



# Safety evaluation of hair-dryers marketed as emitting nano silver particles



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## ABSTRACT

Nanoparticle infused personal care products are becoming more common as consumer products. One example is a hair-dryer marketed as emitting silver nanoparticles (Ag NPs). The purpose of the silver nanoparticles (Ag NPs) is to give hair a sleek, shiny look while also promoting antimicrobial effects. This study investigates release of Ag NPs from hair-dryers and the effects associated with Ag NPs to the human epidural flora. To give an estimation of consumer exposure to Ag NPs with these products, three brands of hair-dryers were selected and particle samples emitted from the hair-dryers were collected based on size fractionation. Collected particles underwent elemental analysis. Silver was not detected in any of the samples. The Kirby-Bauer assay was used to detect a toxicity dose response relationship over a range of silver nanoparticles and silver nitrate (AgNO<sub>3</sub>) concentrations using five model bacteria species. This portion of the work represented the microbial response to Ag NPs and acted as a proxy for epidural microbial exposure to Ag NPs emitted from a hair-dryer. Findings from this study such as the recorded release of nanoparticles from the hair-dryers and the potential microbial toxicity effects caused from nanoparticle exposure will help consumers make more informed decisions regarding nanoparticle infused products.

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## 1. Introduction

Silver nanoparticles (Ag NPs) are becoming increasingly prevalent in common consumer goods due to their antibacterial effects, yet these particles have demonstrated toxicity in numerous organisms and may have negative ecological impacts (Navarro et al., 2008a; Lowry et al., 2010; Marambio-Jones and Hoek, 2010). Previous research has examined nanoparticle exposures to humans within the home and in the environment. Some examples include Ag NP release from clothing articles, human exposure to nanoparticle-containing consumer sprays, effects of laundry surfactants on the release and behavior of Ag NPs, and copper and Ag NP toxicity and transformations in aqueous environments (Benn and Westerhoff, 2008; Benn et al., 2010; Kaegi et al., 2011; Liu et al., 2012; Wirth et al., 2012; Skoglund et al., 2013; Hedberg et al., 2014; Losert et al., 2014; Lin et al., 2015; Taylor et al., 2015). Although, some characterization work with aerosolized Ag NPs has been conducted, a risk assessment and a toxicity

study on hair-dryers marketed as emitting Ag NPs, has not been conducted (Quadros and Marr, 2010, 2011; Holder and Marr, 2013).

Silver is known to have antimicrobial properties (Yang et al., 2011; Maillard and Hartemann, 2013) and silver nanoparticles cause antimicrobial and toxic effects to numerous types of organisms (Fabrega et al., 2009; Gorth et al., 2011; Yang et al., 2011). For example, exposing the skin's microbial community to potentially toxic or antimicrobial particles may have detrimental effects not only on the skin flora, but on overall human health (AshaRani et al., 2008; Panyala et al., 2008; Marambio-Jones and Hoek, 2010). Chronic exposure to silver nanoparticles may also have negative human health impacts such as argyria, kidney and liver damage, and skin, eye, intestinal, and respiratory tract irritation (Panyala et al., 2008; Hussain and Schlager, 2009; Ahamed et al., 2010). Furthermore, during the life cycle of nanoparticles, eventual release into the environment is likely (Keller et al., 2013), where nanoparticles may reduce viability and cause toxicity in freshwater and marine organisms (Griffitt et al., 2008; Navarro et al., 2008b; Chae et al., 2009). Understanding the release of nanomaterials into the environment during a product's lifecycle is an important component of user safety and environmental safety. Therefore, this study aims to: (1) collect and quantify Ag NPs emitted from

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consumer hair-dryers and (2) observe the responses of bacteria to silver nanoparticles collected from these products. The overall objective is an effort to better inform the consumer community when selecting products to use in the home.

## 2. Materials and methods

### 2.1. Hair-dryer selection

Three hair-dryers marketed as containing silver nanoparticles were selected for this study and purchased in 2012: (1) Remington Nano Silver Dryer (\$19.99, Model D-2015), (2) Infinity 230 Nano Silver Tourmaline Ceramic Folding Styler by Conair (\$26.18, Model 230R), and (3) Zazen Professional Nano-Silver Ionic Hair-dryer (\$85.99, Model Z1875); the Zazen's packaging specifically advertises that the Ag NPs "...purify and protect the hair for a silky, healthy finish. The nano sized particles sanitize and condition the hair, while reducing frizz". The dryers encompassed a range of prices and manufacturers that are commercially available to the public. Only three brands of hair-dryers were selected based on the clarity in the product's advertising and packaging. Due to proprietary information; little to no information is available on the Ag NPs within the products. Numerous silver hair-dryers are marketed with additional minerals such as ceramics and tourmaline which are also likely proprietary. Two tourmaline/silver hair-dryer that had clear labeling was selected for this work (Infinity and Zazen). Additionally, a hair-dryer that was not advertised as emitting nanoparticles was selected as a control, the Revlon 1875-watt ionic ceramic dryer (\$34.99, Model RVDR5001). Hair-dryers were bought in duplicate.

