



## Article

# Characterization of Inhalable Aerosols from Cosmetic Powders and Sustainability in Cosmetic Products

Hyeon-Ju Oh <sup>1,2,3,\*</sup>  and Jongbok Kim <sup>2,4,5,\*</sup> <sup>1</sup> Department of Public Health Sciences, Korea University, Seoul 02841, Korea<sup>2</sup> Advanced Materials Research Center, Kumoh National Institute of Technology, Gumi 39177, Korea<sup>3</sup> Department of Environmental Sciences, The State University of New Jersey, Rutgers, 14 College Farm Road, New Brunswick, NJ 08901, USA<sup>4</sup> Department of Materials Science and Engineering, Kumoh National Institute of Technology, 61 Daehak-ro (Yangho-dong), Gumi 39177, Korea<sup>5</sup> Department of Energy Engineering Convergence, Kumoh National Institute of Technology, Gumi 39177, Korea

\* Correspondence: ho95@envsci.rutgers.edu (H.-J.O.); jbkim@kumoh.ac.kr (J.K.)

Received: 14 September 2020; Accepted: 1 October 2020; Published: 4 October 2020



**Abstract:** Consumers may be exposed to aerosols that penetrate the lungs while applying cosmetics in a powder form. Toxic ingredients contained in aerosols can have a detrimental effect on the respiratory system. Two types of cosmetic powders were selected to evaluate the quantitative exposure of aerosols released from facial and eyeshadow products for five minutes. Scanning electron microscopy and energy-dispersive X-ray spectroscopy were used to analyze the morphology of the cosmetic particles and to measure the inorganic components in the related aerosol. Deposition fractions were calculated using the International Commission on Radiological Protection model to evaluate the deposition patterns in the regions based on the respiratory tract. The aerosol dosage was calculated from the aerosol concentrations. For all cosmetic powders, 78% of aerosol deposition occurred in the head airways, while less than 2.5% was deposited in the tracheobronchial region, and less than 1% was deposited in the alveolar regions. The calculated dosage for this study was 700  $\mu\text{g}$  for  $\text{PM}_{10}$  and 200  $\mu\text{g}$  for  $\text{PM}_{2.5}$ . This study presents a strategy for improving the sustainability of the cosmetic industry by providing a model for the quantitative evaluation and respiratory-based deposition of aerosols released from cosmetic powders.

**Keywords:** cosmetic powder; inhalable aerosol; sustainability; respiratory tract; deposition; dosage

## 1. Introduction

Cosmetics are attractive to consumers of various ages [1–3] because they enhance or change appearance without affecting the structure or function of the body [4]. According to the Environmental Working Group, women use an average of 12 products per day, containing 168 different chemicals [5,6]. Over 3000 chemicals are used to formulate a large range of fragrances used in consumer products worldwide [7]. In the United States alone, there are approximately 12,500 unique chemical ingredients approved for use in the manufacture of personal care products. The combination of active ingredients in cosmetics is essential for improving skin health in areas such as anti-aging, moisturizing, and acne treatment [8], and cosmetic manufacturers are constantly developing new products to meet the needs of users.

European Regulation (EC) No. 1223/2009 states that “cosmetics are any substance or mixture intended to come into contact with the external parts of the human body (epidermis, hair system, nails).” In particular, the EC regulations, which took effect 11 July 2013, stipulate that cosmetics found

in the European market must be safe for consumer health. Some commonly used cosmetics include products that can be rinsed immediately (e.g., shampoo, toothpaste), but each type of product includes a body emulsion that can touch the skin for several hours, especially a powder or spray that can be directly exposed to the body's respiratory system.

When using consumer products, airborne particles can be released as a respirable fraction of the health-related particle size [9–11]. Moreover, people may be exposed to nanosized and unsafe ingredients. For example, Zn [12,13], TiO<sub>2</sub> [14–29], SiO<sub>2</sub> [30–33], Ag [34–37] and Au substances [38,39] were included in respirable particles, and these airborne particles could penetrate deep into the gas-exchange regions of the lungs [40–45].

Currently, nano-cosmetics are an area of particular interest because nanomaterials can be used to create new types of products. Since nanotechnology is a key driver of product innovation, it has the potential to change many parts of everyday consumer goods, especially cosmetics, and a variety of products are already on the market. However, respirable-sized particles (including nanoparticles) in cosmetics have been used as unstable particles or insoluble particles that are decomposed into molecular components [46–51], and consumers must be assured about the safety of the particles used [52]. Ingredients present in cosmetics are used as antioxidants, preservatives, emollients, surfactants, pigments, fragrances, and ultraviolet absorbers, but are strictly regulated by relevant laws in many countries [53]. In addition, some toxicity studies have tested manufactured nanomaterial products in different exposure situations to demonstrate the adverse effects of nanoparticles containing metal that can induce significant neurotoxicity, cytotoxicity, and genotoxicity in human cell cultures, which is critical for assessing the health risk to human or animal cells. However, these studies only observed a dose-dependent and time-dependent relationship at the highest dose at 24 h and 48 h post-exposure in cultured human cells and did not consider a realistic exposure approach [54–60].

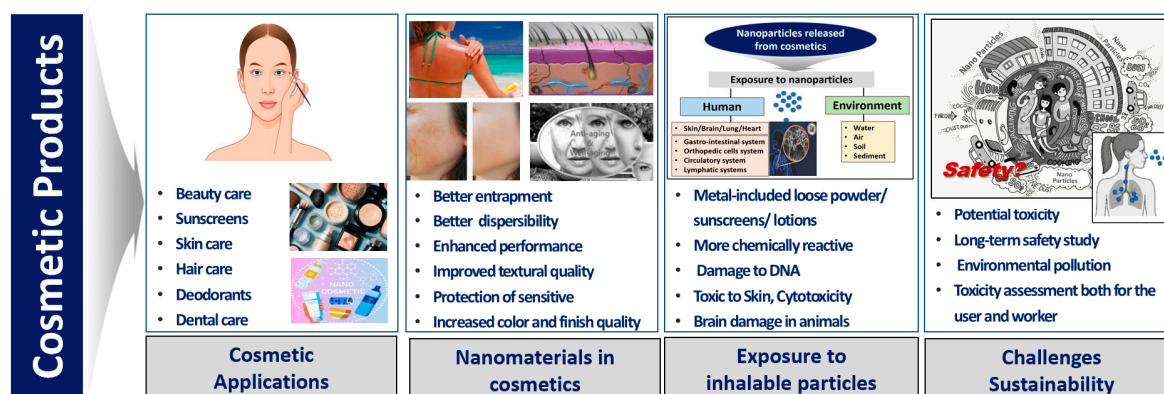
These issues raise concerns about potential consumer exposure to penetrating particles in the lungs, including the use of cosmetics and personal care products, and, in particular, the toxic inorganic components contained within them [53]. At the same time, relatively little is known about the quantitative exposure assessment to inhalable aerosols when using cosmetics in general. In a recent study investigating the potential inhalation exposure and lung deposition resulting from the use of cosmetic powders, including nanoparticle formulations [61], it was found that particles of respirable size (< 10 µm) were released and potentially inhaled. In the case of respirable-sized cosmetics, once inhaled, these particles settle in all areas of the respiratory system from the head airways to the alveoli. To this end, it is necessary to conduct a quantitative exposure assessment of aerosols generated when using cosmetics and to investigate possible toxic substances contained in the exposed aerosols.

