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**Air Pollution and Non-Communicable Diseases: A review by  
the Forum of International Respiratory Societies'  
Environmental Committee. Part 2: Air pollution and organ  
systems**

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**Chest 18-2053.R1 Clean****Air Pollution and Non-Communicable Diseases: A review by the Forum of International Respiratory Societies' Environmental Committee. Part 2: Air pollution and organ systems**

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**Abstract**

Although air pollution is well-known to be harmful to the lung and airways, it can also damage most other organ systems of the body. It is estimated that about 500,000 lung cancer deaths and 1.6 million chronic obstructive pulmonary disease (COPD) deaths can be attributed to air pollution, but air pollution may also account for 19% of all cardiovascular deaths and 21% of all stroke deaths. Air pollution has been linked to other malignancies, such as bladder cancer and childhood leukemia. Lung development in childhood is stymied with exposure to air pollutants, and poor lung development in children predicts lung impairment in adults. Air pollution is associated with reduced cognitive function and increased risk of dementia. Particulate matter in the air (PM<sub>2.5</sub>) is associated with delayed psychomotor development and lower child intelligence. Studies link air pollution with diabetes mellitus prevalence, morbidity, and mortality. Pollution affects the immune system and is associated with allergic rhinitis, allergic sensitization, and autoimmunity. It is also associated with osteoporosis and bone fractures, conjunctivitis, dry eye disease, and blepharitis, inflammatory bowel disease, increased intravascular coagulation, and decreased glomerular filtration rate. Atopic and urticarial skin disease, acne, and skin aging are linked to air pollution. Air pollution is controllable and, therefore, many of these adverse health effects can be prevented.

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3 This second of the 2-part report describes specific conditions associated with air pollution. The  
4 conditions are listed alphabetically. In addition to the text, the **figure** shows organ associates  
5 and the **table** shows other effects of air pollution that are generally not associated with specific  
6 organs. It is important to note that for many of the diseases, the associations with exposures to  
7 air pollution in observational epidemiological studies are not causal and may be subject to  
8 residual confounding due to other factors, such as smoking, lower socioeconomic status, and  
9 neighborhood factors. However, exposure dose and time relationships and animal studies  
10 corroborate and add strength to the conclusions from the epidemiologic studies.  
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## 25 **Allergic and immunologic diseases**

### 26 *Allergic sensitization and rhinitis*

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35 It is well established that air pollution can exacerbate allergic responses in sensitized persons  
36  
37 (1). Clinical epidemiological studies show that ambient air pollution may also enhance allergic  
38 sensitization in children, and also increase IgE levels in the very young (2).  
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45 There is considerable evidence that air pollution plays a role in both the development and  
46 exacerbation of allergic rhinitis. A study of pre-school children found that exposure to traffic-  
47 related air pollution prenatally and in early life was associated with increased risk of allergic  
48 rhinitis (3). A recent study from China found a 10% and 11% increase in the incidence of  
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3 medical utilization for allergic rhinitis among adults for each standard deviation increase in  
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5  
6  $PM_{2.5}$  and  $NO_2$  levels, respectively (4).  
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### 10 *Autoimmune disease*

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15 Environmental exposures may bear on the risk of autoimmune diseases. The lung has an  
16  
17 enormous surface area that comes in contact with a myriad of antigens. It has an efficient  
18  
19 sensitization and antigen presenting system that could set up individuals for autoimmune  
20  
21 disorders. Air pollution is a potential contributor to diseases such as rheumatoid arthritis and  
22  
23 systemic lupus erythematosus (5, 6). A recent Canadian study found increased odds of having a  
24  
25 diagnosis of a rheumatic disease with increased ambient  $PM_{2.5}$  exposure (7). Air pollutants have  
26  
27 also been implicated in triggering or exacerbating juvenile idiopathic arthritis (5), but  
28  
29 autoimmunity related to air pollution exposure has been largely understudied.  
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### 37 **Bone diseases**

42  
43 Environmental factors play a role in bone density and mineralization. To evaluate the effect of  
44  
45 air pollution on bone structure and function, a recent analysis of more than 9 million US  
46  
47 Medicare enrollees found that osteoporosis-related bone fractures were statistically more  
48  
49 common in areas of higher ambient  $PM_{2.5}$  concentrations. The effect was greater when only  
50  
51 low-income communities were included in a sensitivity analysis (8).  
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3 The same investigators studied 692 middle-aged men with low-incomes from the Boston Area  
4  
5 Community Health Bone Survey cohort and found exposures to ambient black carbon and PM<sub>2.5</sub>  
6  
7 to be associated with markers of increased bone turnover and bone mineral loss (8). The  
8  
9 National Health Insurance Research Database of Taiwan and the Taiwan Environmental  
10  
11 Protection Agency found an association between exposure to CO and NO<sub>2</sub> and osteoporosis (9).  
12  
13 The Oslo Health Study found long-term air pollution exposure (PM and NO<sub>2</sub>) was associated  
14  
15 with a reduction in bone mineral density (10) and fractures (11) in elderly men.  
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### 23 **Cancers**

24  
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27 Outdoor air pollution has been recently classified as carcinogenic to humans by the  
28  
29 International Agency for Research on Cancer based on evidence from epidemiological and  
30  
31 animal studies and mechanistic data (12). Many studies have shown an association between  
32  
33 exposure to PM<sub>2.5</sub> and PM<sub>10</sub> and risk of lung cancer (13). In addition, NO<sub>2</sub> and O<sub>3</sub> have been  
34  
35 experimentally linked to cellular changes related to neoplasia: altered telomere length,  
36  
37 expression of genes involved in DNA damage and repair, inflammation, immune and oxidative  
38  
39 stress response, and epigenetic effects, such as DNA methylation (14). Diesel engine exhaust  
40  
41 has been identified by the World Health Organization as a carcinogen based on evidence of a  
42  
43 link with lung cancer (15) (16). Exposure to diesel exhaust or traffic pollution has also been  
44  
45 associated with benign and malignant lung tumors in laboratory animals (17), colorectal cancer  
46  
47 (18), and deaths from gastric cancer (19).  
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3 Air pollution exposure is implicated in both the incidence and mortality of bladder cancer. A  
4  
5 Spanish study reported an association between emissions of polycyclic aromatic hydrocarbons  
6  
7 and diesel exhaust and bladder cancer in long-term residents of an industrially polluted area  
8  
9 (20). Studies from Taiwan have shown an increased risk of bladder cancer deaths associated  
10  
11 with ambient benzene and other hydrocarbons from evaporative losses of petroleum products  
12  
13 and motor vehicle emissions (21). Another study from Sao Paulo found an association between  
14  
15  $PM_{10}$  exposure and risk of bladder cancer but not bladder cancer mortality (22). The American  
16  
17 Cancer Society's prospective Cancer Prevention Study II of 623,048 participants followed for 22  
18  
19 years (1982-2004) found that  $PM_{2.5}$  was associated with death from cancers of the kidney and  
20  
21 bladder, and that  $NO_2$  was associated with colorectal cancer mortality (23).  
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30 Benzene exposure from vehicular exhaust, especially during the prenatal period and in the early  
31  
32 years of childhood, has been associated with the risk of childhood leukemia (24). Prenatal  
33  
34 exposure to  $PM_{2.5}$  during pregnancy may increase a child's risk of developing leukemia and  
35  
36 astrocytomas (25).  
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## 42 **Cardiovascular diseases**