### 2.2. Particulate collection

A Micro-Orifice Uniform Deposition Impactor Model 110 (MOUDI) (MSP Corporation, Shoreview, MN) was used to collect size fractionated aerosol particle samples from the hair-dryers. The eleven MOUDI filter stages for size fractionation collection are 0.056, 0.1, 0.18, 0.32, 0.56, 1.0, 1.8, 3.2, 5.6, 10, and 18  $\mu\text{m}$  from bottom to top, respectively. The four hair-dryers (three Ag NP hair-dryers and one control) were each run for six hours with the hair-dryers positioned within approximately 3–6 inches of the MOUDI intake port. The hair-dryers were aimed directly at the MOUDI sampling intake port with a flow rate of 30 L/min. Aluminum filters were placed on each filter stage and weighed before and after the experiment with a Mettler Toledo UMX2 ultra-microbalance (Mettler-Toledo, LLC, Columbus, OH) to determine the amount of particulate matter emitted and collected from the hair-dryers. Additionally, as a positive control, 200 mg Ag NPs (Sigma Aldrich, USA) with a size of  $57 \pm 27$  nm were injected into the MOUDI and weighed.

Experiments were carried out in the Atmospheric Processes Laboratory (APL) at UC Riverside; the hair-dryer emission measurements were performed in the ambient air inside the APL facility. The APL facility has a highly controlled airflow system for atmospheric experiments. The control hair-dryer was first used to establish an ambient air particle mass by allowing the hair-dryer to emit ambient air into the MOUDI. Ambient mass collected on the filters was low, barely above measurement capability of the UMX2 ultra-microbalance. The low particle mass indicated that particle concentration found in the ambient air was minimal and experiments with the Ag NP hair-dryers did not need to be performed inside an indoor environmental chamber with stricter ambient particle regulation (Carter et al., 2005). The particle sizes in the ambient air ranged from 1 nm to slightly more than 10  $\mu\text{m}$  and this measurement is similar to the particle size distribution

of the ambient air (Kamens et al., 1991). The flow rate generated by each hair-dryer would have played a crucial role if silver nanoparticles were collected on the MOUDI filters because particle size distribution, silver density, and the flow rate of the hair-dryer are used to calculate mass accumulation as a quality control. However, no silver nanoparticles were detected with physicochemical characterization of the collected particulate matter and subsequently any variability due to flow rates was ignored.

Additionally, the three replicate test hair-dryers were disassembled and interior samples were collected for further elemental analysis by scraping the coils and interior areas in an attempt to detect the source of the Ag NPs. Specifically, the heating element, the bracket on the heating element that maintains the structure, the wire coils on the heating element, the grill, and the sheeting surrounding the heating element were scrapped for samples. No easily identifiable vessel was noted as a potential storage source of Ag NPs.

### 2.3. Physicochemical characterization

A scanning electron microscope (SEM) (Model FEI XL30-FEG, FEI, Hillsboro, OR) was used to image the particulate matter collected on the MOUDI aluminum foil filters. The SEM is equipped with an energy dispersive X-ray spectroscopy (EDS) EDAX Genesis system with a Si(Li) detector (EDAX, Mahwah, NJ). EDS provides elemental composition information of a sample. The samples were analyzed with EDS software EDAX Genesis Spectrum 6.2. Particulate matter samples collected from interior areas of the hair-dryer were also analyzed for silver using the EDS. Using a handheld X-ray fluorescence spectrometer Bruker Tracer IV (XRF) (Billerica, Massachusetts), further elemental analysis for silver detection was conducted on the outer portions of the hair-dryer body, such as on the handles and grills. The XRF instrument was capable of detecting down to 50 ppm of Ag NPs in test solutions with an organic amine solvent. Detection in aqueous solutions was limited in the ppm range, which is the range potentially expected in the hair-dryers (Furno et al., 2004).

A model Ag NP (Sigma Aldrich, USA) used to simulate NPs emitted from a hair-dryer for microbial exposure with the Kirby Bauer assay. The model Ag NPs were characterized by the University of California Center for Environmental Implications of Nanotechnology (UC-CEIN) with dynamic light scattering (DLS), transmission electron microscopy (TEM), and with inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Perkin Elmer Optima 2000 DV Model, PerkinElmer Inc., MA). Characterization showed the primary particle size as  $57 \pm 27$  nm using TEM (JEOL 1200 EX with 80 kV accelerating voltage, Jeol, Tokyo, Japan) and a zeta potential (ZetaPALS, Brookhaven Instruments, Holtsville, NY) of  $-44.7 \pm 1.6$  mV in deionized water (DI H<sub>2</sub>O). Further characterization measurements on the Ag NPs are found in Baptista et al. (2015).

### 2.4. Kirby Bauer assay

A standard bacterial assay traditionally used to measure antibiotic susceptibility and resistance, the Kirby Bauer (KB) assay, was applied to assess susceptibility of model bacteria to a model Ag NP and a silver nitrate (AgNO<sub>3</sub>) control. AgNO<sub>3</sub> represents an ionic silver form. The purpose of this portion of the study was to simulate the potential exposure of the skin flora to Ag NPs emitted from a hair-dryer. Both silver forms were prepared with the following methods. AgNO<sub>3</sub> standards and Ag NP test samples were made at the following concentrations: 0.1, 1, 10, and 100 mg/L in DI H<sub>2</sub>O. Before sampling, both the standard and test solutions were sonicated for five minutes to ensure even distribution. ICP-AES was used to validate the Ag NP and AgNO<sub>3</sub> concentrations used in the

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