

An ecological alliance against air pollution and cardiovascular disease

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ABSTRACT

This narrative review article summarizes the strong available evidence that casually links indoor and outdoor air pollution to cardiovascular disease. It also discusses as a possible approach to mitigate this ubiquitous risk factor the use in the household of ornamental potted plants, and their variable degree of effectiveness for the removal of different indoor pollutants such as volatile organic compounds (formaldehyde, benzene, toluene, xylene). Thus, the choice of the plants should be tailored to the types and concentrations of the pollutants present in each household. Outdoor air is less polluted than indoor air in terms of concentrations of the gaseous (NO₂) and particulate components (PM₁₀, PM_{2.5}, PM_{0.1}), but it does hamper to a higher extent health because a large fraction of the population is inevitably exposed at the time of breezing. Being cognizant of the difficulties currently encountered in the attempts to mitigate the major sources of ambient air pollution (vehicle traffic and domestic heating) a strategy based upon a massive increase of green spaces in urban areas has been shown not only to positively mitigate air pollution but also improve life expectancy, general health and resilience.

INTRODUCTION

The first cogent example of the ominous effects of bad air on human health dates back to the last few months of 1952. In the metropolitan area of London, the combined effect of the unusual absence of rain and wind, coupled with high atmospheric pressure and very low ambient temperatures, led to very intensive domestic and public heating mainly based upon the use of solid fuels such as coal of poor quality and rich in sulfur. The great London smog lasted only for the first 10 days of December until the arrival from the Atlantic of wind and rain that washed away the smog. However, during the next

fortnight hospital admissions for pneumonia, asthma and bronchitis progressively increased and peaked in severity to reach 12.000 fatalities. This number is impressive and only marginally lower than that of the 30.000 deaths due to the London bombing by the Luftwaffe, thus explaining the deep emotional reactions of Londoners who were just starting to recover from the mayhem of the second world war.

This historical preamble is meant to emphasize that air pollution was initially thought to target the lungs and respiratory airways and that the excess deaths documented during and soon after the great London smog were due to pneumonia and other acute respiratory illness. It is only in this century that it was unequivocally understood that the short- and long-term human exposure to particulate and gaseous pollutants contained in ambient air, such as PM_{2.5}, PM₁₀, PM_{0.1} and nitric dioxide (NO₂), are also risk factors for cardiovascular morbidity and mortality.¹⁻⁵

In order to provide upfront in this essay cogent information on the magnitude of the risk of cardiovascular disease and ultimately suggest some strategies for mitigation of the risk associated with air pollution and its consequences at the individual as well as community levels, it is a fact and deed that the World Health Organization (WHO) and the Global Burden of Disease (GBD) study had concordantly estimated that air pollution is globally the fourth leading cause of morbidity and mortality, being casually responsible each year for 7 million excess deaths, approximately half due to ambient (outdoor) pollution and the remaining half to household (indoor) pollution.^{6,7} According to recent estimates based upon more accurate measures of exposure and new exposure-response functions, the forementioned dramatic number of avoidable deaths underestimates the real burden, that is above 9 millions.^{5,8,9}

Pertaining to the non-communicable diseases globally

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Key words: Outdoor pollutants, Indoor pollutants, Green space, Organic volatile compounds, Air quality guidelines.

Conflict of interest: The author declares no potential conflict of interest.

Funding: None.

Received for publication: 23 February 2022.

Accepted for publication: 23 February 2022.

