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The influence of lifestyle on airborne particle surface area doses received by different Western populations☆

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ABSTRACT

In the present study, the daily dose in terms of particle surface area received by citizens living in five cities in Western countries, characterized by different lifestyle, culture, climate and built-up environment, was evaluated and compared. For this purpose, the exposure to sub-micron particle concentration levels of the population living in Barcelona (Spain), Cassino (Italy), Guilford (United Kingdom), Lund (Sweden), and Brisbane (Australia) was measured through a direct exposure assessment approach. In particular, measurements of the exposure at a personal scale were performed by volunteers (15 per each population) that used a personal particle counter for different days in order to obtain exposure data in microenvironments/activities they resided/performed. Non-smoking volunteers performing non-industrial jobs were considered in the study.

Particle concentration data allowed obtaining the exposure of the population living in each city. Such data were combined in a Monte Carlo method with the time activity pattern data characteristics of each population and inhalation rate to obtain the most probable daily dose in term of particle surface area as a function of the population gender, age, and nationality.

The highest daily dose was estimated for citizens living in Cassino and Guilford (>1000 mm^2), whereas the lowest value was recognized for Lund citizens (around 100 mm^2). Indoor air quality, and in particular cooking and eating activities, was recognized as the main influencing factor in terms of exposure (and thus dose) of the population: then confirming that lifestyle (e.g. time spent in cooking activities) strongly affect the daily dose of the population. On the contrary, a minor or negligible contribution of the outdoor microenvironments was documented.

1. Introduction

People can be exposed to high concentration of airborne particles both in indoors and outdoors. Many studies highlighted the link between inhalation (and consequent deposition) of airborne particles in human respiratory tracts and health effects, such as respiratory diseases and inflammation (Buonanno et al., 2013; Pope III and Dockery, 2006; Schmid et al., 2009), cardiovascular diseases (Buteau and Goldberg, 2016), diabetes (Brook et al., 2008), higher systolic blood pressure and pulse pressure (Auchincloss et al., 2008), and decreased cognitive function in older men (Power et al., 2011). Moreover, the International Agency for Research on Cancer (IARC) has recently classified the particular matter (PM) as carcinogenic to humans (group 1) on the basis of the evidence presented by studies that showed a significant correlation between lung cancer and the exposure to PM (Beelen et al., 2014;

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International Agency for Research on Cancer, 2013). The harmful potential of airborne particles stems from their ability to penetrate, and deposit in the deepest areas of human respiratory tract, causing irritation, inflammation, and possibly translocate to the blood system, carrying with them carcinogenic and toxic compounds (Unfried et al., 2007; Weichenthal, 2012), and depositing in secondary organs (Semmler et al., 2004) including brain tissues (Power et al., 2011).

Even though the scientific community has not reached a definitive conclusion whether morphology, size or chemical composition of the particles are the key factor in affecting human health, the focus of scientific studies has shifted from super-micron particles (whose contribution is expressed in terms of mass concentrations of particles smaller than 10 and 2.5 μm, i.e. PM_{10} and $PM_{2.5}$) (Loomis, 2000; Pope, 2000) to sub-micron and ultrafine particles (UFPs, particles smaller than 100 nm) whose contribution is better related to particle number (Franck et al., 2011; Kumar et al., 2014) and surface area concentration (Giechaskiel et al., 2009) than mass concentration. In fact, numerous toxicity-based studies have shown that surface area is a more appropriate metric for UFP-related health effects (Cauda et al., 2012; Sager and Castranova, 2009) and that the biological response depends more on the surface area of the particles deposited in the lungs than on other exposure metrics (Schmid and Stoeger, 2016; Stoeger et al., 2006). This could be due to their large surface area and the related high probability to carry and transmit toxic compounds (Brown et al., 2001; Nygaar et al., 2004).

1.1. Exposure versus dose

In order to evaluate the health effect of the exposure to airborne particles, a dose-response relationship is needed (Sayes et al., 2007). To this purpose the daily dose of airborne particles received by people, along with the toxicity of such particles, is a key parameter to be evaluated and provided to medical experts (Cauda et al., 2012; Oberdorster et al., 2005; Tran et al., 2000). Moreover, the airborne particle daily dose is the main input data for a human health risk model (Scungio et al., 2016; Stabile et al.; Sze-To et al., 2012).

