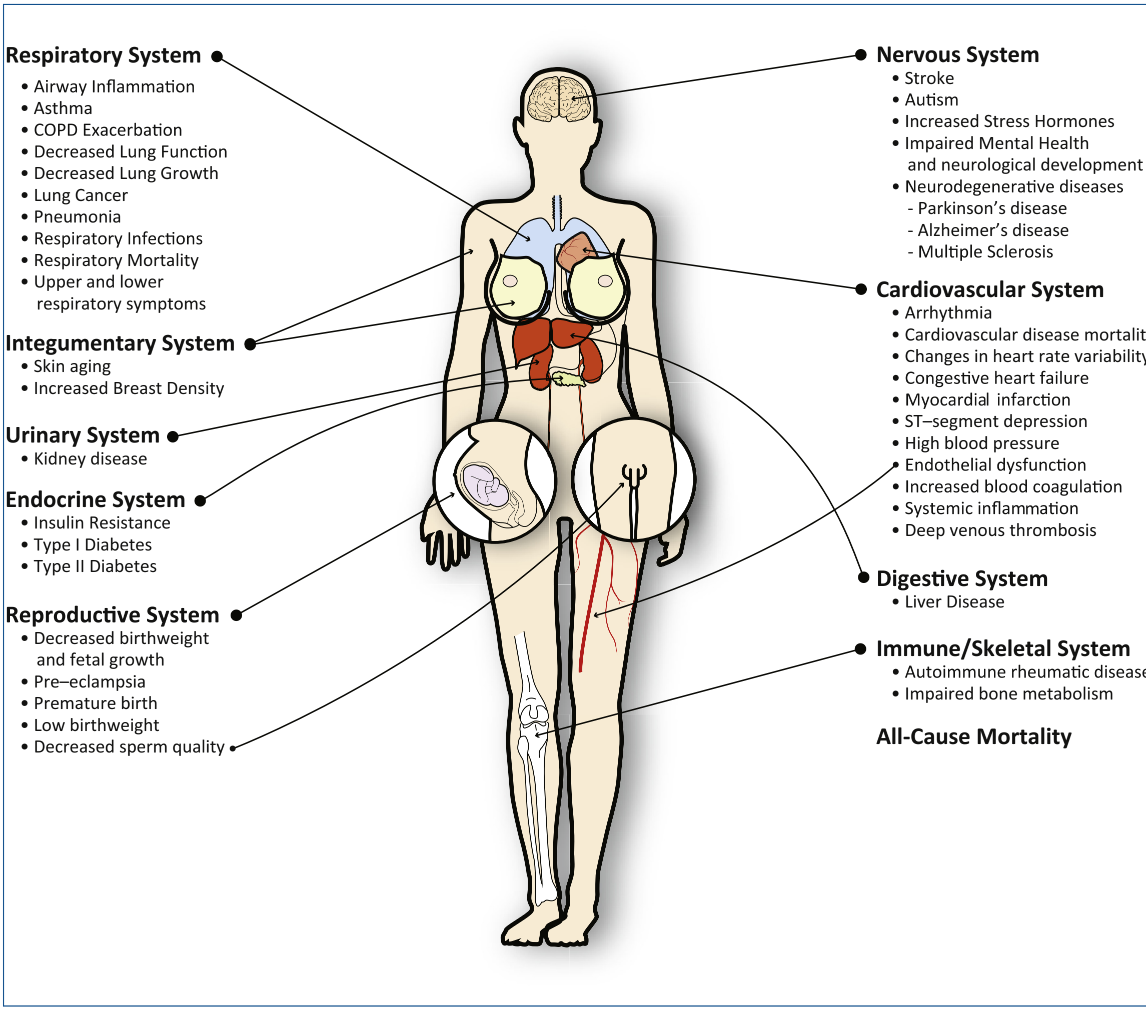

FIGURE 1. Deleterious effects of air pollution on the human body. COPD, chronic obstructive pulmonary disease.

Filtering interventions

Household HVAC. Indoor air purifying devices can be in the form of portable devices to clean individual rooms or installed into the ducts of a home's heating, ventilating, and air conditioning (HVAC) system. In-duct filters are primarily designed to protect the HVAC equipment and may be limited in removing particles because particles must pass through that duct to be filtered [9].

The US Environmental Protection Agency publishes a guide [9] to air cleaners in the home and identifies 3 types of air cleaners:

1. Ultraviolet light air cleaners destroy pollutants in indoor air and are not recommended unless used in conjunction with filters. Without a filter, the "cleaner" may circulate or produce particles and/or ozone [9].
2. Electronic air cleaners use electrostatic attraction to trap particles and may be called an ionizer; these may also produce ozone and may be ineffective if they do not have a clean, functional collection plate [9].
3. Mechanical air filters capture particles (dust, pollen, cockroach allergens, animal dander, some molds) on filter materials. Filters can be ineffective if particles do not reach or are not captured by the filter [9].

Air filter effectiveness is rated using the minimum efficiency reporting value (MERV). High-efficiency particulate air (HEPA) filters with a MERV between 17 and 19 have a minimum efficiency between 99.97% and 99.999% in removing 0.3-μm particles. HEPA filters are not typically installed in residential HVAC systems; this would require professional modification of the system. Medium-efficiency air filters (MERV 7 to 13) are likely to be nearly as effective as true HEPA filters at reducing the concentrations of most indoor particles linked to health effects [9].

