**Final report**

# Adverse cardiovascular health effects of exposure to short-term air pollution: measures to protect populations at risk

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## Summary

**Why we did this review**

The adverse consequences of air pollution on health have been well documented. In order to protect those most vulnerable from the short-term effects of high pollution levels, clinicians and public health professionals have attached health advice to air quality information. Our study identifies the evidence supporting this advice, with a specific focus on advice directed to persons affected by or at risk for cardiovascular disease.

**This review is exploratory. Through a comprehensive search of the literature, our aim is to assist clinicians and public health professionals in developing health protection measures that are most likely to protect the population from the cardiovascular effects of short-term air pollution and are based on best current evidence.**

Based on our appraisal of recent systematic reviews and on patient information, this report provides an overview of (A) the evidence available to generate health protection measures, (B) health protection advice currently recommended to persons with or at risk of cardio-vascular diseases through public health, medical, patient information, environmental, and meteorological websites, (C) a general framework to develop health protection measures based on current evidence and knowledge.

**What we know**

- The commonly monitored air pollutants, particulate matter (PM), sulphur dioxide ($S0_2$), nitrogen oxides ($NO_x$), carbon monoxide (CO) and ozone are all known to be harmful to human health. Among monitored outdoor air pollutants, PM appears to be the most important and best documented cause of cardiovascular adverse effects, both short and long-term.
- Currently, there is no firm understanding of the specific populations or individuals most vulnerable to the cardiovascular effects of air pollution during the day of and days following exposure. However, it is generally recognized that certain groups are more at risk: the elderly, persons with pre-existing respiratory and cardiovascular diseases, and persons of low socio-economic status.
- There is increasing understanding of the pathophysiological mechanisms underlying the effects of air pollution on the cardiovascular system. They probably include: lung inflammation, systemic inflammation, lung oxidative stress, increased plasma viscosity, decreased cardiac vagal control, increased sympathetic activity, and increased arrhythmic susceptibility.
- Although we do not have a full understanding of what determines an individual's exposure to air pollution, it is suspected that exposure is influenced by diurnal concentrations of air pollutants, building characteristics, location, and individual rates of inhalation.
- Our review of current health protection measures against short-term air pollution demonstrates that these focus mainly on decreasing the exposure to short-term air pollution through reduction, rescheduling or relocation of outdoor activities.

**What we don't know**

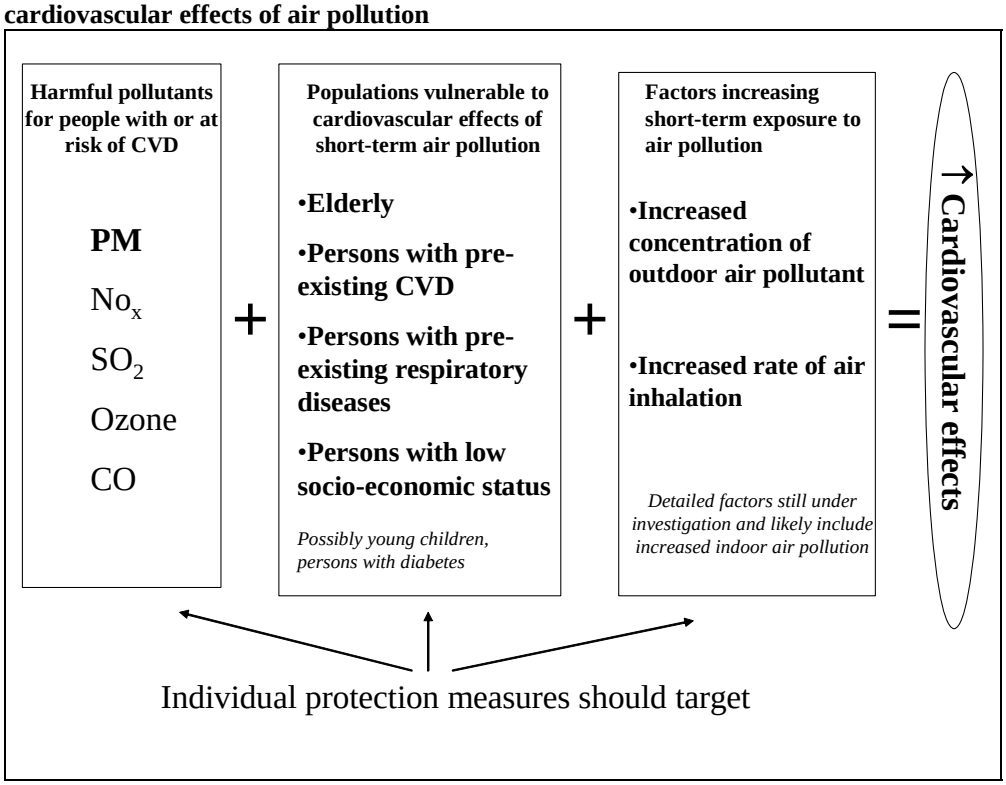
- We do not fully understand who is most at risk of the short-term effects of air pollution.
- We do not fully understand how air pollution results in increased cardiovascular disease.
- We do not know precisely how outdoor air pollutant levels vary during a day, within a city or in indoor spaces. The relationship between outdoor and indoor air pollutant is understudied.
- We do not fully understand what specifically increases individuals' exposure to air pollution in real-life circumstances.
- We do not fully understand what people should do to counteract short-term air pollution.

- We do not know if health protection messages lead to safer behaviours among vulnerable populations and whether they decrease the adverse health effects of air pollution.

**What we can recommend**

The following figure illustrates our summary of the information that can be used to devise health protection measures.