The respiratory exposure characteristics depend on the chemical manufacturing route, the manufacturing process, and the conflicting views of manufacturers [62]. The report “Our Common Future” highlighted the need for a sustainable way of life [63]. Since then, the world has changed dramatically socially and economically, raising consumer awareness of environmental and social issues regarding resources consumed at an unsustainable rate. Based on these issues, the main decision to purchase cosmetics still depends on personal preferences, but environmental and ethical considerations are becoming increasingly important [64].

Another factor driving the cosmetics industry to a more sustainable path is the availability of raw materials that are advantageous from a sustainability perspective [65]. Some countries in the European Union have already banned the use of microplastics in cosmetics [66]. The use of plastic microbeads has decreased by 97.6% between 2012 and 2017; 4250 tons of plastic has been replaced [67]. From another sustainability perspective, some countries mandate the labeling of environmental indicators and impose various environmental taxes such as a packaging tax or landfill tax, which affects purchasing behaviors [68].

Furthermore, the cosmetic supply chain can have an impact on sustainability, so every step in the product lifecycle must be considered from the initial design and sourcing of raw materials to manufacturing, packaging, and distribution. The term “eco-innovation” is crucially an overall

assessment of the environmental impacts and risks [69], which can be a tool to support assessment within the environmental dimension of cosmetic sustainability [70] (Figure 1).



**Figure 1.** Cosmetic applications, exposure to inhalable particles released from cosmetics and sustainability challenges of future strategies [8,51,70].

In this study, we selected two types of cosmetic powders that can induce inhalable aerosols—facial cosmetics and eyeshadow cosmetics. We measured the amount of aerosol released when using them, investigated the morphology and chemical components of the particles, and estimated the respiratory dosage on women during cosmetic application. Thus, our study aimed to characterize particulate matter (PM) concentrations released during the application of cosmetic powders, estimate the respiratory dosage for the different cosmetic powder types, and evaluate the sustainability based on the environmental and health effects.

## 2. Materials and Methods

### 2.1. Tested Cosmetic Powders

Four products of two types (loose facial and eyeshadow cosmetic powders) were selected, and the ingredients for each product are shown in Table 1. We tested all cosmetic powders in their original condition as received without any pre-treatment or other modification. As a reference for the facial powder, a clean puff was used, while a clean, small brush was used for the eyeshadow.

**Table 1.** Cosmetic product types and ingredients as indicated by product labels.

Cosmetic Type		Ingredients
Facial Cosmetic Powder	FCP-a	Cruelty-free, Paraben-Free and Gluten-free. Mica, Silica, Phenoxyethanol, Ethylhexylglycerin. Iron Oxides (CI 77499, CI 77492, CI 77491)
	FCP-b	Talc, Calcium Silicate, Isopropyl Palmitate, Cetyl Acetate, Zinc Stearate, Fragrances, Stearyl Acetate, Imidazolidinyl Urea, Methylparaben, Acetylated Lanolin Alcohol, Oleyl Acetate, Propylparaben, (may contain: Titanium Dioxide, Iron Oxides, Zinc Oxide).
Eyeshadow Cosmetic Powder	ECP-a	Mica, Iron Oxides, Titanium Dioxide.
	ECP-b	Titanium Dioxide, Zinc Oxide, Iron Oxide, Sericite, Rose Powder, Kosher Grade Rice Powder, Mica, Kaolin Clay.

### 2.2. Sample Collection for Inhalable Aerosol from Cosmetic Products

For inhalable aerosol sampling, cosmetic powders, facial powder and eyeshadow were applied respectively on the face and under the eyelids of a soft silicone mannequin head with a smooth texture similar to human skin. The application time for each powder was 5 min based on realistic cosmetic

application, and the aerosol released from the cosmetics was sampled between the nose and mouth. To apply each cosmetic powder to the face and eyelids, a cosmetic puff or eyeshadow brush is tapped in a powder container or powder palette for 3 s and applied under the mannequin's face or eyelid for 10 s. The powder loading and application on the face or eyelids were repeated for 5 min.

Two sampling lines were mounted between the nose and mouth of the mannequin. One (left) line was connected to a real-time aerosol measurement device (Grimm 1.109 OPC, Grimm Technologies Inc., Douglasville, GA, USA) with a flow rate of 1.2 L/min and a GK 2.69 cyclone (Mesa Labs, Inc., Butler, NJ, USA) with a flow rate of 1.6 L/min. In order to meet the typical respiration rate of 11 L/min while sitting and performing light activity [71,72], a filter holder with a flow rate of 2.7 L/min was connected. Similarly, in the other (right) line, a filter holder with a flow rate of 5.5 L/min was connected to maintain a total flow rate of 11 L/min.

### 2.3. Morphology and Chemical Composition of Cosmetic Powders

The size, shape, and degree of aggregation for the original product state (i.e., at the time of purchase) and aerosols (PM<sub>10</sub>) generated during actual use were investigated using field emission scanning electron microscopy (FE-SEM, Zeiss Sigma, Oberkochen, Germany). For the original product, a powder sample was placed on the carbon tab of the sample mount and then dispersed throughout the tab using an air duster. The PM<sub>10</sub> released during this cosmetic application was collected using a 1 µm pore size filter (Isopore™, MilliporeSigma, St. Louis, MO, USA). After collecting the particles, the filters were cut to fit the tab size and all particles in the microscope view were observed. In addition, the inorganic elements present in the particles were analyzed using energy dispersive X-ray spectroscopy (Aztec EDX, Oxford Instruments plc, Abingdon, UK).

### 2.4. Quantification of Deposited Doses for Aerosols

The deposition fraction (DF) is the fraction of the number of inhaled particles that were deposited in the human respiratory tract (HRT). Based on the breathing rate, tidal volume, and aerodynamic diameter, DF can be calculated using different mathematical models, such as the International Commission on Radiological Protection (ICRP) model, the National Council on Radiation Protection and Measurements (NCRP) model, and the Multiple-Path Particle Dosimetry Model (MPPD v 3.04) model. In this study, the ICRP model was used [73].

As part of the exposure assessment and health risk prediction, dose is the amount of a contaminant inhaled by a person due to a specific activity or exposure to a contaminant over a defined period of time [73]. This mainly depends on the pollutant concentration, sedimentation rate according to particle size, breathing pattern (respiration frequency and tidal volume), and amount of breathing. In this study, the respiration rate was determined based on a sedentary woman (11.0 L/min) [71,72].

The DF during cosmetic application (5 min) was used to calculate the corresponding dose [µg] using Equation (1) [73]:

$$Dose = DF \times PM \times TV \times f \times t \quad (1)$$

where *DF* is the deposition fraction in the head, tracheobronchial, and pulmonary regions of the HRT using the ICRP model; *PM* (µg/m<sup>3</sup>) is the concentration released from the cosmetic powder during application, *TV* (0.5 m<sup>3</sup>/breath) is tidal volume, *f* is breathing frequency (15 breaths/min), and *t* is the exposure time (5 min).

