P. Straehl
Swiss Agency for the Environment, Forests and Landscape
BUWAL
Bern
Switzerland

5

Health Effects of fine Particles - Immediate Action Imperative?

Health effects of fine particles – immediate action imperative?

Dr. Peter Straehl, Swiss Agency for the Environment, Forests and Landscape
Air Pollution Control Division, CH-3003 Bern Switzerland

An association between human health and air pollution has been proposed for more than 50 years. About 100 relevant and published epidemiological studies have investigated the health effects of particulate air pollution. Various researchers with different training, interests and research skills have conducted a wide variety of studies. Currently available studies typically fall within two broad classifications of study design which include: 1) acute exposure studies which are typically time-series studies and use short-term changes in air pollution over time (usually 1-5 days) as the source of exposure variability and 2) chronic exposure studies which are principally cross sectional in design and use longer-term pollution data (usually 1 year or more) and spatial differences in pollution as their source of exposure variability. These studies can also be subdivided into population-based (ecological) studies where the units of comparison are entire populations of communities or neighbourhoods, and cohort-based in which the unit of comparison for heath outcomes and co-risk factors are individuals in a well defined cohort or sample (see **Figure 1**). **Table 1** presents ranges of effect estimates relating particulate exposure to various health end points. Although the biological linkages remain poorly understood, the results of the acute and chronic studies are complementary. The current epidemiological evidence shows that respirable particulate air pollution, at levels common to many urban and industrial areas in Europe and the United States, contributes to human morbidity and mortality. Long-term, repeated exposure increases the risk of chronic respiratory disease and the risk of cardiorespiratory mortality. Short-term exposures can exacerbate existing cardiovascular and pulmonary disease and increase the number of persons in a population who become symptomatic, require medical attention or die. The pattern of cardiopulmonary health effects associated with particulate air pollution that has been observed by epidemiological studies is the strongest evidence of the health effect of this pollution. Much of the recent epidemiological effort has focused on effects of acute exposure, primarily because of the relative availability of relevant time series data sets. However, the effects of chronic exposure may be more important in terms of overall public health relevance.

Review of the potential mechanisms by which present ambient concentrations of inhaled particles could be associated with mortality highlights the gaps in the toxicological evidence now available. Particle dosimetry in the respiratory tract is an excellent starting point for considering biological plausibility of the epidemiological findings, as it addresses key issues from a perspective independent of specific particle composition. When different ventilatory regions of the lung are compromised with respect to their ventilatory capacity, as in persons with asthma, COPD, or congestive hearth failure, those regions of the lung that are unaffected may receive disproportionately high dose of particles. Alternative explanations for the relationship between particles and mortality include an increased likelihood of respiratory infections in individuals with COPD or asthma. Particle exposure could increase susceptibility to infection from bacteria or respiratory viruses, leading to an increased incidence of and death from pneumonia. A list of potential pathophysiological mechanisms underlying the association of particulate air pollution with mortality is presented in **Table 2**. A list of possible toxicological mechanisms is given in **Table 3**. One general mechanism of interest is pulmonary inflammation. Possible mechanisms for induction of an inflammatory response have been described for 1) ultrafine particles, 2) transition metal ions and 3) aerosol acidity. Recently Seaton et al. (1995) have proposed that the mechanism of particle induced injury involves the production of an inflammatory response by ultrafine particles in the urban particulate cloud. As a result, mediators are released capable of causing exacerbation of lung disease in susceptible individuals and increased coagulability of the blood. Several haematological factors, including plasma viscosity, fibrinogen, factor VII, and plasminogen activator inhibitor not only predict cardiovascular disease but also rise as a consequence of inflammatory reactions. In support of Seatons proposed mechanism is the observation in an animal model that ultrafine particles cause greater inflammation than larger particles of the same substance (Oberdörster et al. 1995). But despite the increasing effort to identify a mechanism, by which low concentrations of particle cause cardiopulmonary toxicity, to date we are left with only speculative hypotheses.

A question that is still a matter of debate, is the definition of an optimal metric for particles for ambient air quality and emissions measurements. For ambient air quality measurements three metrics are proposed (see **Table 4**). 1) One for the mass as all of the ambient air quality standards in Europe and the United States are mass based - PM10 or even better PM2.5 are good candidates as they fit best with the health outcomes observed in epidemiological studies. 2) One for the chemistry – elemental carbon may be a good candidate to reflect the carcinogenic risk of fine particles. 3) One for the surface of the particles as the surface may be a good indicator for the biological mechanisms causing the observed health effects. For emissions measurement it's the total mass, which is the basis of today's legislation. But new data on particle numbers indicate that they are a much more sensitive indicator of vehicle emissions than the total mass or PM10 and even PM2.5 (see **Table 5**). For emissions measurements a metric taking into account the importance of the fine and ultrafine particles, which may be their number, should be evaluated and used in a forthcoming legislation process.

