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Cardiovascular and lung function in relation to outdoor and indoor exposure to fine and ultrafine particulate matter in middle-aged subjects

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ABSTRACT

This cross-sectional study investigated the relationship between exposure to airborne indoor and outdoor particulate matter (PM) and cardiovascular and respiratory health in a population-based sample of 58 residences in Copenhagen, Denmark. Over a 2-day period indoor particle number concentrations (PNC, 10–300 nm) and $PM_{2.5}$ (aerodynamic diameter < 2.5 μm) were monitored for each of the residences in the living room, and outdoor PNC (10–280 nm), $PM_{2.5}$ and PM_{10} (aerodynamic diameter < 10 μm) were monitored at an urban background station in Copenhagen. In the morning, after the 2-day monitoring period, we measured microvascular function (MVF) and lung function and collected blood samples for biomarkers related to inflammation, in 78 middle-aged residents. Bacteria, endotoxin and fungi were analyzed in material from electrostatic dust fall collectors placed in the residences for 4 weeks. Data were analyzed using linear regression with the generalized estimating equation approach. Statistically significant associations were found between indoor PNC, dominated by indoor use of candles, and lower lung function, the prediabetic marker HbA1c and systemic inflammatory markers observed as changes in leukocyte differential count and expression of adhesion markers on monocytes, whereas C-reactive protein was significantly associated with indoor $PM_{2.5}$. The presence of indoor endotoxin was associated with lower lung function and expression of adhesion markers on monocytes. An inverse association between outdoor PNC and MVF was also statistically significant. The study suggests that PNC in the outdoor environment may be associated with decreased MVF, while PNC, mainly driven by candle burning, and bioaerosols in the indoor environment may have a negative effect on lung function and markers of systemic inflammation and diabetes.

1. Introduction

Long-term exposure to particulate air pollution from traffic and other combustion sources is associated with an increase in general mortality and morbidity from respiratory and cardiovascular diseases, especially among elderly and people with previous respiratory and cardiovascular diseases (Hoek et al., 2013). Short-term exposure to elevated levels of outdoor air pollution, lasting hours to several days, has been linked to increased mortality and hospital admissions due to heart and lung diseases (Ruckerl et al., 2011).

Ambient air particulate matter (PM) is usually assessed by mass concentration in terms of PM_{10} (aerodynamic diameter < 10 μm) or $PM_{2.5}$, (aerodynamic diameter < 2.5 μm), whereas ultrafine particles (UFP, diameter < 0.1 μm), contributing only few percent to the total mass, are often characterized by particle number concentration (PNC). The composition of ambient air PM varies widely and depends on the emission source, particle size, geographic location, atmospheric chemical transformations, and meteorology (Putaud et al., 2010). UFP, especially from combustion processes, are thought to be more harmful than larger particles due to their large reactive surface area, chemical composition, high alveolar deposition, poor clearance and the potential for translocation to the systemic circulation (Franck et al., 2011). Nevertheless, epidemiological evidence supporting the specific hazards of UFP is relatively scarce, possibly due to problems in exposure assessment, including high spatial variation (Ruckerl et al., 2011). The mechanisms involved in the health effects of

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PM include pulmonary and systemic inflammation, oxidative stress, altered cardiac autonomic function, altered balance between coagulation and fibrinolysis, endothelial and microvascular dysfunction, atherosclerosis progression and plaque instability, as studied in panel and cross-sectional studies with short-term exposure assessed from monitoring stations or after controlled exposure (Brook et al., 2010). However, results have shown less consistency for prognostic markers for cardiovascular risk, including blood markers reflecting inflammation such as C-reactive protein (CRP) and circulating leukocyte counts, cell expression of adhesion molecules and impaired endothelial function (Li et al., 2012; Pope et al., 2011; Ruckerl et al., 2011).

Assessing adverse health effects of exposure to indoor air PM at home is important because people spend 80–90% of their time indoor and the indoor pollutant levels are often greater than the outdoor pollutant levels (Klepeis et al., 2001; Wallace, 1996). Of special global concern is the indoor use of solid fuel. More than 3 mill deaths were attributed to this cause in 2010 (Lim et al., 2012). Particles from outdoors can be transported into the indoor environment by ventilation and infiltration (Chen and Zhao, 2011). Indoor concentrations of PM that originates from outdoor sources are affected by multiple factors such as location, weather conditions (including outdoor temperature and wind speed), outdoor PM concentrations, the chemical and physical properties of the pollutants (specifically deposition and resuspension rate, and chemical reactions), building characteristics, air exchange rates, window openings and personal behaviors (Morawska et al., 2013). In addition, a variety of indoor emission sources such as candle burning, cooking, heating devices, environmental tobacco smoke, office equipment, biological sources, and human activity contribute substantially to the total personal exposure (Morawska et al., 2013; Wallace and Ott, 2011). Indoor air PM also include bioaerosols such as bacteria, fungi, endotoxin and other components found in settled dust which can have inflammatory potential and effect on e.g. respiratory health (Tischer et al., 2011). In addition, indoor suspended PM including soot particles may act as potential allergen carriers (Ormstad, 2000). Inhalation of indoor air pollutants together with these indoor aeroallergens or endotoxin may induce airway inflammation, leading to the exacerbation of airway and allergic diseases, including asthma (Leung et al., 2002). Studies on adults with asthma and rhinitis have shown that the indoor home environment was associated with lung dysfunction, poor health status, and disease severity (Blanc et al., 2005). Nevertheless, there is a lack of studies relating indoor concentrations of UFPs to respiratory and cardiovascular health outcomes, especially with parallel assessment of associations with outdoor pollutants.