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Bleeding, Thrombosis and Vascular Biology 2022; 1:21
doi:10.4081/btvb.2022.21

association with air pollution, cardiovascular diseases account for 5.1 million annual deaths, many more than those due to chronic pulmonary disease (1.2 million), cancer (more than 700.000), diabetes and chronic kidney disease (more than 500.000).¹⁰ Within the category of atherothrombotic cardiovascular diseases, ischemic heart disease contributes with more than 2.6 million annual deaths, ischemic stroke with nearly 2.3 millions and hypertension with 170.000.¹⁰ Pertaining to the role of the different components of air pollution, PM_{2.5} is regarded as the main culprit, both for short-term exposure (within hours to days) and long-term exposure (years) to this fine particulate matter, that is also a proxy of primary and secondary gaseous pollutants such as nitric dioxide and ozone.¹⁰ A large meta-analysis of 35 studies demonstrated that a daily increase of as little as 10 micrograms per cubic milliliter of PM_{2.5} is associated with a 10% increase of cardiovascular mortality due to ischemic heart disease, stroke but also congestive heart failure, atrial fibrillation and ventricular arrhythmias,¹¹ including sudden deaths due to cardiac arrest.¹²

The mechanistic transition of pollution exposure towards these cardiovascular outcomes occurs in different steps, initiating with generalized oxidative inflammation and activation of neuro reflex arcs.¹³⁻¹⁵ The subsequent effector pathways act through such mechanistic intermediates as autonomic dysfunction and endocrine disruption, that in turn lead endothelial perturbation, plaque instability, hypercoagulability and hypertension, ultimately resulting in the forementioned cardiovascular events.¹³⁻¹⁵

With this background on the large dimension of the damage of air pollution on human health, explained by a high population-attributable fraction of this risk factor and its inescapability with breezing, what can be done to tackle this problem at the level of the community but also of the individual? The latter is able to play a key role mainly in the mitigation of indoor air pollution, whereas actions from the community and its governmental representatives are essential in the context of the formidable attempts to mitigate ambient air pollution and thereby manage to decrease the associated risk of cardiovascular morbidity and mortality.¹⁶

MITIGATION OF INDOOR POLLUTION

It is generally believed that this problem afflicts almost exclusively low-income countries that make an abundant use in the house of biomass or fossil fuels for cooking and heating. Even though, this is indeed a gigantic problem there is less awareness that indoor pollution is a cogent issue also in high income countries, considering that human beings spend at least 70-90% of their lives indoor doing an array of activities. Active and passive tobacco smoking is a prominent and avoidable source of in-

door pollutants such as particulate matter, benzene and formaldehyde, but also of carcinogen compounds such as benzo a-pyrene. Any type of fire is a source of pollution, particularly when heating and cooking make use of fireplaces and stoves that burn biomass such as wood and pellets. Computers, printers and copy machines are sources of such carcinogen organic volatile compounds as xylene and toluene. Moreover, human beings living in closed environments produce beside CO₂ such bioeffluents as acetone, methane and ammonia. Air purifiers with filters of high quality and efficiency are useful but very expensive at the time being. Airing the ambients, particularly those more densely inhabited, is an obvious and inexpensive approach to limit the indoor concentrations of pollutants but open windows inevitably cause the introduction into the household of outdoor pollution. In dense urban areas a meaningful strategy is to choose ventilate the house in the early hours of the morning and late afternoon, at a time when outdoor pollutants due to motor vehicle traffic are in smaller concentrations.

Tobacco smoke, fires and human effluents are not the only sources of indoor pollution. Products commonly employed for house furnishing and cleaning such as volatile detergents, covering plastic glues, fitted carpets and wooden panels often contain and release in the ambient such carcinogens as formaldehyde and benzene. Moreover, organic volatile compounds are also released by furniture, paints and toys.

It is refreshing to realize that indoor pollution can be mitigated by plants. In 2017 the NASA tested different ornamental potted plants for their properties to remove harmful agents such as formaldehyde, benzene, xylene and toluene. The study led to a 70% reduction in the offices of this agency of the indoor concentrations of volatile organic compounds by using the most efficient house plants, such as bamboo palm, English ivy, weeping fig, gerbera, dracena and others.¹⁷ For instance, the removing capacity of the weeping fig (*Ficus benjamina*) is of 20 g/h for formaldehyde, 7 g/h for benzene, 19 g/h acetone and 5 g/h ammonia.¹⁸ So, the ecological transition that stems from these findings is that it is possible to clean houses and offices with natural weapons and to use ornamental houseplants as a sort of green liver.^{18,19}