TABLE 1. Specific recommendations for optimal particulate exposure mitigation

Intervention	Consideration	Specific Recommendation
Face masks and respirators	Cloth face masks	We do not recommend use of cloth or surgical masks for personal protection against $PM_{2.5}$.
	Gauze face mas N95/N99 respirators	Wear validated N95 or N99 respirator when outdoors, with or without a valve.
In-home particle removal	Mechanical in-duct air filters Electronic air cleaners Portable air purifiers	Use the most efficient in-duct particle air filter that your furnace is rated for. This is likely to be a medium-efficiency filter with a MERV rating of 7 to 13. Do not use electronic air filters because they can produce ozone and smaller, harmful particles. Choose a model with a Clean Air Delivery Rate noted on packaging to meet the room size specifications. Compare different models using the Association of Home Appliance Manufacturers certification program available at www.cadr.org. Avoid ozone producing models such as electrostatic precipitators and ionizers. Use HEPA filters and replace them when their capacity is reached (saturated with particles).
HVAC	Ventilation	Open windows as frequently as possible using cross-ventilation technique to remove allergens and particles when indoor sources are present, such as during cooking.
	Air conditioning	Use air conditioning during high pollution times. Open windows during cool, low pollution times or nights to conserve energy. Limit indoor penetrance of fine $PM_{2.5}$ during polluted times by closing windows and using air conditioning systems with filters with high MERV rating (as above).
Automobiles	Automobile models	Use a newer, fuel-efficient model vehicle because they typically have a better sealed cabin and produce less pollution for the driver and the environment.
	HVAC considerations	Keep windows closed in polluted areas (such as heavy freeways, rush-hour traffic, near diesel trucks). Use recirculation mode to ventilate the cabin when passenger CO_2 build-up is not a concern. Use air conditioning rather than open windows on highly polluted roadways. Use the highest efficiency air filter available for your vehicle's cabin; this may not be the original manufacturer's filter. Note: This is an interior vehicle cabin filter, not to be confused with the engine air filter.
	Avoidance	Drive less, particularly during high pollution times.

(continued)

TABLE 1. Continued

Intervention	Consideration	Specific Recommendation
Behavioral/avoidance	Alerts	Be aware of local AQI and pollution forecasts. Follow advice from air quality regulators in relation to AQI (see Table 2).
	Avoidance	Avoid outdoor activity during peak pollution times and locations. Recommend activity in the early morning before rush hour and prior to higher ozone levels that occur in afternoon. Activity should be at least 400 m from main roadways to lessen pollution exposure. Exercise outdoors during low traffic times or in geographic areas away from pollution sources or indoors. If one must exercise during peak traffic times or near many roadways or point sources of pollution (industry), consider indoor activities (treadmill)
Travel		Very high-risk patients (recent acute cardiovascular event, unstable heart conditions) should consider postponing or canceling any nonmandatory travel to high-polluted regions. High-risk cardiac patients who are stable and without recent event within past few weeks to months should avoid travel to highly polluted regions. Patients should be aware of the risks of precipitating cardiovascular events due to short-term $PM_{2.5}$ exposures. Each individual can weigh the risk versus benefit and necessity of travel with shared decision making with their health care provider. Please refer to the algorithm in Figure 3.

AQI, Air Quality Index; HEPA, high-efficiency particulate air; HVAC, heating, ventilating, and air conditioning; MERV, minimum efficiency reporting value; $PM_{2.5}$, fine particulate matter, defined as particles $\leq$2.5 μm in diameter.

Portable air purifiers. Association of Home Appliance Manufacturers has developed the Clean Air Delivery Rate score that can help consumers to evaluate a portable air cleaner's effectiveness [9]. Portable air purifiers without a fan are typically much less effective than units with a fan.

Studies show that portable air cleaners consistently reduce $PM_{2.5}$ by 50% to 65%, and these studies are summarized in Table 2 [10−19]. Removal rates vary depending on room size and ventilation and flow rate of the cleaner [9].

Three similar studies recruited elderly subjects to have HEPA filtration and sham filtration in their living rooms and bedrooms. One study [18] was conducted in the heavily polluted city of Beijing over a 2-week period. Two separate studies [14,17] were conducted in the relatively clean city of Copenhagen over 2 weeks [14] and 2 days [17], respectively (Table 2). However, the Copenhagen studies only included subjects who lived near roadways. The Beijing study compared seniors with and without chronic obstructive pulmonary disease, and the Copenhagen studies recruited relatively healthy seniors. Following active filtration, indoor $PM_{2.5}$ was significantly reduced from 60 $\pm$ 45 to 24 $\pm$ 15 $\mu g/m^3$ in Beijing subjects [17] and from 8 to 4 $\mu g/m^3$ [14] and from 12.6 to 4.7 $\mu g/m^3$ [17] in Copenhagen subjects. Despite dramatic improvement in Beijing indoor air quality, there was no improvement in lung function, blood pressure, and heart rate variability. However, a reduction in blood interleukin-8 concentration suggested decreased systemic inflammation. Karottki et al. [14] reported no effects of filtration on microvascular and lung function or biomarkers of systemic inflammation but Bräuner et al. [17] reported 8.1% improvement in microvascular function. However, Karottki et al. [14] found an association between a reduction of $PM_{2.5}$ and improved microvascular function from data collected in the bedroom during post hoc analyses. These studies did not control for the outdoor $PM_{2.5}$ exposure during the study period.

In the highly polluted city of Shanghai, China, Chen et al. [12] reduced $PM_{2.5}$ concentration from 96.2 to 41.3 $\mu g/m^3$ within hours of using a portable air purifier and showed improved health outcomes in young, healthy college students. Several circulating inflammatory and thrombogenic biomarkers, blood pressure, and fractional exhaled NO were significantly decreased. However, decreases in lung function and vasoconstriction biomarkers were not statistically significant.