**Framework of potential information to include in health protection measures against the short-term cardiovascular effects of air pollution**




**Implications for public health practice and policy**

- Public health practitioners should inform the population of the cardiovascular risks of air pollution. Based on the evidence reviewed in this study, health protection measures should probably target the entire population, with a special focus on the elderly, persons with pre-existing cardiovascular and respiratory diseases, and those with low socio economic status. Measures should encourage them to decrease their exposure to air pollution, primarily by decreasing proximity to air pollution sources including traffic, and by decreasing strenuous activity during days or periods of the day of high pollution.
- Health protection measures remain an insufficient mitigation strategy given their uncertain efficacy. Aiming for long-term reduction and reduced exposure to air pollution should remain primary goals.

**Key references**

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Brook RD. Franklin B. Cascio W. Hong Y. Howard G. Lipsett M. Luepker R. Mittleman M. Samet J. Smith SC Jr. Tager I. Expert Panel on Population and Prevention Science of the American Heart Association. 2004. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation. 109(21):2655-71.

Pope CA, Dockery DW. 2006. Health effects of fine particulate air pollution: lines that connect. J Air Waste Manage Assoc 56: 709-742.

Routledge HC, Ayres JG. 2005. Air pollution and the heart. Occupational medicine. 55: 439-447.

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## Tables



## Figures

# 1. Background

**Adverse health effects of air pollution**

Adverse health effects of short-term (Dominici et al 2002, Katsouyanni et al. 2001, Peters et al. 2001, Samet et al. 2000, Katsouyanni et al. 1997) and long-term air pollution (Miller et al 2007, Pope et al. 2004, Hoek et al 2002, Dockery et al. 1993) are well documented. In Canada, it is estimated that air pollution results in 5,900 excess deaths annually mostly due to long-term exposure and, to a lesser extent, to acute responses to air pollution (Judek et al. 2004).

**Alerting vulnerable populations to the risk of short-term air pollution**

Most cities and provinces currently use a variety of air quality indices and short-term pollution alert systems for public health protection purposes. One objective of these indices is to reduce morbidity and mortality associated with current day exposure to air pollution. It is assumed that this can be achieved by alerting persons most susceptible to the adverse health effects of air pollution and by inciting them to adopt health protection behaviours (Environment Canada 2006).

In an attempt to protect vulnerable individuals from short-term air pollution, clinicians and public health professionals have proposed various health protection measures to accompany air quality indices (Canadian Public Health Association 2007, Health Canada 2005, Environmental Protection Agency 2007). However, no review of the diversity or efficacy of individual health protection measures against short-term air pollution has yet been performed.

**Our focus on the cardiovascular risks of short-term air pollution**

The risks of pollution-related mortality and morbidity are greatest for persons suffering from respiratory and cardiovascular diseases. Given the higher prevalence of cardiovascular disease in the general population compared to respiratory diseases, it is estimated that air pollution has greater cardiovascular than respiratory effects (Routledge et al. 2003). Furthermore, because a large proportion of people at risk of cardiovascular diseases are relatively young compared to those with chronic respiratory diseases, the potential years of life lost due to air pollution are possibly more important among people at risk of cardiovascular diseases (Routledge et al. 2003). For these reasons, we focus on health protection measures for people with or at risk of cardiovascular diseases.

**Review of health protection measures against short-term air pollution**

This review is exploratory. Our aim is to assist clinicians and public health professionals in developing health protection measures most likely to protect the population from the acute cardiovascular effects of air pollution.

Based on our comprehensive appraisal of the scientific literature, our report will provide an introductory overview of (A) the evidence available to generate health protection measures. We will (B) present our systematic review of existing health protection measures available to patients through istitutional websites. In order to do so, we will present our search strategy, selection criteria, data collection process, analysis and results. Based on these findings, we will (C) propose a general framework to develop health protection measures based on the current evidence and knowledge gaps and will discuss implications for further research.

## 2. Objectives

**Initial research objectives**

Our initial goal was to perform a systematic literature review to determine the efficacy of individual health protection measures in decreasing morbidity and/ or mortality among persons at risk of the short-term cardiovascular consequences of air pollution.

We had planned to (1) review health protection short-term measures against air pollution in the scientific literature, public health sources, pollution advisories and clinical sources, in Canada and internationally, (2) review risk factors associated with morbidity or mortality related to air pollution, (3) systematically review the efficacy of existing and potential individual health protection measures to reduce air pollution health effects, (4) develop a framework to assist environmental health practitioners in identifying whether short-term individual health protection measures against air pollution are valid and suitable.

**Challenges encountered**

Our project was carried out between February and September 2007. The National Collaborating Centre for Environmental Health (NCCEH) provided funding for approximately 200 hours of research work. This study was more complex than anticipated due to a number of factors:

- **Scarcity of scientific literature on health protection measures.** Our initial scoping of the peer-reviewed literature on health protection measures against short-term air pollution has been more labour intensive than anticipated. Despite various searches within Medline, EMBASE, Cochrane Database of Systematic Reviews, EBM reviews and UpToDate, our various search terms led to large amounts of literature and very few articles specifically describing health protection measures against air pollution. Furthermore, an informal consultation of policymakers and environmental health practitioners confirmed the scarcity of peer-reviewed literature on this topic.
- **Little evidence supporting current health protection measures.** Given the iterative and exploratory nature of our study, we discovered as we were completing review that most health protection measures were not consigned in the scientific literature but rather in patient-focused literature such as medical websites. Furthermore, we found no references documenting evidence of their efficacy or effectiveness.
- **Individual susceptibility and pathophysiological processes still under investigation.** In our review of air pollution and health, we discovered that populations at risk of short-term effects from air pollution are still ill defined. Furthermore, most studies exploring pathophysiological pathways between air pollution and cardiovascular diseases emerged during the last decade and many still require further validation. This greatly reduces the evidence available to generate sound health protection measures.
- **Larger scale in-depth reviews needed to generate evidence.** An in-depth review of factors modulating human exposure to outdoor air pollutants is an important pre-requisite for evidence-based health protection measures against short-term air pollution. For instance, a better understanding of factors such as the level of physical activity, proximity to air pollution sources, dose-response relations between concentration of outdoor air pollutants and pathophysiological responses, types of physical barriers halting outdoor air pollutants, indoor air penetration rates would all facilitate the development of valid health protection measures. Our study allowed us to identify these knowledge gaps but not to research them adequately.

