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Effects of the exposure to indoor cooking-generated particles on nitric oxide exhaled by women

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HIGHLIGHTS

- Measurements of particle exposure and nitric oxide exhaled by women were performed.
- Women using gas and electric stoves were considered in the study.
- Cooking leads to high women exposures to ultrafine particles.
- Women received alveolar-deposited surface area higher than 100 mm^2/h.
- A reduction of eNO was measured when the received particle doses increased.

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ABSTRACT

In this study short-term respiratory effects due to the exposure to cooking-generated aerosols were assessed through a marker of airway inflammation (exhaled Nitric Oxide, eNO). The exposure of 43 non-atopic, non-smoking women in terms of particle number and surface area concentration was monitored during their normal cooking activities through hand-held aerosol monitors. Women using gas ($n = 23$) and electric ($n = 20$) stoves were considered in the survey.

Surface area particle doses deposited in the alveolar region of the lungs (mm^2) received by each woman were measured as well as their levels of eNO concentration.

Associations between woman exposure to cooking-generated aerosol and short-term changes of eNO were found. In particular, women using electric stoves reported a statistically significant eNO reduction during the cooking sessions, whereas an increase in eNO was measured in women using gas stoves.

The results support the potential link between short-term exposures to cooking-generated particles and women's respiratory inflammation responses.

1. Introduction

Indoor aerosol exposure is recognized as one of the major environmental health concerns affecting both developed and developing countries (WHO, 2002). Indoor aerosol is made up of ambient particles penetrated from outdoor, particles emitted indoors, and particles formed indoors through reactions of gas-phase precursors (Meng et al., 2005; Morawska et al., 2013; Morawska and Salthammer, 2003; Uhde and Salthammer, 2007). Such particles can be classified in different fractions: a) PM_1, $PM_{2.5}$ and PM_{10}, representing the mass concentration of collected particles with aerodynamic diameter smaller than 1, 2.5 and 10 μm, respectively, and b) ultrafine particles (UFPs, with a diameter less than 100 nm) whose contribution to the overall particle mass concentration is negligible whereas they significantly affect number and surface area concentrations (Brugge et al., 2007; Pope and Dockery, 2006).

Recently, attention was focused on UFPs due to their capability to penetrate more deeply into the respiratory system (Unfried et al., 2007), to translocate from the airways into the blood circulation (Peters et al., 2004; Schins et al., 2004; Weichenthal, 2012), and to deposit in secondary organs (Semmler et al., 2004) including brain tissue (Calderon-Garciduenas et al., 2004). In addition, UFPs are hypothesized to be more toxic than larger particles also because of their larger surface area and the related higher probability to carry and transmit toxic chemicals (Brown et al., 2001; Nygaard et al., 2004; Schmid et al., 2009).

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Since people spend 80%–90% of their time indoors (Brasche and Bischof, 2005; Hussein et al., 2012; Morawska et al., 2013), indoor micro-environments need to be monitored because they can affect the human health. To this purpose, many laboratory-based and in-situ measurement studies reported that several activities, such as cooking, cigarette smoking, cleaning activities, incense and candle combustions, can produce high indoor particle concentrations (Stabile et al., 2012; Wallace et al., 2003); among them, cooking was recognized as the most important indoor source in terms of people exposure to particles (Buonanno et al., 2009, 2014; He et al., 2004; Morawska et al., 2003; See and Balasubramanian, 2006a; Stabile et al., 2014; Wallace et al., 2008). Cooking activities, using both electric or gas stoves, increase particle levels more significantly in terms of number and surface area than mass concentration (Buonanno et al., 2009). In particular, Wan et al. (2011) measured an increase of total particle number concentration during cooking activities 20–40-fold the kitchen's background level, whereas the particle mass concentration increased by four-fold with respect to the background. Similarly, others studies, investigating the particle surface area concentration during cooking activity, found out that it was about 5–14 times the background level (Buonanno et al., 2010; Wan et al., 2011).

An exposure and risk assessment study was performed by Sze-To et al. (2012) to estimate the effect of the exposure to particles generated during cooking activities (data of 16 gas stove-equipped Hong Kong homes were considered in their model). They showed that the risk induced by UFPs was much higher than that induced by $PM_{2.5}$: it was two orders of magnitude higher than the US EPA acceptable level (U.S. Environmental Protection Agency, 2005).

To summarize, because of the higher exposure levels, the enhanced penetration in the respiratory system (dose), the toxicity, and the related risks, sub-micrometric and ultrafine particles can be considered much more responsible than fine and coarse ones in terms of possible health effect due to indoor cooking activities.