Three different studies [13,15,16] compared indoor air filtration and sham filtration for 7 days each in Canada. Two used HEPA filtration [13,16] and one [15] used a portable electrostatic filter during the winter season in a population of First Nations reserve residents in southern Manitoba. Results of the First Nations study revealed indoor $PM_{2.5}$ values 5× greater than outdoor $PM_{2.5}$ values, which the investigators explained by indoor smoking. Compared with sham filtration, on average, true air filtration decreased $PM_{2.5}$ by 37 $\mu g/m^3$ and was associated with improvements in lung function (a mean 1-s forced expiratory volume increase by 217 ml) and blood pressure (a mean reduction in systolic and diastolic blood pressure by 7.9 and 4.5 mm Hg, respectively). Kajbafzadeh et al. [13] reported that HEPA filtration decreased indoor $PM_{2.5}$ by 40%, but they found no significant change in endothelial function, interleukin 6, or band cells. Conversely, Allen et al. [16] reported that HEPA filtration reduced $PM_{2.5}$ by 60% and improved microvascular endothelial function and reduced levels of systemic inflammation. Filtration was associated with a 9.4% increase in reactive hyperemia index and a 32.6% decrease in C-reactive protein (CRP). No associations were noted for oxidative stress markers (malondialdehyde or 8-iso-prostaglandin F2a).

Padró-Martínez et al. [11] conducted perhaps the longest trial of HEPA filtration to date, in which 20 subjects residing in public housing near a highway participated in a crossover of HEPA versus sham filtration for 21 days. Particle number concentration reduction ranged from 21% to 68%. There were no significant differences between the HEPA and sham conditions in blood pressure, high-sensitivity CRP (systemic inflammatory marker), fibrinogen (thrombosis risk marker), and tumor necrosis factor receptor 2 (inflammatory marker). Contrary to the expectation, there was an increase in interleukin 6 (inflammatory marker) concentrations following HEPA filtration.

Li et al. [10] compared a high-efficiency and a sham filter for 9 days in the dormitories of college students in Shanghai. $PM_{2.5}$ was decreased by 82% on average and the reduction in $PM_{2.5}$ was associated with significant decreases in cortisol, cortisone, epinephrine, norepinephrine, blood pressure, hormones, insulin resistance, and biomarkers of oxidative stress and inflammation.

In a recently completed study [19], 40 elderly adults in urban Detroit experienced significantly reduced arterial blood pressure (3.2/1.5 mm Hg) after 3 days of HEPA air filtration, which lowered $PM_{2.5}$ by 42% (15.7 to 9.1 $\mu g/m^3$) as compared to blinded sham filtration. Obese adults derived an even greater reduction in blood pressure from the intervention.

Indoor particle filtration was shown to be a cost-effective means of reducing mortality [20]; the predicted reductions in mortality range from approximately 0.25 to 2.4 per 10,000 population. Fisk et al. [20] concluded that some interventions had an annual mortality-related economic benefit >$1,000 per person and even greater benefits were possible in the homes of the elderly. In sum, the overall results support that air filtration may be a cost-effective personal preventive strategy in both heavily polluted and relatively clean environments.

However, some studies also provide evidence for caution [21]. During 2015 to 2016 in Delhi, India, the efficacy of indoor air filters was tested. Due to the extraordinarily high levels of outdoor ambient $PM_{2.5}$ (often exceeding 200 to 500 $\mu g/m^3$), even after successful air filtration (by 30% to 50%), the indoor concentration of particles remained very high. In fact, the indoor levels exceeded those found in most outdoor urban settings across the globe. These findings support that while air filters can provide some degree of partial protection, they also suffer from some limitations particularly in heavily polluted regions. Most notably, they can only reduce exposures while people remain indoors nearby the filtration devices and they can only reduce particle concentrations by roughly 50%. This can leave some individuals still highly exposed to $PM_{2.5}$.

Air conditioning/closing windows. In addition to portable indoor HEPA filters, a simpler strategy of using air conditioning units may also provide some protection from air pollution. Investigators have studied the efficacy and long-term benefits of air filtration provided by air conditioners [22]. One year of active filtration in metropolitan Taipei, Taiwan, reduced indoor $PM_{2.5}$ by nearly one-half and significantly reduced blood pressure and markers of systemic inflammation [22]. One study of 300 healthy adults in Taipei showed improvements in markers of cardiovascular disease risk (decreased plasma CRP and fibrinogen, increased heart rate variability) by closing windows for 2 weeks [23]. A longer term study [24], also from Taipei, recruited 200 healthy homemakers to air conditioning filtration or control intervention for 1 year each in a randomized, crossover design. Air conditioning filtration decreased $PM_{2.5}$ and total volatile organic compounds and also significantly lowered the measured health variables high-sensitivity CRP, 8-hydroxy-2′-deoxyguanosine, fibrinogen, and blood pressure when compared with the control intervention. These results led the investigators to conclude that long-term air conditioning filtration was associated with improved cardiovascular health of adults [24]. These simple approaches can therefore be prudent measures to take that can lower indoor penetration of ambient air pollutants and potentially provide health protection while indoors and at home.

Automobile air filters. TRAP is one of the most important sources of exposure worldwide. Recent traffic exposure is in fact the leading trigger of myocardial infarctions globally [1]. Modern automobiles have improved traffic-related health risks because of in-cabin air filters, air conditioning, and improved door seals. However, most air filters in passenger vehicles are relatively low efficiency [7].