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47 Particulate air pollution has been strongly associated with an increased risk of cardiovascular  
48  
49 disease mortality, myocardial infarction, stroke, and hospital admission for congestive heart  
50  
51 failure (26) and has been estimated to account for 19% of all cardiovascular deaths, 23% of all  
52  
53 ischemic heart disease deaths, and 21% of all stroke deaths (27). A  $10 \mu g/m^3$  increase in  $PM_{2.5}$   
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3 in a 2-day period was associated with about a 2% increase in myocardial infarctions and  
4  
5 hospital admissions for heart failure in a 26-city US survey (28). Other studies have found  
6  
7 similar associations between acutely increased ambient PM<sub>2.5</sub> and increases in mortality from  
8  
9 myocardial infarction, stroke, heart failure, and hypertension (29). Mild increases in  
10  
11 carboxyhemoglobin levels (in the 3-6% range) can occur when individuals are exposed to traffic  
12  
13 pollution and may trigger angina and arrhythmias in individuals with coronary heart disease  
14  
15 (30). In Medicare recipients in 9 US cities, PM concentrations during the 2 days before the  
16  
17 event were associated with ischemic, but not hemorrhagic, stroke hospital admissions. This  
18  
19 study also found a correlation between CO, NO<sub>2</sub>, and SO<sub>2</sub> levels and stroke (31). In a separate  
20  
21 paper, the increased risk of stroke was greatest within 12 to 14 hours of exposure to PM<sub>2.5</sub> and  
22  
23 the relation held up even with PM<sub>2.5</sub> levels below those considered safe by the US  
24  
25 Environmental Protection Agency (32). These acute effects of PM exposure are likely mediated  
26  
27 by autonomic dysregulation, endothelial dysfunction, or thrombosis or a combination of them  
28  
29 (33). Many studies have found cardiovascular parameters, such as heart rate variability,  
30  
31 associated with air pollution, especially exposure with PM<sub>2.5</sub> (34). A decrease in heart rate  
32  
33 variability, as occurs with air pollution exposure, is associated with many poor health outcomes,  
34  
35 such as an increased risk of adverse cardiovascular events and all-cause mortality in selected  
36  
37 populations (35).

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40 Long-term effects of exposure to air pollution on the risk of cardiovascular diseases have been  
41  
42 well-documented (36) (37). These effects can shorten life expectancy even at relatively low PM  
43  
44 levels (38). Studies have found a relationship between air pollution and atherosclerosis, which  
45  
46 is a central mechanism for ischemic heart disease and stroke and may explain the long-term  
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3 effects of pollution on risk of many cardiovascular diseases (26). The relationship of PM and  
4  
5 ischemic mortality appears to vary with the composition and source of the PM<sub>2.5</sub>; the most  
6  
7 damaging PM<sub>2.5</sub> may come from coal combustion (39).  
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### 10 11 12 **Cognitive function and neurologic diseases**

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18 Air pollution has deleterious effects on the central nervous system, including impairment of  
19  
20 cognitive function and increased risk of dementia and stroke in older adults. A Canadian study  
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22 of 4.4 million people showed the risk of dementia was correlated in a “dose-dependent”  
23  
24 manner with distance from a major roadway. People living within 50 meters had a hazard ratio  
25  
26 of 1.07, whereas those living 50-100 meters away had a hazard ratio of 1.04, and those living  
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28 101-200 meters away had one of 1.02 compared to those living more than 300 meters from a  
29  
30 major roadway. Living near a busy roadway is a marker of air pollution exposure (40).  
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38 Inflammation in the bloodstream in response to pollutants has been found to cause systemic  
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40 vascular, including cerebral vascular, dysfunction (41). Studies in animals have shown that  
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42 inhaled ultrafine particles can travel from the nose via the olfactory nerve directly into the  
43  
44 brain, where they may cause inflammation and oxidative stress (42).  
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49  
50 Air pollution may damage the developing brain, which is of special concern because this may  
51  
52 impair cognitive function across the lifespan. Many studies have found that prenatal and early  
53  
54 childhood exposure to PM<sub>2.5</sub> is associated with delayed psychomotor development (43) and  
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3 lower child intelligence (44). A study in Mexico City found that children living in more polluted  
4  
5 areas had worse cognitive performance and more prefrontal brain lesions on magnetic  
6  
7 resonance imaging (MRI). In the same paper, the authors reported that dogs exposed to  
8  
9 comparable levels of pollution had similar prefrontal lesions and deposits of ultrafine particles  
10  
11 within those lesions (45).  
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18 More than 1000 papers have been written on air pollution and autism (46), which has been  
19  
20 associated with exposure to polycyclic aromatic hydrocarbons, diesel exhaust, PM, CO, NO<sub>2</sub>, O<sub>3</sub>,  
21  
22 and SO<sub>2</sub> in prenatal or early life (47), and there are several animal studies to support these  
23  
24 findings. However, many studies have not found associations and there is lack of consistency on  
25  
26 the pollutant (48).  
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32 Air pollution is also harmful to the aging brain. Older adults more heavily exposed to air  
33  
34 pollution perform more poorly on cognitive testing and are at increased risk of dementia  
35  
36 compared to less exposed adults (49). Long-term exposure to PM<sub>2.5</sub> was associated with a  
37  
38 smaller brain volume by MRI (an indicator of brain aging) and higher odds of sub-clinical strokes  
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40 among generally healthy adults (50). Short-term exposure to fine particles increased the risk of  
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42 hospitalizations and all-cause mortality in Parkinson's disease (51).  
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#### 49 **Diabetes, obesity, and endocrine diseases**

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3 Evidence from several studies links air pollution and Type 2 diabetes mellitus (52). PM<sub>2.5</sub> and  
4  
5 NO<sub>2</sub> exposures are associated with prevalence of diabetes and increased glycosylated  
6  
7 hemoglobin (HbA1c) levels among both diabetic and non-diabetic individuals (53). There is also  
8  
9 a higher morbidity and mortality related to ambient air pollution among diabetic patients (54).  
10  
11 Several studies have described increased risk for metabolic syndrome in adults exposed to high  
12  
13 ambient PM<sub>10</sub> (55). It appears that air pollution affects accumulation of visceral adipose tissue  
14  
15 (56) or brown to white adipose tissue transition (57), which may worsen insulin resistance (58),  
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17 oxidative stress, and systemic inflammation.  
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25 Several metabolic changes affecting fat deposition occur with exposure to air pollution.

