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Mini-Symposium: Nanoparticles and Children's Lungs

The occurrence of ultrafine particles in the specific environment of children

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EDUCATIONAL AIMS

- To provide an overview where nanoparticle exposure arises
- To demonstrate where nanoparticle exposure is a concern in regard to the specific environments where children spend a lot of time
- To understand that this exposure differs between adults and children
- To show that nanoparticle exposure with current assessment methods is often underestimated

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SUMMARY

Interest in ultrafine particles (UFP) has been increasing due to their specific physico-chemical characteristics. Ultrafine particles are those with an aerodynamic diameter of < 0.1 μm and are also commonly know as nanoparticles (0.1 μm = 100 nm). Due to their small size UFP contribute mostly to particle number concentrations and are therefore underestimated in actual pollution measurements, which commonly measure mass concentration. Children represent the most vulnerable group in regard to particulate exposure due to their developing status and different exposures compared to adults. This review discusses the sources of ultrafine particles as well as the specific exposures of children highlighting the importance and uniqueness of this age group.

INTRODUCTION

Particulate matter, ozone and nitrogen oxides are considered to be the most important pollutants in ambient air. The effects of particulate air pollution upon human health have extensively been studied, showing significant health effects of both outdoor as well as indoor exposure.[1] Most studies on exposure to particulate matter consider particle mass (μg/m^3), usually in terms of PM10 or, more recently, PM2.5 (particles with an aerodynamic diameter smaller than 10 or 2.5 μm respectively). Ultrafine particles, also known as nanoparticles, are those with with an aerodynamic diameter of < 0.1 μm (100 nm). Due to their small mass ultrafine particles dominate the number concentration, but have only a minor contribution to mass concentration and are therefore often underestimated.

Recent epidemiological studies indicate that ultrafine particles with diameters smaller than 100 nm may be of particular importance in terms of adverse health effects.[2] Ultrafine particles have been shown to penetrate cell membranes,[3] deposit in secondary organs,[4] deposit in brain tissue[5] and even more alarmingly nanoparticles are able to penetrate through the placenta to the fetus.[6]

Numerous toxic materials produced by combustion processes are in the ultrafine size range. Polyaromatic hydrocarbons (PAH), which are known to be carcinogenic and toxic metals, fall into this category. Also materials which are not inherently toxic, such as bulk materials and carbon or silicon dioxide, show adverse health effects when inhaled as particles in this size range. Many air filters do not efficiently filter particles in the nanosize range, e.g. those in the ventilation system of most cars.[7] Whereas PM10 has relatively small spatial and temporal variation in a given location, ultrafine particle concentrations vary widely. Their concentration in urban areas has a pronounced maximum at rush hours and the concentration rapidly decreases with increasing distance from source. This implies that exposure evaluations for ultrafine particles has to be done differently from those for coarse particles and data from air quality monitoring stations are only of very limited value in assessing such exposure.

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Abbreviations: UFP, Ultrafine particles; PM, Particulate Matter; PM 10, Particles less than 10 μm; PM 2.5, Particles less than 2.5 μm; PAH, Polyaromatic hydrocarbons; SOx, Sulphur Oxide; NOx, Nitrogen oxides; NH3, Amonia; NMVOC, Non-Methane Volatile Organic compounds.

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Most studies on health effects of air pollution include adults. However, the World Health Organization estimates that outdoor air pollution (PM10 above 20 μg/m^3) causes the death of approximately 5000 infants and young children each year in Europe due to respiratory diseases.[8] In principle, adults and children are largely exposed to the same pollutants. However, several factors discussed in detail elsewhere in this series may lead to a different personal exposure and very different effects. The lungs of children are still developing and thus early exposure to air pollution may affect lung growth[9] resulting in disease in later life. Children spend more time outside, predominantly in the afternoon when concentrations are higher. They are more physically active than adults and have an increased breathing rate and hence enhanced deposition of pollutants in the respiratory tract.[10,11] The higher breathing rate also leads to a larger number of small particles penetrating deeper into the lung. In addition, children can have greater exposures than adults in some locations, for example due to their smaller size as will be considered later. Mouth breathing is more frequent in children, which bypasses the filtering function of the nose.[10,12] As a result, particle dose in the pulmonary region can be two to fourfold higher among young children compared with adults.[13]

Exposure to particulate matter begins before birth. However, very little is known regarding the fetal effects of maternal exposure to specific nanosized particles. The placenta does not constitute an efficient filter for ultrafine particles.[6] Lee et al showed furthermore that prenatal exposure to ultrafine particulate matter disrupted airway development.[14] Another study showed that mice exposed to ultrafine particles demonstrated not only lung inflammation in themselves, but that their offspring also showed neurobehavioral alterations as adults.[15]

THE OCCURRENCE OF ULTRAFINE PARTICLES IN AMBIENT AIR: SOURCES, SINKS, COMPOSITION, SIZE DISTRIBUTIONS, PM10 AND ULTRAFINE PARTICLES

Ambient particulate matter in an urban environment is a complex mixture of many substances, including minerals, salts, metals and elemental and organic carbon. The composition is strongly size dependent, ultrafine particles (UFP) have a higher carbon content, larger total surface area, and greater potential for carrying toxic compounds than coarse particles.