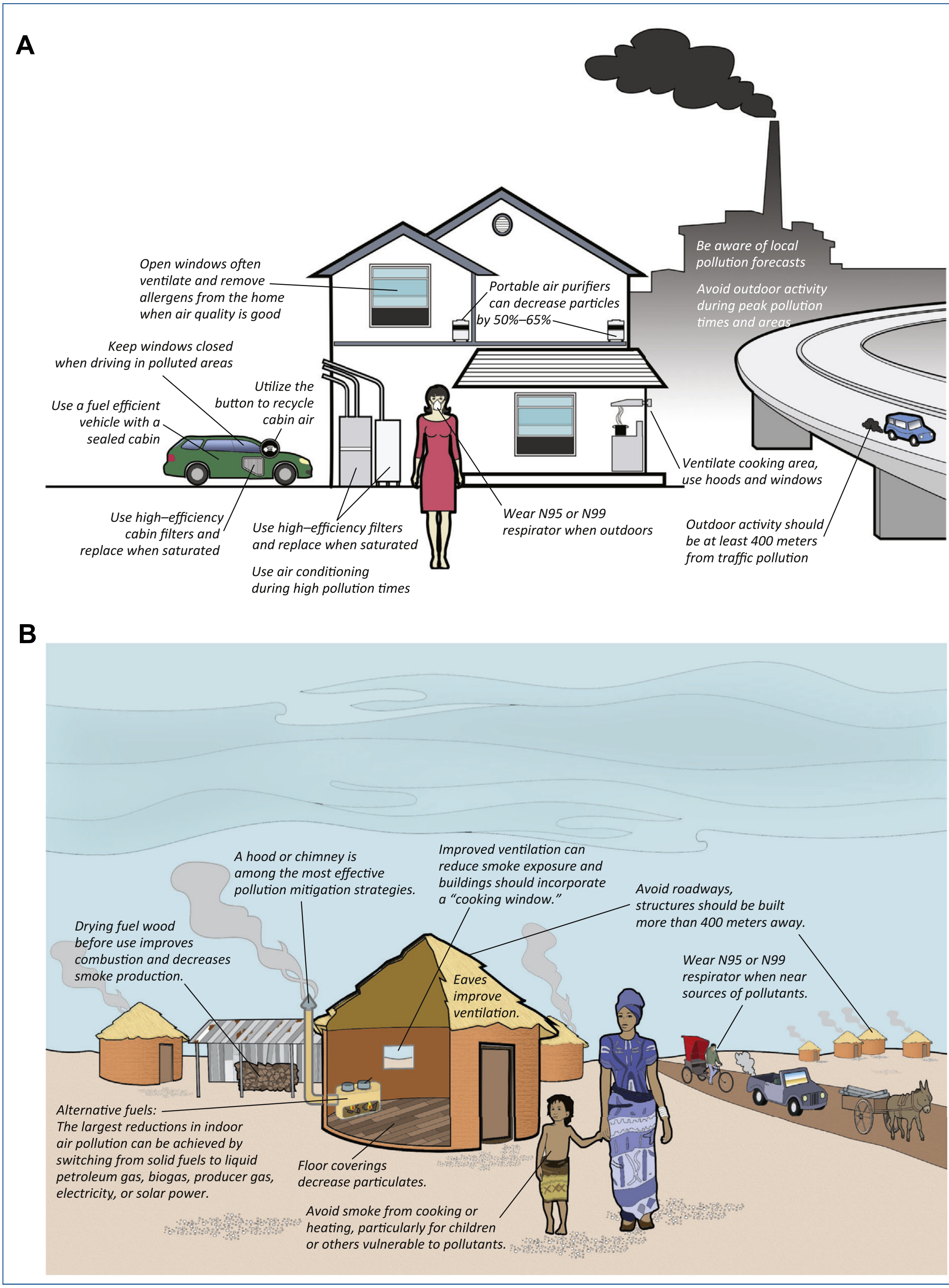

FIGURE 2. Approaches to limit routine exposure to air pollution in developed areas (A) and underdeveloped areas (B).

