Measured Indoor Aerosol Concentration Arising from Commonly-Used Food and Medicinal Powders: A Pilot Study

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ABSTRACT

Inhalation exposures in the ambient environment may trigger allergic or other adverse responses in susceptible individuals, and this study aims to elucidate the contribution, if any, of airborne particles resulting from commonly-used medicinal and food powders to this response. In a laboratory room, six powders (two types of paracetamol-containing sachet, dried skimmed milk, instant coffee powder containing milk, a non-dairy coffee whitener containing milk protein, and a powdered peanut butter) were individually utilised under representative “real life” conditions, with ten replicates in each case. Particle concentrations were measured at the emission location and at a distance of 1 m. For each powder, a large variation in evolved particle concentrations is seen between individual events. Of the powders tested, only flavoured paracetamol demonstrated any potential for dispersion to a distance of 1 m from the source. Short term exposures were estimated and from these, it was concluded that the particle concentrations evolving from powdered peanut butter and paracetamol powders were of little concern, although further investigation of specific scenarios is merited. The range of short-term exposures calculated for milk powder products was 0.019–0.087 µg, which was comparable to estimated levels that have elicited adverse health responses in other studies.

Keywords: Powder; Human Exposure; Indoor air pollution.

INTRODUCTION

In recent years, it has been recognised that inhalation exposures in the ambient environment may trigger allergic or other adverse responses in susceptible individuals. In the United States, peanut allergy in children has increased from 0.4% in 1997 to 1.4% in 2008 (Sicherer et al., 2010); peanuts are no longer supplied as snack-foods on most airlines and epinephrine is made available on commercial flights (Greenhawt et al., 2009). Allergy to cow’s milk is predominantly associated with infants, with 80–90% outgrowing the condition in early childhood. However, Larramendi et al. (2013) describe the case of a 6 year old milk-allergic child who developed asthma and rhinoconjunctivitis due to exposure to dust-free chalk, which contained the milk protein casein, while at school. Further, Maleki et al. (2006) describe a case in which a nurse developed occupational rhinitis and asthma due to the inhalation of casein protein that was present in a medicinal dermatological powder.

Various instances of unwitting self-exposure are also reported. Nazarenko et al. (2012) highlight the potential for inhalation exposure associated with the personal use of nanotechnology-based cosmetic powders, and Lin et al. (2010) indicate that the use of culinary spices and topical application of powders for cultural reasons may result in lead inhalation. In addition, Vargiu et al. (1994) describe the respiratory distress encountered by a Sardinian sheep farmer, due to milk vapour inhalation during sheep-milking.

Many studies have investigated the inhalation potential of talcum powder, especially with regard to reporting on the health effects encountered (Dekel et al., 2004; van Huisstede et al., 2010), but little quantitative particulate data is available regarding talcum powder inhalation. Further, there is an absence of quantitative particulate information available regarding other powders that are in wide personal usage, such as milk powder products. Consumer milk products such as instant latte and cappuccino are in wide usage in the domestic environment, and may be transported by individuals to communal kitchens in workplaces, thus providing the potential for exposure of other individuals who are intolerant of milk or milk proteins. For those that do not outgrow childhood milk allergy, the casein milk protein becomes the main cause of concern for older children and adults (Bonadonna et al., 2003; Maleki et al., 2006). Other exposures in this type of communal food preparation area
can be easily envisaged, e.g., exposure to nut products.

Soluble paracetamol (acetaminophen) powders for the treatment of cold and influenza symptoms, are commonly used in the home environment. Although hypersensitivity to paracetamol is considered to be a rare occurrence, reactions may be represented by urticaria, angioedema, dyspnea and rhinitis or very rarely, an anaphylactic reaction (Boussetta et al., 2005; Couto and Gaspar, 2012). There have also been several studies carried out which link the use of paracetamol in early infancy to the later onset of asthma and allergic rhinitis (Bakkeheim et al., 2011). In the United Kingdom, 60 mg of paracetamol administered 4 times per day is the recommended optimum dose for a 3–6 month infant.

In this laboratory study, to enhance the knowledge base regarding the inhalation potential, if any, of common powdered food and medicinal products, and establish whether there is any associated health concern, a pilot programme of experiments was conducted, in which airborne particulate matter evolving from the normal usage of (a) common milk powder products (b) common paracetamol products and (c) a powdered peanut product was characterised in terms of particle size distribution, particle mass concentration and distance of dispersal from the source. Additionally, short-term exposure estimates were made for each powder, based on the evolved mass concentrations in each case.

**METHODS**

Six powders were chosen for analysis, and their physical properties are described in Table 1. A range of widely-used medicinal and food powders were selected, as informed by industry data. For example, it has been determined that 62% of coffee drinkers use a coffee whitener (Coffee Creamer Industry Statistics, 2016), and for this reason a leading brand cough remedy products, 16% are in the powder/liquid category (Statista, 2016).