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27 Children in Mexico City exposed to high PM<sub>2.5</sub> levels had higher leptin and endothelin-1 levels  
28  
29 and lower glucagon-like peptide-1, ghrelin, and glucagon compared to those living in low PM<sub>2.5</sub>  
30  
31 areas. Leptin was strongly correlated to PM<sub>2.5</sub> cumulative exposures. Residing in a high PM<sub>2.5</sub>  
32  
33 and O<sub>3</sub> environment was associated with 12-hour fasting hyperleptinemia, altered appetite-  
34  
35 regulating peptides, vitamin D deficiency, and increases in endothelin-1 (ET-1) in healthy  
36  
37 children (59). Air pollution-associated glucose and lipid dysregulation appear to be mediated  
38  
39 through pathways that increase insulin resistance (60). Children living in areas with more  
40  
41 traffic-related air pollution have been found to have a higher body-mass index after adjusting  
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43 for confounders (61), which may be a consequence of metabolic changes including insulin  
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45 resistance in response to pollution exposure.  
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#### 54 **Eye diseases**

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6 Tearing and ocular irritation may occur as a reaction to visible haze, and this is often worse for  
7  
8 contact lens wearers. Conjunctivitis is most associated with O<sub>3</sub> and NO<sub>2</sub> exposure, although  
9  
10 PM<sub>10</sub> and SO<sub>2</sub> are also correlated (62). Cataract formation has been described in women  
11  
12 exposed to household air pollution in low-income countries (63). Ozone levels and decreased  
13  
14 humidity have been associated with dry eye disease (64). Air pollution, specifically PM and CO,  
15  
16 have been associated with acute worsening of blepharitis (65).  
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### 23 **Gastrointestinal diseases**

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27 Although less investigated, air pollution has been linked to several gastrointestinal conditions,  
28  
29 including inflammatory bowel disease, enteritis, gastric ulcer, and appendicitis. A case-control  
30  
31 study of chronic pollution exposure in the United Kingdom found that younger individuals were  
32  
33 more likely to have Crohn's disease if they lived in areas with high NO<sub>2</sub> or SO<sub>2</sub>, although there  
34  
35 was no overall association between exposure to air pollutants and risk of inflammatory bowel  
36  
37 disease (66). Other studies, however, have suggested a possible link to inflammatory bowel  
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39 disease (67).  
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47 A small number of studies have found associations between short-term exposure to pollution  
48  
49 and acute episodes of enteritis, gastric ulcer disease, and appendicitis. A Chinese study of more  
50  
51 than 12,000 hospital visits for enteritis found that PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, and CO levels were  
52  
53 significantly elevated on days of outpatient visits, whereas O<sub>3</sub> was not. Lag models showed that  
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3 the pollution association was most prominent on the day of admission (68). A study of elderly  
4  
5 Hong Kong Chinese found that long-term exposure to PM<sub>2.5</sub> was associated with  
6  
7 hospitalizations for gastric ulcer disease (69). A Canadian study of the 7-day accumulated  
8  
9 average of ground level O<sub>3</sub> showed a modest correlation with appendicitis and a stronger  
10  
11 relationship with perforated appendicitis (70).  
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### 18 **Hematologic diseases**

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22 It has been known since the 1970s that air pollution containing lead from gasoline caused  
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24 anemia. Other pollutants released during fuel combustion may also contribute to hematologic  
25  
26 disease, either by directly entering the blood stream after inhalation, or by activating  
27  
28 inflammatory pathways in the lung that then result in intravascular inflammation. PM<sub>2.5</sub>  
29  
30 promotes an imbalanced coagulative state through platelet and endothelial activation by  
31  
32 inflammatory cytokines (71). These increase the risk of thrombotic events, including myocardial  
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34 infarction (72), stroke (31), and most likely deep venous thrombosis and pulmonary embolism  
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40 (73).  
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45 Exposure to lead in air pollution affects the formation of hemoglobin (74). Indoor air pollution  
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47 has been shown to be a risk factor for anemia in young children (75) and the elderly (76). Air  
48  
49 pollution may increase hemoglobin distortion in sickle cell disease. The resulting microvascular  
50  
51 obstruction leads to oxygen lack and severe pain. Poor air quality, including increased O<sub>3</sub> levels,  
52  
53 has been correlated with emergency room visits for sickle cell pain crises (77).  
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## Liver diseases

Living near a major roadway, which is associated with increased air pollution, is linked to an increased prevalence of hepatic steatosis (78). There are several potential reasons for this as air pollution has many damaging effects on liver cells through inflammatory mediators, genotoxicity, mitochondrial damage, and damage to other organs, which affect the liver secondarily (79). The liver is the main detoxifying organ and a variety of substances that enter the body, including toxic components on PM, are presented to the liver for catabolism.

A Taiwanese study, of 23,820 persons followed for a median of 16.9 years found exposure to PM<sub>2.5</sub> was associated with an increased risk to hepatocellular cancer. This group also found alanine aminotransferase (ALT) elevated and hypothesized that carcinoma may result from chronic inflammation (80). A Chinese study found that high PM<sub>2.5</sub> exposure after the diagnosis of hepatocellular carcinoma was associated with shortened survival in a dose dependent manner (81).

Alpha-1-antitrypsin deficiency is a genetic disorder associated with decreased release from the liver of the enzyme that catabolizes the proteolytic enzyme products of inflammation. Persons with this disorder are more susceptible to detrimental effects of inflammation. Exposure to O<sub>3</sub> and PM<sub>10</sub> was associated with a more rapid decline of lung function in the persons with the PiZZ variant of this disease (82).

## Renal diseases

The kidney, a highly vascular organ, is vulnerable to both large and small vessel dysfunction and, therefore, likely to be susceptible to the oxidative stress and systemic inflammatory effects of air pollution exposure. Animal models have shown that breathing diesel exhaust fumes exacerbates chronic renal failure by worsening renal oxidative stress, inflammation, and DNA damage (83). Living closer to a major highway has been found to be associated with a lower estimated glomerular filtration rate (84); the association of decreased renal function with pollution was greater for exposure to PM (85).

## Respiratory diseases

The respiratory tract is the main organ affected by air pollution and the most studied—there are more than 13,000 entries in Pubmed for air pollution and respiratory disease. Ambient air pollution is estimated to cause the death of more than 800,000 persons from COPD and 280,000 persons from lung cancer (86). Indoor air pollution is estimated to cause the death of more than 750,000 persons from COPD and 300,000 persons from lung cancer (87, 88), making the toll for both forms of air pollution 1.6 million deaths for COPD and more than 500,000 for lung cancer. There is overlap in the two forms of pollution and the 2 diseases.



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3 In addition, it causes breathlessness in most patients with severe chronic respiratory diseases.  
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5 Air pollutants can affect all parts of the respiratory system and throughout a person's life cycle.  
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8 As discussed in Part 1 of this report, prenatal exposure to air pollutants is associated with  
9  
10 wheezing and asthma in early childhood. The rate of lung function growth in childhood is  
11  
12 decreased by exposure to pollutants (89) (90) and is a predictor of adult lung disease. Among  
13  
14 adults, long-term exposure to air pollution is a risk for accelerated lung function decline with  
15  
16 aging (91). Childhood exposure to air pollution has been linked to the risk of asthma in many  
17  
18 studies (92), and pollution exposure has also been found to increase the incidence of asthma in  
19  
20 adults (93), although the evidence for this is less consistent.  
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28 In addition to asthma, air pollution is associated with risk of chronic obstructive pulmonary  
29  
30 disease (94), lung cancer (95), and chronic laryngitis (96). It may be a factor in transforming  
31  
32 asthma into COPD (97). Household air pollution may be more hazardous than outdoor air  
33  
34 pollution because of the concentration and duration of exposure; it is a major risk factor for  
35  
36 COPD and chronic bronchitis in low income countries (98).  
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42 Air pollutants are also well-known triggers of respiratory disease exacerbations. Many different  
43  
44 pollutants, such as O<sub>3</sub>, PM, SO<sub>2</sub>, and NO<sub>2</sub> have irritant effects that may induce cough, phlegm,  
45  
46 and bronchial hyper-responsiveness. Increases in PM levels are associated with increased visits  
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48 to the emergency department for asthma (99), COPD (100), and respiratory symptoms that are  
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50 often attributed to respiratory infections (101).  
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### **Skin diseases**

Several biologic parameters affecting skin quality are affected by pollution, such as change in sebum excretion rate and composition, level of carbonylated proteins in the stratum corneum, and a higher erythematous index on the face of highly exposed subjects (102). The change in sebum may be a cause for increased acne occurring with air pollution (103).