TABLE 2. Studies evaluating filtration effects on biomarker outcomes

First Author (Ref. #)	Subject Description	Intervention Duration	Purifier Type	Pollution Decrease	Location	Biomarkers Improved With Intervention
Li et al. [10]	College students residing in dormitories 20 ± 1 yrs	2 × 9 days, 12 d; washout	Portable HEPA	$PM_{2.5}$: 46.8 $\mu g/m^3$ (82%)	Shanghai, China	Cortisol, cortisone, epinephrine, norepinephrine, glucose, amino acids, fatty acids, and lipids. Blood pressure, hormones, insulin resistance, and biomarkers of oxidative stress and inflammation.
Padró-Martinez et al. [11]	Near roadway apartment residents 54 ± 9 yrs	2 × 21 days; no washout	Window-mounted HEPA	PNC: 4,900/cm^3 (42%)	Copenhagen, Denmark	None
Chen et al. [12]	College students residing in dormitories 23 ± 2 yrs	2 × 48 h; 2-week washout	Portable electrostatic filter (non-HEPA)	$PM_{2.5}$: 55 $\mu g/m^3$ (57%)	Shanghai, China	SBP, DBP, sCD40L, FeNO, MCP-1, IL-1β, MPO
Kajbafzadeh et al. [13]	Residents in traffic- or woodsmoke-impacted areas 44 ± 13 yrs	2 × 7 days; no washout	Portable HEPA + activated carbon	$PM_{2.5}$: 2.8 $\mu g/m^3$ (40%)	Vancouver, British Columbia, Canada	None
Karottki et al. [14]	Near roadway elderly 67 ± 7 yrs	2 × 14 days; no washout	House AHU H11 HEPA	$PM_{2.5}$: 3.8 $\mu g/m^3$ (50%)	Copenhagen, Denmark	Monocyte CD62L (only on day 2 of intervention)
Weichenthal et a1. [15]	First Nations residents mean age 32 yrs range 11—64 yrs	2 × 7 days; 1-week washout	Portable electrostatic filter (non-HEPA)	$PM_{2.5}$: 37 $\mu g/m^3$ (~60%)	Manitoba, Canada	FEV_1 and PEFR (both dependent on 2 outlying subjects)
Allen et al. [16]	Small rural town members 43 ± 10 yrs	2 × 7 days; no washout	Portable HEPA	$PM_{2.5}$: 6.2 $\mu g/m^3$ (—60%)	Smithers, British Columbia, Canada	RHI; males only: CRP, IL-6, band cell counts
Bräuner et al. [17]	Near roadway elderly 60—75 yrs median 67 yrs	2 × 48 h; no washout	Portable HEPA	$PM_{2.5}$: 12.6 $\mu g/m^3$ (63%)	Copenhagen, Denmark	RHI, hemoglobin
Shao et al. [18]	Elderly: 67 ± 8 yrs COPD: 66 ± 7 yrs	2. × 14 days, no washout	Portable HEPA + activated carbon	$PM_{2.5}$: 60 $\mu g/m^3$ (60%)	Beijing, China	IL-8

AHU, air handling unit; COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; DBP, diastolic blood pressure; FeNO, fractional exhaled nitric oxide; FEV_1, 1-s forced expiratory volume; IL, interleukin; MCP-1, monocyte chemoattractant protein 1; MPO, myeloperoxidase; PEFR, peak expiratory filling rate; PNC, Particle Number Concentration; RHI, Reactive Hypermia Index; SBP, systolic blood pressure; other abbreviations as in Table 1.

Air conditioning with recirculated air during 2 h of commuting in heavy traffic has improved heart rate variability (indicative of reduced risk for cardiac arrhythmia) and was associated with a reduction in $PM_{2.5}$ exposure compared with air conditioning without recirculation or no air conditioning [22]. A more complex study [25] of 6 different vehicles at 76 combinations of driving speeds and ventilation conditions concluded that cabin filters exhibited low removal efficiencies and that better filters were warranted. The investigators also found that speed of travel and age of the vehicle influenced the air exchange between the outside air and the vehicle's cabin [25].

Others have developed a high-efficiency cabin air filter that is capable of solving the dilemma between using the recirculation mode at the expense of CO_2 build-up from passenger exhalation. Lee et al. [26] monitored air pollution inside and outside of 12 different vehicles under 3 driving conditions (stationary, roadways, freeways) using 4 different filter conditions (no filter, original manufacturer filter, 2 types of high-efficiency filter) while cabin ventilation was set for outside air. The high-efficiency filters reduced in-cabin ultrafine particles by 93% compared with about 50% for the original manufacturer's filters while reducing CO_2 levels by about one-fourth as compared to the recirculation mode.

In a recent study conducted among 17 taxi drivers in Los Angeles [27], the efficacy of high-efficiency air filters was tested. Closing windows plus using air filters lowered in-cabin $PM_{2.5}$ levels by 37%. A urinary metric of lipid oxidative stress, malondialdehyde, was lowered by the intervention and was correlated to in-cabin $PM_{2.5}$ concentrations. Given the enormous global burden of TRAP, these findings are important and suggest that practical measures can be taken to reduce exposure and provide health benefits.

Respirator face masks. It is important to distinguish between "respirator" face masks and other types of masks such as surgical, cloth, or improvised masks. Respirator face masks are designed to protect the wearer from the inhalation of particles while other types are most often designed to protect others (e.g., patients) from sputum and larger particles. Some surgical and cloth masks can reduce the inhalation of $PM_{2.5}$ but they are unreliable and variable [28]. Respirators must fit properly and be worn with a tight facial seal to prevent leakage to be fully protective; they are tested and officially designated by governing agencies such as the National Institute of Occupational Safety and Health in the United States by their capacity to reduce particulate exposure (N95 or N99 removes >95% or 99% of inhaled particles at 0.3 μm in size). It is also important to note that most respirators have been validated for usage during occupational settings and only recently have commercially available products become available for the public at-large specifically to provide protection against ambient $PM_{2.5}$. This is a very new concept that has only recently been studied for its potential health benefits.

The use of face masks in heavily polluted areas can be effective in decreasing exposure, but studies investigating protective behaviors report face mask adherence between 6.4% and 8.1%. Adherence may be hindered in the general public due to the social stigma associated with wearing face masks, though in some cultures face masks are embraced by the public as demonstrated by their marketing and appearances at fashion shows [28]. Elsewhere, adherence may be limited because of impaired communication, appearance, inconvenience, and/or discomfort during use.

Some individuals may experience anxiety or perceive breathing to be difficult while wearing a face mask. Facial hair or shape may make it impossible to achieve a seal; a common limitation in children [7]. More advanced masks may include a latex valve or microventilator fan to prevent the feeling of warmth or pressure and have been shown to also protect the user from influenza and rhinoviruses in addition to $PM_{2.5}$ [29]. A study found no differences when health care workers wore masks *indoor* with or without exhalation valves in heart rate, respiratory rate, tidal volume, minute volume, blood oxygen saturation, transcutaneously measured partial pressure of CO_2, comfort scores, or moisture retention. However, the study found that partial pressure of CO_2 levels were elevated in some subjects wearing masks without an exhalation valve [30].

