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*A Narrative Medical Review*

# Ambient Air Pollution and Cardiopulmonary Health in Beijing, China: Evidence, Vulnerable Populations, Exposure Pathways and Clinical Implications

**Kong Jen* and Guo Ch'ang**

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## Abstract

**Ambient air pollution remains an important environmental determinant of health in large Chinese cities despite substantial improvements in air quality over the past decade. Beijing provides an informative case study because of its large population, complex urban structure, historical particulate pollution, seasonal meteorological variability, traffic emissions, regional pollutant transport and continuing transition toward a more ozone- and secondary-aerosol dominated pollution profile. This narrative review examines the medical evidence concerning ambient particulate matter and gaseous pollutants in Beijing, with emphasis on PM2.5, PM10, ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Evidence from Beijing time-series, case-crossover, hospital-based and exposure-assessment studies indicates that short-term exposure is associated with increased risks of respiratory and cardiovascular morbidity, including respiratory hospital admissions, acute exacerbations of chronic obstructive pulmonary disease, asthma-related healthcare use, ischemic stroke and cardiovascular admissions. Studies also indicate that combined PM2.5 and ozone exposure can have interactive effects on respiratory admissions. Vulnerability varies by age, underlying disease, season, occupation and exposure setting. Children and older adults warrant particular attention, while people with cardiovascular disease, chronic respiratory disease and other chronic conditions may experience clinically important effects at relatively modest increases in pollutant concentration. Medical interpretation should distinguish population-level epidemiological associations from individual diagnosis or prognosis. The review argues for closer integration of air-quality surveillance with clinical preparedness, exposure reduction, disease prevention and urban environmental management. Beijing's experience also illustrates the importance of controlling multiple pollutants simultaneously rather than focusing exclusively on particulate matter. Continued reductions in PM2.5, prevention of ozone episodes, improved personal exposure assessment and targeted protection of susceptible populations are important components of an evidence-informed urban health strategy.**

**Keywords:** Beijing; China; air pollution; PM2.5; ozone; cardiovascular disease; respiratory disease; stroke; asthma; environmental health; epidemiology

## 1. Introduction

Ambient air pollution is a major environmental risk factor for human disease. The health consequences arise from a complex mixture of particulate matter and gases generated by transportation, fuel combustion, industrial activity, construction, secondary atmospheric chemistry and regional pollutant transport. The clinical significance of this exposure extends beyond acute respiratory irritation. Epidemiological and toxicological evidence links air pollution with cardiovascular events, respiratory exacerbations, cerebrovascular disease, impaired lung function, adverse pregnancy outcomes and cancer. The World Health Organization (WHO) therefore treats air pollution as a major public-health concern and provides health-based air-quality guidelines for PM2.5, PM10, ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.

Beijing is particularly relevant to environmental medicine because its population experiences a mixture of local and regional emissions under strong seasonal meteorological influences. The city has undergone major changes in its energy system, vehicle fleet, industrial structure and emission-control policies. These changes have contributed to improvements in particulate pollution, while ozone and secondary particulate formation remain important challenges. A Beijing surveillance study covering 2015–2022 reported that PM2.5 concentrations had reached their lowest levels in the study period and nevertheless identified continuing carcinogenic-risk questions associated with PM2.5 components.

Medical research in Beijing has generated a substantial body of evidence. Large hospital datasets have allowed investigators to examine associations between pollution and emergency visits, admissions, length of hospital stay and healthcare costs. A study using data from 242 hospitals between 2014 and 2019 included 1,969,755 patients with cardiovascular disease and diabetes and found positive associations between several pollutants and hospital admissions. Other studies have examined stroke, transient ischemic attack, COPD, asthma and respiratory admissions. The objective of this review is to integrate these findings into a clinically oriented framework and identify implications for prevention, clinical practice and future research.

## 2. Review Approach

This manuscript is a narrative review of medical and environmental-health literature concerning ambient air pollution in Beijing, China. The literature base emphasizes peer-reviewed studies conducted in Beijing that evaluated hospital admissions, emergency care, mortality, respiratory or cardiovascular outcomes, vulnerable populations, pollutant interactions and exposure assessment. WHO air-quality guidance was used to provide a health-based reference framework.