### 2.5. Data Analysis

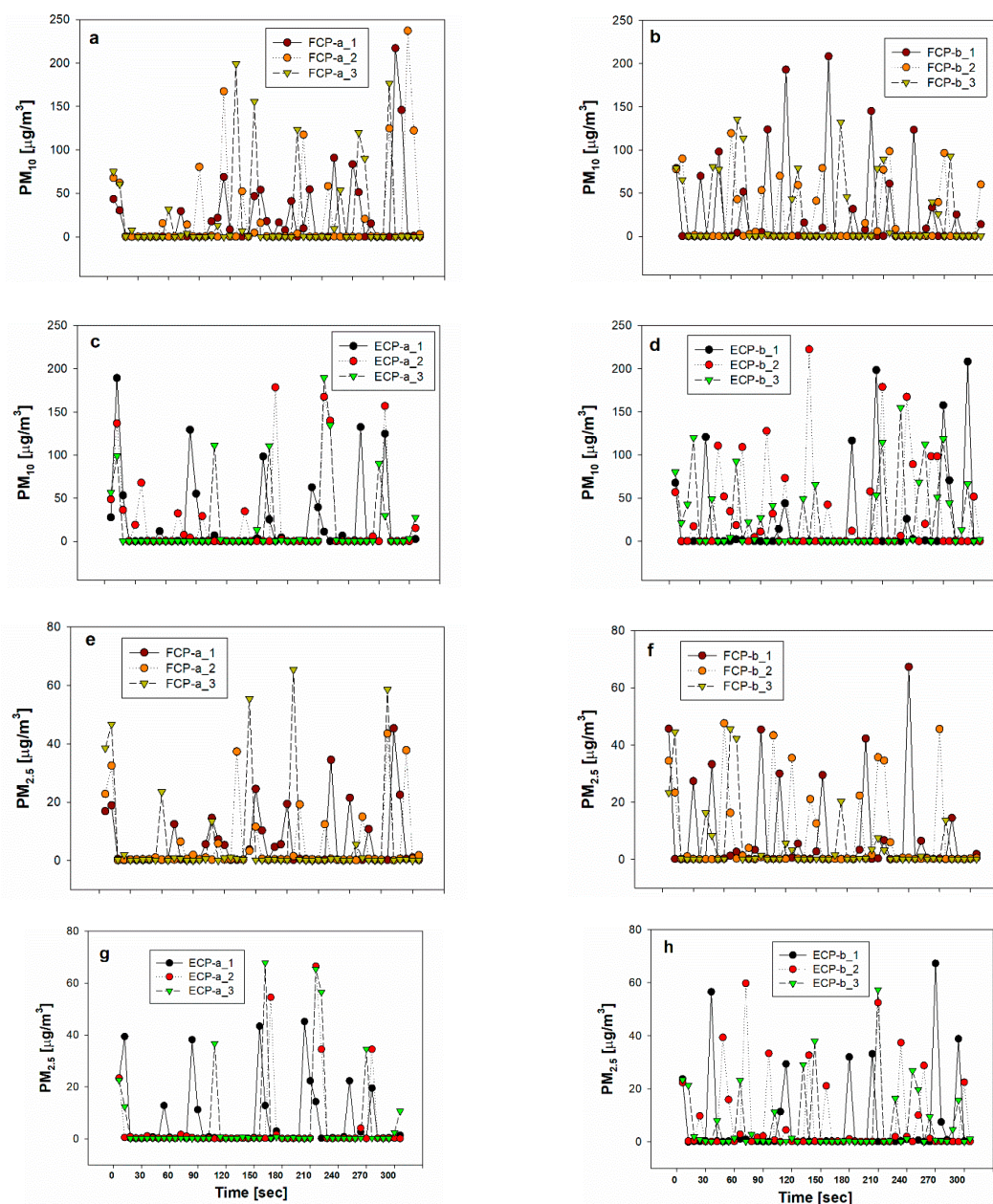
The average PM concentrations were analyzed as a function of cosmetic product types (facial cosmetic powder—FCP-a, FCP-b, eyeshadow cosmetic powder—ECP-a, and ECP-b) using one-way ANOVA with Sigmaplot 2011 (Version 12.3, Systat Software Inc., San Jose, CA, USA).



### 3. Results

#### 3.1. Inhalable Aerosol ( $PM_{10}$ , $PM_{2.5}$ ) Concentrations from Cosmetic Powders

As inhaled aerosol particles, the real-time  $PM_{10}$  and  $PM_{2.5}$  concentrations measured by Grimm 1.109 OPC during cosmetic powder application are shown in Figure 2. For each product, the results during 5 min of application are shown. The highest  $PM_{10}$  concentration ranged from 189.3 to 222.4  $\mu\text{g}/\text{m}^3$  (217.1  $\mu\text{g}/\text{m}^3$ , 208.5  $\mu\text{g}/\text{m}^3$ , 189.3  $\mu\text{g}/\text{m}^3$ , and 222.4  $\mu\text{g}/\text{m}^3$  for FCP-a, FCP-b, ECP-a, and ECP-b, respectively), and the highest concentration of  $PM_{2.5}$  ranged from 55.4 to 67.9  $\mu\text{g}/\text{m}^3$ , (55.4, 67.3, 67.9, and 67.3  $\mu\text{g}/\text{m}^3$  for FCP-a, FCP-b, ECP-a, and ECP-b, respectively) depending on the cosmetic product.

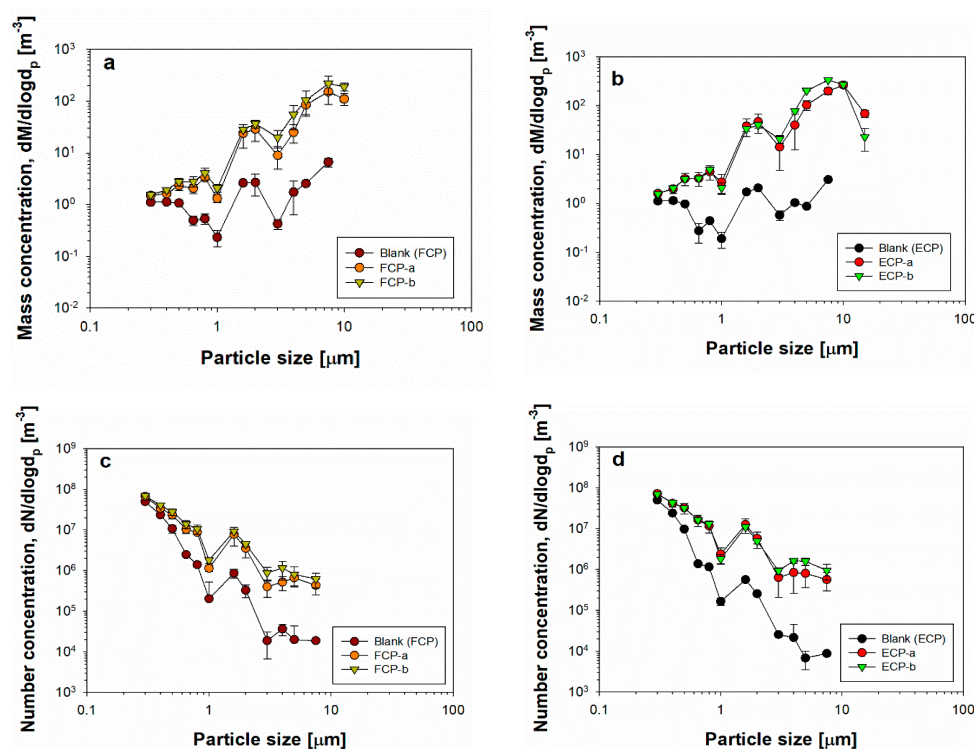


**Figure 2.** Temporal patterns of  $PM_{10}$  concentrations for (a) FCP-a, (b) FCP-b, (c) ECP-a and (d) ECP-b and  $PM_{2.5}$  concentrations for (e) FCP-a, (f) FCP-b, (g) ECP-a and (h) ECP-b.

