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Endotoxin health risk associated with high pressure cleaning using reclaimed water

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ABSTRACT

As water scarcity increases globally, reclaimed water is becoming an increasingly valuable and environmentally sustainable water source. In particular, use of reclaimed water in occupational settings involving high volume water use can potentially confer significant benefits. Prior to expansion of the use of reclaimed water, it is important that potential health risks associated with different modes of exposure are thoroughly investigated. Reclaimed water regulation has predominantly focused on health risks presented by enteric pathogens via ingestion of contaminated water; however, less is known about the risk of infection and inflammatory responses associated with inhalation exposures. High pressure cleaning has been identified as causing increased exposure to aerosol components and is an activity performed in both domestic and occupational settings. We developed a method to estimate water exposure volumes deposited into the lungs during high pressure cleaning. This was achieved by using data from two earlier experimental studies: one which quantified the size distribution of aerosols generated by a high pressure spray device and another which measured the total volume of water ingested and/or inhaled by subjects undertaking a 10 min car washing activity. Using available information about endotoxin levels in reclaimed water and the deposition profile of aerosol particles in the lungs, we used Quantitative Risk Assessment to model the health risks of exposure to high pressure cleaning sprays. The model results suggest that using reclaimed water treated without membrane filtration may pose a health risk to workers spending 6 h per working day using high pressure sprays. In contrast, use of reclaimed water in domestic settings is likely to result in inhaled endotoxin exposures below the No Observed Effects Level (NOEL) even for reclaimed water without membrane filtration treatment. While this case study pertains to the cleaning of vehicles, it is relevant to the broader use of high pressure cleaning devices, illustrating how health risks associated with inhalation exposure may be determined for a range of water types and contaminants to inform the design of appropriate water treatment and other intervention measures. It is also the first time that experimental water exposure data have been combined with aerosol generation and deposition data to partition ingestion and inhalation exposure volumes. This method restricts upper estimates of exposure volumes that might otherwise be overestimated if it was assumed that all aerosols generated from the high pressure device were inhaled.

1. Introduction

As water scarcity increases globally, reclaimed water is becoming an increasingly valuable and environmentally sustainable water source. In particular, use of reclaimed water in occupational settings involving high volume water use may offer significant benefits. Prior to expansion of the use of reclaimed water for a variety of purposes, it is important that potential health risks associated with different modes of exposure are thoroughly investigated.

To date regulation of the quality of reclaimed waters has focused on reduction of infection risks for enteric pathogens. The Australian Guidelines for Water Recycling (NRMMC EPHC and AHMC, 2006) typify this approach with ingestion exposures for non-potable water being estimated for a range of end uses, and water treatment requirements then calculated to achieve a predetermined low level of health burden from residual enteric pathogens. However, as transmission via inhalation, not ingestion, is the more important route for some microorganisms (e.g. *Legionella, Mycobacteria*) and biological components (e.g. endotoxin),

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it is important that information gaps about inhalation exposure during specific water-using activities are addressed. This information is important to provide input to future iterations of reclaimed water guidelines, for application to new reclaimed water schemes, and to determine water treatment and/or protective equipment requirements for the protection of public health during occupational and other high use activities where exposures to sprays and aerosols of reclaimed water may occur.

Results of previous experimentation have suggested that microorganisms and biological components transmitted via the inhalation route (if present in the water supply) are of potentially greater health concern than those transmitted via the ingestion route when a high pressure rather than a conventional trigger nozzle spray device is used. This is based on an increased likelihood that water aerosols reach the alveolar region of the lungs because more than 96% of the aerosol mass generated by the high pressure device comprises particles within the respirable range (up to 10 µm diameter) as compared with 59–95% for conventional devices (O'Toole et al., 2009). As well, the potential for adverse health effects is higher in occupational settings (e.g. use of high pressure devices for machine wash-down or cleaning of fleet cars and surfaces) as compared with domestic ones, because of the increased duration and frequency of exposure.

In this paper we uniquely combine data from earlier experimental studies that were generated for disparate purposes. Firstly we use data on water exposure (combined indirect ingestion and inhalation) during car washing with a high pressure spray device (Sinclair et al., 2016). We combine these data with information about the size of aerosols and droplets generated by such a device during car washing (O'Toole et al., 2009) and finally, we develop a model to estimate the partitioning between ingestion and inhalation exposure volumes utilizing an existing model of lung deposition based on particle sizes (Yeh and Schum, 1980). Combined with information about frequency and duration of car washing, we use Quantitative Risk Assessment (QRA) modelling techniques to estimate the health effects associated with endotoxin transmitted via the inhalation route in both occupational and domestic settings where a high pressure cleaning device is used with reclaimed water produced with, and without, membrane treatment.