Inexpensive face masks made from cloth, cotton, or gauze are widely available at pharmacies and street vendors in both developed and developing countries but they do not actively filter $PM_{2.5}$, but rather they act as a weak barrier. If properly fitted, the filtration efficiency of N95 respirators is greater than other masks while still being cost-effective (about US$1.40 each).

In Indonesia, Patel et al. [31] evaluated 9 different masks that were classified into 3 categories: bandana, biker, and surgical. Within each category there was variability in shape, tightness, manufacturer, and source. Surgical masks were the only class of mask to significantly decrease $PM_{2.5}$, but they had a large performance range and did not improve $PM_{2.5}$ exposure in all subjects.

In a similar study [28], investigators tested on mannequins 3 different cloth masks, 1 surgical mask, and a N95 respirator. Cloth mask performance was unpredictable, with a performance of 45% to 80%, due in part to the inability to seal the face. Disposable surgical masks were more effective, but N95 masks were the most effective in removing particles. Unfortunately, the least effective cloth masks are also inexpensive, reusable, and are widely used in developing countries [28].

During 2 seasons, 53 traffic officers in Katmandu Valley, Nepal, were observed continuously for 6 days [32], and investigators reported that N95 masks prevented the lung function impairment due to TRAP. In Beijing, 2 different randomized crossover trials studied healthy volunteers [33] and coronary heart disease patients [34] while walking. In both studies, N95 face masks decreased blood pressure and increased heart rate variability; mask use did not appear to influence heart rate or energy expenditure.

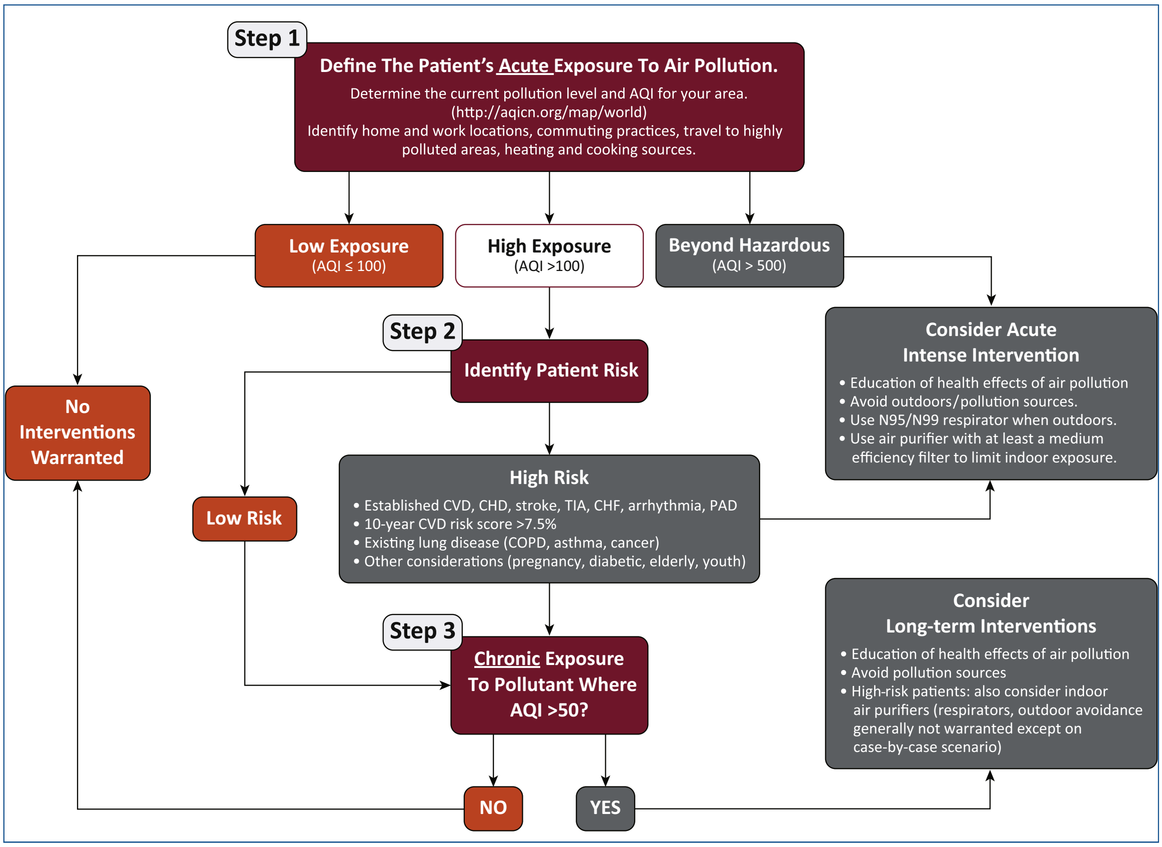

FIGURE 3. Algorithm to determine whether personal-level interventions are warranted. Acute exposure is defined as less than a 2-week period. Chronic is defined as greater than a 2-week period or as a person's routine exposure. AQI, Air Quality Index; CHD, coronary heart disease; CHF, chronic heart failure; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; PAD, peripheral arterial disease; TIA, transient ischemic attacks.