For the applied cosmetic powder, all real-time data is the result of subtracting the background particle concentration of the measured indoor space. As shown in Figure 2, some PM<sub>10</sub> peaks reached 250 µg/m<sup>3</sup> and 80 µg/m<sup>3</sup> for PM<sub>2.5</sub> during 5 min of application of each cosmetic product, and the maximum concentration values of the facial and eyeshadow cosmetic powders were similar.

### 3.2. Mass and Number Concentrations for Cosmetic Particles

The particle size distribution of all released and inhaled powders measured by Grimm 1.109 OPC relative to the mass and number concentrations is shown in Figure 3. As a reference before each cosmetic application, an initial test was performed by applying a clean puff for the facial cosmetic powder and a clean brush for the eyeshadow cosmetic powder.



**Figure 3.** Particle size distribution during cosmetic powder application. Mass concentration (a,b) and number concentration (c,d) for facial cosmetic powders (FCP-a, b) and eyeshadow cosmetic powders (ECP-a, b).

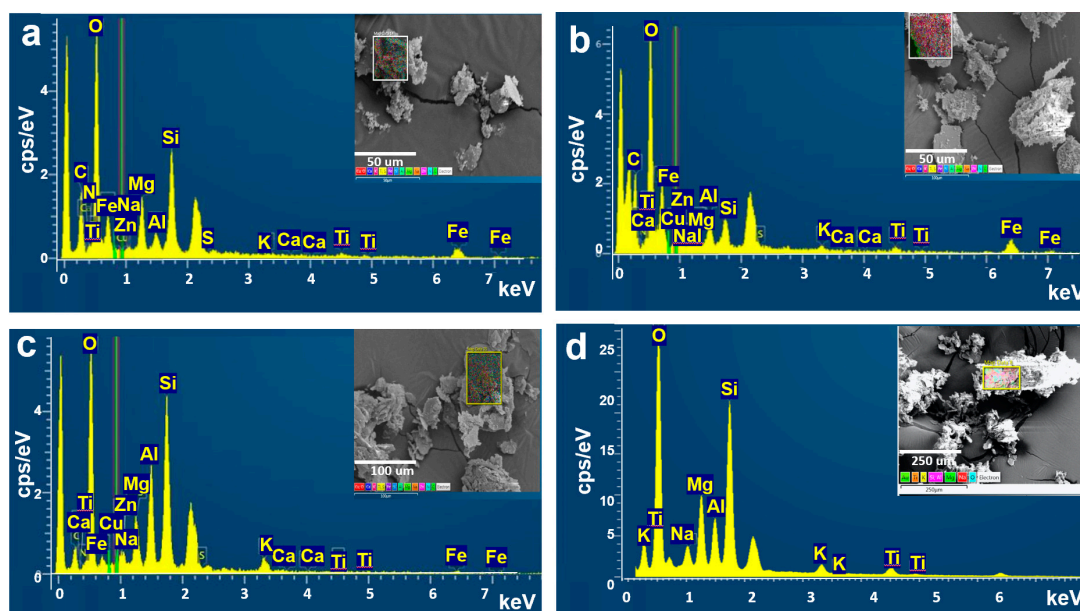
The mass concentration increased as particle size increased (Figure 3a,b). The mass concentration ranged from  $1.0 \times 10^0$  µg/m<sup>3</sup> at 0.3 µm to  $1.0 \times 10^2$  µg/m<sup>3</sup> at 8 µm. In addition, the mass and number concentration profiles of the individual products were comparable, except for the mass concentration profile for ECP-a and ECP-b.

Both facial and eyeshadow cosmetic powders showed a number concentration increase of  $1.0 \times 10^2$  particles/m<sup>3</sup> or more at a particle size of 1 µm or larger. For the number concentration, the highest value was observed at 1 µm or smaller for the smallest particle ( $1.0 \times 10^8$  particles/m<sup>3</sup>). In addition, there was a peak again at 2 µm, where the concentration was approximately  $1.0 \times 10^7$  particles/m<sup>3</sup>.

Overall, the concentration profiles of all products were similar. The concentration of the number of particles released when using a clean brush was over 2 times lower than when applying powder, and the profiles are slightly different. The distribution profile of the particles coming out of the clean brush closely follows the powder distribution from 0.6 µm to 1 µm and then decreases substantially.

### 3.3. Characterization of Morphology and Chemical Components

The particle size fraction and the size, shape, and agglomeration of the original samples were examined via FE-SEM before applying the cosmetics. All photographs of the powder were investigated by uniformly distributing some particles on the carbon tab during FE-SEM measurement. Representative micrographs are shown in the insets of Figure 4.



**Figure 4.** FE-SEM and EDX analysis of cosmetic powders (a) FCP-a, (b) FCP-b, (c) ECP-a, and (d) ECP-b.

The micrographs of the original cosmetic powder showed the presence of large particles, agglomerates, and aggregates with a size of 10  $\mu\text{m}$  or larger, mostly containing plate-shaped particles. All the products applied were present as complex aggregates.

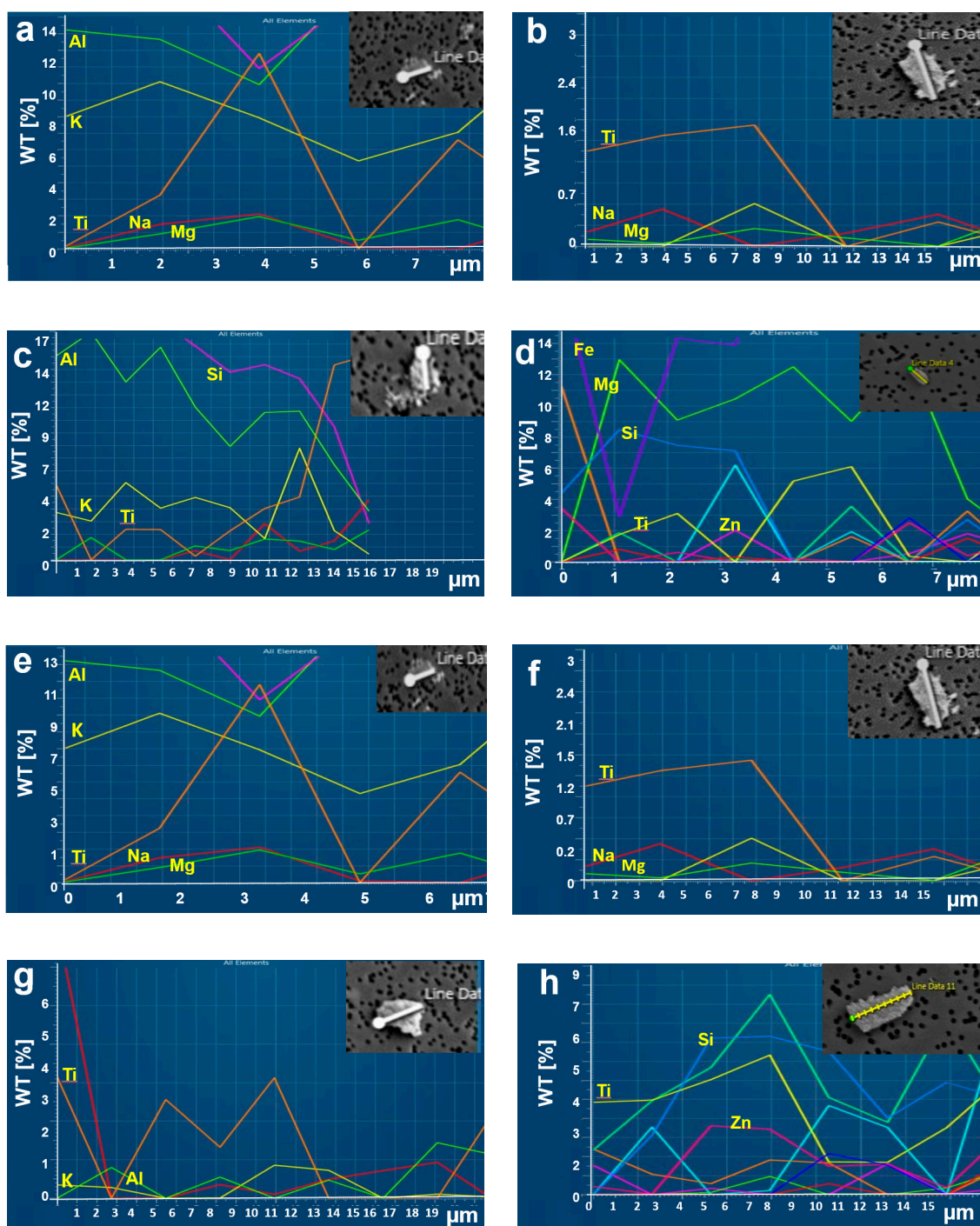
EDX was used to estimate the presence of inorganic components based on the FE-SEM map analysis of the particles in Figure 4. Each component in the particle map analysis is reported as wt. (%). Since the wt. (%) is determined based on the element selected for EDX, there may be slight variations in the true content. In addition, the content of each component may vary depending on the selected particles. In this study, the content of the inorganic elements was investigated based on the inorganic components present in the label of each product. In the analysis, at least three microscope views were examined for each sample and several particles were examined within each view.