Several skin diseases have been associated with air pollution. A multicenter study found that air pollution was associated with a higher frequency of atopic and urticarial skin disease, dermatographism, and seborrhea (but a lower frequency of dandruff) (102). Urticaria is among the skin pathologies that have been associated with pollution. Emergency Department visits for urticaria have been correlated with poorer air quality over a 2- to 3-day lag (104). A number of studies have found positive associations between air pollution and prevalence and exacerbations of eczema, primarily in children with traffic-related exposures (105).

Outdoor and indoor air pollution exposure has been associated with increased skin aging after controlling for sun exposure, smoking, and other confounders. Cooking with solid fuels was associated with 5-8% more severe wrinkle appearance on face and 74% increased risk of having fine wrinkles on the dorsal surface of hands independent of age and other influences on skin aging (106).

### **The role of the health care provider**

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6 Assessing exposure by primary care providers may be difficult because the source of air  
7  
8 pollution varies between communities and within household situations. Studies on indoor air  
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10 pollution use extensive surveys to report on smoke exposure, burning conditions, and  
11  
12 symptoms during cooking and household work. Research on outdoor air pollution relies on  
13  
14 monitoring of the individual pollutants by sophisticated means, including personal monitors.  
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16 For primary care health care providers, simply asking a few questions and documenting the  
17  
18 answers in the medical record can help gauge the extent of exposure. For indoor air pollution,  
19  
20 asking what type of fuel is used, how the home is ventilated, and how much time is spent  
21  
22 around the fire may give important information. For outdoor air pollution exposure, the  
23  
24 questions should center around the proximity to sources of pollution (usually industrial and  
25  
26 roadway) and exposure time (27).  
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35 In advising patients, avoidance is the most important intervention. Almost any means that  
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37 reduces air pollution may be beneficial. Much international effort has gone into developing and  
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39 deploying better household stoves (107). Reducing cookstove toxic emissions reduced blood  
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41 pressure in pregnant women at their regular prenatal visits. The reduction was greatest in those  
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43 who were hypertensive (108).  
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50 Personal respirators (facemasks) can reduce inhaled particulates. Wearing personal respirators  
51  
52 while being active in central Beijing reduced blood pressure and heart rate variability, markers  
53  
54 associated with cardiovascular morbidity (109). The beneficial effects of personal respirators  
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3 extended to other cardiovascular markers and were almost immediate and lasted during the  
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5 exposure time (110).  
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10 Air purifiers also reduce PM. Air purification for just 48 hours significantly decreased PM<sub>2.5</sub> and  
11  
12 reduced circulating inflammatory and thrombogenic biomarkers as well as systolic and diastolic  
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14 blood pressure (111). In another study, air filtration improved endothelial function and  
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16 decreased concentrations of inflammatory biomarkers, but not markers of oxidative stress  
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18 (112).  
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25 Last, health care workers are often influential members of communities, and it is their duty to  
26  
27 advocate for clean air on behalf of their patients. Their influence can mobilize the attitudes of  
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29 communities to cleaner and safer air.  
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### 35 **Summary and resolve**

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40 Air pollution is one of the most important avoidable risks to health globally. Air pollution has  
41  
42 been termed the “silent killer” by the World Health Organization because its effects often go  
43  
44 unnoticed or are not easily measured. Even when there is organ harm, it is usually attributed to  
45  
46 an unknown or chance malfunction of that organ. Although the lungs have been the most  
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48 studied organ, air pollution impacts most systems. Many studies have found harmful effects of  
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50 air pollution on a continuum of exposure that extends down into levels considered safe by  
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52 national standards.  
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6 The good news is that the problem of air pollution can be addressed and ameliorated.  
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8 Improving air quality may have almost immediate benefit, seen as increased infant birth weight  
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10 with the 2008 Beijing Olympics (113), improved lung-function growth in children in the  
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12 Children's Health Study (90), and improved mortality seen in the Harvard Six Cities study (114).  
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15 Improving air quality, then, may give us better and longer lives in a relatively short time (115).  
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3 **Table.** Pollution has been associated with these pathobiologic processes in addition to the  
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5 effects in the organ figure.  
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10 **Allergy:** Allergic sensitization  
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12 **Blood and blood vessels:** endothelial dysfunction, atherosclerosis, thrombosis, impaired  
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14 hemoglobin formation; carboxyhemoglobinemia  
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19 **Bone:** bone demineralization  
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23 **Brain:** cognitive dysfunction; impaired psychomotor development and intelligence  
24  
25 development; social stress; mood disorders; unfavorable emotional symptoms  
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30 **Cancer:** shortened telomere length; detrimental expression of genes involved in DNA damage  
31  
32 and repair; inflammation; immune and oxidative stress response; epigenetic effects  
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40 **Diabetes and metabolism:** increased glycosylated hemoglobin, insulin resistance, leptin, and  
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42 endothelin-1 levels; lower glucagon-like peptide-1, ghrelin, and glucagon  
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47 **Eye:** Increased tearing (acutely) and drying (chronically)  
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51 **Heart:** Changes in heart rate, blood pressure, and vascular tone; reduced heart rate variability;  
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53 conduction defects  
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6 **Kidney:** Decreased glomerular filtration rate; Increased mortality in dialysis patients  
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10 **Respiratory tract:** Cough, phlegm, difficulty breathing, and bronchial hyper-responsiveness;  
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12 exacerbations of many respiratory conditions; impeded lung development; transformation of  
13  
14 asthma into COPD; decreased exercise performance; decreased spirometric measurements  
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17 (lung function)  
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22 **Reproductive:** premature birth; low birthweight; poor sperm quality; impaired fetal growth;  
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24 intrauterine inflammation; reduced fertility rates; increased risk of miscarriage, spontaneous  
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26 abortions, premature rupture of membranes, and preeclampsia. Exposure during pregnancy is  
27  
28 associated with childhood neoplasms and childhood asthma.  
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35 **Skin:** aging  
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40 **Sleep:** associated with increased sleep apnea symptoms  
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45 **Overall:** Shortened life expectancy, with additive or multiplicative effects in vulnerable persons  
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**Legend for figure:** Many conditions are associated with air pollution. This figure lists diseases linked to air pollution by organ systems.