<table>
<thead>
<tr>
<th>Powder Type</th>
<th>Presentation</th>
<th>Dispensed Amount/Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paracetamol powder</td>
<td>Paper sachets, containing 1000 mg paracetamol</td>
<td>Tap sachet to encourage powder to fall to bottom; tear open; empty contents into mug</td>
</tr>
<tr>
<td>Flavoured paracetamol powder</td>
<td>Paper sachets, containing 500 mg paracetamol</td>
<td>Tap sachet to encourage powder to fall to bottom; tear open; empty contents into mug</td>
</tr>
<tr>
<td>Dried skimmed milk powder</td>
<td>Foil-liner cardboard container, plastic lid, containing 340 g powder</td>
<td>Dispense two teaspoons (5 mL) into mug</td>
</tr>
<tr>
<td>Instant coffee with skimmed milk powder, sugar and vegetable oil</td>
<td>Paper sachet, containing 19.5 g powder</td>
<td>Tap sachet to encourage powder to fall to bottom; tear open; empty contents into mug</td>
</tr>
<tr>
<td>Non-dairy coffee whitener, containing 2% sodium caseinate (a milk derivative)</td>
<td>Foil-liner cardboard container, plastic lid, containing 500 g powder</td>
<td>Dispense two teaspoons (5 mL) into mug</td>
</tr>
<tr>
<td>Powdered peanut butter</td>
<td>Plastic container, screw-cap, containing 453 g powder</td>
<td>Dispense two dessert (15 mL) spoons into bowl with tapping action</td>
</tr>
</tbody>
</table>

To compare the size distributions of the different powders under controlled conditions, each powder was dispersed into a 2 m³ test chamber, using a Palas RBG-1000 dry powder dispersion generator. Before entering the chamber, the particles passed an array of 12 × 33 kBq Am²³⁹ radioactive sources: using the calculations of Cooper and Reist (1973) it was estimated that, for the airflow rate used, this source strength would be sufficient to achieve electrostatic charge neutralisation of the powder. A fan mounted on the chamber’s interior ensured uniform mixing. A Model 3321 Aerodynamic Particle Sizer (APS), manufactured by Trust Science Innovation (TSI), was used to measure the aerosol size distributions inside the chamber at 20 second intervals; the sizer categorises particles into 52 size bins within an overall range of 0.5–20 μm. For each powder, five replicate dispersion actions were carried out.

In a separate series of experiments, each powder was individually utilised under “real life” conditions, in room air, as detailed in Table 1. A 6.5 m × 2.3 m laboratory room was used, and the door and double-glazed windows were both closed throughout the measurement period; the air exchange rate in the room was measured retrospectively during comparable weather conditions, and found to be 1.7 air changes per hour. During the measurement period, the average room temperature was 13.6°C and the average relative humidity was 60%. One APS sizer was positioned adjacent to the powder-handling location, and an identical APS sizer was placed one metre away. According to a common classification of interpersonal distance (Sundstrom and Altman, 1976), the “casual-personal zone” ranges from 0.5 to 1.2 m, and 1 m was therefore considered to be a representative distance at which a bystander might preside in an environment such as a communal kitchen, for example.

Both particle counters were set to sample at 20 second intervals. For each powder, ten replicate usage activities were carried out by the same volunteer, with the ambient aerosol concentration returning to a background level, through use of an air filtration system, between each trial.

A sample of each powder was subjected to scanning
electron microscope analysis, so that the physical appearance of the powders could be compared.

RESULTS

Table 2 shows the modal particle number diameter, and its geometric standard deviation, for each of the powders. The modal mass diameter (derived from the number diameter based on a differential mass density distribution, \( m(r) \) which represents the mass contained in particles with radii between \( r \) and \( r + dr \) per unit volume) is also shown. In Table 3, the mass concentration of powder evolving for the different powders, averaged over the ten events, is presented, and the inter-event variability for each powder is also shown. To calculate short-term exposure, a breathing rate of 0.012 m\(^3\) min\(^{-1}\) (representative of adults aged between 21 and 41 undergoing light intensity activities), recommended in the US EPA Exposure Factors Handbook (2011) was used, and the estimated values are shown in Table 3. In the case of paracetamol powder, it should be noted that only a proportion of the powder is composed of the actual medicinal compound, and so exposure estimates for paracetamol and paracetamol-containing powders are both presented.

No significant variation was observed when the modes of the number distribution of the six powders are compared. In the case of the derived mass diameter, the peanut powder has a mode value of 10.4 µm, while all of the other powders have mode mass diameters in the range 3.05–6.26 µm. Fig. 1(f), a scanning electron micrograph at × 40 magnification, shows evidence of agglomeration of small particles in the case of the peanut powder, and it is likely that these agglomerations were interpreted by the APS sizer as being large individual particles, which would explain the reporting of a larger mass diameter than in the case of the other powders. Table 3 indicates zero airborne powder mass concentration in the case of the peanut powder, which is consistent with the presence of agglomerates.