### 3.4. Characterization of Chemical Components Based on Particle Size

Using line map analysis in EDX, we determined the content of the inorganic elements based on the individual particle sizes. In previous *in vitro* and *in vivo* studies, the existence of Ti and Zn, which are toxic components, was confirmed.

Since the content analysis is based on a specified inorganic element, the content may vary depending on the element chosen, and the fraction of the inorganic element may differ depending on the chosen particle. We found that Ti and Zn existed in respirable sizes (less than 4  $\mu\text{m}$ ): 1.3–7.0% for Ti (Figure 5b,e) and 2% for Zn (Figure 5d,h). In addition, the distribution of inorganic components could be different depending on the particle size, and the respirable-sized inorganic components could penetrate the respiratory system when each particle is released from the original cosmetic powders.





**Figure 5.** Line-scanning measured by EDX analysis. (a–d): Inhalable particles released from FCP (facial cosmetic powders); (e–h): inhalable particles released from ECP (eyeshadow cosmetic powders).

Although the use of EDX to determine the inorganic component for each particle is evaluated by the randomness of the particle distribution of a limited portion of the sample, the presence of potentially toxic components, such as Ti and Zn, in cosmetics could provide important information regarding the use of the powders.

### 3.5. PM Deposition Fraction and Dosage in Respiratory System

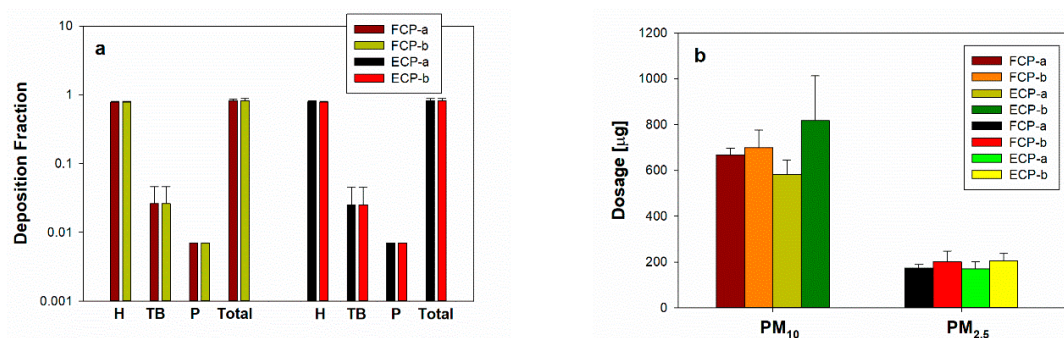
For the cosmetic powder particles investigated (FCP-a, FCP-b, ECP-a, and ECP-b), 78–79% of aerosol deposition occurred in the head airways, while less than 2.5% was deposited in the



tracheobronchial region, and less than 1% was deposited in the alveolar regions. In the respiratory system, less than 1% of the respirable particles penetrated into the lungs, but the value of DF for various particle sizes depends primarily on the deposition mechanism within the respiratory tract. In fact, in the case of particles generated when using cosmetics, each particle is associated with an increase in the diffusion deposition rate due to a decrease in the respirable size. A DF value was calculated; however, due to the variations in ventilation and respiration patterns (tidal volume), respiration frequency, age, and activity, the value could vary given the small number of particles in the lungs.

Dosage is a common indicator used in exposure assessments to predict health effects. In this study, the inhalable capacity (based on  $PM_{10}$ ) and respirable capacity (based on  $PM_{2.5}$ ) were calculated from Grimm 1.109 OPC using the concentration of the number of PMs generated in the cosmetic powder.

The calculated dosage for  $PM_{10}$  generated from facial cosmetic powders (FCP-a, FCP-b) ranged from 667.72 to 698.16  $\mu\text{g}$  while the calculated dosage for eyeshadow cosmetic powders (ECP-a, ECP-b) ranged from 581.57 to 816.98  $\mu\text{g}$  (Figure 6b). For  $PM_{2.5}$ , the calculated dose ranged from 173.61 to 200.41  $\mu\text{g}$  for the facial cosmetic powders and from 170.98 to 2014.61  $\mu\text{g}$  for the eyeshadow cosmetic powders. Table 2 showed the simulated dosage of women during cosmetics applications for facial powders and eyeshadow powders.



**Figure 6.** Deposition fraction (a) and deposited dosage (b) of PM obtained from cosmetic powders. FCP-a, FCP-b: facial cosmetic powders; ECP-a, ECP-b: eyeshadow cosmetic powders. H: head; TB: tracheobronchial; P: pulmonary.

**Table 2.** Simulated dosage of women calculated using a soft silicone mannequin head during cosmetics application for cosmetic powders.

Cosmetics	$PM_{10}$ [ $\mu\text{g}$ ]			$PM_{2.5}$ [ $\mu\text{g}$ ]		
	H	TB	P	H	TB	P
FCP-a	651.02 $\pm$ 28.54	21.70 $\pm$ 0.95	5.84 $\pm$ 0.26	169.27 $\pm$ 15.70	5.64 $\pm$ 0.52	1.52 $\pm$ 0.14
FCP-b	680.70 $\pm$ 76.11	22.69 $\pm$ 2.54	6.11 $\pm$ 0.68	195.40 $\pm$ 46.05	6.51 $\pm$ 1.53	1.75 $\pm$ 0.41
ECP-a	567.03 $\pm$ 60.49	18.90 $\pm$ 2.02	5.09 $\pm$ 0.54	166.71 $\pm$ 29.15	5.56 $\pm$ 0.97	1.50 $\pm$ 0.26
ECP-b	796.56 $\pm$ 190.30	26.55 $\pm$ 6.34	7.15 $\pm$ 1.71	199.49 $\pm$ 30.87	6.65 $\pm$ 1.03	1.79 $\pm$ 0.28

Note: H: head; TB: tracheobronchial; P: pulmonary.