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**Brain:** Stroke, Dementia, Parkinson's Disease

**Eye:** Conjunctivitis, Dry Eye Disease, Blepharitis, Cataracts



**Heart:** Ischemic Heart Disease, Hypertension, Congestive Heart Failure, Arrhythmias

**Lung:** Chronic Obstructive Pulmonary Disease Asthma, Lung Cancer, Chronic Laryngitis, Acute and Chronic Bronchitis



**Liver:** Hepatic Steatosis, Hepatocellular carcinoma

**Blood:** Leukemia, Intravascular Coagulation, Anemia, Sickle Cell Pain Crises



**Fat:** Metabolic Syndrome, Obesity

**Pancreas:** Type I and II Diabetes



**Gastrointestinal:** Gastric Cancer, Colorectal Cancer, Inflammatory Bowel Disease, Crohn's Disease, Appendicitis



**Urogenital:** Bladder Cancer, Kidney Cancer, Prostate Hyperplasia



**Joints:** Rheumatic Diseases

**Bone:** Osteoporosis, Fractures



**Nose:** Allergic Rhinitis

**Skin:** Atopic Skin Disease, Skin Aging, Urticaria, Dermographism, Seborrhea, Acne

Many conditions are associated with air pollution. This figure lists diseases linked to air pollution by organ systems.

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3 **Chest 18-2053.R1 Tracked**  
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5 **Air Pollution and Non-Communicable Diseases: A review by the Forum of International Respiratory**  
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7 **Societies' Environmental Committee. Part 2: Air pollution and organ systems**  
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**Abstract**

Although air pollution is well-known to be harmful to the lung and airways, it can also damage most other organ systems of the body. It is estimated that about 500,000 lung cancer deaths and 1.6 million chronic obstructive pulmonary disease (COPD) deaths can be attributed to air pollution, but air pollution may also account for 19% of all cardiovascular deaths and 21% of all stroke deaths. Air pollution has been linked to other malignancies, such as bladder cancer and childhood leukemia. Lung development in childhood is stymied with exposure to air pollutants, and poor lung development in children predicts lung impairment in adults. Air pollution is associated with reduced cognitive function and increased risk of dementia. Particulate matter in the air (PM<sub>2.5</sub>) is associated with delayed psychomotor development and lower child intelligence. Studies link air pollution with diabetes mellitus prevalence, morbidity, and mortality. Pollution affects the immune system and is associated with allergic rhinitis, allergic sensitization, and autoimmunity. It is also associated with osteoporosis and bone fractures, conjunctivitis, dry eye disease, and blepharitis, inflammatory bowel disease, increased intravascular coagulation, and decreased glomerular filtration rate. Atopic and urticarial skin disease, acne, and skin aging are linked to air pollution. Air pollution is controllable and, therefore, many of these adverse health effects can be prevented.

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3 This second of the 2-part report describes specific conditions associated with air pollution. The  
4 conditions are listed alphabetically. In addition to the text, the **figure** shows organ associates and the  
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6 **table** shows other effects of air pollution that are generally not associated with specific organs. It is  
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8 important to note that for many of the diseases, the associations with exposures to air pollution in  
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10 observational epidemiological studies are not causal and may be subject to residual confounding due to  
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12 other factors, such as smoking, lower socioeconomic status, and neighborhood factors. However,  
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14 exposure dose and time relationships and animal studies corroborate and add strength to the  
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16 conclusions from the epidemiologic studies.  
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### 23 **Allergic and immunologic diseases**

#### 24 *Allergic sensitization and rhinitis*

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28 It is well established that air pollution can exacerbate allergic responses in sensitized persons (1). Clinical  
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30 epidemiological studies show that ambient air pollution may also enhance allergic sensitization in  
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32 children, and also increase IgE levels in the very young (2).  
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41 There is considerable evidence that air pollution plays a role in both the development and exacerbation  
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43 of allergic rhinitis. A study of pre-school children found that exposure to traffic-related air pollution  
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45 prenatally and in early life was associated with increased risk of allergic rhinitis (3). A recent study from  
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47 China found a 10% and 11% increase in the incidence of medical utilization for allergic rhinitis among  
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49 adults for each standard deviation increase in PM<sub>2.5</sub> and NO<sub>2</sub> levels, respectively (4).  
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#### 54 *Autoimmune disease*

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5 Environmental exposures may bear on the risk of autoimmune diseases. The lung has an enormous  
6 surface area that comes in contact with a myriad of antigens. It has an efficient sensitization and antigen  
7 presenting system that could set up individuals for autoimmune disorders. Air pollution is a potential  
8 contributor to diseases such as rheumatoid arthritis and systemic lupus erythematosus (5, 6). A recent  
9 Canadian study found increased odds of having a diagnosis of a rheumatic disease with increased  
10 ambient PM<sub>2.5</sub> exposure (7). Air pollutants have also been implicated in triggering or exacerbating  
11 juvenile idiopathic arthritis (5), but autoimmunity related to air pollution exposure has been largely  
12 understudied.  
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### 25 **Bone diseases**

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30 Environmental factors play a role in bone density and mineralization. To evaluate the effect of air  
31 pollution on bone structure and function, a recent analysis of more than 9 million US Medicare enrollees  
32 found that osteoporosis-related bone fractures were statistically more common in areas of higher  
33 ambient PM<sub>2.5</sub> concentrations. The effect was greater when only low-income communities were  
34 included in a sensitivity analysis (8).  
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43 The same investigators studied 692 middle-aged men with low-incomes from the Boston Area  
44 Community Health Bone Survey cohort and found exposures to ambient black carbon and PM<sub>2.5</sub> to be  
45 associated with markers of increased bone turnover and bone mineral loss (8). The National Health  
46 Insurance Research Database of Taiwan and the Taiwan Environmental Protection Agency found an  
47 association between exposure to CO and NO<sub>2</sub> and osteoporosis (9). The Oslo Health Study found long-  
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3 term air pollution exposure (PM and NO<sub>2</sub>) was associated with a reduction in bone mineral density (10)  
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5 and fractures (11) in elderly men.  
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## 10 **Cancers**

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14 Outdoor air pollution has been recently classified as carcinogenic to humans by the International Agency  
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16 for Research on Cancer based on evidence from epidemiological and animal studies and mechanistic  
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18 data (12). Many studies have shown an association between exposure to PM<sub>2.5</sub> and PM<sub>10</sub> and risk of lung  
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20 cancer (13). In addition, NO<sub>2</sub> and O<sub>3</sub> have been experimentally linked to cellular changes related to  
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22 neoplasia: altered telomere length, expression of genes involved in DNA damage and repair,  
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24 inflammation, immune and oxidative stress response, and epigenetic effects, such as DNA methylation  
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26 (14). Diesel engine exhaust has been identified by the World Health Organization as a carcinogen based  
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28 on evidence of a link with lung cancer (15) (16). Exposure to diesel exhaust or traffic pollution has also  
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30 been associated with benign and malignant lung tumors in laboratory animals (17), colorectal cancer  
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32 (18), and deaths from gastric cancer (19).  
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39 Air pollution exposure is implicated in both the incidence and mortality of bladder cancer. A Spanish  
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41 study reported an association between emissions of polycyclic aromatic hydrocarbons and diesel  
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43 exhaust and bladder cancer in long-term residents of an industrially polluted area (20). Studies from  
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45 Taiwan have shown an increased risk of bladder cancer deaths associated with ambient benzene and  
46  
47 other hydrocarbons from evaporative losses of petroleum products and motor vehicle emissions (21).  
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49 Another study from Sao Paulo found an association between PM<sub>10</sub> exposure and risk of bladder cancer  
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51 but not bladder cancer mortality (22). The American Cancer Society's prospective Cancer Prevention  
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53 Study II of 623,048 participants followed for 22 years (1982-2004) found that PM<sub>2.5</sub> was associated with  
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3 death from cancers of the kidney and bladder, and that NO<sub>2</sub> was associated with colorectal cancer  
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5 mortality (23).  
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10 Benzene exposure from vehicular exhaust, especially during the prenatal period and in the early years of  
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12 childhood, has been associated with the risk of childhood leukemia (24). Prenatal exposure to PM<sub>2.5</sub>  
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14 during pregnancy may increase a child's risk of developing leukemia and astrocytomas (25).  
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### 19 **Cardiovascular diseases**