Another trial [35], conducted in young adults living in Shanghai (mean $PM_{2.5}$ of 74.2 $\mu g/m^3$), found respirator use for 48 h was associated with improved heart rate variability and an average decreased systolic blood pressure of 2.7 mm Hg. The available data to date provides promising evidence that respirators can effectively lower ambient $PM_{2.5}$ exposures in a manner that translates into cardiometabolic health benefits. However, several limitations such as discomfort, heat, and CO_2 build-up, as well as the potential for increased respiratory burden need to be considered. Several of these issues have been recently addressed by a N95 respirator commercial product employing a microventilator fan to improve wearability and comfort (Dettol SiTi Shield; Reckitt Benckiser, Slough, England; https://www.dettolsitishield.co.in/). The long-term compliance with use and the correct facial fitting (particularly for children and certain individuals such as those with beards) of even validated N95 respirators also need to be evaluated. Respirators may have cultural acceptance in some regions across Asia, but widespread acceptance for less polluted regions is doubtful. Overall, respirators are likely an important part of the comprehensive strategy to reduce $PM_{2.5}$ exposures. Future studies will be helpful to clarify remaining questions.

Behavioral/lifestyle routines. In addition to using personal protection devices, there may be several simple and prudent actions that individuals can take that can help lower their exposures to air pollution. Many of these have been outlined previously [1,4] and in the clinical guidance by Hadley et al. [8]. A recent survey revealed that one-third of the respondents were aware of air quality alerts, but only 10% to 15% reported changing their behavior in response to predicted poor air quality. Respondents who did change their behavior cited the personal perceptions of poor air quality as triggering their behavior change and not the official advisories [36]. It appears that one's immediate risk is an important variable; those who ascribe symptoms to air pollution were more likely to change their behavior [36].

Avoidance strategies implemented into one's lifestyle can help limit air pollution exposure (Table 1). Such strategies include awareness of pollution alerts and avoidance of peak pollution times and geographic areas. Most specifically, avoidance of activities within 400 m of major

TABLE 3. AQI classifications of the public health effects in the United States, China, and India

	United States			China			India		
AQI	Rating	Description	$PM_{2.5}$ ($\mu g/m^3$)*	Rating	Description	$PM_{2.5}$ ($\mu g/m^3$)*	Rating	Description	$PM_{2.5}$ ($\mu g/m^3$)*
50	Good	Air quality is considered satisfactory and poses little or no short-term (acute) risk over the next few days.	≤12	Excellent	No health implications.	0–35	Good	Minimal impact.	0–30
100	Moderate	Air quality is acceptable. Moderate health concerns exist for a very small number of people who are unusually sensitive to some pollutants.	13–34	Good	Few hypersensitive individuals should reduce outdoor exercise.	36–75	Satisfactory	May cause minor breathing discomfort to sensitive people.	31–60
150	Unhealthy for sensitive groups	General public is unlikely to be affected. Elevated ozone can affect people with lung disease, older adults, and children. Elevated particles can affect people with heart and lung disease, older adults, and children.	35–54	Lightly polluted	Slight irritations may occur, individuals with breathing or heart problems should reduce outdoor exercise.	76–115	Moderately polluted	May cause breathing discomfort to people with lung disease such as asthma and discomfort to people with heart disease, children, and older adults.	61–90
200	Unhealthy	Everyone may begin to experience health effects. Sensitive groups are more likely to experience more serious health effects.	55–149	Moderately polluted	Slight irritations may occur, individuals with breathing or heart problems should reduce outdoor exercise.	116–150			
250	Very unhealthy	Health alert: everyone may experience more serious health effects.	150–249	Heavily polluted	Healthy people will be noticeably affected. People with breathing or heart problems will experience reduced endurance in activities. These individuals and elders should remain indoors and restrict activities.	151–250	Poor	May cause breathing discomfort to people on prolonged exposure, and discomfort to people with heart disease.	91–120
300									

350	Hazardous	Health warnings of emergency conditions. The entire population is more likely to be affected.	≥250	Severely polluted	Healthy people will experience reduced endurance in activities. There may be strong irritations and symptoms and may trigger other illnesses. Elders and the sick should remain indoors and avoid exercise. Healthy individuals should avoid outdoor activities.	251–350 351–500	Very poor	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases.	121–250
400									
450							Severe	May cause a respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.	250+
500									
	Beyond hazardous	Extreme levels of pollutants warrant everybody implement precautionary and avoidance measures.							

Abbreviations as in Table 1.

*In the United States, elevated AQI is more likely to be related to ozone. Cutpoints for each classification based on $PM_{2.5}$ are also provided.

roadways is a simple action likely to significantly reduce exposure to TRAP. Health care providers and patients should be aware that while traffic is a leading cause of exposure to air pollution, most of the TRAP components (e.g., ultrafine particles, NO, SO_2) have a limited range and peak within a confined 400-m radius around roadways.

Diet. The American Thoracic Society recommends a diet that contains fruits and vegetables high in antioxidants, which can mitigate the health effects of air pollutants ($PM_{2.5}$, ozone) [37]. Antioxidant supplementation cannot be confidently recommended to counteract air pollution because benefits have not been shown in high-quality randomized trials [7]. Vitamins, fish oil, or antioxidants may prevent subclinical health effects of exposure in theory, but several large outcome studies have shown them to be ineffective at preventing heart disease in numerous locations including those living in urban settings [38]. At present, we do not offer formal advice regarding changing dietary patterns or using health supplements to prevent the adverse effects of air pollution.