1.1. Cooking exposure and respiratory health effects on women

Adverse health effects from domestic indoor pollution have been recently reviewed by Perez-Padilla et al. (2010). The severity of such effects varies according to both the intensity and the time of the exposure and also to the health status of the population exposed (Hoskins, 2003). Despite of the public health implication of indoor particle exposure, the number of studies investigating the health effects due to particles generated from cooking activities is still limited (Couraud et al., 2012; Metayer et al., 2002; Pavanello et al., 2007; Sivertsen et al., 2002; Svedahl et al., 2009; Svendsen et al., 2003; Wang et al., 2009; Yu et al., 2006).

Health effects related to cooking exposure depend on different types of fuels and stoves used (gas, electricity or solid fuels such as wood or coal; Straif et al. (2006)). In countries where solid fuels or biomasses still represent the main fuel for cooking and heating, indoor air pollution has been linked to acute respiratory infection and lung cancer (Owusu Boadi and Kuitunen, 2006; Smith et al., 2000). As example, a nationwide study in India showed that the exposure to combustion products of biomass and solid fuels increases the risk of asthma in women (Agrawal, 2012). Similarly, a study involving 508 adults in USA also showed a positive association between asthma and exposure to cooking indoors when wood and coal were used as fuel (Barry et al., 2010). In developed countries, the use of gas stoves was detected as a cause of respiratory symptoms, particularly in women (Corbo et al., 2001; Eisner and Blanc, 2003; Hecht et al., 2010; Jarvis et al., 1996) and in children (Buonanno et al., 2013b; Kumar et al., 2008; Moshammer et al., 2010; Wong et al., 2004). Anyway, no definitive results were obtained on the association between the use of gas stoves and the related respiratory symptoms (Jarvis et al., 1998; Wong et al., 2013).

Electric cooking is commonly considered a cleaner and safer way of cooking. Actually high emissions in terms of particles, PAHs, aldehydes were recognized during cooking activities with electric stoves too depending on the food cooked, the cooking activity (grilling, frying, types of oils and their characteristics), and the cooking temperature (Afshari et al., 2005; Buonanno et al., 2009; Jorgensen et al., 2013; Sjaastad and Svendsen, 2008). Unlike gas cooking, negligible NOx emissions were measured during electric cooking activities (Dennekamp et al., 2001).

As women are primarily involved in cooking activities, their exposure to particles is much higher than men (Behera et al., 1988; Buonanno et al., 2011). This issue is magnified for Italian women: in fact, Buonanno et al. (2012b, 2014) measured higher particle doses received by Italian women with respect to men and, also, to Australian women because of their different cooking style.

1.2. Exhaled nitric oxide as marker of airway inflammation

Exhaled nitric oxide (eNO) attracted interest as a non-invasive marker of airway inflammation (Häussermann et al., 2013; Junpei et al., 2004; Kharitonov and Barnes, 2006; Leung and Sin, 2013; Munakata, 2012). In the respiratory tract, NO is generated enzymically by three distinct isoforms of NO synthase, 2 are constitutive and the third is inducible (Cobos Barroso et al., 2008). The 2 constitutive isoforms are the neuronal isoform (nNOS, or NOS_1) and the endothelial isoform (eNOS, or NOS_3) which are activated by mediator-induced or stress-induced cell activation. The inducible isoform (iNOS, or NOS_2) is commonly induced by bacterial products and pro-inflammatory cytokines. As such, its activity increases within respiratory epithelial and inflammatory-immune cells during certain inflammatory processes, such as asthma (Ashutosh, 2000; Jain et al., 2013; Jatakanon et al., 1998; Jones et al., 2001), acute respiratory distress syndrome (ARDS) and bronchiectasis. This leads to markedly elevated local production of NO, presumably as an additional host defense mechanism against bacterial or viral infections (Vliet et al., 2000).

Nitric oxide in the airway can be measured with different noninvasive technologies (chemiluminescence, electrochemical sensing and laser-based detection) (Cristescu et al., 2013). The technical issues concerning the measurement of eNO were published by the European Respiratory Society (ERS) and the American Thoracic Society (ATS) in the 1990s (ATS, 1999) and then updated in 2005 (ATS/ERS, 2005).

A number of demographic, anthropometric and biological factors (such as age, gender, height, smoking, infection and allergy) can affect the eNO concentration levels (Abba, 2009). The ATS guideline (Dweik et al., 2011; Olin et al., 2006) reported the median value of eNO levels of an unselected population of 2200 male and female subjects: it was 16.0 ppb with minimum and maximum values equal to 2.4 and 199 ppb, respectively. To the authors' knowledge a few studies were produced by the scientific community to examine the values of eNO using current standard methods as recommended by ATS/ERS (Daniel et al., 2007; Olivieri et al., 2006; Travers et al., 2007).

1.3. Aims of the work

The present study deals with the evaluation of women's exposure during cooking activity using both gas and electric stoves and the related response in terms of exhaled NO concentration, as marker of airway inflammation, of non-atopic, non-smoking women.

In order to study the dose–response relationship between particle doses and eNO changes, exposure levels of women during