Airborne particle doses received by population can be evaluated based on exposure measurements. Nonetheless, even though the scientific community is moving from particle mass-based to number and surface area-based metrics, the current legislation is still limited to outdoor concentration of PM_{10} and $PM_{2.5}$; further, such measurements are limited to a number of fixed outdoor sampling points (FSPs) located in specific regions of interest in the urban area (Buonanno et al., 2010; European Parliament and Council of the European Union, 2008). The number of FSP is a function of the population density, without links to climate nor the community lifestyle, and therefore is not properly representing the actual exposure of citizens to PM (Rizza et al., 2017). Moreover, PM_{10} and $PM_{2.5}$ measurements at FSPs cannot be considered proxies for exposure to sub-micron and ultrafine particles since they present different dynamics (e.g. dilution, deposition) and sources (e.g. sub-micron particles are mainly generated by combustion processes whereas super-micron particles are mostly emitted by mechanical processes, (Kaur et al., 2005; Kumar et al., 2011; Neft et al., 2016; Scungio et al., 2015b)). Therefore, a better representativeness of the overall human exposure to sub-micron and ultrafine particles can be obtained through personal monitoring able to quantify the exposure in indoor micro-environments too. Such an approach is very demanding from a technical-economic point of view since a large sample (in terms of people involved in the experiments) is needed to represent the exposure of an entire population: indeed, the different lifestyles of the people result in exposures to different pollutant sources, in many different microenvironments (both outdoor and indoor), where they live, spend time or pass through during the day (Bekö et al., 2015; Buonanno et al., 2014b; Schweizer et al., 2006). Thus, exposure data are essential to evaluate the dose of airborne particles received by population, but information on the type of activity is also needed to estimate the inhalation and consequent deposition of particles in the different regions of the lungs (International Commission on Radiological Protection, 1994), as well as time activity pattern data (i.e. time spent in each microenvironments). As an example, in previous papers (Buonanno et al., 2011b, 2012) the authors estimated the tracheobronchial and alveolar dose received by Italian and Australian populations on the basis of an “indirect exposure assessment approach”, i.e. characterizing the exposure to airborne particles through fixed monitors (not personal monitoring) placed in each microenvironments where people reside during the typical day (Klepeis, 2006), and evaluating the deposition fraction of such particles as a function of their size through the deposition model proposed by the International Commission on Radiological Protection (1994). That work demonstrated a significant difference between the two populations in terms of daily dose, highlighting the effect of both lifestyle and air quality of the local microenvironments.

1.2. Aims of the work

Previous studies opened up the question about the main parameters affecting the airborne particle doses received by the populations. They also pointed out to the need for further efforts to fill the gap in knowledge about the effect of lifestyle (e.g. culture) and geographical location (e.g. climate, outdoor concentration) in this respect.

To this end, the aim of the present work is to characterize and compare the sub-micron particle daily dose, in terms of surface area, received by population living in five different cities in Western countries: Barcelona (Spain), Cassino (Italy), Guilford (United Kingdom), Lund (Sweden) and Brisbane (Australia). These cities/populations were selected in order to highlight the possible effect of local pollution concentration and population lifestyles; indeed, some of these cities were previously characterized in term of background particle concentrations. The study was limited to non-smoking population (smoking population should be analyzed separately due to the large dose they typically receive, (Fuoco et al., 2017; Stabile et al., 2017a)) and non-industrial working environments.

The study was performed with a “direct exposure assessment approach” measuring the exposure to airborne particle concentrations through personal “portable” monitors capable of measuring the exposure at a personal scale (Buonanno et al., 2014b; Wallace and Ott, 2011). To this end, several volunteers were selected amongst the five populations to perform personal monitoring and obtain the exposure representative of the population living therein. Exposure data were combined in a Monte Carlo method along with statistics on time activity patterns of the citizens to obtain the statistically most probable dose received by such five populations.

2. Methodology

2.1. Study area

Measurements were carried out in Barcelona (Spain), Cassino (Italy), Guilford (United Kingdom), Lund (Sweden) and Brisbane (Australia). Barcelona (inhabitants: 1.6 million; city area: 101 km^2), located on the northeast coast of the Iberian Peninsula (41°23′N 2°11′E), is characterized by a subtropical-Mediterranean climate with warm summers and mild winters. Climate and position contribute to typical low airborne particle concentrations (European