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Associations between ultrafine and fine particles and mortality in five central European cities — Results from the UFIREG study

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ABSTRACT

Background: Evidence on health effects of ultrafine particles (UFP) is still limited as they are usually not monitored routinely. The few epidemiological studies on UFP and (cause-specific) mortality so far have reported inconsistent results.
Objectives: The main objective of the UFIREG project was to investigate the short-term associations between UFP and fine particulate matter (PM) < 2.5 μm ($PM_{2.5}$) and daily (cause-specific) mortality in five European Cities. We also examined the effects of PM < 10 μm (PM_{10}) and coarse particles ($PM_{2.5-10}$).
Methods: UFP (20–100 nm), PM and meteorological data were measured in Dresden and Augsburg (Germany), Prague (Czech Republic), Ljubljana (Slovenia) and Chernivtsi (Ukraine). Daily counts of natural and cardio-respiratory mortality were collected for all five cities. Depending on data availability, the following study periods were chosen: Augsburg and Dresden 2011–2012, Ljubljana and Prague 2012–2013, Chernivtsi 2013–March 2014. The associations between air pollutants and health outcomes were assessed using confounder-adjusted Poisson regression models examining single (lag 0–lag 5) and cumulative lags (lag 0–1, lag 2–5, and lag 0–5). City-specific estimates were pooled using meta-analyses methods.
Results: Results indicated a delayed and prolonged association between UFP and respiratory mortality (9.9% [95%-confidence interval: −6.3%; 28.8%] increase in association with a 6-day average increase of 2750 particles/cm^3 (average interquartile range across all cities)). Cardiovascular mortality increased by 3.0% [−2.7%; 9.1%] and 4.1% [0.4%; 8.0%] in association with a 12.4 μg/m^3 and 4.7 μg/m^3 increase in the $PM_{2.5}$- and $PM_{2.5-10}$-averages of lag 2–5.
Conclusions: We observed positive but not statistically significant associations between prolonged exposures to UFP and respiratory mortality, which were independent of particle mass exposures. Further multi-centre studies are needed investigating several years to produce more precise estimates on health effects of UFP.
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1. Introduction

Epidemiological short-term studies on ultrafine particles (UFP) with a diameter < 100 nm (0.1 μm) and mortality are still rare, whereas a large number of studies investigated the effects of particulate matter (PM) with an aerodynamic diameter < 10 μm (PM_{10}) or <2.5 μm ($PM_{2.5}$, fine particles) (Atkinson et al., 2014; Rückerl et al., 2011). Most of the studies focused on the effects of fine particles on all-cause mortality and mortality due to cardiovascular and respiratory causes (Atkinson et al., 2014; Rückerl et al., 2011). A review by Atkinson et al. (2014) reported a 1.0% [95%-confidence interval: 0.5%; 1.6%] increase in all-cause mortality in association with a 10 μg/m^3 increase in $PM_{2.5}$ based on 23 estimates, but with substantial regional variation. The effect

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estimates associated with $PM_{2.5}$ on respiratory mortality were stronger (1.5% [1.0%; 2.0%]) than estimates for cardiovascular mortality (0.8% [0.4%; 1.3%]).

Due to their small size and little mass the deposition and clearance of UFP in the respiratory tract differ from larger particles (Kreyling et al., 2006). Because of the differences in deposition and the potential for translocation as well as their huge active surface, effects of UFP might be at least partly independent from those of larger particles such as PM_{10} and $PM_{2.5}$ (Brook et al., 2004; HEI, 2013; Peters et al., 2011; Rückerl et al., 2011). So far, experimental studies do not provide sufficient evidence to confirm this hypothesis. Further, there is suggestive, but not consistent epidemiological evidence on the association between short-term exposures to UFP and cardiorespiratory health (HEI, 2013; WHO, 2013a). Moreover, hardly any epidemiological studies of long-term exposures to ambient UFP have been conducted yet (Ostro et al., 2015).

The few epidemiological short-term studies on UFP and (cause-specific) mortality so far have reported inconsistent results (HEI, 2013). One of the first studies on health effects of UFP reported 1-day delayed increases in respiratory mortality (15.5% [5.5%; 26.4%]) and 4-days delayed increases in cardiovascular mortality (5.1% [−1.0%; 11.5%]) in association with an interquartile range (IQR) increase in UFP (12,680 particles/cm^3) (Wichmann et al., 2000). Increases in natural and cardiorespiratory mortality with a delay of at least two days in association with UFP increases were also found in other analyses (Breitner et al., 2009; Breitner et al., 2011; Stolzel et al., 2007). However, shorter time lags were also reported (Atkinson et al., 2010; Forastiere et al., 2005). In a study conducted in London an IQR increase of 10,166 particles/cm^3 in total particle number concentration (PNC) was associated with increases in all-cause mortality (1.4% [0.5%; 2.4%]), cardiovascular mortality (2.2% [0.6%; 3.8%]) and respiratory mortality (2.3% [−0.1%; 4.8%]) with a 1-day delay, while no associations were found for other time lags (Atkinson et al., 2010). Moreover, two studies conducted in Helsinki and Prague studying the association between PNC in different size ranges and (cause-specific) mortality found only weak or no associations (Branis et al., 2010; Halonen et al., 2009).