**Modified objectives**

It is estimated that systematic reviews in public health require on average 1000 hours of full-time research (Cochrane Collaboration 2007). Given the constraints listed above and limited time available for this study, we were not able to systematically review the efficacy of existing and potential individual health protection measures.

By necessity, we modified our study as follows. Our revised objective is to assist clinicians and public health professionals in developing health protection measures most likely to protect the population from the cardiovascular effects of short-term air pollution. In order to do so we (A) identified the evidence available to generate health protection measures, (B) we reviewed existing health protection measures against short-term air pollution available to patients through valid websites, (C) we proposed a general framework to develop health protection measures based on the current evidence and knowledge gaps.

This is an exploratory study in which we attempt to systematically weigh and present the available evidence. However, it is not a formal systematic review. Given the emerging state of the relevant research, we believe that a systematic review would probably not allow us to modify our present conclusions.

## 3.Search Strategy and selection criteria for quality of evidence

**A. Evidence for health protection measures**

In this attempt to identify evidence for short-term individual health protection measures against air pollution, we systematically examined review articles according to criteria summarized in Table 1. We purposefully used broad search terms and minimized exclusion and inclusion criteria.

Given the low number of relevant articles found with this systematic strategy, we performed an additional search to identify specific research articles and other public health documents related to our review topics. For this strategy, we searched Medline 1950-2007, hand searched references of identified reviews and articles, consulted colleagues and internet search engines (Google Scholar). This strategy is summarized in Appendix 1. Most selection criteria (included languages, populations, review topics and exclusion criteria) were similar to our systematic search criteria. However we expanded the publication categories to include policy statements, public health reports and individual articles, and expanded our subject headings as described in Appendix 1.

Of note: due to time constraints, we exclusively searched health sciences databases. However, we suspect that chemical, toxicological, atmospheric and general environmental databases would have provided additional information.

**Table 1. Selection criteria to identify evidence for health protection measures against short-term air pollution.**

| | |
|---|---|
| Databases | Medline 1950-2007, EBM reviews – Database of abstracts of reviews of effects, Uptodate online version 14.3, Cochrane database of systematic review, EMBASE 1980-2007. |
| Type of studies | Review articles |
| Included languages | English, Spanish, French. |
| Included population | Humans. |
| Included review topics | (1) Outdoor air pollutants having adverse cardiovascular effects after |

| | |
|---|---|
| | short-term exposure, (2) population vulnerable to adverse health effects of air pollution, (3) pathophysiological processes underlying adverse health effects of air pollution, (4) factors increasing individual exposure to short-term air pollution, (5) mitigation measures against short-term air pollution exposure, (6) individual health protection measures against air pollution. |
| Subject/ MeSH headings | "air pollution" (with a focus on adverse effects), "mortality", "morbidity", "risk factors" (see Appendix 1 for more detail). |
| Excluded studies | Although non-review articles were excluded from our systematic database search, they were included in our searches and hand-searching of references (see Appendix 1). |
| Excluded population | Non-human. |
| Excluded review topics | Collective health protection measures against air pollution such as air pollution source reduction. |

**B. Health protection measures against short-term air pollution**

In this second part of our study, we identify individual health protection measures against short-term cardiovascular effects of air pollution available to Canadian patients. In order to access patient information, we developed and carried out a systematic search of web-accessible health protection measures. Our search criteria are summarized in Table 2.

A complete list of websites searched can be found in Appendix 2. We generally searched four categories of websites as described in Table 2. Given limited time resources, we narrowed our search of Canadian websites to Canadian federal government websites, to provincial government websites (Québec, Ontario, British Columbia) of the three largest cities in Canada (Montréal, Toronto, Vancouver), and to their medical professional associations (Québec, Ontario, British Columbia).

**Table 2. Selection criteria to identify health protection measures against short-term air pollution (see Appendix 2)**

| | |
|---|---|
| Included websites: | Websites potentially accessed by Canadian patients at risk or suffering from cardiovascular disease and searching for individual health protection measures against short-term air pollution:<br>1. Canadian governmental institutions related to air pollution and health (Quebec, Ontario, BC, Federal),<br>2. Canadian professional medical associations (Quebec, Ontario, BC, Canada)<br>3. Prominent international institutions related to health and air pollution<br>4. Websites of international air pollution indices |
| Included languages | English, Spanish, French. |
| Key words on website search engines | "air pollution", "pollution", "pollution de l'air" or "smog" |
| Website sections systematically consulted | Air pollution, air quality, frequently asked questions, information for patients. |
| Included populations | General population or patients at risk or suffering from cardiovascular disease. |
| Included health protection measures | Individual protection measures aimed at reducing adverse general and cardiovascular health effects of short-term outdoor air pollutants |

| | |
|---|---|
| | (including commonly monitored pollutants $O_3$, $PM_{10}$, $PM_{2.5}$, $SO_2$, $NO_x$). |
| Excluded measures | Health protection measures exclusively targeting patients with chronic respiratory diseases or workers in occupational health settings non-applicable to the general population (hog farms for example). |

## 4. Data collection and analysis

Data collection was performed according to selection the criteria above. Data compilation was performed using Excel spreadsheets.