For each powder, a large variation in evolved particle concentrations is seen between individual events. In the case of paracetamol, the variation is such that the upper end of the range represents a concentration that doubles the mean value, even though these data arise from ten repeated powder administration events by a single user.

The large standard deviation of the mass concentration (as illustrated in Table 3) was, based on observations during the experiments, likely to be due to the inconsistent texture of the powders throughout their containers and the stiff nature of the sachets sometimes causing the powder to be forcibly expelled upon opening. These assumptions regarding the cause of variability are supported by other research and published work. For example, Lay Ma et al. (2008) observed the presence of agglomerates in milk powders that had high sugar content (as was the case with the milk powder studied in the current work). The effective administration of pharmaceuticals from sachets is user-dependent, although many manufacturers give instruction regarding opening procedures, and many suggest tapping sachets to ensure settling of powder (Bouwman et al., 2015).

For each of the six powders, the particle number concentration at the emission location was measured and this was compared with the corresponding particle number concentration at a distance of 1 metre. For the flavoured

<table>
<thead>
<tr>
<th>Mode Particle Number Diameter µm</th>
<th>GSD Number</th>
<th>Mode Particle Mass Diameter µm</th>
<th>GSD* Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paracetamol</td>
<td>0.898</td>
<td>1.79</td>
<td>3.05</td>
</tr>
<tr>
<td>Flavoured paracetamol</td>
<td>0.898</td>
<td>1.82</td>
<td>3.52</td>
</tr>
<tr>
<td>Skimmed milk</td>
<td>0.835</td>
<td>1.93</td>
<td>6.26</td>
</tr>
<tr>
<td>Coffee powder with milk</td>
<td>0.835</td>
<td>1.87</td>
<td>5.05</td>
</tr>
<tr>
<td>Whitener</td>
<td>1.49</td>
<td>1.90</td>
<td>3.28</td>
</tr>
<tr>
<td>Peanut Powder</td>
<td>0.835</td>
<td>2.42</td>
<td>10.4</td>
</tr>
</tbody>
</table>

* The geometric standard deviation (GSD), a dimensionless quantity with values greater than or equal to unity, indicates the range of aerosol sizes (calculated in either particle number or mass terms) found in the distribution. GSD values close to unity indicate a narrow distribution (Hinds, 1999)

<table>
<thead>
<tr>
<th>Mass Concentration µg m(^{-3})</th>
<th>SD µg m(^{-3}) (n = 10)</th>
<th>Short-term Exposure µg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paracetamol</td>
<td>7.9</td>
<td>6.8</td>
</tr>
<tr>
<td>Flavoured paracetamol</td>
<td>42.6</td>
<td>22.9</td>
</tr>
<tr>
<td>Skimmed milk</td>
<td>14.8</td>
<td>8.6</td>
</tr>
<tr>
<td>Coffee powder with milk</td>
<td>4.8</td>
<td>6.6</td>
</tr>
<tr>
<td>Whitener</td>
<td>21.7</td>
<td>16.8</td>
</tr>
<tr>
<td>Peanut Powder</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
paracetamol powder, a discernible increase in particle number concentration was observed for a 40 second period, with a maximum concentration of 1000 particles cm$^{-3}$ adjacent to the source of the release. At a distance of 1 m from the source, an elevation in particle concentration for the same duration was observed, but with a 20 second time lag, and a peak concentration of only 10% of the source concentration. No discernible peak concentration elevation at 1 m distance was observed for the five other powders. Fig. 1(b) shows an electron micrograph of the lemon-flavoured paracetamol particles, and shows evidence of a greater number of small particles than is the case for the other five powders (Fig. 1(a) and Figs. 1(c)–1(f)). Despite the size statistics for this powder, as determined by the APS, showing a broadly similar distribution to the unflavoured paracetamol, it can be seen from Table 3 that the mass concentration evolved through usage of the flavoured paracetamol is considerably greater than the case for the other five powders, and this explains the detection of this powder alone at a 1 metre distance from the source.

DISCUSSION AND CONCLUSION

In this preliminary study, the size distribution and range of particle concentrations arising from a number of domestic powder usage applications has been investigated in a systematic fashion. As reported, a large variation in evolved particle concentration is seen between individual events, despite all trials being carried out by the same user. The large variation does not however diminish the validity of the results but instead it demonstrates the ranges of particulate matter exposure that may be expected from applying or preparing such powders. The effect of inter-user variability has not been examined in this pilot study, and should represent a topic for investigation in future work. In the paragraphs that follow, evidence from literature is presented regarding exposure to peanut, milk protein and paracetamol and associated adverse health responses. Based on these literature findings, the presence of any health concern associated with short-term exposure to the tested powders is evaluated, and presented below.