The project "Ultrafine particles — an evidence based contribution to the development of regional and European environmental and health policy" (UFIREG) had the goal to monitor UFP with the same instrumentation and assess the short-term health effects of ultrafine and fine particles on daily (cause-specific) mortality in time-series analyses. So far, European studies on short-term associations between UFP and mortality were primarily focused on Western European countries (HEI, 2013). However, the UFIREG project involved cities from Central and Eastern European countries using harmonised exposure and epidemiological methodology in all cities. Five cities in four Central and Eastern European countries participated in the study: Augsburg and Dresden (Germany), Chernivtsi (Ukraine), Ljubljana (Slovenia) and Prague (Czech Republic). The UFIREG project started in July 2011 and ended in December 2014. We hypothesised that we would be able to observe independent associations of ultrafine PNC and fine particle mass concentrations on (cause-specific) mortality. Moreover, we also investigated PNC, PM_{10}, coarse particles with an aerodynamic diameter > 2.5 μm and <10 μm ($PM_{2.5–10}$) and nitrogen dioxide (NO_2) as pollutants of secondary interest.

2. Methods

The study population comprised residents of Augsburg, Chernivtsi, Dresden, Ljubljana and Prague. Daily counts of (cause-specific) deaths were obtained from official statistics for each of the five cities. Only residents of a city who died in that city were considered. Infants younger than one year were excluded from the analyses. The causes of death are based on the International Statistical Classification of Diseases and Related Health Problems (ICD-10). Deaths due to natural causes (ICD-10: A00-R99) and deaths due to cardiovascular (ICD-10: I00-I99) and respiratory diseases (ICD-10: J00-J99) were considered. Mortality data for Augsburg and Dresden were obtained from the Research Data Centres of the Federal Statistical Office and the Statistical Offices of the Free States of Bavaria and Saxony, respectively. For Ljubljana, mortality data were obtained from the National Institute of Public Health in Slovenia. All data for Prague were provided by the Institute of Health Information and Statistics of the Czech Republic. For Chernivtsi, mortality data were provided by the Main Department of Statistics in Chernivtsi Region.

We also obtained information on additional variables for confounding adjustment, including indicator variables for weekdays and holidays, meteorological parameters (air temperature, relative humidity, barometric pressure), and – if available – influenza epidemics. Information on influenza epidemics in Augsburg and Dresden were provided by the German Influenza Working Group of the Robert Koch Institute (https://influenza.rki.de/Default.aspx). Data on influenza epidemics in Prague were obtained from the National Institute of Public Health in Prague and the Hygiene Station of the City of Prague. In Ljubljana, these data were provided by the National Institute of Public Health in Slovenia. No information on influenza epidemics was available in Chernivtsi. Sociodemographic data such as number of inhabitants (per age-group and sex), estimated percentage of smokers, population density or number of newborns and deceased persons was used to describe the population in the cities involved in the project. Data for Augsburg derived from the Statistical Yearbook of Augsburg. For Dresden, data were obtained from the census in 2011 and the Statistical Office of the Free State of Saxony. The Statistical Office of the Republic of Slovenia provided sociodemographic data for Ljubljana. Data for Prague were obtained from the Institute of Health Information and Statistics of the Czech Republic and the Czech statistical office. For Chernivtsi data derived from the Main Statistic Department in Chernivtsi Region.

Air pollution and meteorological parameters were measured on an hourly basis at local fixed measurement sites. The providers of air pollution and meteorological data are described elsewhere (UFIREG-report 2014). The measurement stations in Augsburg, Chernivtsi, Dresden and Ljubljana were located at urban background sites. The monitoring station in Prague was located at a suburban background site. Meteorological parameters included air temperature, relative humidity and barometric pressure. PM_{10}, $PM_{2.5}$, and NO_2 were measured in Augsburg, Dresden, Ljubljana and Prague. However, these parameters were not available in Chernivtsi. In Augsburg, Dresden, Ljubljana and Prague $PM_{2.5}$ and PM_{10} were measured at the same measurement site. $PM_{2.5–10}$ was calculated as the difference between site specific PM_{10} and $PM_{2.5}$. PNC were measured using custom-made mobility particle size spectrometers, either Differential or Scanning Mobility Particle Sizers. They enabled highly size-resolved PNC measurements in the range from 10 to 800 nm, except for Prague, where PNC were measured from 10 to 500 nm. The mobility particle size spectrometers delivered data in a 5- to 20-minute time-resolution. Hourly averages were calculated with a threshold of 75% data availability. The overall availability of PNC data reached more than 75% at all stations (UFIREG-report 2014). Imputation of hourly missing PM data was only possible for Augsburg and Prague where an additional urban background measurement station was available. Imputation was performed using a modified APHEA (Air Pollution and Health: A European Approach) procedure (Berglind et al., 2009; Katsouyanni et al., 1996). Missing hours of one monitor were imputed by a weighted average of the other monitor. If the respective hourly mean value was not available at both monitors, the average of the preceding and the following hourly means was used. Daily 24-hour averages of all air pollutants and meteorological parameters were only calculated if 75% of the hourly values were available.

An extensive quality assurance programme was an essential part of the high standards for data collection. It comprised staff training, an initial comparison of spectrometers in a laboratory, frequent on-site comparisons against reference instruments, remote monitoring, and automated function control units at two sites (Dresden and Chernivtsi). The quality assurance programme showed that the deviation for

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