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23 Particulate air pollution has been strongly associated with an increased risk of cardiovascular disease mortality, myocardial infarction, stroke, and hospital admission  
24 for congestive heart failure (26) and has been estimated to account for 19% of all cardiovascular deaths, 23% of all ischemic heart disease deaths, and 21% of all  
25 stroke deaths (27). A 10 µg/m<sup>3</sup> increase in PM<sub>2.5</sub> in a 2-day period was associated with about a 2% increase in myocardial infarctions and hospital admissions for heart  
26 failure in a 26-city US survey (28). Other studies have found similar associations between acutely increased ambient PM<sub>2.5</sub> and increases in mortality from myocardial  
27 infarction, stroke, heart failure, and hypertension (29). Mild increases in carboxyhemoglobin levels (in the 3-6% range) can occur when individuals are exposed to  
28 traffic pollution and may trigger angina and arrhythmias in individuals with coronary heart disease (30). In Medicare recipients in 9 US cities, PM concentrations  
29 during the 2 days before the event were associated with ischemic, but not hemorrhagic, stroke hospital admissions. This study also found a correlation between CO,  
30 NO<sub>2</sub>, and SO<sub>2</sub> levels and stroke (31). In a separate paper, the increased risk of stroke was greatest within 12 to 14 hours of exposure to PM<sub>2.5</sub> and the relation held up  
31 even with PM<sub>2.5</sub> levels below those considered safe by the US Environmental Protection Agency (32). These acute effects of PM exposure are likely mediated by  
32 autonomic dysregulation, endothelial dysfunction, or thrombosis or a combination of them (33). Many studies have found cardiovascular parameters, such as heart rate  
33 variability, associated with air pollution, especially exposure with PM<sub>2.5</sub> (34). A decrease in heart rate variability, as occurs with air pollution exposure, is associated  
34 with many poor health outcomes, such as an increased risk of adverse cardiovascular events and all-cause mortality in selected populations (35).  
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39 Long-term effects of exposure to air pollution on the risk of cardiovascular diseases have been well-  
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41 documented (36) (37). These effects can shorten life expectancy even at relatively low PM levels (38).  
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44 Studies have found a relationship between air pollution and atherosclerosis, which is a central  
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46 mechanism for ischemic heart disease and stroke and may explain the long-term effects of pollution on  
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48 risk of many cardiovascular diseases (26). The relationship of PM and ischemic mortality appears to vary  
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50 with the composition and source of the PM<sub>2.5</sub>; the most damaging PM<sub>2.5</sub> may come from coal  
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52 combustion (39).  
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### Cognitive function and neurologic diseases

Air pollution has deleterious effects on the central nervous system, including impairment of cognitive function and increased risk of dementia and stroke in older adults. A Canadian study of 4.4 million people showed the risk of dementia was correlated in a “dose-dependent” manner with distance from a major roadway. People living within 50 meters had a hazard ratio of 1.07, whereas those living 50-100 meters away had a hazard ratio of 1.04, and those living 101-200 meters away had one of 1.02 compared to those living more than 300 meters from a major roadway. Living near a busy roadway is a marker of air pollution exposure (40).

Inflammation in the bloodstream in response to pollutants has been found to cause systemic vascular, including cerebral vascular, dysfunction (41). Studies in animals have shown that inhaled ultrafine particles can travel from the nose via the olfactory nerve directly into the brain, where they may cause inflammation and oxidative stress (42).

Air pollution may damage the developing brain, which is of special concern because this may impair cognitive function across the lifespan. Many studies have found that prenatal and early childhood exposure to  $PM_{2.5}$  is associated with delayed psychomotor development (43) and lower child intelligence (44). A study in Mexico City found that children living in more polluted areas had worse cognitive performance and more prefrontal brain lesions on magnetic resonance imaging (MRI). In the same paper, the authors reported that dogs exposed to comparable levels of pollution had similar prefrontal lesions and deposits of ultrafine particles within those lesions (45).

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3 More than 1000 papers have been written on air pollution and autism (46), which has been associated  
4 with exposure to polycyclic aromatic hydrocarbons, diesel exhaust, PM, CO, NO<sub>2</sub>, O<sub>3</sub>, and SO<sub>2</sub> in prenatal  
5 or early life (47), and there are several animal studies to support these findings. However, many studies  
6 have not found associations and there is lack of consistency on the pollutant (48).  
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14 Air pollution is also harmful to the aging brain. Older adults more heavily exposed to air pollution  
15 perform more poorly on cognitive testing and are at increased risk of dementia compared to less  
16 exposed adults (49). Long-term exposure to PM<sub>2.5</sub> was associated with a smaller brain volume by MRI (an  
17 indicator of brain aging) and higher odds of sub-clinical strokes among generally healthy adults (50).  
18  
19 Short-term exposure to fine particles increased the risk of hospitalizations and all-cause mortality in  
20 Parkinson's disease (51).  
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### 30 **Diabetes, obesity, and endocrine diseases**

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34 Evidence from several studies links air pollution and Type 2 diabetes mellitus (52). PM<sub>2.5</sub> and NO<sub>2</sub>  
35 exposures are associated with prevalence of diabetes and increased glycosylated hemoglobin (HbA1c)  
36 levels among both diabetic and non-diabetic individuals (53). There is also a higher morbidity and  
37 mortality related to ambient air pollution among diabetic patients (54). Several studies have described  
38 increased risk for metabolic syndrome in adults exposed to high ambient PM<sub>10</sub> (55). It appears that air  
39 pollution affects accumulation of visceral adipose tissue (56) or brown to white adipose tissue transition  
40 (57), which may worsen insulin resistance (58), oxidative stress, and systemic inflammation.  
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52 Several metabolic changes affecting fat deposition occur with exposure to air pollution. Children in  
53 Mexico City exposed to high PM<sub>2.5</sub> levels had higher leptin and endothelin-1 levels and lower glucagon-  
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3 like peptide-1, ghrelin, and glucagon compared to those living in low PM<sub>2.5</sub> areas. Leptin was strongly  
4 correlated to PM<sub>2.5</sub> cumulative exposures. Residing in a high PM<sub>2.5</sub> and O<sub>3</sub> environment was associated  
5  
6 with 12-hour fasting hyperleptinemia, altered appetite-regulating peptides, vitamin D deficiency, and  
7  
8 increases in endothelin-1 (ET-1) in healthy children (59). Air pollution-associated glucose and lipid  
9  
10 dysregulation appear to be mediated through pathways that increase insulin resistance (60). Children  
11  
12 living in areas with more traffic-related air pollution have been found to have a higher body-mass index  
13  
14 after adjusting for confounders (61), which may be a consequence of metabolic changes including  
15  
16 insulin resistance in response to pollution exposure.  
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### 23 **Eye diseases**