### 3.6. Sustainability Aspects of Cosmetic Products

The median global production of  $TiO_2$  (3000 tons/year) and  $ZnO$  (550 tons/year) exceeds that of Ag (55 tons/year) [62]. The FDA and large cosmetic companies claim that the chemicals commonly used in beauty products (e.g., parabens, sodium lauryl sulfate, petrolatum, phthalates, synthetic polymers, synthetic fragrances) are safe in small amounts, but none have long-term benefits. Although the FDA has recommended that manufacturers ensure the safety of their products and ingredients, it is not necessary for companies to share safety information with the FDA or to perform specific tests to prove the safety of the individual products or ingredients, and cosmetic companies do not require formal reporting of their products.

There is no legal obligation for cosmetics to evaluate environmental and health effects. Although these legal regulations have not been specifically established, and the health and safety implications of exposure to cosmetic ingredients are uncertain, it is essential for the cosmetic industry to demonstrate the safety of the components of concern to support sustainability in terms of industrial, environmental, and human health.

For the FDA, some of the key points that should be included in the safety assessment under recent guidelines [19] are the physicochemical properties, agglomeration and size distribution, morphology, solubility, density, porosity, stability, and impurities of the nanomaterials. In addition, potential routes of exposure to the nanomaterials should be identified, and in vitro and in vivo toxicological analyses should be performed, including inhalation studies of genotoxicity and cytotoxicity [14]. In June 2014, to address the nanotechnology problem in cosmetics, the FDA published separate guidance on the safety of nanomaterials in cosmetics.

The guidelines for the cosmetic industry will improve its sustainability based on environmental safety and human health. They have already provided guidance and potential solutions for industry and other stakeholders regarding the safety evaluation of nanomaterials. In addition, these guidelines help to identify safety issues in particulate matter of respirable size as well as in the penetration of harmful components into the respiratory system. They also offer guidance in how to understand and evaluate the mechanisms. Ensuring the safety of cosmetics that introduce harmful ingredients into the respiratory system, including nanomaterials, could be a key strategy for the sustainability of the cosmetics industry [74].

#### 4. Discussion

In this study, the amount of aerosol PM released during the application of the makeup was measured using cosmetic powders and formed the basis for preparing product, environmental, and health evaluation strategies based on the sustainability of the cosmetic industry.

The shape of the particles released from the original and cosmetic powders was characterized, and the amount of aerosol released during the application of the cosmetic product was quantified (Figures 2 and 3). The results provide quantitative means to assess toxicity through actual exposure compared with the toxicity assessment of a single substance conducted in past studies.

Through EDX analysis, it was shown that for aerosols generated during the application of the cosmetics, the content of components from the aerosol particles generated in the same cosmetic material may vary depending on the particle size, and their component content may vary between particles. Thus, EDX analysis provided comprehensive results for conducting health risk assessments and identifying cosmetic sources through aerosol measurements. The highest concentration of PM<sub>10</sub> released from the facial and eyeshadow powders applied for 5 min was approximately 250 µg/m<sup>3</sup>, and the maximum concentration of PM<sub>2.5</sub> was 80 µg/m<sup>3</sup> (Figure 2).

Poor indoor air quality can lead to numerous adverse health problems, such as nausea, headaches, skin irritation, sick building syndrome, kidney failure, and even cancer [75]. Especially, exposure to PM<sub>2.5</sub> (2.5 µm or less in diameter) can also affect lung function and worsen medical conditions such as asthma and heart disease. IAQ (Indoor Air Quality) standard limit value for PM<sub>2.5</sub> is 25 µg/m<sup>3</sup>, based on 24-h data [75] and the instantaneous maximum exposure concentration to PM<sub>2.5</sub> released from cosmetic powders in this study reached 80 µg/m<sup>3</sup>. Thus, inhaled particles, especially PM<sub>2.5</sub> released from cosmetic powder could exist as one of the indoor pollutant sources when cosmetic powders are used by consumers daily.

The regional pattern of deposition of inhaled particles in the respiratory system is often a determinant of pathogenic potential and is clearly related to the topographical distribution of certain lung diseases [76]. Due to the size-related properties of particles, the deposited doses in the respirable system have shown potential problems, including retention and mobility in the human body [73,76]. The amount of inhaled and deposited doses in the respiratory system may vary depending on the

individual inhalation rate, body weight, lung capacity and powder application time, but the estimated dosage in this study was 700 µg for PM<sub>10</sub> and 200 µg for PM<sub>2.5</sub> (Figure 6).

Considering the human inhalation rate (11 L/min) applied in this study and IAQ standard limit value for PM<sub>2.5</sub> (25 µg/m<sup>3</sup>), calculated inhalation dose of PM<sub>2.5</sub> is 396 µg. The estimated inhalation PM<sub>2.5</sub> dose was 200 µg during applying cosmetics, which reached 50% of the amount of PM<sub>2.5</sub> that could be inhaled per day.

The DF calculated using the ICRP model was less than 1% (Figure 6), but based on SEM and EDX analysis, if respirable-sized particles were deposited in the pulmonary system, toxic components, such as Zn and Ti, could be present together. In addition, it was found that the content of ingredients may vary depending on the size of the aerosol particles produced in the same product, suggesting that not only quantitative exposure but also ingredient exposure should be considered when using cosmetics. It has been shown that aerosols, including nano-sized aerosols, can be more lethal.

Currently, the cosmetic industry has adopted a nanotechnology-based synthesis of various ingredients. Considering the sustainability of the cosmetic industry and the fate of inhaled cosmetic particles in the respiratory system, guidelines for environmental safety and health risk assessment based on real quantification and analysis of ingredients is essential for the sustainability of the consumer goods industry, including cosmetics.

## 5. Conclusions

This study presented a strategy for improving the sustainability of the cosmetic industry by providing a model for the quantitative evaluation and respiratory system-based deposition of aerosols released from cosmetic powders. We proposed an effective method for quantitatively measuring aerosol exposure in order to improve the sustainability of the cosmetic industry and enhance the personal health impact assessment.

A new aspect of this approach is an integrated risk-based strategic analysis study for the sustainability of the cosmetics industry, along with a personal model that allows quantitative exposure assessments in the use of consumer goods, including cosmetics.