The aim of the study "Health Costs due to Road Traffic-related Air Pollution", a common project of the national administrations of Austria, France and Switzerland, was to obtain comparable results for the three countries and to provide a common methodological framework applicable in other countries as well. The project was based on an interdisciplinary co-operation in the fields of air pollution, epidemiology and economy. It clearly showed the big public health impact and the resulting enormous monetary health costs, which are external costs not covered by the polluters, of particulate air pollution in these countries.
As one single indicator for urban air pollution, the exposure assessment was limited to PM10 (particulate matter of less than 10 μm aerodynamic diameter). For Austria, France and Switzerland the population exposure shows relatively similar results (**Table 6**), indicating that about two third of the population live in areas where the annual average of the PM10 concentrations exceeds 20 μg/m3. This is the annual limit value for the protection of human health of the European community (Stage 2) and the ambient air quality standard (annual average) in Switzerland.

Effect estimates from epidemiological studies are a key component for the assessment of air pollution impacts on health. If available, short- and long-term effects were considered for the assessment. However, overlapping health measures had to be excluded in order to prevent double counting of the impact, especially when monetarizing the effects. In the present study, the following health outcomes were selected: total mortality based on cohort studies, respiratory hospital admissions, cardiovascular hospital admissions, chronic bronchitis in adults, acute bronchitis in children, restricted activity days in adults, asthma attacks in children and asthma attacks in adults. For each health endpoint, epidemiological exposure-response curves were derived from the available literature, using a meta-analytic approach to calculate the variance weighted mean relative risks and applied to the national epidemiological baseline data for each health outcome (incidence, prevalence). For the three countries, the number of cases attributable to total air pollution and to road traffic-related air pollution, assessed for 1996, was impressive (**Table 7**). In 1996, air pollution caused some 5 600 cases of premature death in Austria, some 31 700 cases in France and some 3 300 cases in Switzerland. In Austria 2 400, in France 17 600 and in Switzerland 1 800 cases are attributable to road traffic-related air pollution. According to the epidemiological surveys, the increase in premature mortality is only considered for adult's ≥30 years of age. Within the additional morbidity cases attributable to road traffic, the highest incidence in all three countries is registered for acute bronchitis in children younger than 15 years. Some 21 000 cases in Austria, some 250 000 cases in France and some 24 000 cases in Switzerland were attributable to road traffic-related air pollution in 1996.
For the monetary valuation of the air pollution related health outcomes, the willingness-to-pay approach was chosen as a common methodological framework. This approach is based on a theoretical foundation of welfare economics in considering the individual utility improvement for a reduction in health related risk. The cost factors applied in the present study are chosen from the most recent economic literature. The results are presented in **Table 8**. All three countries together bear some 49 700 million EUR (≈80'500 Mio. SFr.) of air pollution related health costs, of which some 26 700 million EUR (≈43'250 Mio. SFr.) are road-traffic related. Due to the similar size of their population, in Austria and Switzerland the air pollution related health costs reach similar level. In each country, the mortality costs are predominant, amounting to more than 70 %. Since the same methodology was used in all three countries and the environmental, medical and socio-economic context is quite similar for the three neighbouring countries, the similarity of the results is not astonishing.

In order to interpret the magnitude of these results, the premature mortality attributable to road traffic-related air pollution has to be seen in a wider context. Compared to road accidents an interesting development can be observed. In 1970 in all three countries the number of fatal road accidents reached the same level as today's premature mortality attributable to traffic related air pollution. The example of Austria is shown in **Figure 2.**

To conclude (see **Tables 9 and 10**) it can be said, that today's exposure to fine particles is a serious public health problem. To reduce this risk, exposures must be reduced. Therefore regulatory strategies based on emissions should include reduction measures for fine particles. Reduction techniques as particlefilters for on- and offroad engines are available today and should be used. The emissions of particles of all size categories independent of their chemical composition should be reduced. This can be done by particlefilters. Measures leading to the reduction of the mass of the emitted particles but increasing their number should be avoided.

References:

Oberdörster G. et al: Association of particulate air pollution and acute mortality: Involvement of ultrafine particles? *Inhal. Toxicol.* 7: 111-124 (1995).

Pope c. A. et al.: Health effects of particulate air pollution: Time for reassessment? *Environ. Health. Perspect.* 103: 472-480 (1995).