On the whole, the take-home messages for those who aim to reduce indoor pollution is to strictly avoid both active and passive smoking, skip fireplaces, increase house ventilation in the most suitable hours of the day and choose furniture, toys, tools and paints with low ambient impact and emission of carcinogen organic volatile compounds. In addition, one should clean the house with natural detergents and use as green liver house plants, chosen on the basis of their varied ability to remove those pollutants that are more prominent in each indoor context.^{18,19}

CONTROL OF OUTDOOR, AMBIENT AIR POLLUTION

At global, national and urban scales the main sources of pollutants in the ambient air are automobile traffic, domestic and office heating, industrial and shipping activities, power stations and intensive farming. The relative burden of each source depends on the site of human exposure, but urban areas are definitely the most polluted, not only in high income countries but also in middle- low-income countries. It is difficult to establish with accuracy which of the major sources of outdoor pollution carries the greatest burden in terms of related disease occurrence. Diesel motor engines are considered the major contributors to the air concentrations of NO₂ but also of pollutants such as particulate matter and ozone that form secondarily in the atmosphere. However, any fossil fuel is a source of pollution, and there is mounting evidence that also allegedly clean engines using super unleaded gasoline are an important source of ultrafine particulate matter (PM_{0.1}), more and more shown to be a most dangerous pollutant for human health and the cardiovascular system.^{20,21}

Another important point to be emphasized in the context of the potential approaches towards mitigation of ambient air pollution is the threshold of each pollutant that should not be exceeded for the preservation of human health, using as references guidelines or standards set by WHO and various national or multinational organizations. For instance, the USA Environmental Protection Agency (EPA) recommends ceilings not to be exceeded daily and annually and air quality guidelines have been set also by the European Environmental Agency (Table 1). Pertaining to gaseous components such as NO₂ and particulate matter such as PM_{2.5} and PM₁₀, the ceilings recommended by EPA are much more stringent (lower) than those of the European Agency. Nevertheless, a report on air quality released in 2016 by the European Agency found that at least 15% of the people living in urban areas of the continent exceed even the scarcely demanding ceilings of the European guidelines, let alone those of WHO with a 90% exceeding rate! The current situation of several urban

Table 1. Comparison of the ceilings of mean annual concentrations ($\mu\text{g}/\text{mm}^3$) of the main ambient air pollutants according to the current directions for ambient air quality of the European Union (EU), USA Environment Protection Agency (EPA) and World Health Organization (WHO).

Pollutant	EU	EPA	WHO
PM10	40	-	15
PM2.5	25	12	5
NO2	40	30	10
Ozone	120	100	60

areas, particularly those in the Po plain in Italy and Eastern Europe (Poland, but also Romania and Bulgaria) is particularly gloomy, considering that WHO released in 2021 new and much more stringent air quality guidelines to be attained in order to truly preserve human health. Table 1 shows the WHO newly recommended daily and annual ceilings and also shows the huge gaps between them, those of EPA (that is however updating and lowering them soon) and of the European Union that, released as early as in 2008, are unfortunately still not updated despite their poor adequacy to preserve the health of European citizens.²²

Standards and guidelines represent a target, but their actual implementation is a formidable task. In general, there is tendency to blame the road traffic of motor vehicles using fossil fuels, and thus to worship electric engines as the optimal solution. Accordingly, a few countries, in Europe and elsewhere, have set a deadline for the complete ban of internal combustion engines. The implementation of this goal without significant economic and employment problems is a formidable task, in Italy and other countries. Moreover, the scourge of the coronavirus pandemic that obliged to stop motor traffic in many urban areas of the world has shown as a bad teacher that automobile traffic is not necessarily the main culprit. In China, where the lockdown was strictly implemented in the winter of 2020 with the involvement of the army, air pollution and particularly NO₂ concentrations were dramatically reduced in the central and southern urban areas, but not in Beijing and other northern cities, where heating of the domestic and public ambients could not be stopped in the cold months.²³ A similar pattern was observed in the Italian region of Lombardy, the first in Europe to be dramatically hit by the SARS-CoV-2 pandemic in the early months of 2020. Thus, domestic and office heating is an important cause of the burden of ambient air pollution, even though the proportion between this component and that due motor vehicle traffic varies depending on the geographic locations and other characteristics of urban areas.