Because the included studies differ in design, exposure windows, pollutants, outcome definitions and statistical models, effect estimates are not pooled into a new meta-analysis. Reported numerical estimates are presented as findings of the cited studies and should not be interpreted as a single causal estimate for all Beijing residents. The review avoids attributing individual clinical outcomes to air pollution without appropriate diagnostic and epidemiological evidence.

## 3. Air Pollution in Beijing: Medical and Environmental Context

Beijing's air-pollution profile has changed substantially over time. Earlier periods were characterized by severe particulate pollution associated with coal combustion, traffic, industrial emissions, construction and regional transport. Emission-control programs, cleaner energy use and changes in industrial activity have reduced concentrations of several pollutants. Nevertheless, pollution episodes continue to occur, and secondary aerosols and ozone remain important because their formation involves atmospheric chemistry and precursor emissions across administrative boundaries.

PM2.5 is especially important medically because its small aerodynamic diameter permits deep penetration into the respiratory tract. The WHO 2021 guideline recommends an annual mean PM2.5 concentration of 5 μg/m³ and a 24-hour mean of 15 μg/m³. For PM10, the corresponding values are 15 μg/m³ annually and 45 μg/m³ over 24 hours; for NO2 they are 10 μg/m³ annually and 25 μg/m³ over 24 hours. These are health-based guideline levels rather than automatically applicable legal standards.

Beijing also illustrates the importance of multipollutant exposure. During warm seasons, ozone can increase while particulate concentrations follow different temporal patterns. A 2013–2019 Beijing study involving more than 1.19 million respiratory admissions found interaction between PM2.5 and ozone for upper respiratory infection, pneumonia, COPD and total respiratory disease, highlighting the importance of addressing both pollutants.

## 4. Biological Pathways Linking Air Pollution to Disease

### 4.1 Respiratory mechanisms

Inhaled particles can deposit throughout the respiratory tract according to their aerodynamic properties. Coarse particles tend to deposit in the upper airways, whereas fine particles can reach the small airways and alveolar regions. Exposure can activate epithelial cells and alveolar macrophages, induce oxidative stress and inflammatory signaling, and alter airway responsiveness. Repeated exposure may contribute to exacerbation of pre-existing respiratory disease. Ozone can injure airway epithelium and promote inflammation, while nitrogen dioxide contributes to oxidative stress and airway irritation.

### 4.2 Cardiovascular mechanisms

Cardiovascular effects may occur through systemic inflammation, oxidative stress, autonomic nervous-system disturbance, endothelial dysfunction, altered vascular tone and changes in thrombogenicity. These mechanisms provide biological plausibility for the observed epidemiological associations between air pollution and cardiovascular events. Beijing studies have reported associations with cardiovascular admissions, including coronary heart disease and atrial fibrillation, and with admissions among people with cardiovascular disease and diabetes.

### 4.3 Neurological and cerebrovascular mechanisms

Cerebrovascular effects may arise through systemic vascular inflammation, endothelial dysfunction and thrombosis, with possible additional contributions from inflammatory and vascular effects of ultrafine particles. Beijing studies have reported associations between short-term pollution exposure and ischemic stroke or transient ischemic attack admissions. Such findings represent population-level risk associations rather than deterministic effects in individual patients.

## 5. Respiratory Health Outcomes

### 5.1 Asthma

Asthma is sensitive to environmental triggers. A Beijing study identified 978,658 asthma-related healthcare visits between 2010 and 2012 and evaluated acute associations with PM2.5. The study provides evidence relevant to asthma-related outpatient, emergency and inpatient healthcare use. Clinically, patients with asthma may benefit from individualized exposure-reduction advice during pollution episodes, particularly when disease control is suboptimal.

### 5.2 Chronic obstructive pulmonary disease

COPD patients may have limited respiratory reserve. A Beijing study of 7,884 admissions for acute exacerbation of COPD during 2014–2015 reported positive associations between PM2.5 and PM10 and COPD exacerbation admissions, with stronger associations in some older and female subgroups. These findings support incorporating environmental exposure into COPD prevention and exacerbation-management strategies.

### 5.3 Respiratory infections and pneumonia

Air pollution may influence respiratory infection risk through airway inflammation and impaired host defenses. The Beijing PM2.5–ozone interaction study identified associations with pneumonia and upper respiratory infections, suggesting that respiratory morbidity should be evaluated in a multipollutant framework rather than attributing all observed effects to PM2.5 alone.