Seaton A. et al.: Particulate air pollution and acute health effects. *Lancet* 345: 176-178 (1995).

Seethaler R. et al: Health costs due to road traffic-related air pollution. An impact assessment project of Austria, France and Switzerland. Synthesis report. WHO Europe. Published by *Federal Department of Environment, Transport, Energy and Communications*, CH 3003 Bern (1999)

Wilson R. and Spengler J. (Editors): Particles in our air – Concentrations and health effects. Distributed by *Harvard University Press, Harvard School of Public Health* (1996).

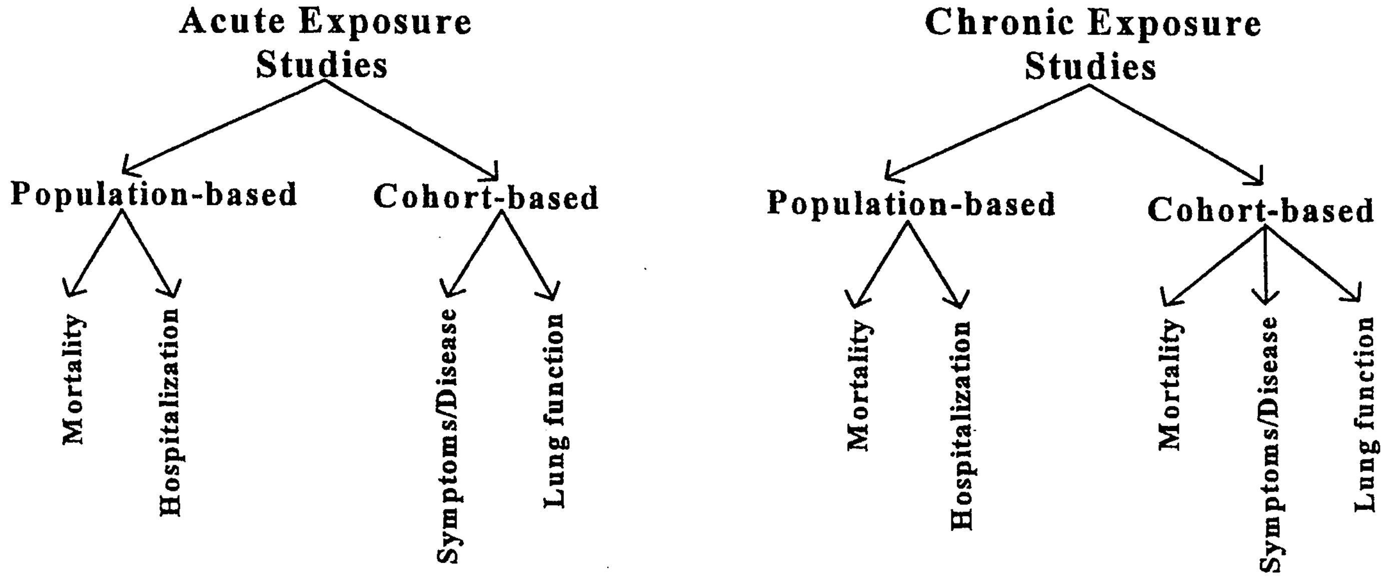

FIGURE 1. Basic study designs of currently published studies of health effects of particulate air pollution.

Table 1:

pproximate Range of Estimated Effects Measure as Percent Change n Health Endpoint per 10 µg/m³ Increase in PM_{10} for the Different asic Study Designs

ealth ndpoints	Acute Exposure: Population-Based	Acute Exposure: Cohort-Based	Chronic Exposure: Population-Based	Chronic Exposure: Cohort- or Sample-Based
ortality	Total: 0.5–1.5 Resp: 1.5–4.0 Cardio: 0.5–2.0		Total: 0–5	Total: 3–9 Cardiopulmonary: 5–9 Lung cancer: 0–9
espiratory ealth Care	Hospit. Admit: 0.5–4.0 Emergency Visits: 0.5–3.5			
ecrease in ung Function		FEV: 0.05–0.35 PEF: 0.04–0.25		Lung function 0–2
espiratory ymptoms, isease		Lower: 0–15 Upper: 0–7 Cough: 0–25 Asthmatic attacks: 1–12		Emphysema, Chronic bronchitis or cough 10–25
estricted ctivity	Grade school absences: 1.0–4.0	Restricted activity days: 1.0–5.0		

dapted from Pope 1996.