Putting aside as being currently unrealistic the myth of deep decarbonization and the global implementation of renewable energy sources, an ecological approach to a cleaner air based upon more greenness is being implemented in highly polluted countries such as China and India, that are aggressively developing nationwide programs of intensive forestation.²⁴ Greenness reduces air and noise pollution and has additional health benefits by promoting physical activities such as walking, cycling and running that ultimately help to mitigate the adverse effects of pollution on cardiovascular morbidity and mortality.²⁵⁻²⁷ Furthermore, a prospective cohort study carried out in the USA by the Harvard School of Public Health on 108 nurses showed that those with residence in areas with higher greenness have a significantly lower all-cause mor-

tality than those with residence in the so-called grey areas with little or no green space.²⁸ The most plausible mechanisms for these positive effects of green space are the ecosystem services offered by trees, that remove significant amount of particulate and gaseous pollutants. For instance, a study carried out in 55 urban areas of the USA showed that 711 tons of pollutants (ozone, PM, NO₂) were removed annually, with a monetary value of 3.8 billion dollars owing to health fostering and illness avoidance.²⁹ On behalf of the Ecological Services of Urban Forest, Barò *et al.* conducted in Barcelona a study that measured the number of pollutants removed by urban green and calculated the corresponding monetary value. They found that 306 tons of air pollutants are annually removed and that the corresponding monetary values are 1.15 million Euro.³⁰ The main biomechanism of removal of air pollutants by trees is primarily by uptake via leaf stomata, but also via the green surface and bark with disposal through the roots. An additional mechanism is that airborne particles intercepted by the plant are washed off by rain or dropped to the ground when leaves fall. The degree of pollution disposal is variable and depends on the tree species, Table 2 showing the mitigation effect of various common species of trees.³¹

CONCLUSIONS

What can urban areas, responsible for 75% of carbon emission, do to mitigate at the same time climate change and air pollution? Universal access to low carbon energy, affordable and efficient public transport and active travelling are the ultimate weapons to try to attain mitigation and adaptation. An easier and more timely strategy for resilience is based on the ecosystem and the increase of green space, in the form of open undeveloped land or in the form of urban parks, gardens and public streets.³² In the last 10-15 years epidemiologists and clinicians were increasingly exploring if and how neighborhood greenness benefits human health. Strong and emerging evidence shows that human exposure to greenness reduces all cause mortality, particularly for cardiopulmonary and cancer causes. The health benefits stemming from greenness are multiple and help to thwart the dire effects of indoor and

Table 2. Tree species according to their capacity of removal of outdoor air pollution.

Removal effect	Species
Excellent	Elm, common ash, wild lime, verrucous birch, maple, hackberry, curry leaf
Good	White hornbeam, country maple, cherry, tulip tree, laurel, whitethorn, robinia, apple tree
Medium	Elder, mulberry, Judas tree

outdoor pollution emphasized in this essay. Other benefits of green space are stress reduction, more physical activity, more social interactions and lower exposure to other environmental risk factors for health and wellbeing such as noise, heat and humidity.^{25,26} About half of the premature deaths attributed to exposure to indoor and outdoor pollution occur in fragile individuals (children, older and poor people, pregnant women) and in those living in low-income countries. We hope that this essay will help to convince the readership of this new journal that more trees and forests are able to restore clean air much more easily than the currently too difficult and demanding actions on heating and traffic.

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