2. Material and methods

2.1. Hazard assessment and exposure model

Endotoxin was selected as the hazard of concern for this risk assessment based a number of factors: (i) adverse health effects have been shown to be associated with inhalation of endotoxin contained within water aerosols; (ii) there are documented threshold levels at which endotoxin in air elicits no adverse health effects (No Observed Effect Level –NOEL) and, (iii) measurements are available for endotoxin in reclaimed water produced using a variety of treatment processes, including membrane filtration.

Endotoxin is a component of the lipopolysaccharide (LPS) complexes that make up a part of the outer layer of the cell wall of most gram negative bacteria and some cyanobacteria (Anderson et al., 2007). The term endotoxin is used to describe the toxic activities associated with bacterial envelope components. Endotoxins are part of the structure of the bacterium and are usually released as 'blebs' of outer membrane that are heavily impregnated with lipopolysaccharide (Walker, 1998). Therefore for the most part, they are in particulate form. Documented symptoms of endotoxin exposure in humans from inhalation of water include coughs, breathing difficulties, chills, fever, muscle pain and aching of joints (Muittari et al., 1980). Endotoxin can cause profound inflammation of any exposed tissues, including lung tissue, but in order to elicit fever the endotoxin must enter the bloodstream. A potential mode of entry of endotoxin into the bloodstream associated with water usage is via the lungs following inhalation of aerosolized water droplets. The dermal mode of transmission is deemed to be of lesser significance based on it being unlikely that endotoxin can penetrate human skin and the relatively inefficient transfer from the dermis to the blood, as compared with transfer from the lung to the blood (Anderson et al., 2007). While ingestion is the most obvious transmission route for endotoxin in water, evidence for adverse health effects by this route has been considered generally lacking (Anderson et al., 2007), in contrast to a number of documented case reports and illness outbreaks for endotoxin inhalation (Anderson et al., 1996; Rose et al., 1998; Rylander, 1999). However, recent work has revealed disruptive effects of LPS on cellular tight junction permeability (considered the first line of defence against ingested toxic substances) in a human intestinal cell line (Narita et al., 2007), although the significance of this for human health remains to be determined.

Input parameters for the inhalation exposure model are presented in Table 1.

The starting point for construction of the model was the consumed volume of water (v_c; mL), obtained from a recent study of exposure to water spray generated during car washing with a high-pressure hose (Sinclair et al., 2016). In this instance we have defined *consumed* as the volume of water that enters the body from both inhalation (into the lungs) and ingestion (into the gastrointestinal (GI) tract) determined by measuring urinary excretion of the swimming pool chemical, cyanuric acid, in human subjects following performance of a car washing activity using water spiked with the chemical. The smallest volume able to be quantified in the experimental scenario was 0.06 mL. Where trace levels of cyanuric acid (above the assay limit of detection but below the limit of reliable quantitation) were detected in urine, we used half the limit of detection (0.025 mL) while non-detect samples were assumed to be 0.005 mL. A Lognormal distribution was assumed and defined ($n = 26$; refer to Table 1). For the occupational exposure scenario, we have assumed that a worker would spend 6 h per day (360 min; t_{ind}) using a high pressure hose for car washing. For the domestic scenario (t_{dom}), we have assumed that the average time using the high pressure hose during car washing was 10 min (O'Toole et al., 2008). We have also assumed that any variation in exposure during the time spent car washing has been captured by the measured exposure study (which spanned 10 min for each of 26 individuals).

In this assessment we were concerned only with inhalation; therefore, a model to partition the consumed volume between inhalation and ingestion pathways was constructed. The distribution of aerosol particle sizes in the breathing zone generated by a high pressure spray device was taken from a prior study (O'Toole et al., 2009). Concentrations of dried aerosols ($c_{aerosols}$; # cm^{-3}) were measured across 7 size ranges (from 0.06 to 20 µm) and these measurements were then adjusted to yield the size ranges for the original "wet" aerosols. This was done by multiplying by the hygroscopic growth factor (1.45) for ammonium sulphate which is commonly used as a reference value for typical indoor atmospheric particles (Gysel et al., 2002; Sjogren et al., 2007). The mean of background aerosol measurements ($n = 2$ for each size range) was subtracted from all experimental measurements and negative values were assumed to be zero. This subtraction was necessitated by the limitations of experimental conditions under which aerosol data were initially collected. Experiments were performed in a 'clean room' which was a positively pressurised enclosure within a larger space. The replacement rate of particles generated by the high pressure hose device exceeded that of their removal. Only two measurements of background particles were performed hence the average of these were subtracted from experimental results in each size bin. All aerosol measurements collected from the high