**Author Contributions:** Conceptualization, H.-J.O. and J.K.; methodology, H.-J.O. and J.K.; investigation, H.-J.O.; data curation, H.-J.O. and J.K.; modeling, H.-J.O. and J.K.; writing—original draft preparation, H.-J.O.; writing—review and editing, H.-J.O. and J.K. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the National Research Foundation of Korea Grant, grant numbers NRF-2018R1A6A1A03025761 and NRF-2018R1A6A3A11048705.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Ficheux, A.S.; Dornic, N.; Bernard, A.; Chevillotte, G.; Roudot, A.C. Probabilistic assessment of exposure to cosmetic products by French children aged 0-3 years. *Food Chem. Toxicol. Int. J. Publ. Br. Ind. Biol. Res. Assoc.* **2016**, *94*, 85–92. [CrossRef] [PubMed]
2. Biesterbos, J.W.; Dudzina, T.; Delmaar, C.J.; Bakker, M.I.; Russel, F.G.; von Goetz, N.; Scheepers, P.T.; Roeleveld, N. Usage patterns of personal care products: Important factors for exposure assessment. *Food Chem. Toxicol. Int. J. Publ. Br. Ind. Biol. Res. Assoc.* **2013**, *55*, 8–17. [CrossRef] [PubMed]
3. Gomez-Berrada, M.P.; Ficheux, A.S.; Guillou, S.; Berge, C.; de Javel, D.; Roudot, A.C.; Ferret, P.J. Consumption and exposure assessment to cosmetic products for children under 2 years old. *Food Chem. Toxicol. Int. J. Publ. Br. Ind. Biol. Res. Assoc.* **2017**, *105*, 151–160. [CrossRef] [PubMed]
4. Nourmoradi, H.; Foroghi, M.; Farhadkhani, M.; Vahid Dastjerdi, M. Assessment of lead and cadmium levels in frequently used cosmetic products in Iran. *J. Environ. Public Health* **2013**, *2013*, 962727. [CrossRef]
5. Lupkin, S. Women Put an Average of 168 Chemicals on Their Bodies Each Day, Consumer Group Says. Available online: <https://abcnews.go.com/Health/women-put-average-168-chemicals-bodies-day-consumer/story?id=30615324> (accessed on 10 August 2020).

6. Chow, L. Women Apply an Average of 168 Chemicals on Their Bodies Every Day. Available online: <https://www.ecowatch.com/women-apply-an-average-of-168-chemicals-on-their-bodies-every-day-1882041568.html> (accessed on 5 September 2020).
7. Jones, O.; Sellinger, B. The Chemistry of Cosmetics. *Australian Academy of Science*. Available online: <https://www.science.org.au/curious/people-medicine/chemistry-cosmetics> (accessed on 13 August 2020).
8. Kumud, M.; Sanju, N. Nanotechnology Driven Cosmetic Products: Commercial and Regulatory Milestones. *Appl. Clin. Res. Clin. Trials Regul. Aff.* **2018**, *5*, 112–121. [[CrossRef](#)]
9. Baan, R.A. Carcinogenic hazards from inhaled carbon black, titanium dioxide, and talc not containing asbestos or asbestiform fibers: Recent evaluations by an IARC Monographs Working Group. *Inhal. Toxicol.* **2007**, *19*, 213–228. [[CrossRef](#)]
10. CCOHS How Do Particulates Enter the Respiratory System? Available online: [https://www.ccohs.ca/oshanswers/chemicals/how\\_do.html](https://www.ccohs.ca/oshanswers/chemicals/how_do.html) (accessed on 26 August 2020).
11. IARC. *Carbon Black, Titanium Dioxide, and Talc*; IARC Monographs on the Evaluation of Carcinogenic Risks to Humans; IARC Press, International Agency for Research on Cancer: Lyon, France, 2010; Volume 93.
12. Guan RK, T.; Lu, F.; Zhang, Z.; Shen, H.; Liu, M. Cytotoxicity, oxidative stress, and genotoxicity in human hepatocyte and embryonic kidney cells exposed to ZnO nanoparticles. *Nanoscale Res. Lett.* **2012**, *7*, 602–608. [[CrossRef](#)]
13. Alarifi, S.; Ali, D.; Alhadlaq, H.A. Induction of oxidative stress, DNA damage, and apoptosis in a malignant human skin melanoma cell line after exposure to zinc oxide nanoparticles. *Int. J. Nanomed.* **2013**, *8*, 983–993.
14. Donner, E.M.; Myhre, A.; Brown, S.C.; Boatman, R.; Warheit, D.B. In vivo micronucleus studies with 6 Titanium Dioxide materials (3 pigment-grade & 3 nanoscale) in orally-exposed rats. *Regul Toxicol Pharm.* **2016**, *74*, 64–74.
15. Guichard, Y.S.J.; Darne, C.; Gaté, L.; Goutet, M.; Rousset, D.; Binet, S. Cytotoxicity and genotoxicity of nanosized and micro-sized Titanium Dioxide and Iron Oxide particles in Syrian Hamster embryo cells. *Ann. Occup. Hyg.* **2015**, *56*, 631–644.
16. Hamzeh, M.; Sunahara, G.I. In vitro cytotoxicity and genotoxicity studies of titanium dioxide (TiO<sub>2</sub>) nanoparticles in Chinese hamster lung fibroblast cells. *Toxicol. In Vitro* **2013**, *27*, 864–873. [[CrossRef](#)] [[PubMed](#)]
17. Jomini, S.L.J.; Bauda, P.; Pagnout, C. Modifications of the bacterial reverse mutation test reveals mutagenicity of TiO<sub>2</sub> nanoparticles and byproducts from a sunscreen TiO<sub>2</sub>-based nanocomposite. *Toxicol Lett.* **2012**, *215*, 54–61. [[CrossRef](#)] [[PubMed](#)]
18. Landsiedel, R.M.-H.L.; Van Ravenzwaay, B.; Schulz, M.; Wiench, K.; Champ, S.; Oesch, F. Gene toxicity studies on titanium dioxide and zinc oxide nanomaterials used for UV-protection in cosmetic formulations. *Nanotoxicology* **2010**, *4*, 364–381. [[CrossRef](#)] [[PubMed](#)]
19. Lindberg, H.K.; Falk, G.-M.; Catalán, J.; Koivisto, A.J.; Suhonen, S.; Järventaus, H.; Norppa, H. Genotoxicity of inhaled nanosized TiO<sub>2</sub> in mice. *Mutat. Res. Genet. Toxicol. Environ. Mutagen.* **2012**, *745*, 58–64. [[CrossRef](#)] [[PubMed](#)]
20. Naya, M.; Kobayashi, N.; Ema, M.; Kasamoto, S.; Fukumuro, M.; Takami, S.; Nakanishi, J. In vivo genotoxicity study of titanium dioxide nanoparticles using comet assay following intratracheal instillation in rats. *Regul. Toxicol. Pharm.* **2012**, *62*, 1–6. [[CrossRef](#)]
21. Sadiq, R.; Bhalli, J.A.; Yan, J.; Woodruff, R.S.; Pearce, M.G.; Li, Y.; Chen, T. Genotoxicity of TiO<sub>2</sub> anatase nanoparticles in B6C3F1 male mice evaluated using Pig-a and flow cytometric micronucleus assays. *Mutat. Res.* **2012**, *745*, 65–72. [[CrossRef](#)] [[PubMed](#)]
22. Tavares, A.M.; Louro, H.; Antunes, S.; Quarré, S.; Simar, S.; De Temmerman, P.-J.; Silva, M.J. Genotoxicity evaluation of nanosized titanium dioxide, synthetic amorphous silica and multi-walled carbon nanotubes in human lymphocytes. *Toxicol. In Vitro* **2014**, *28*, 60–69. [[CrossRef](#)]
23. Wang, S.; Hunter, L.A.; Arslan, Z.; Wilkerson, M.G.; Wickliffe, J.K. Chronic exposure to nanosized, anatase titanium dioxide is not cyto- or genotoxic to Chinese hamster ovary cells. *Environ. Mol. Mutagen.* **2011**, *52*, 614–622. [[CrossRef](#)]
24. Woodruff, R.S.; Li, Y.; Yan, J.; Bishop, M.; Jones, M.Y.; Watanabe, F.; Chen, T. Genotoxicity evaluation of titanium dioxide nanoparticles using the Ames test and Comet assay. *J. Appl. Toxicol.* **2012**, *32*, 934–943. [[CrossRef](#)]