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28 Tearing and ocular irritation may occur as a reaction to visible haze, and this is often worse for contact  
29  
30 lens wearers. Conjunctivitis is most associated with O<sub>3</sub> and NO<sub>2</sub> exposure, although PM<sub>10</sub> and SO<sub>2</sub> are  
31  
32 also correlated (62). Cataract formation has been described in women exposed to household air  
33  
34 pollution in low-income countries (63). Ozone levels and decreased humidity have been associated with  
35  
36 dry eye disease (64). Air pollution, specifically PM and CO, have been associated with acute worsening of  
37  
38 blepharitis (65).  
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### 43 **Gastrointestinal diseases**

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48 Although less investigated, air pollution has been linked to several gastrointestinal conditions, including  
49  
50 inflammatory bowel disease, enteritis, gastric ulcer, and appendicitis. A case-control study of chronic  
51  
52 pollution exposure in the United Kingdom found that younger individuals were more likely to have  
53  
54 Crohn's disease if they lived in areas with high NO<sub>2</sub> or SO<sub>2</sub>, although there was no overall association  
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3 between exposure to air pollutants and risk of inflammatory bowel disease (66). Other studies, however,  
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5 have suggested a possible link to inflammatory bowel disease (67).  
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10 A small number of studies have found associations between short-term exposure to pollution and acute  
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12 episodes of enteritis, gastric ulcer disease, and appendicitis. A Chinese study of more than 12,000  
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14 hospital visits for enteritis found that PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, and CO levels were significantly elevated on  
15  
16 days of outpatient visits, whereas O<sub>3</sub> was not. Lag models showed that the pollution association was  
17  
18 most prominent on the day of admission (68). A study of elderly Hong Kong Chinese found that long-  
19  
20 term exposure to PM<sub>2.5</sub> was associated with hospitalizations for gastric ulcer disease (69). A Canadian  
21  
22 study of the 7-day accumulated average of ground level O<sub>3</sub> showed a modest correlation with  
23  
24 appendicitis and a stronger relationship with perforated appendicitis (70).  
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### 30 **Hematologic diseases**

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34 It has been known since the 1970s that air pollution containing lead from gasoline caused anemia. Other  
35  
36 pollutants released during fuel combustion may also contribute to hematologic disease, either by  
37  
38 directly entering the blood stream after inhalation, or by activating inflammatory pathways in the lung  
39  
40 that then result in intravascular inflammation. PM<sub>2.5</sub> promotes an imbalanced coagulative state through  
41  
42 platelet and endothelial activation by inflammatory cytokines (71). These increase the risk of thrombotic  
43  
44 events, including myocardial infarction (72), stroke (31), and most likely deep venous thrombosis and  
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46 pulmonary embolism (73).  
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52 Exposure to lead in air pollution affects the formation of hemoglobin (74). Indoor air pollution has been  
53  
54 shown to be a risk factor for anemia in young children (75) and the elderly (76). Air pollution may  
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3 increase hemoglobin distortion in sickle cell disease. The resulting microvascular obstruction leads to  
4 oxygen lack and severe pain. Poor air quality, including increased O<sub>3</sub> levels, has been correlated with  
5 emergency room visits for sickle cell pain crises (77).  
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## 11 **Liver diseases**

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16 Living near a major roadway, which is associated with increased air pollution, is linked to an increased  
17 prevalence of hepatic steatosis (78). There are several potential reasons for this as air pollution has  
18 many damaging effects on liver cells through inflammatory mediators, genotoxicity, mitochondrial  
19 damage, and damage to other organs, which affect the liver secondarily (79). The liver is the main  
20 detoxifying organ and a variety of substances that enter the body, including toxic components on PM,  
21 are presented to the liver for catabolism.  
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32 A Taiwanese study, of 23,820 persons followed for a median of 16.9 years found exposure to PM<sub>2.5</sub> was  
33 associated with an increased risk to hepatocellular cancer. This group also found alanine  
34 aminotransferase (ALT) elevated and hypothesized that carcinoma may result from chronic  
35 inflammation (80). A Chinese study found that high PM<sub>2.5</sub> exposure after the diagnosis of hepatocellular  
36 carcinoma was associated with shortened survival in a dose dependent manner (81).  
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45 Alpha-1-antitrypsin deficiency is a genetic disorder associated with decreased release from the liver of  
46 the enzyme that catabolizes the proteolytic enzyme products of inflammation. Persons with this  
47 disorder are more susceptible to detrimental effects of inflammation. Exposure to O<sub>3</sub> and PM<sub>10</sub> was  
48 associated with a more rapid decline of lung function in the persons with the PiZZ variant of this disease  
49 (82).  
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### Renal diseases

The kidney, a highly vascular organ, is vulnerable to both large and small vessel dysfunction and, therefore, likely to be susceptible to the oxidative stress and systemic inflammatory effects of air pollution exposure. Animal models have shown that breathing diesel exhaust fumes exacerbates chronic renal failure by worsening renal oxidative stress, inflammation, and DNA damage (83). Living closer to a major highway has been found to be associated with a lower estimated glomerular filtration rate (84); the association of decreased renal function with pollution was greater for exposure to PM (85).

### Respiratory diseases

The respiratory tract is the main organ affected by air pollution and the most studied—there are more than 13,000 entries in Pubmed for air pollution and respiratory disease. Ambient air pollution is estimated to cause the death of more than 800,000 persons from COPD and 280,000 persons from lung cancer (86). Indoor air pollution is estimated to cause the death of more than 750,000 persons from COPD and 300,000 persons from lung cancer (87, 88), making the toll for both forms of air pollution 1.6 million deaths for COPD and more than 500,000 for lung cancer. There is overlap in the two forms of pollution and the 2 diseases.