Table 2:

Potential Mechanisms Underlying the Association of Particulate Air Pollution with Mortality

- Increased susceptibility to infection from impaired host defenses
- Airways inflammation leading to impaired gas exchange and hypoxia
- Provocation of alveolar inflammation by ultrafine particles with release of mediators that exacerbate underlying lung disease and increase blood coagulability
- Increased lung permeability leading to pulmonary edema
- Precipitaton of heart failure in those with chromic cardiac disease by acute bronchiolitis or pneumonia induced by pollution

Table 3: Toxicological mechanisms

- **Ultrafine particles**: Particles <20 nanometers are most harmful, specially when freshly generated.
- **Transition metal ions**: Surface complexed metals generate hydroxyl radicals with high toxicity.
- **Aerosol acidity**: Acidic particles cause inflammations.

Cave: Overload can lead to other toxicological mechanisms than nomal load.

Table 4: **Optimal metric for particles**

- **Ambient air quality:**
  - One for the mass (PM10, **PM2.5**, PM1)
  - One for the chemistry (**EC**, OC, TC)
  - One for the surface (number, research level)
- **Emissions:**
  - Mass is todays legislation.
  - A metric taking into account the importance of fine particles should be evaluated und used.

Table 5:

- **Atmospheric data are only just emerging on numbers, but the indications are that they are a much more sensitive indicator of vehicle emissions than PM_{10} and probably $PM_{2.5}$**

Table 7: Air pollution attributable health outcomes in Austria, France and Switzerland (1996)

Health outcome	Additional cases or days due to air pollution					
	Cases or days attributable to total air pollution			Cases or days attributable to road traffic		
	Austria	France	Switzerland	Austria	France	Switzerland
Long-term mortality (adults≥30 years)	5'576 3'370-7'813	31'692 19'202-44'369	3'314 1'986-4'651	2'411 1'457-3'378	17'629 10'681-24'680	1'762 1'056-2'472
Respiratory hospital admissions (all ages)	3'399 358-6456	13'796 1'491-26'286	1'308 138-2'488	1'470 155-2'792	7'674 829-14'622	694 73-1'320
Cardiovascular hospital admissions (all ages)	6'695 3'489-9'960	19'761 10'440-29'362	2'979 1'544-4'425	2'885 1'509-4'307	10'992 5'807-16'333	1'580 819-2'348
Chronic bronchitis incidence (adults ≥25 years)	6'158 552-12'241	36'726 3'262-73'079	4'238 374-8'436	2'663 239-5'293	20'429 1'814-40'650	2'248 199-4'475
Bronchitis (children < 15 years)	47'652 21'008-86'090	450'218 198'450-813'562	45'446 20'029-82'121	20'606 9'085-37'228	250'434 110'388-452'544	24'109 10'626-43'565
Restricted activity days (adults ≥20 years)	3'106'544 2'615'175-3'604'519	24'579'872 20'692'055-28'519'982	2'762'682 2'325'699-3'205'536	1'343'371 1'130'886-1'558'711	13'672'554 11'509'956-15'864'240	1'465'600 1'233'782-1'700'534
Asthmatics: asthma attacks (children < 15 years)	34'665 21'321-48'174	242'633 149'141-337'151	23'637 14'532-32'850	14'990 9'220-20'832	134'965 82'960-187'540	12'539 7'709-17'427
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	93'619 45'594-142'598	577'174 281'130-879'091	62'593 30'490-95'345	40'484 19'716-61'664	321'053 156'378-488'994	33'205 16'175-50'580

Table 6: Frequency distribution of PM10 population exposure in Austria, France and Switzerland

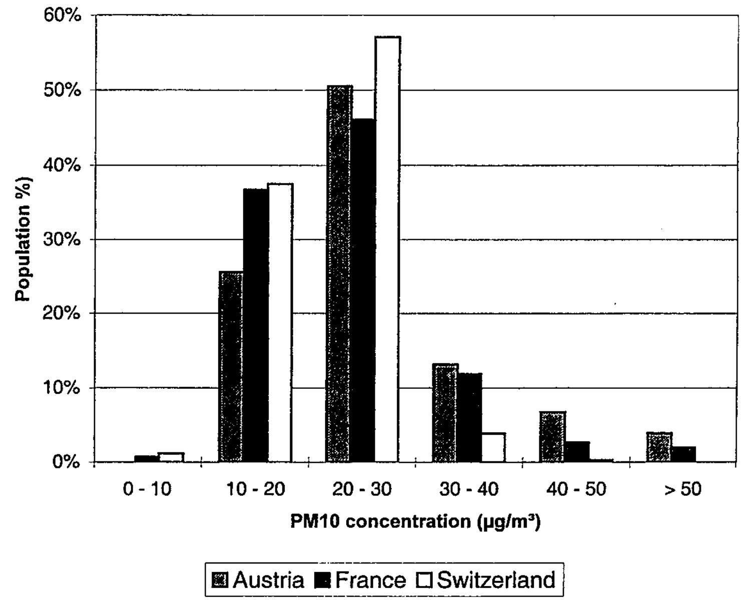

Table 8: Air pollution related health costs in Austria, France and Switzerland in 1996 based on the willingness-to-pay approach (VPF 0.9 Mio. EUR)