Ambient air contains a mixture of directly emitted primary aerosol particles and secondary aerosol particles formed in the atmosphere. Coarse particles from primary aerosols originate mainly from mechanical processes (construction activities, road dust, re-suspension, wind etc.) whereas fine particles are particularly produced through combustion.[16] Outdoor concentrations of UFP are dominated by traffic emissions at many places with the most important source being diesel engines.[17] Due to their adverse health effects and their abundance in the vicinity of roads, in particular in urban areas, they have become of great concern in the past years.[18,19] However, other combustion systems (eg as used for biomass combustion) also have a significant contribution.[20] Globally, almost half of the world's population rely on burning biomass for cooking and heating. In Europe, this exposure is mainly due to burning wood for heating purposes, often in small stoves where combustion is incomplete and emissions are high. The situation is even worse when wood or other biomass is used for cooking.

Secondary aerosols are formed in the atmosphere through conversion of gaseous precursors such as sulphur oxides (SO_2, SO_3), nitrogen oxides (NO, NO_2), ammonia (NH_3) and Non-Methane Volatile Organic Compounds (NMVOC). Reaction products include ammonium sulphates and ammonium nitrate, which often dominate PM mass in ambient air. Important sources of precursors for secondary aerosols are agriculture (NH_3), diesel engines (NO_X), other combustion processes (SO_2, SO_3 and NO_x) and the use of solvents, chemical industry and petro chemistry (NMVOC).[21] Particles arising from biomass combustion are dominated by secondary aerosols as found in ambient air measurements.[20] This fraction is emitted in the gas phase and therefore not measured during particle emission measurements, which leads to a strong mismatch between emission and ambient air measurements. A summary of sources, typical concentrations and characteristics of ambient air particles can be found in Burtscher,[22] and details of more specific properties of particles in engine emissions in Maricq.[23]

Ambient PM10 concentrations have decreased substantially over the past 30 years due to legal restrictions enforcing lower emissions. However, control strategies have been aiming to lower the levels of contaminants where limits exist, i.e. PM10, and PM2.5. The levels of ultrafine particles and other important constituents of particulate matter such as metals and elemental carbon are neither limited nor monitored routinely, thus how these have changed over time is not known. Elevated levels of several pollutants, including ultrafine particulate matter, elemental carbon, and NO_2, have been shown to be associated with close proximity to main roads. Thus, even within an area considered to be ''low-pollution'' (according to measurements made at a central monitoring station), children living or going to school near a busy road may be exposed to unacceptably high levels of air pollution.[24]

In contrast to PM10 values, the number concentration, which is dominated by UFP strongly, depends on the distance from the source. As an example, Figure 1 shows the particle number concentration (= UFP) as function of distance to a heavy traffic road. At a distance of only 80m the concentration drops to about 25%. Figure 2 shows results for PM 10 (μg m^{-3}) and number concentration (part./cm^3) from a measurement site close to a frequented road and a site in a park nearby.[25] PM10 values are more or less the same at both sites and show no significant variation during the day, the number concentration on the other hand clearly shows the morning rush hour and more than two times higher concentrations close to the road. This shows the importance of the right measurement strategies as exposure might otherwise be underestimated. Additionally, the strong spatial variation limits the use of data from monitoring stations to determine the effective exposure to ultrafine particles. Personal monitoring measuring very close to the person or even on the person is therefore required. A comparison of results in the microenvirionment of a person ('individual sampling') to data

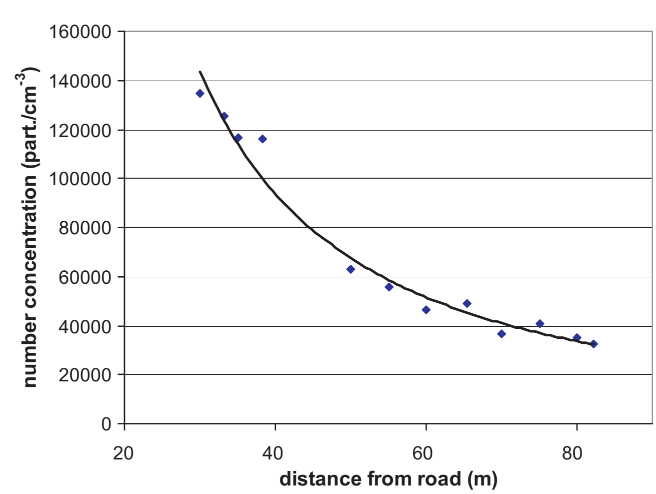

Figure 1. Particle number concentration (representing concentration of UFP, part./cm^3) as function of the distance from a highway (from Rundell et al[31]).