**A. Evidence for health protection measures**

Our systematic search was carried out in March 2007 and yielded a total of 325 review articles. Titles and abstracts were analyzed by AG and from those, 64 were selected of which 45 were available and reviewed. A complete summary of our search strategy can be found in Appendix 1.

Our automated and hand searches were carried out between March and June 2007. A total of 345 titles of review and non-review articles, policy statements and public health reports were identified, of which 62 were selected. Among those 62 selected documents, several had been identified in our systematic search. All were available and analyzed by AG.

**B. Health protection measures against short-term air pollution**

Our systematic search of health protection measures available to patients at risk or suffering from cardiovascular diseases was carried out in websites matching our selection criteria as described in Table 2. It took place between February and March 2007. A total of 110 websites were searched (see Appendix 2) and 137 separate individual protection measures against air pollution were identified in 44 documents (see Appendix 3). A database of the 137 individual health protection measures, their category, target population, source and whether they have scientific references was developed using the Excel software.

## 5. Results

Results are organized according to our revised objectives:

(A) Evidence required to generate sound health protection measures,
(B) Existing health protection measures against short-term air pollution,
(C) Proposed framework to develop evidence-based health protection measures

**A. Evidence required to generate sound health protection measures**[1]

This section summarizes the evidence required to generate valid health protection measures according to our review of the literature. We suggest that five important research questions can guide the elaboration of evidence-based health protection measures:

1. What are the major outdoor air pollutants known to have adverse cardiovascular effects after short-term exposure?
2. Who is vulnerable to the short-term cardiovascular effects of air pollution?
3. What pathophysiological processes underlie air pollution effects on the cardiovascular system?
4. What increases our short-term exposure to air pollution?

[1] **New information:** Following the completion of this review, we identified a thorough report published by the UK Department of Health which adresses the epidemiology and potential mechanisms underlying the cardiovascular effects of air pollutants : Ayres JG, Cardiovascular Disease and air Pollution, UK Department of Health. February 2006.

5. What can mitigate our short-term exposure to air pollution

**1. What are the major outdoor air pollutants known to have adverse cardiovascular effects after short-term exposure?**

Particulate matter (PM), sulphur dioxide (S02), nitrogen oxides (NOx), carbon monoxide (CO) and ozone are among the major air pollutants known to be harmful to human health. They are also known as "criteria pollutants" from their historical inclusion in the United States Clean Air Act (Pope 2000). Most of the literature on outdoor air pollutants focuses on these gases and particles.

Among all criteria outdoor air pollutants, PM appear to be the most important and well documented cause of cardiovascular adverse short and long-term effects (Nemmar et al. 2006, Routledge & Ayres 2005). PM are a complex mixture of solid and liquid particles in suspension. Particles smaller than 2.5 microns can be deposited deeply in the lung and are more harmful than coarse (>2.5μ) particles (Health Canada, 2006). Effects of PM on the cardiovascular system have emerged more clearly in the last decade (American Lung Association 2001). The adverse effects of short-term air pollution include increases in overall mortality, cardiopulmonary mortality, hospital admissions, emergency admissions, cardiopulmonary symptoms, arrhythmias, heart failure, acute myocardial infarction, implantable cardioverter defibrillator discharges, blood pressure and ischaemic stroke (Pope & Dockery 2006, WHO 2004, Brook et al. 2004). Of note, it is generally recognized that PM as they are currently measured may also be a proxy for co-pollutants.

$NO_x$, $S0_2$ and ozone primarily affect lung function through bronchochonstriction and inflammation. Short-term pollution due to these gases as well as CO can also lead to cardiopulmonary adverse effects (Neher & Koenig 1994, Routledge & Ayres 2005, WHO 2004, American Lung Association 2001). The combined health effects of air pollutants are still under investigation (Brook et al. 2004).

**2. Who is vulnerable to short-term air pollution?**

Although it is now clear that short-term air pollution leads to adverse health effects, there are still significant research gaps in identifying populations and individuals who are most vulnerable to cardiovascular effects of short-term air pollution (Pope & Dockery 2006, Brook et al. 2004).

It is generally recognized that certain groups are more at risk of cardiovascular mortality due to short-term air pollution. Brook and co-authors identify these groups as being the elderly, people with less than high school education (low socio-economic status), people with pre-existing respiratory disease, coronary heart disease, heart failure and diabetes mellitus (Brook et al. 2004). Pope and Dockery identify similar groups although they add very young children, as a probable population at risk, and do not include diabetic patients (Pope & Dockery 2006). They also document additional characteristics that have been shown to influence susceptibility to air pollution: medication use, age, gender, ethnic background, socioeconomic status and healthcare availability, educational attainment, housing characteristics and genetic differences.

Vulnerability to short-term increases in $NO_2$ and $SO_2$ is likely highest among persons with pre-existing respiratory diseases (WHO 2003, Neher & Koenig 1994). Sensitivity to short-term CO outdoor air pollution is likely highest among heavy smokers, those who have an elevated baseline carboxyhemoglobin and people with impaired tissue oxygen delivery (Neher & Koenig 1994). Susceptibility to ozone seems to be highly variable and largely unexplained between individuals (WHO 2003).

**3. What pathophysiological processes may underlie air pollution effects on the cardiovascular status?**

Pathophysiological mechanisms underlying the effects of air pollution on the cardiovascular system are still under investigation (Dockery & Stone 2007).

Several reviews summarize hypothesized pathophysiological processes (Routledge et al. 2003, Brook et al. 2004, Vermylen et al. 2005, Routledge & Ayres 2005, Pope & Dockery 2006, Nemmar et al. 2006, Godleski 2006). These processes generally include lung inflammation, systemic inflammation, lung oxidative stress, increased plasma viscosity, decreased cardiac vagal control, increased sympathetic activity, and increased arrhythmic susceptibility.