	Austria		France		Switzerland	
	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic
Costs of mortality (Mio. EUR) (Mio. SFr)**	**5 019** 3'033-7'031 (8 131)	**2 170** 1'311–3'041 (3 515)	**28 523** 17'282-39'932 (46'207)	**15 866** 9'613 – 22'212 (25'703)	**2 983** 1'787–4'186 (4 832)	**1 586** 950 – 2'225 (2 569)
Costs of morbidity (Mio. EUR) (Mio. SFr)**	**1 669** 396-3 044 (2 704)	**722** 171–1 316 (1 170)	**10 335** 2 760–18537 (16'743)	**5 749** 1 535–10311 (9 313)	**1 188** 314– 2 134 (1 925)	**630** 167–1132 (1 020)
Total costs (Mio. EUR) (Mio. SFr)**	**6 687** 3 429-10 075 (10 833)	**2 892** 1 483-4 357 (4 685)	**38 858** 20 042-58 469 (62 950)	**21 615** 11 148-32 523 (35 016)	**4 170** 2 101-6 319 (6 755)	**2 216** 1 117-3 357 (3 590)

* Willingness-to-pay per prevented premature fatality=0.9 Mio. EUR
** Exchange rate: 1 EURO=1.62 Swiss Francs

Figure 2:
Comparison: fatal road accidents and air pollution related mortality

For example: Austria

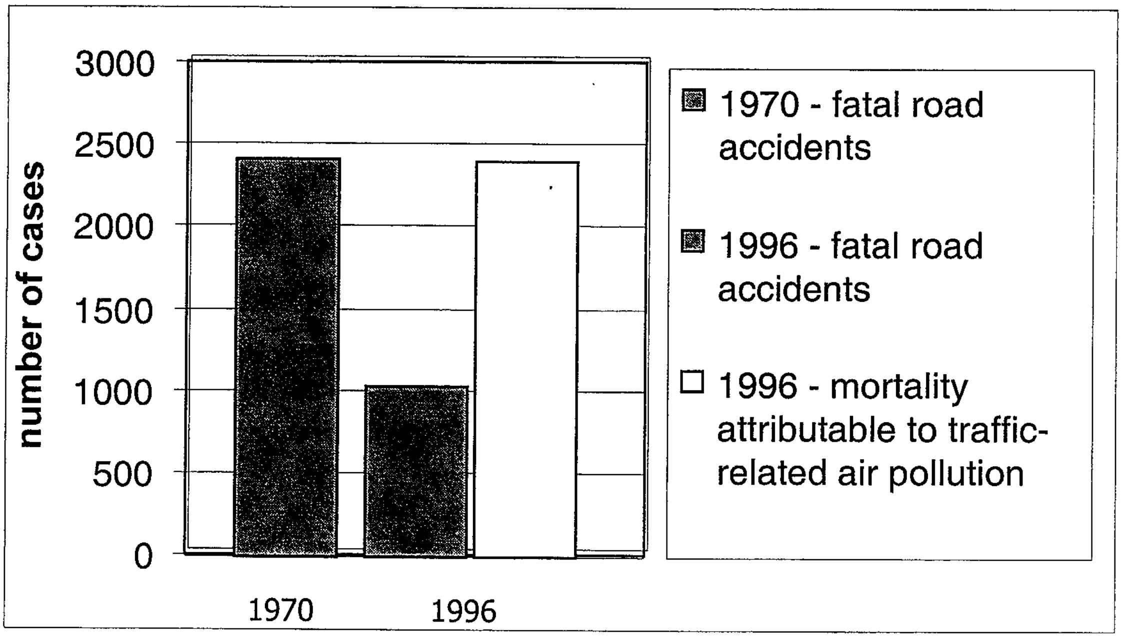

Table 9: Conclusions

- Todays exposure to fine particles is a **serious public health problem.**
- To reduce this risk, exposures must be reduced.
- Reduction measures, in particular **reduction techniques as particlefilters** are available today and should be used.

Table 10: Strategie for the reduction of particles

- Emissions of particles of **all** size categories independent of their chemical composition should be reduced
- Measures leading to the reduction of the mass of the emitted particles but **increasing their number** should be avoided