DEVELOPING A FRAMEWORK FOR CLINICAL RECOMMENDATIONS

Here, we provide an evidentiary review of the available approaches to reduce personal-level $PM_{2.5}$ exposures to help lower health risks. The American Heart Association [1], the American Thoracic Society [37], and the European Society of Cardiology [39] have long recognized the global importance of this issue. Nevertheless, until recently, clinicians have lacked any practical guidance to counsel patients. We fear this silence may inadvertently produce (or foster) unwanted outcomes. First, there is growing public use of ineffective (e.g., cloth, surgical) face masks across China and India. This intervention is not evidence-based and may provide a false sense of security. Furthermore, face mask use may not be warranted, particularly among young healthy people. Second, the health benefits of N95 respirators may be discounted without recommendations from medical professionals and at-risk patients may go unprotected. Third, other interventions (e.g., indoor air filters) may be inappropriately used or ineffectually utilized. Finally, simple lifestyle changes may be neglected, such as high-risk patients avoiding TRAP or travel to polluted regions. Negative behavioral patterns could develop, such as healthy individuals avoiding outdoor exercise [40].

We recognize that without randomized trials, clinical recommendations will remain "expert opinion−based." Nevertheless, Hadley et al. [8] recently provided a clinical guidance. We endorse their approach and expand it. Our goal is to provide health care professionals with recommendations they can provide to patients to avoid air pollution. First, the recommendations must be practical, safe, and inexpensive and not interfere with other prudent medical advice. For example, guiding healthy people to avoid outdoor activity produces greater harm than benefit [40]. Conversely, advising patients with heart disease to continue to exercise but to remain >400 m away from major roadways is simple and prudent given recent study findings [41]. Second, the aggressiveness of the intervention should be tailored to the health risk of the patient. The most aggressive interventions, such as N95 respirators, should be focused toward higher risk populations (e.g., patients with or at high risk for cardiovascular or pulmonary disease). This will markedly reduce the number needed to treat and improve the potential cost-effectiveness of the intervention(s). It is important to keep in mind that the daily inhaled doses of $PM_{2.5}$, even in highly polluted cities, are 10- to 100-fold less than those from active cigarette smoking [1,42]. Air pollution poses a global public health threat not because of a high relative risk of exposure (1% to 10% per 10 $\mu g/m^3$), but because its small health risks affect an enormous population. The absolute mortality risk for any 1 individual is exceedingly small, whereby there are only a few excess deaths per million people per day due to air pollution [1,43]. Advising the entire population of India to wear N95 respirators is not feasible, economically sound, nor warranted in this context. Third, the aggressiveness of 1 or more interventions should also match the magnitude of air pollution exposure. Simple advice to avoid TRAP and to install high-efficiency vehicle cabin air filters may suffice in clean environments, whereas cardiac patients living in a heavily polluted city (such as in India or China) may benefit from more aggressive actions (indoor air filters, N95 respirators). Finally, health care providers should educate all patients (even individuals at low risk) regarding the harmful health effects of air pollution and provide simple inexpensive lifestyle advice to reduce exposures—such as avoiding activities near high-traffic roadways. This poses no financial strain or potential harm and can improve public awareness.

"WORKING" RECOMMENDATIONS FOR HEALTH CARE PROVIDERS

Figure 3 provides a "working" clinical approach for health care providers that considers a patient's health risk and their acute and chronic exposure to air pollution to determine whether personal-level interventions are warranted. By using the term "working," we recognize that this proposed strategy (based on the available evidence) needs to be continually revised as more information becomes available. Given the extreme $PM_{2.5}$ levels in some regions (i.e., India or China), combined approaches (air purifiers plus N95 respirators and behavioral methods) should be considered on a case-by-case basis. We acknowledge this guidance remains "expert opinion" and is limited by the lack of randomized clinical trials. Nonetheless, it is a starting point providing health care providers with practical advice.

Step 1: Define the patient's acute exposure to air pollution

Identify patient's routine exposure considering their residence, commuting practices, occupation, and nearby pollution sources (freeways, factories). PM levels vary substantially both geographically and temporally in many areas and clinicians may have to consult a local source to determine pollution levels. Daily Internet-based forecasts are available for many cities around the world. At the population level there is no safe threshold of pollution, but the Air Quality Index (AQI) offers a strategy to assess risk that is derived from the highest pollutant (ozone, $PM_{2.5}$) during any given day. We recommend the AQI because of its wider use and acceptance by governing bodies than other measures such as the Air Pollution Index and the Air Quality Health Index. Table 3 provides AQI classifications and its corresponding risks that have been instituted in the United States, China, and India.

Step 2: Determine the patient's health risk

Identify highest risk individuals from the health effects of air pollution including those with a high cardiovascular risk (>7.5% risk per 10 years for a cardiovascular event), preexisting lung diseases (chronic obstructive pulmonary disease, asthma, lung cancer) or other conditions that may be considered on an individual basis (pregnancy, elderly, very young, diabetics). Low-risk patients would warrant intervention under extremely polluted conditions such as "hazardous" and "beyond hazardous" strata (Table 3) and higher risk patients will have lower AQI thresholds for intervention consideration.

Step 3: Further stratify the high-risk patients

Interventions are warranted in high-risk patients when the AQI acutely (<2 weeks) exceeds 100 or chronically exceeds 50.

CONCLUSIONS

$PM_{2.5}$ remains a leading cause of global morbidity and mortality. Given the growing and aging population and our incessant reliance on fossil fuels, worldwide air quality is not likely to improve (particularly within developing regions) anytime soon. In the meantime, we believe it is important to increase awareness of this public health threat among clinicians and the general public alike. We have herein provided a general framework and "working" algorithm for health care providers to help them better inform their patients and thereby advance the global effort to combat the adverse effects of air pollution.

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