Routledge and Ayres propose a comprehensive model that accounts for the combined effects of gases and particles (Routledge & Ayres 2005). In this model, particles including carbon, acid condensates and transitional metals may specifically induce lung inflammation and oxidative stress, and an alteration in the synthesis of fibrinogen and clotting factors. Gases including $SO_2$, $NO_2$, CO and ozone may specifically induce cardiac autonomic changes, nervous system alterations and decreases in the cardiac vagal control leading to arrhythmic susceptibility. Both particles and gases may increase systemic inflammation, destabilization and rupture of atheromatous plaques, modify thrombosis and eventually lead to acute coronary syndrome or ventricular arrhythmia.

**4. What increases our exposure to air pollutants?**

Human exposure to outdoor air pollutants is primarily modulated by the surrounding concentration of air pollutants and the rate of air inhalation.

Factors influencing diurnal concentrations of air pollutants are probably best reviewed in the environment, atmospheric and chemical literature. In the health sciences databases reviewed, we found no systematic review of factors influencing individual exposure to air pollutants and only a few articles addressing diurnal concentration of pollutants in relation to health effects (Abelsohn et al. 20003, Campbell et al. 2005, WHO 2003). As Abelsohn and colleagues summarize, it is generally understood that in urban areas, increased concentration of air pollutants often occur with peak vehicle exhaust concentrations. These tend to occur during traffic rush hours. Furthermore, due to its photochemical generation, ozone appears to have more sustained peaks during the afternoon and evenings. No similar diurnal pattern can be established for PM (Abelsohn et al. 2002).

Factors influencing the rates of air pollutant inhalation are probably best reviewed in the physiological literature. Nonetheless, our initial scoping of the health sciences literature did not identify any article systematically reviewing rates of inhalation of air pollutants.

This scarcity of readily accessible literature on individual exposure to air pollutants could be due to several factors. First, our scoping strategy was limited to review articles. Second, there appears to be important technical difficulties in assessing individual exposure to air pollution. These are partly due to the challenge of recording individual exposure to outdoor air pollution given the diversity of spatial circumstances for an individual in any given day, and also related to the inadequacy of fixed regional sensors as proxies of individual exposure (WHO 2003).

**5. What can mitigate our exposure to air pollutants?**

Factors mitigating individual exposure to air pollution have not been systematically reviewed in the health sciences literature. Among all review articles on air pollution and health identified, we

only found one article potentially linking decreased inhalation of outdoor PM to air conditioning and closed windows (Janssen 2002 quoted in American Lung Association 2002)

**B. What health protection measures are currently available**

Among all review articles examined, only 4 articles proposed individual health protection measures against short-term air pollution for persons at risk or suffering from CVD (Brook et al. 2004, Neher & Koenig 1994, Abelshohn 2002, Bernstein et al. 2004).

These health protection measures can be summarized as follows:

- Adjust intensity of outdoor exercise or reduce outdoor activities according to daily air pollution ( Brook et al. 2004, Neher & Koenig 1994, Abelshohn 2002, Bernstein et al. 2004)
- Adjust timing or reschedule outdoor activities to avoid diurnal peaks of air pollution (Neher & Koenig 1994, Abelshohn 2002)
- Stay indoors if air pollution is high ((Neher & Koenig 1994)
- Improve indoor air quality by avoiding smoking (Neher & Koenig 1994)
- Know current air pollution levels (ex. Consult your AQI) (Abelshohn 2002)
- Improve own symptom awareness (Abelshohn 2002)

Our search of health protection measures against short-term air pollution in the Internet based patient literature was more fruitful. A total of 137 individual measures were identified. These measures most frequently targeted populations perceived to be vulnerable, including persons with cardio-respiratory disease, children and seniors. Less frequently, target populations also included diabetes patients, pregnant women, outdoor workers, persons who exercise outdoors, smokers, populations living near high traffic roads, travelers headed for polluted areas, persons with general poor health. Of all the air quality indices reviewed, only the US Environmental Protection Agency (EPA) air quality index, the London COMEAP air quality index, and the Hong Kong air pollution index appear to have individual health protection measures that are automatically disseminated with the index value. All individual health protection measures were issued by a total of 30 organizations (see organizations in bold font in Appendix 2).
Identified measures were grouped into categories promoting similar behaviours. The categories are presented in frequency of order of appearance:

1. Adjust intensity or reduce outdoor activities (ex. Avoid strenuous activity…)[33/137]
2. Adjust timing or reschedule outdoor activities (ex. Reschedule early morning and late at night)[19/137]
3. Adjust location of outdoor activities (ex. Away from traffic…)[18/137]
4. Know current air pollution levels (ex. Consult your AQI) [18/137]
5. Stay indoors (ex. If there's an air pollution advisory, it is best if you stay inside) [14/137]
6. Consult your physician/follow medical advice as needed (ex. If you very unwell, get medical assistance )[13/137]
7. Improve own symptom awareness (ex. Listen to your body…)[8/137]
8. Use individual protection equipment such as masks (ex. Protect your airways by using masks….)[5/137]
9. Improve indoor air quality (ex. Avoid smoking, improve ventilation)[4/137]
10. Use air-conditioning to avoid outdoor air exposure (ex. Stay inside in clean air-conditioned rooms)[4/137]

Additional but less frequent recommendations included: rehydration during hot smoggy days to decrease pollution effect [3/137], specific recommendations during forest fires (avoid participating in clean-up if at risk[1/137], ensure car windows are closed[1/137], temporary relocation [1/137]), adjusting