## 6. Cardiovascular and Cerebrovascular Outcomes

Cardiovascular disease represents an important component of the medical burden associated with air pollution. A Beijing time-series study reported that each 10 μg/m³ increase in PM2.5 over the preceding day-to-day exposure window was associated with an increase in total cardiovascular admissions, with stronger associations reported for coronary heart disease and atrial fibrillation. Older adults appeared particularly susceptible in that analysis.

A large Beijing investigation used data from 242 hospitals and 1,969,755 cases with cardiovascular disease and comorbid diabetes mellitus. In that analysis, increases in PM2.5, PM10, sulfur dioxide, nitrogen dioxide, carbon monoxide and ozone were each associated with higher admission rates. PM2.5 and PM10 were also associated with length of stay and hospital cost. This is clinically relevant because cardiovascular disease and diabetes are common chronic conditions in which environmental stress may contribute to acute healthcare utilization.

Cerebrovascular disease is another important outcome. A Beijing study of 476,659 ischemic-stroke inpatients from 2013–2018 reported positive associations between several pollutants and hospital admissions. Another study involving 109,975 transient ischemic attack admissions from 2014–2016 reported positive associations between PM2.5, PM10 and several gaseous pollutants. Together, these studies support the interpretation that air pollution is a modifiable population-level risk factor for cerebrovascular morbidity.

## 7. Children, Older Adults and Other Vulnerable Groups

Children have developing lungs, higher ventilation relative to body size and substantial time spent in schools and outdoor environments. A Beijing school study found that indoor air quality was strongly influenced by outdoor pollution and identified traffic-related sources as important contributors. The investigators reported adverse respiratory health implications associated with PM2.5, PM10 and ozone exposure in the school environment.

Older adults frequently have a higher prevalence of cardiovascular and respiratory disease and may therefore have reduced physiological reserve. Beijing studies have reported stronger associations for some outcomes among older adults, including COPD exacerbation and cardiovascular admissions. People with asthma, COPD, ischemic heart disease, heart failure, arrhythmias, diabetes and prior cerebrovascular disease may also warrant particular attention.

Occupationally exposed groups, including traffic workers, construction workers, waste workers and outdoor vendors, may experience higher cumulative exposure. Future studies should combine occupational information with ambient monitoring to better characterize exposure inequality.

## 8. Indoor and Personal Exposure

Ambient monitoring provides essential population information, but fixed monitoring stations cannot fully capture personal exposure. People commute, work indoors and outdoors, attend schools, exercise and spend time near specific sources. Indoor infiltration can transport outdoor particles into buildings, while cooking and other indoor activities may create additional exposure.

The Beijing school evidence illustrates this problem: outdoor pollution can influence classroom concentrations, and source proximity can affect both indoor and outdoor exposure. Personal exposure monitoring, portable sensors and time-activity assessment should therefore complement fixed-site monitoring in future epidemiological research.

## 9. Clinical Implications

The medical response to air pollution should emphasize prevention. During high-pollution periods, clinicians caring for susceptible patients can reinforce adherence to established treatment plans, recognize worsening respiratory symptoms, discuss exposure-reduction strategies and encourage patients to follow reliable local air-quality information. Advice should be individualized and should not replace prescribed medication or emergency evaluation when clinically indicated.

For asthma and COPD, pollution episodes may warrant heightened attention to symptom control and exacerbation warning signs. Cardiovascular patients should be advised to seek urgent care for symptoms such as chest pain, severe dyspnea, syncope or acute neurological deficits. Air pollution should nevertheless be considered one risk factor among many, and clinical decisions should remain based on the patient's complete medical presentation.

Hospitals can incorporate environmental exposure into preparedness planning. During severe pollution episodes, increased respiratory and cardiovascular healthcare demand may place additional pressure on emergency departments. Surveillance systems linking air-quality information with hospital activity could help public-health agencies anticipate changes in service demand.

## 10. Public-Health and Prevention Strategies

The most effective long-term intervention is reduction of emissions at source. Transport strategies that reduce vehicle emissions, cleaner energy generation, industrial emission controls, improved public transportation and coordinated regional control of pollutant precursors can reduce population exposure. Beijing's experience demonstrates that sustained multidisciplinary interventions can produce major improvements in air quality.