We conducted a cross-sectional study to investigate whether microvascular function (MVF) and lung function were inversely associated with exposure to real-life levels of air pollution in the indoor and outdoor environments in an urban population. MVF and endothelial function have been widely used for cardiovascular hazard identification of PM (Moller et al., 2011). The outdoor air pollution levels were assessed by urban background monitoring in terms of PM_{10}, $PM_{2.5}$, mean particle diameter and PNC (size range 10–280 nm), which is highly dominated by UFP. The indoor exposure assessment included measurements of PNC (size range 10–300 nm) also highly dominated by UFP from candle burning, which is an important source in the winter period in Denmark (Bekö et al., 2013), mean particle diameter, $PM_{2.5}$, and presence of bioaerosol components in settled dust. To explore possible mechanisms, we investigated inflammation markers in terms of CRP and leukocyte counts, as well as expression levels of surface adhesion molecules on circulating monocytes by flow cytometry, because monocyte activation with attachment to the endothelium is an important event in the atherosclerotic process (Libby et al., 2002).

2. Materials and methods

The study protocol was approved by The Committees on Health Research Ethics in the Capital Region of Denmark (file no H-4-2010-102), in accordance with the Declaration of Helsinki. All participants gave written informed consent prior to enrolment in the study.

2.1. Study subjects

We recruited participants from the Copenhagen Aging and Midlife Biobank (CAMB) (Avlund et al., 2014). A total of 80 (22 couples and 36 singles) non-smoking volunteers participated in the study. They had been living in Copenhagen for more than 6 months, in residences within distances of not more than 500 m from major roads (>10,000 vehicles per day). Two participants with very high CRP levels were excluded from the data analysis due to recent infections treated with antibiotics.

The characteristics of the 78 participants are presented in Table 1. The mean age was 55 years with a range from 41 to 68 years, and the average body mass index (BMI) was 25 kg/m^2 with a range from 17 to 37 kg/m^2. Thirteen participants were taking vasoactive medications (angiotensin-converting enzyme (ACE) inhibitors, angiotensin II receptor blockers, calcium channel blockers, or β-adrenoreceptor blockers), and 2 participants were also taking statins.

2.2. Study procedure

The study had a cross-sectional design with exposure monitoring for a 2-day period (on average 45 h) prior to the assessment of health outcomes. The participants were asked to fill out a questionnaire about their health, lifestyle and time–activity, including use of candles and cooking, and with detailed inquiry about their housing and indoor climate. Measurements of MVF and lung function, and the collection of blood samples were carried out at the end of the 2-day indoor air monitoring period. The study lasted from late October 2011 to mid-February 2012.

2.3. Exposure assessment

Data from the measurements of indoor PNC has been reported earlier (Bekö et al., 2013). In brief, indoor PNC was monitored for about 48 h with Philips NanoTracer1000 (Philips Aerasense, Eindhoven, Netherlands) particle counters, which operated continuously with a time resolution of 16 s. The instrument detected the number concentration and mean diameter in the size range of particles between 10 and 300 nm in mobility diameter. We have shown a reasonable agreement between the NanoTracer and a stationary Scanning Mobility Particle Sizer (Bekö et al., 2013). In each residence one instrument was placed at a height between 0.5 and 1.5 m above floor level in the living room (Bekö et al., 2013). The average PNC over the whole measured period in each residence was used in the analyses. Source events with sudden

Table 1
Characteristics of the study participants Values are numbers or mean ± SD. LDL, low-density lipoprotein; HDL, high-density lipoprotein.

Characteristics of participants	Men	Women	Total
Gender	45	33	78
Age (years)	56 ± 4	53 ± 5	55 ± 5
Height (cm)	180 ± 6	169 ± 5	175 ± 8
Weight (kg)	85 ± 10.5	68 ± 9	78 ± 13
Body mass index (kg/m^2)	26 ± 3	24 ± 3	25 ± 3
Diastolic blood pressure (mm Hg)	82 ± 8	79 ± 7	81 ± 8
Systolic blood pressure (mm Hg)	127 ± 13	124 ± 14	126 ± 13
Hemoglobin (mmol/L)	10 ± 1.1	9.2 ± 1.2	9.7 ± 1.2
Total cholesterol (mmol/L)	4.0 ± 0.8	4.2 ± 0.9	4.0 ± 0.8
LDL cholesterol (mmol/L)	2.6 ± 0.9	2.3 ± 0.6	2.4 ± 0.8
HDL cholesterol (mmol/L)	0.9 ± 0.2	1.4 ± 0.3	1.1 ± 0.3
Triglycerides (mmol/L)	1.5 ± 1.1	0.9 ± 0.5	1.2 ± 0.9
Subjects taking vasoactive medication	10	3	13
Subjects taking statins	1	1	2
Subjects not taking any drugs	35	30	65