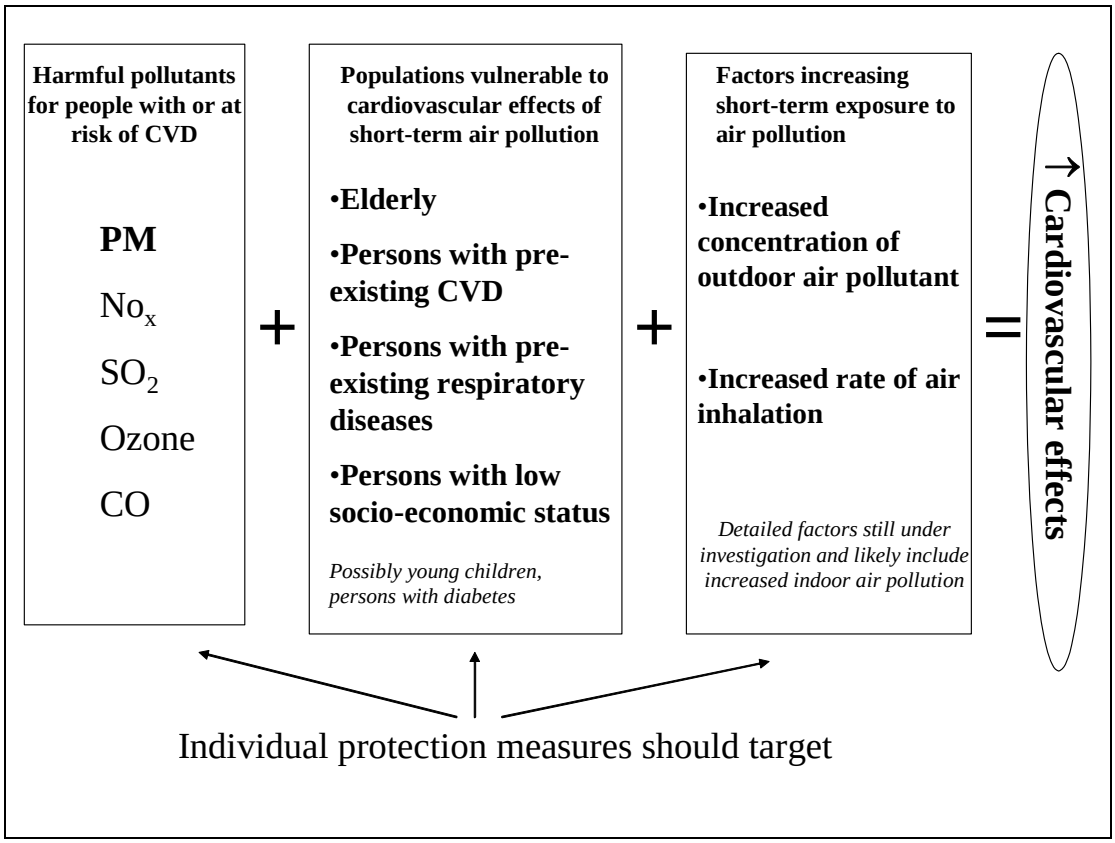
timing of house ventilation with outdoor air[1/137] , stopping smoking[1/137], using "quick-relief medications" as needed[2/137], using antioxidants [1/137], not wearing a mask: it is inefficacious[1/137], determining in advance the intensity of physical activity so that workers opt for alternative activities when pollution is high [1/137].

**C. Decision framework for evidence based health protection measures**

As described above, current health protection measures mostly focus on decreasing the exposure to short-term air pollution through reduction, rescheduling or relocation of outdoor activities. Even if we did not find research trials or observation studies to support the efficacy or effectiveness of such measures, they could be consistent with current pathophysiological hypotheses linking air pollution to cardiovascular effects.

In this part of the results section, our goal is to propose a framework based on the evidence we collected, which can assist public health authorities in developing health protection measures against short-term air pollution. We therefore suggest that certain pollutants, populations and parameters modulating exposure to short-term air pollution be specifically identified and targeted in health protection measures. These are summarized in Figure 1 below.

**Figure 1 : Framework of potential information to include in health protection measures against the short-term cardiovascular effects of air pollution.**




## 6. Potential sources of errors, bias and confounders

In this exploratory study, we tried to fulfill most of the criteria of a systematic review: we identified in advance the scope of the review questions, we performed a comprehensive search of the literature, we used explicit criteria to include and exclude information. We also explicitly

stated our extraction methods (Appendix 1). For these reasons, we believe that our findings, although exploratory, are meaningful and relevant.

Nonetheless, potential sources of errors, bias and confounding may have influenced our results:

- Selection bias. By focusing on health sciences database and restricting our search to reviews for practical reasons, we may have omitted important sources of evidence from other scientific fields or from non-review articles. By delineating our search with the use of public health oriented keywords, we did not benefit from the potential insights and analogies from other fields of research such as acute cardiology. In addition, our list of pertinent websites used to identify current health protection measures could not be exhaustive due to time constraints. This possibly decreased our qualitative assessment of the variety of health protection measures currently disseminated.
- Subjectivity in data collection. Despite our efforts to systematize our searches, exploratory iterations were necessary to unearth relevant literature and were influenced by the authors knowledge of the literature and underlying science. The appraisal of review articles and websites was mostly performed by AG and pertinent information may have escaped this process.
- Validity and reliability of data collection tools. As this was an exploratory study with limited time resources, the validity and reliability of our search strategies could not be established independently.

