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Comparison of modeled estimates of inhalation exposure to aerosols during use of consumer spray products

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ABSTRACT

In the field of exposure science, various exposure assessment models have been developed to complement experimental measurements; however, few studies have been published on their validity. This study compares the estimated inhaled aerosol doses of several inhalation exposure models to experimental measurements of aerosols released from consumer spray products, and then compares deposited doses within different parts of the human respiratory tract according to deposition models. Exposure models, including the European Center for Ecotoxicology of Chemicals Targeted Risk Assessment (ECETOC TRA), the Consumer Exposure Model (CEM), SprayExpo, ConsExpo Web and ConsExpo Nano, were used to estimate the inhaled dose under various exposure scenarios, and modeled and experimental estimates were compared. The deposited dose in different respiratory regions was estimated using the International Commission on Radiological Protection model and multiple-path particle dosimetry models under the assumption of polydispersed particles. The modeled estimates of the inhaled doses were accurate in the short term, i.e., within 10 min of the initial spraying, with a differences from experimental estimates ranging from 0 to 73% among the models. However, the estimates for long-term exposure, i.e., exposure times of several hours, deviated significantly from the experimental estimates in the absence of ventilation. The differences between the experimental and modeled estimates of particle number and surface area were constant over time under ventilated conditions. ConsExpo Nano, as a nano-scale model, showed stable estimates of short-term exposure, with a difference from the experimental estimates of less than 60% for all metrics. The deposited particle estimates were similar among the deposition models, particularly in the nanoparticle range for the head airway and alveolar regions. In conclusion, the results showed that the inhalation exposure models tested in this study are suitable for estimating short-term aerosol exposure (within half an hour), but not for estimating long-term exposure.

1. Introduction

Consumers use various products that contain complex chemical compounds and are exposed to unknown hazards daily in several places such as the workplace and home. A limited number of chemicals are known to have toxicological effects, but there is little publicly available information for the remaining majority of chemicals in the markets (Dionisio et al., 2015). Some exposure models have been developed to determine the population-level exposure to a chemical by aggregating doses from years of simulated individual human interactions with various exposure pathways as they navigate daily life activities. These simulations require sufficient data to determine the daily life aspects that may cause exposure to a specific chemical (Dionisio et al., 2015; Price and Chaisson, 2005). Exposure models may be required to provide estimates of exposure as a screening tool because the environmental monitoring for consumer exposure assessment is relatively complex and time-consuming to conduct (Schneider et al., 2011).

With the introduction of engineered nanomaterials (ENMs) contained products in the market, the scope of exposure risk for ENMs is expanded from workers in the workplace to consumers in homes. In particular, the exposure to ENMs via the respiratory region is considered as the most likely situation that can cause adverse health effects for consumers (Hagendorfer et al., 2010). Risk assessment for ENMs is challenging because of the scarcity of quantitative exposure data and uncertainties about their hazard. Previous studies have used several exposure models to estimate the inhalation exposure to chemicals such as ECETOC TRA (Delmaar et al., 2013; ECETOC, 2004, 2009; ECETOC, 2012, 2014; Oltmanns et al., 2015), Stoffenmanager (Landberg et al.,

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Table 1
Summary of basic information on the selected models.

Model		Developer	Subject	Tier level	Exposure route	Input parameters	Output parameters	Note
Exposure model	CEM	US EPA	Consumer	Screening	Inhalation Dermal Oral	- Chemical properties - Product properties - Environmental conditions - Receptor exposure factors - Activity patterns	Acute dose (mg/kgbw/day) Chronic average daily dose (mg/kgbw/day)	–
	ECETOC TRA	ECETOC	Consumer Worker	Screening	Inhalation Dermal	- Product information - Chemical properties - Spraying patterns - Exposure factors - Activity patterns	Airborne concentration (mg/m^3) Inhaled dose (mg/kgbw)	–
	SprayExpo	BAuA	Worker	Higher tier	Inhalation Dermal	- Exposure scenario - Room size and ventilation - Spraying patterns - Product characterization - Spray nozzle characterization - Droplet spectrum	Airborne concentration (mg/m^3) Inhaled dose (mg/kgbw)	For spray products
	ConsExpo	RIVM	Consumer Worker	Higher tier	Inhalation Dermal Oral	- Exposure factors - Spraying patterns - Room size and ventilation - Nanomaterial characterization - Exposure scenario	Inhaled dose (mg/kgbw)	–
	ConsExpo Nano	RIVM	Consumer Worker	Higher tier	Inhalation Dermal Oral	- Exposure factors - Spraying patterns - Room size and ventilation - Nanomaterial characterization - Exposure scenario	Inhaled dose by metrics (number, mass, surface area)	Nano-specific model
Deposition model	ICRP Model	ICRP	Human	Higher tier	Inhalation	- Functional reserve capacity - Breathing rate - Breathing frequency - Deposition fractions	Inhaled dose by metrics Deposited dose by metrics	Nano-enabled model
	MPPD Model	ARA Inc.	Human Animal	Higher tier	Inhalation	- Airway morphometry - Inhalation properties - Exposure conditions - Deposition/clearance	Airborne concentration (mg/m^3) Deposited dose (mg/kgbw/day)	Nano-enabled model

Abbreviations: EPA, Environmental Protection Agency (USA; ECETOC, European Centre for Ecotoxicology and Toxicology of Chemicals (EU; BAuA, Federal Institute for Occupational Safety and Health (Germany; RIVM, National Institute for Public Health and the Environment (Netherlands; ARA, Applied Research Associates Inc. (USA; MSEA, Dutch Ministry of Social Affairs and Employment (Netherlands; CEM, Consumer Exposure Model; TRA, Targeted Risk Assessment; ICRP, International Commission on Radiological Protection; MPPD, Multi-Path Particle Dosimetry.

2015; Marquart et al., 2008; Schinkel et al., 2009; Tielemans et al., 2008) and Advanced REACH (Registration, Evaluation, Authorization and restriction of CHemical) Tool (ART) model (Fransman et al., 2011; Tielemans et al., 2011; Van Tongeren et al., 2011), but these models have limitations that may not be applicable for exposure to ENMs because the they are only mass-based. There are also some control banding tools regarding exposure to ENMs from spray products such as Stoffenmanager Nano, Nanosafer and Control Banding tool, but these models can only provide the conservative control measures to reduce the exposure risks at low tiered-level.

The objectives of this study were to compare estimates of inhaled aerosol doses of several inhalation exposure models to experimental measurements of aerosols released from consumer spray products, and then to compare deposited doses within different parts of the human respiratory tract using deposition models.

2. Methods

2.1. Realistic spraying experiment

2.1.1. Product spraying and measurement

An actual spraying experiment was conducted to compare between realistic exposure data and the modeled results. The entire processes including experimental settings to calculate the exposure dose were similar with the study we conducted previously (Park et al., 2017). The experiment was conducted in a cleanroom (40 m^3) which could control the background particles using a ventilation system with a high-efficiency particulate air (HEPA) filter (Fig. A.1 of Appendices in Supplementary material).

A nano-silver (AgNP) contained propellant spray product for indoor air deodorizer was selected for spraying because it is known that the product generally produces smaller aerosolized particles (less than a few micrometer range) which can penetrate into alveolar regions (Bekker et al., 2014; Hagendorfer et al., 2010; Lorenz et al., 2011; Losert et al., 2014). The weight fraction of AgNP in the product was 10% according to the safety data sheet (SDS) provided by the