In addition, it causes breathlessness in most patients with severe chronic respiratory diseases. Air pollutants can affect all parts of the respiratory system and throughout a person's life cycle. As discussed in Part 1 of this report, prenatal exposure to air pollutants is associated with wheezing and asthma in early childhood. The rate of lung function growth in childhood is decreased by exposure to

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3 pollutants (89) (90) and is a predictor of adult lung disease. Among adults, long-term exposure to air  
4  
5 pollution is a risk for accelerated lung function decline with aging (91). Childhood exposure to air  
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7 pollution has been linked to the risk of asthma in many studies (92), and pollution exposure has also  
8  
9 been found to increase the incidence of asthma in adults (93), although the evidence for this is less  
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11 consistent.  
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16 In addition to asthma, air pollution is associated with risk of chronic obstructive pulmonary disease (94),  
17  
18 lung cancer (95), and chronic laryngitis (96). It may be a factor in transforming asthma into COPD (97).  
19  
20 Household air pollution may be more hazardous than outdoor air pollution because of the concentration  
21  
22 and duration of exposure; it is a major risk factor for COPD and chronic bronchitis in low income  
23  
24 countries (98).  
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29 Air pollutants are also well-known triggers of respiratory disease exacerbations. Many different  
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31 pollutants, such as O<sub>3</sub>, PM, SO<sub>2</sub>, and NO<sub>2</sub> have irritant effects that may induce cough, phlegm, and  
32  
33 bronchial hyper-responsiveness. Increases in PM levels are associated with increased visits to the  
34  
35 emergency department for asthma (99), COPD (100), and respiratory symptoms that are often  
36  
37 attributed to respiratory infections (101).  
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### 43 **Skin diseases**

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48 Several biologic parameters affecting skin quality are affected by pollution, such as change in sebum  
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50 excretion rate and composition, level of carbonylated proteins in the stratum corneum, and a higher  
51  
52 erythematous index on the face of highly exposed subjects (102). The change in sebum may be a cause  
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54 for increased acne occurring with air pollution (103).  
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Several skin diseases have been associated with air pollution. A multicenter study found that air pollution was associated with a higher frequency of atopic and urticarial skin disease, dermatographism, and seborrhea (but a lower frequency of dandruff) (102). Urticaria is among the skin pathologies that have been associated with pollution. Emergency Department visits for urticaria have been correlated with poorer air quality over a 2- to 3-day lag (104). A number of studies have found positive associations between air pollution and prevalence and exacerbations of eczema, primarily in children with traffic-related exposures (105).

Outdoor and indoor air pollution exposure has been associated with increased skin aging after controlling for sun exposure, smoking, and other confounders. Cooking with solid fuels was associated with 5-8% more severe wrinkle appearance on face and 74% increased risk of having fine wrinkles on the dorsal surface of hands independent of age and other influences on skin aging (106).

### **Summary and resolve**

#### **The role of the health care provider**

Assessing exposure by primary care providers may be difficult because the source of air pollution varies between communities and within household situations. Studies on indoor air pollution use extensive surveys to report on smoke exposure, burning conditions, and symptoms during cooking and household work. Research on outdoor air pollution relies on monitoring of the individual pollutants by sophisticated means, including personal monitors. For primary care health care providers, simply asking a few questions and documenting the answers in the medical record can help gauge the extent of

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3 exposure. For indoor air pollution, asking what type of fuel is used, how the home is ventilated, and how  
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5 much time is spent around the fire may give important information. For outdoor air pollution exposure,  
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7 the questions should center around the proximity to sources of pollution (usually industrial and  
8  
9 roadway) and exposure time (27).

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14 In advising patients, avoidance is the most important intervention. Almost any means that reduces air  
15  
16 pollution may be beneficial. Much international effort has gone into developing and deploying better  
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18 household stoves (107). Reducing cookstove toxic emissions reduced blood pressure in pregnant women  
19  
20 at their regular prenatal visits. The reduction was greatest in those who were hypertensive (108).

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25 Personal respirators (facemasks) can reduce inhaled particulates. Wearing personal respirators while  
26  
27 being active in central Beijing reduced blood pressure and heart rate variability, markers associated with  
28  
29 cardiovascular morbidity (109). The beneficial effects of personal respirators extended to other  
30  
31 cardiovascular markers and were almost immediate and lasted during the exposure time (110).

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37 Air purifiers also reduce PM. Air purification for just 48 hours significantly decreased  $PM_{2.5}$  and reduced  
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39 circulating inflammatory and thrombogenic biomarkers as well as systolic and diastolic blood pressure  
40  
41 (111). In another study, air filtration improved endothelial function and decreased concentrations of  
42  
43 inflammatory biomarkers, but not markers of oxidative stress (112).

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48 Last, health care workers are often influential members of communities, and it is their duty to advocate  
49  
50 for clean air on behalf of their patients. Their influence can mobilize the attitudes of communities to  
51  
52 cleaner and safer air.

### Summary and resolve

Air pollution is one of the most important avoidable risks to health globally. Air pollution has been termed the “silent killer” by the World Health Organization because its effects often go unnoticed or are not easily measured. Even when there is organ harm, it is usually attributed to an unknown or chance malfunction of that organ. Although the lungs have been the most studied organ, air pollution impacts most systems. Many studies have found harmful effects of air pollution on a continuum of exposure that extends down into levels considered safe by national standards.

The good news is that the problem of air pollution can be addressed and ameliorated. Improving air quality may have almost immediate benefit, seen as increased infant birth weight with the 2008 Beijing Olympics (113), improved lung-function growth in children in the Children’s Health Study (90), and improved mortality seen in the Harvard Six Cities study (114). Improving air quality, then, may give us better and longer lives in a relatively short time (115).

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3 **Table.** Pollution has been associated with these pathobiologic processes in addition to the effects in the  
4 organ figure.  
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10 **Allergy:** Allergic sensitization

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12 **Blood and blood vessels:** endothelial dysfunction, atherosclerosis, thrombosis, impaired hemoglobin  
13 formation; carboxyhemoglobinemia  
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19 **Bone:** bone demineralization

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23 **Brain:** cognitive dysfunction; impaired psychomotor development and intelligence development; social  
24 stress; mood disorders; unfavorable emotional symptoms  
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30 **Cancer:** shortened telomere length; detrimental expression of genes involved in DNA damage and  
31 repair; inflammation; immune and oxidative stress response; epigenetic effects  
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37 **Diabetes and metabolism:** increased glycosylated hemoglobin, insulin resistance, leptin, and  
38 endothelin-1 levels; lower glucagon-like peptide-1, ghrelin, and glucagon  
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43 **Eye:** Increased tearing (acutely) and drying (chronically)  
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48 **Heart:** Changes in heart rate, blood pressure, and vascular tone; reduced heart rate variability;  
49 conduction defects  
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54 **Kidney:** Decreased glomerular filtration rate; Increased mortality in dialysis patients  
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5 **Respiratory tract:** Cough, phlegm, difficulty breathing, and bronchial hyper-responsiveness;  
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7 exacerbations of many respiratory conditions; impeded lung development; transformation of asthma  
8  
9 into COPD; decreased exercise performance; decreased spirometric measurements (lung function)  
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14 **Reproductive:** premature birth; low birthweight; poor sperm quality; impaired fetal growth; intrauterine  
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16 inflammation; reduced fertility rates; increased risk of miscarriage, spontaneous abortions, premature  
17  
18 rupture of membranes, and preeclampsia. Exposure during pregnancy is associated with childhood  
19  
20 neoplasms and childhood asthma.  
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25 **Skin:** aging  
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30 **Sleep:** associated with increased sleep apnea symptoms  
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34 **Overall:** Shortened life expectancy, with additive or multiplicative effects in vulnerable persons  
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**Legend for figure:** Many conditions are associated with air pollution. This figure lists diseases linked to air pollution by organ systems.

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3 **Acknowledgement**  
4

5 Laura Feldman contributed content regarding maternal exposure to air pollution and adverse effects on  
6 fetal health.  
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