## 7. Implications for further research

Further research is needed to generate evidence to will support effective health protection measures against short-term air pollution. The following research areas would particularly help public health policymakers and practitioners in developing evidence-based health protection measures:

- **Pathophysiology**. Additional toxicological and epidemiological studies would be useful to better understand adverse pathophysiological effects of health pollution (Vedal 2002). Furthermore, we still need to improve our understanding of the effects of co-pollutants as a group (Brook et al. 2004). Of interest, environmental cardiology is a growing discipline which may contribute to this field (Bhatnagar 2006).
- **Populations at risk.** Our current knowledge on populations at risk of cardiovascular effects of short-term air pollution needs to be strengthened (Brook et al. 2004, Pope & Dockery 2006).
- **Factors modulating individual exposure**. Our understanding of individual exposure to air pollution as it varies in time and space is still minimal. Exposure assessments in air pollution studies are always subject to measurement error due to variable spatial and temporal air pollution levels combined to the high mobility of individuals between numerous microenvironments (Brook et al. 2004). It is hoped that new tools such as GIS, personal monitoring devices, exposure studies using airborne particle concentrators that recreate short-term air pollution in experimental settings (Vedal 2002, Ghio et al. 2004), and better measures of the entire air pollution mix will improve this knowledge area and better guide the development of health protection measures.
- **Environmental behaviour of air pollutants.** As indicated by various authors**,** additional chemical and pollutant exposure studies are needed to better understand the environmental behaviour of air pollutants and assess the validity of our health protection measures (Lioy 1989, WHO 2003, Poschl 2005).
- **Health protection measures.** After our search was completed, we became aware that there is some evidence to support the use of medication, such as ASA, to increase

resilience to short-term air pollution. This literature is emerging in the cardiology circles and deserves to be explored in-depth. In addition, multiple mitigations measures are currently proposed and many of them, possibly among the least frequently proposed (see result section 5B), would deserve additional inquiry.

- **Effectiveness of air pollution information to modify behaviour.** Air pollution information does not necessarily lead to behaviour change: only one third of people exposed to air pollution notification changed their behaviour in a 1988 review (Evans 1988 quoted in Neher & Koenig 1994). Furthermore, a better assessment of the potential for undesirable effects of health protection measures needs to take place (Rissel 2005, Campbell et al. 2005).

## Conclusion

Public health policy makers and practitioners currently face the challenge of communicating the risk of short-term air pollution to vulnerable populations while the underlying knowledge that would help identify vulnerable populations and behaviours to modify is scarce and still emerging.

To our knowledge, there is currently no other review identifying the type of evidence required to generate health protection measures against short-term air pollution. We believe that this study identifies key areas in which evidence must be gathered in order to develop potentially effective and efficacious health protection measures. Based on our preliminary findings, we also propose a framework of key air pollutants, target populations and exposure factors to include in health protection measures against short-term cardiovascular effects of air pollution.

We suggest that it is likely premature to look for scientific evidence strongly supporting health protection measures against short-term air pollution since vulnerable populations, pathophysiological processes, and factors modifying individual exposure are still under investigation. As research findings emerge, more systematic reviews might be useful on these topics. Meanwhile, a precautionary approach is probably best and should include: advising the elderly, persons with pre-existing cardiovascular or respiratory diseases as well as persons from low socio-economic status to decrease their exposure to air pollution by changing the timing, location or intensity of their outdoor activities on days where air pollution is high.

Whether these health protection measures will be efficacious and effective in decreasing the cardiovascular effects of air pollution remains to be proven. In this context, a fundamental goal in preventing human exposure to air pollution is the reduction of air pollutants production. Meanwhile, research is needed on air pollution sources, its effects on health, and on the optimal adaptation processes and mitigation interventions. The search for optimal health protection measures against air pollution constitutes one aspect of this urgently needed integrated and large scale plan to reduce air pollution and its impacts.

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# Appendix 1: Databases searched

**Systematic searches**

| Database | Keywords | Publications | Criteria | Retrieved | Selected articles |
|---|---|---|---|---|---|
| Ovid Medline 1950 - 2007 | Air pollution and mortality | reviews | humans | 14 | 3 |
| Ovid Medline 1950 - 2007 | Air pollution and morbidity | reviews | humans | 3 | 0 |
| Ovid Medline 1950 - 2007 | Air pollution (adverse effects) | reviews | humans | 250 | 58 |
| Uptodate version 14.3 | Air pollution | all | none | 28 | 2 |
| EBM reviews - Database of abstracts of reviews of effects 1st quarter 2007 | Air pollution | all | none | 3 | 0 |
| Cochrane database of systematic reviews 1st quarter 2007 | Air pollution | all | none | 9 | 0 |
| EMBASE 1980-2007 | Air pollution and Risk factors | all | humans | 18 | 1 |
| | | | **Total** | **325** | **64** |

**Searches & hand searching**

| Database | Keywords | Publications | Criteria | Retrieved | Selected articles |
|---|---|---|---|---|---|
| Ovid Medline 1950 - 2007 | Air pollution (not adverse effects), Air pollutants and Public health | articles | humans | 80 | 6 |
| Ovid Medline 1950 - 2007 | Air pollution (not adverse effects), Air pollutants and Health Education | articles | humans | 12 | 0 |
| Ovid Medline 1950 - 2007 | Air pollution (not adverse effects) and public health | articles | humans | 126 | 0 |
| Ovid Medline 1950 - 2007 | Air pollution and Preventive medicine | articles | humans | 14 | 0 |
| Ovid Medline 1950 - 2007 | Air pollutants and Preventive medicine | articles | humans | 2 | 1 |
| Ovid Medline 1950 - 2007 | Air pollution and air pollutants and "prevention and control" | articles | humans | 50 | 3 |
| Ovid Medline 1950 - 2007 | Air pollution (not adverse effects), Air pollutants and Health Education | articles | humans | 12 | 3 |
| Hand searching & grey literature | Air pollution, individual health protection measures | all | none | 49 | 49 |
| | | | **Total** | **345** | **62** |