Ozone control is more complex because ozone is a secondary pollutant formed from precursor emissions under particular atmospheric conditions. Strategies should therefore be guided by local atmospheric chemistry rather than assuming that controlling one precursor in isolation will always reduce ozone.

Public-health communication should provide clear, actionable information without unnecessary alarm. Air-quality information can be integrated into clinical education, school health programs and occupational safety guidance. For vulnerable patients, the emphasis should be on reducing exposure during high-pollution periods while maintaining appropriate medical care and physical activity.

## 11. Research Priorities

| Research priority | Key question | Potential contribution |
|---|---|---|
| Multipollutant epidemiology | How do PM2.5, ozone and traffic-related gases jointly affect disease? | More realistic exposure-risk estimates |
| Personal exposure | How different are personal exposures from station measurements? | Better individual exposure classification |
| Vulnerable populations | Which patients have the greatest excess risk? | Targeted clinical prevention |
| Long-term outcomes | What are the chronic effects of lower but persistent exposure? | Evidence for prevention and policy |
| Chemical composition | Which PM components drive toxicity? | Source-specific interventions |
| Health-system surveillance | How do pollution episodes affect hospital demand? | Emergency preparedness |
| Climate-air quality | How will changing weather alter pollution patterns? | Integrated climate-health planning |

*Table 1. Priority areas for future medical and environmental-health research in Beijing.*

## 12. Strengths and Limitations of the Evidence

A major strength of the Beijing evidence base is the availability of large administrative healthcare datasets and long-term environmental monitoring. Studies involving hundreds of thousands or millions of admissions provide substantial statistical power and allow evaluation of vulnerable subgroups. The availability of multiple study designs also permits comparison across outcomes.

Important limitations remain. Most observational studies cannot establish individual-level causation with certainty because exposure is assigned from population monitoring or modeled estimates. Residual confounding, exposure measurement error, co-pollutant correlation and changes in healthcare-seeking behavior may affect estimates. Different studies also use different lag structures, outcome definitions and pollutant metrics. Consequently, effect estimates should be interpreted as population-level associations rather than deterministic effects in individual patients.

## 13. Discussion

The medical evidence from Beijing indicates that air pollution remains relevant even as overall pollution levels have improved. The epidemiological literature points toward acute effects on respiratory and cardiovascular health, while newer research highlights multipollutant interactions and the health significance of smaller particles and specific particle components. The reduction in PM2.5 over time should therefore be understood as an important public-health achievement that does not eliminate the need for continued monitoring and emission control.

An important shift in environmental medicine is movement from a single-pollutant framework toward an exposure-mixture framework. Patients do not inhale PM2.5 in isolation. They experience combinations of particles, ozone, nitrogen dioxide and other pollutants whose effects may interact. The Beijing evidence concerning PM2.5 and ozone illustrates this point. Future studies should increasingly examine realistic mixtures and identify which combinations produce the greatest health burden.

Another issue is exposure inequality. Population averages can conceal differences caused by residence, occupation, commuting patterns, housing quality and access to healthcare. Environmental-health interventions should therefore identify high-exposure communities and susceptible populations rather than relying exclusively on city-wide averages.

From a clinical perspective, medicine can identify susceptible patients, incorporate environmental exposure into preventive counseling, recognize pollution-associated exacerbations and collaborate with public-health authorities. From a population perspective, however, clinical advice cannot substitute for emission reduction. The greatest health benefits are expected when exposure is reduced across the population through sustained environmental management.

## 14. Conclusion

Ambient air pollution remains an important medical and public-health issue in Beijing, China. Evidence from hospital-based and population-level studies indicates associations between particulate and gaseous pollutants and respiratory, cardiovascular and cerebrovascular morbidity. PM2.5 is particularly important, while ozone and multipollutant exposure require increasing attention. Children, older adults and patients with chronic cardiopulmonary disease may be particularly vulnerable. Beijing's experience demonstrates that sustained environmental interventions can reduce pollution, but the persistence of health-relevant exposure means that monitoring and prevention should continue. Future medical research should emphasize multipollutant exposures, personal exposure, particle composition, vulnerable populations, long-term outcomes and integration of air-quality data with healthcare surveillance. Clinicians and public-health practitioners can contribute by incorporating environmental exposure into prevention, patient education and health-system preparedness, while long-term risk reduction ultimately depends on coordinated emission-control strategies.

## 15. Declarations

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Data availability: No original patient-level dataset was generated for this review.

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