Milk Protein

In the literature, while various values have been established for the lowest observed adverse effect level (LOAEL) following milk protein exposure, it is clear that these values fall mainly in the milligram range. In an infant study (Cordle et al., 2013), 14 reports of cow’s milk allergy reactions to intact milk protein challenges show an average LOAEL of 83.7 mg milk protein (range = 0.36–280 mg). Morisset et al. (2003) found that the ingestion of 0.1 mL of milk (0.103 mg) or < 10 mg of solid milk particles produced allergic reactions in some instances. As mentioned earlier, a case report by Larramendi et al. (2013) revealed that the casein protein which was present in a ‘dust free chalk’ was responsible for the development of rhinoconjunctivitis and asthma in a 6 year old schoolchild. To estimate the likely exposure of this child, data were extracted from a recent study (Lin et al., 2015) of chalk dust concentration in 150 Taiwanese schools, where a mean respirable dust
concentration of 72.15 µg m⁻³ was measured. Using US EPA exposure factors as in the present work, this concentration is estimated to correspond to an inhalation exposure value of 0.29 µg. The largest exposure value presented for milk powders in Table 3 of the current study (corresponding to the coffee additive) is 33% of this estimated value of 0.29 µg, and the wide variation in milk-related sensitivity reactions reported in literature adds significance to the present findings. Bystander exposures may merit particular attention; in a communal workplace kitchen, for example, a milk-allergic individual may be susceptible to inhalation exposure from colleagues’ food preparation activities.

**Paracetamol**

Paracetamol is a well-established non-prescription medicinal drug which is well tolerated and whose side effects are infrequent. Although hypersensitivity to paracetamol is considered to be a rare occurrence, reactions may be represented by urticaria, angioedema, dyspnea, rhinitis or very rarely an anaphylactic reaction (Boussettel et al., 2005; Couto and Gaspar, 2012). According to Dart et al. (2006), the adult threshold for toxicity, which accounts for body weight, is 200 mg kg⁻¹. Toxicity can also occur when multiple smaller doses within 24 hours exceed these levels. Accidental overdose can occur from not reading or fully understanding the relevant instructions or by unwittingly ingesting different pharmaceutical products which contain the same drug (Sharif et al., 2003).

In the present study, the short-term exposure assessment (presented in Table 3) revealed that there was a possibility of an exposure of 0.02 µg associated with inhaling the lemon-flavoured paracetamol beverage. In light of the above discussion, a mass concentration of this magnitude represents little concern in terms of toxicity. However, as ill-health associated with normal usage has been reported in isolated cases (Vuppalanchi et al., 2007), and as the lemon-flavoured paracetamol powder was observed to produce an elevated particle concentration 1 m away from the event source, its significance should be considered from the aspect of secondary inhalation in particular scenarios. These could include, for example, the scenario where a common cold pervades a household, and an already-medicated infant inhales paracetamol powder while in close proximity to an adult who is preparing a soluble paracetamol beverage.

**Peanut**

Sicherer and Sampson (2007), in a review of peanut exposure, cautions that threshold studies are influenced by patient selection, the form of peanut used for testing, and study procedures. A study in adults (Wensing et al., 2002) noted mild reactions at as low as 0.1 mg ingested peanut protein. More recently, Zurzolo et al. (2013) report that the eliciting dose for a peanut allergic reaction, in 5% of the peanut allergic population, is 1.5 mg of peanut protein. References to allergic reactions resulting from peanut protein inhalation are few; in a self-report study (Sicherer et al., 1999) of peanut-induced allergy events aboard commercial flights, 14 out of 42 reactions were thought to have resulted from inhalation. Simonte et al. (2003) exposed children highly allergic to peanut to inhalation of peanut butter for ten minutes and to skin contact with a small amount of peanut butter for one minute; only local contact reactions were observed. They cautioned, however, that the situation would likely be different for powdery forms of peanut that can become airborne. In the present study, peanut powder rather than peanuts were tested, and it was found that due to the tendency of the particles to agglomerate, and not to become airborne, negligible aerosolisation was observed.

In summary, it has been found in this pilot study that short-term exposure during isolated events is of little concern in the case of the selected powdered peanut butter and paracetamol powders, although further investigation of specific scenarios is merited. Concentrations of milk powder particles in aerosol form were detected in this work at levels comparable to those found to elicit adverse health responses in other studies. This work is one of very few systematic investigations of aerosol exposures resulting from routine usage of consumer powder products, and there is clearly scope for a full-scale study that considers other commonly-used food and medicinal powders, and also explores interpersonal factors in terms of powder usage.

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**REFERENCES**