## Appendix 2: Websites searched.

(Legend: **Bold**: website contains individual health protection measures against short-term air pollution)

### 1. Governmental institutions related to air pollution and health

| | |
|---|---|
| Quebec | **Ministère de la Santé et des services sociaux: Smog**<br>**Ministère de la Santé et des services sociaux : Direction de Santé Publique de Montréal**<br>**Institut National de Santé Publique du Québec**<br>Transport Quebec<br>Ministère du Développement Durable, de l'Environnement et des Parcs: Info Smog<br>**Réseau de surveillance de la qualité de l'air de la Ville de Montréal** |
| Ontario | Greater Toronto Area Clean Air Council<br>Ontario ministry of health and long-term care<br>Ontario Ministry of the Environment<br>**City of Toronto & Toronto Public health** |
| British Columbia | Ministry of Health<br>Greater Vancouver Regional District<br>Ministry of the environment<br>**British Columbia Air Quality Health Index pilot project**<br>Vancouver Coastal health |
| Federal | **Health Canada**<br>**Public Health Agency of Canada (PHAC)**<br>**Canadian Health Network (PHAC and Health Canada)**<br>Environment Canada : Info Smog<br>Transport Canada<br>Canadian Institute for Health Information |

### 2. Professional Medical Associations

| | |
|---|---|
| Quebec | Fédération des Médecins Omnipraticiens du Québec<br>Fédération des Médecins Spécialistes du Québec<br>Association Médicale du Québec<br>Association des Conseils des Médecins, Dentistes et Pharmaciens du Québec<br>Association des jeunes médecins du Québec<br>Collège des Médecins du Québec<br>Fédération des Médecins Résidents du Québec<br>Association des allergologues et immunologues du Québec<br>Association des Médecins spécialistes en Santé Communautaire<br>Association des spécialistes de médecine interne du Québec<br>Association de Santé Publique du Québec<br>Heart and stroke foundation - Québec<br>Association Pulmonaire du Québec |
| Ontario | **Ontario Medical Association: Smog wise**<br>Ontario public health association (OPHA)<br>Heart Health Resource center (OPHA project)<br>The lung association (Ontario)<br>Heart and Stroke foundation - Ontario<br>Ontario College of Family physicians<br>**Occupational health clinics for Ontario workers** |
| British Columbia | British Columbia Medical Association<br>**British Columbia lung association**<br>Heart and Stroke Foundation BC & Yukon<br>British Columbia College of family physicians<br>British Columbia Public health association<br>Society of General Practitioners |
| Canadian | Canadian Medical Association |

| | |
|---|---|
| | **Canadian Public Health Association**<br>Canadian Taskforce on preventive health care<br>College of Family Physicians of Canada<br>Canadian Cardiovascular society<br>Canadian society of internal medicine<br>Canadian academy of sports medicine<br>Canadian association of physicians for the environment<br>Canadian geriatrics society<br>National specialty society for community medicine<br>Occupational and environmental medical association of Canada<br>Heart and stroke Foundation (Canada)<br>**The Lung association (Canada)** |

**3. Prominent international institutions in the area of air pollution and health**

| | |
|---|---|
| Public Health | **Department of Environment, Food and Rural Affairs UK**<br>World Health Organization<br>World Health Organization Regional office for Europe<br>World Health Organization European Centre for Environment and Health (ECEH)<br>United Nations Environment Programme<br>Institut National de Veille Sanitaire - France<br>Center for Disease Control - National Center for Environmental health<br>Agency for Toxic Substances and Disease Registry<br>**US National Institute of Environmental Health Sciences**<br>European Environment Agency<br>International society of travel medicine<br>APHEIS.net (Air Pollution and Health: a European Information System)<br>European Commission - CAFE (Clean Air For Europe)<br>AIRNET (Network on Air Pollution and Health)<br>International Society of Doctors for the Environment<br>Organisation for Economic Cooperation and Development<br>Envirofacts data warehouse: Environmental Protection Agency |
| Professional Medical Association | American College of Cardiology<br>American Medical Association<br>**American Academy of Family Physicians**<br>American Public Health Association **x**<br>**American Lung Association**<br>**American Heart Association**<br>Mayo Clinic<br>Medline plus<br>Health effects institute |

**4. International air pollution indices**

| | |
|---|---|
| | **US Environmental Protection Agency (EPA): Airnow**<br>China: Air Pollution Index (API) daily reports<br>**Government of Hong Kong: Current Air Pollution Index (API)**<br>Shanghai: Environmental Monitoring Center Chinese<br>Taiwan: Current PSI<br>India: Air Quality Index<br>Japan: Tokyo Real-time data Japanese<br>Saudi Arabia: PME Air Quality Data<br>South Korea: Air Quality Information<br>Thailand: Latest Air Quality Index<br>New South Wales: 24-hour Air Quality Summary<br>Western Australia: Department of Environmental Protection - Air Quality<br>**Victoria (Australia) EPA Victoria**<br>New Zealand: New Zealand Ministry for the Environment - Air Quality |

| | |
|---|---|
| | Belgium: Ambient Air Quality<br>**France: Paris AIRPARIF Surveillance de la qualité de l'air**<br>France and Europe: PREV'AIR<br>Germany: Federal Environmental Agency Germany - Air Quality Data<br>Ireland: Air Quality Readings<br>United Kingdom: UK National Air Quality Information Archive<br>**Central London Cambridge Environmental Research Consultants (CERC**<br>The London Air Quality Network<br>**Mexico: Mexico City Air Quality Index** |

## Appendix 3: Individual health protection measures against air pollution.

(see attached Excel document)