25. Mavon, A.; Miquel, C.; Lejeune, O.; Payre, B.; Moretto, P. In vitro percutaneous absorption and in vivo stratum corneum distribution of an organic and a mineral sunscreen. *Skin Pharmacol. Physiol.* **2007**, *20*, 10–20. [[CrossRef](#)]
26. Bernardeschi, M.; Guidi, P.; Scarcelli, V.; Frenzilli, G.; Nigro, M. Genotoxic potential of TiO<sub>2</sub> on bottlenose dolphin leukocytes. *Anal. Bioanal. Chem.* **2010**, *396*, 619–623. [[CrossRef](#)] [[PubMed](#)]
27. Osman, I.F.; Baumgartner, A.; Cemeli, E.; Fletcher, J.N.; Anderson, D. Genotoxicity and cytotoxicity of zinc oxide and titanium dioxide in HEp-2 cells. *Nanomedicine* **2010**, *5*, 1193–2203. [[CrossRef](#)] [[PubMed](#)]
28. Shukla, R.K.; Sharma, V.; Pandey, A.K.; Singh, S.; Sultana, S.; Dhawan, A. ROS-mediated genotoxicity induced by titanium dioxide nanoparticles in human epidermal cells. *Toxicol. In Vitro* **2011**, *25*, 231–241. [[CrossRef](#)] [[PubMed](#)]
29. Sycheva, L.P.; Zhurkov, V.S.; Iurchenko, V.V.; Daugel-Dauge, N.O.; Kovalenko, M.A.; Krivtsova, E.K.; Durnev, A.D. Investigation of genotoxic and cytotoxic effects of micro- and nanosized titanium dioxide in six organs of mice in vivo. *Mutat. Res. Genet. Toxicol. Environ. Mutagen.* **2011**, *726*, 8–14. [[CrossRef](#)] [[PubMed](#)]
30. Kwon, J.Y.; Koedrith, P.; Seo, Y.R. Current investigations into the genotoxicity of zinc oxide and silica nanoparticles in mammalian models in vitro and in vivo: Carcinogenic/genotoxic potential, relevant mechanisms and biomarkers, artifacts, and limitations. *Int. J. Nanomed.* **2014**, *9*, 271–286.
31. Liu, X.; Keane, M.J.; Zhong, B.Z.; Ong, T.M.; Wallace, W.E. Micronucleus formation in V79 cells treated with respirable silica dispersed in medium and in simulated pulmonary surfactant. *Mutat. Res.* **1996**, *361*, 89–94. [[CrossRef](#)]
32. Yang, H.; Liu, C.; Yang, D.; Zhang, H.; Xi, Z. Comparative study of cytotoxicity, oxidative stress and genotoxicity induced by four typical nanomaterials: The role of particle size, shape and composition. *J. Appl. Toxicol.* **2009**, *29*, 69–78. [[CrossRef](#)]
33. Wang, J.J.; Sanderson, B.J.S.; Wang, H. Cytotoxicity and genotoxicity of ultrafine crystalline SiO<sub>2</sub> particulate in cultured human lymphoblastoid cells. *Environ. Mol. Mutagen.* **2007**, *48*, 151–157. [[CrossRef](#)]
34. Asharani, P.V.; Mun, L.G.K.; Hande, M.P.; Valiyaveetil, S. Cytotoxicity and Genotoxicity of Silver Nanoparticles in Human Cells. *ACS Nano* **2009**, *3*, 279–290. [[CrossRef](#)]
35. Kaiser, J.P.; Roesslein, M.; Diener, L.; Wichser, A.; Nowack, B.; Wick, P. Cytotoxic effects of nanosilver are highly dependent on the chloride concentration and the presence of organic compounds in the cell culture media. *J. Nanobiotechnol.* **2017**, *15*, 1–11. [[CrossRef](#)]
36. Dobrzyńska, M.M.; Gajowik, A.; Radzikowska, J.; Lankoff, A.; Dušínská, M.; Kruszewski, M. Genotoxicity of Silver and Titanium Dioxide nanoparticles in bone marrow cells of rats in vivo. *Toxicology* **2014**, *315*, 86–91. [[CrossRef](#)] [[PubMed](#)]
37. Plotnikov, E.; Zhuravkov, S.; Gapeyev, A.; Plotnikov, V.; Martemianova, I.; Martemianov, D. Comparative study of genotoxicity of Silver and Gold nanoparticles prepared by the electric spark dispersion method. *J. Appl. Pharm. Sci.* **2017**, *7*, 35–39.
38. Jia, Y.-P.; Ma, B.-Y.; Wei, X.-W.; Qian, Z.-Y. The in vitro and in vivo toxicity of gold nanoparticles. *Chin. Chem. Lett.* **2017**, *28*, 691–702. [[CrossRef](#)]
39. De Alteriis, E.; Falanga, A.; Galdiero, S.; Guida, M.; Maselli, C.; Galdiero, E. Genotoxicity of gold nanoparticles functionalized with indolicidin towards *Saccharomyces cerevisiae*. *J. Environ. Sci.* **2017**, *66*, 138–145. [[CrossRef](#)] [[PubMed](#)]
40. Kreyling, W.G.; Semmler, M.; Erbe, F.; Mayer, P.; Takenaka, S.; Schulz, H.; Oberdorster, G.; Ziesenis, A. Translocation of ultrafine insoluble iridium particles from lung epithelium to extrapulmonary organs is size dependent but very low. *J. Toxicol. Environ. Health Part A* **2002**, *65*, 1513–1530. [[CrossRef](#)] [[PubMed](#)]
41. Bérubé, V.; Radtke, G.; Dresselhaus, M.; Chen, G. Size effects on the hydrogen storage properties of nanostructured metal hydrides: A review. *Int. J. Energy Res.* **2007**, *31*, 637–663. [[CrossRef](#)]
42. Warheit, D.B.; Webb, T.R.; Reed, K.L.; Frerichs, S.; Sayes, C.M. Pulmonary toxicity study in rats with three forms of ultrafine-TiO<sub>2</sub> particles: Differential responses related to surface properties. *Toxicology* **2007**, *230*, 90–104. [[CrossRef](#)]
43. Gate, L.; Disdier, C.; Cosnier, F.; Gagnaire, F.; Devoy, J.; Saba, W.; Brun, E.; Chalansonnet, M.; Mabondzo, A. Biopersistence and translocation to extrapulmonary organs of titanium dioxide nanoparticles after subacute inhalation exposure to aerosol in adult and elderly rats. *Toxicol. Lett.* **2017**, *265*, 61–69. [[CrossRef](#)]
44. IARC. *Titanium Dioxide Group 2B*; IARC Monographs on the Evaluation of Carcinogenic Risks to Humans; IARC Press, International Agency for Research on Cancer: Lyon, France, 2006; Volume 9.

45. OEHHA. *Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates*; Air Resources Board, California Environmental Protection Agency: Sacramento, CA, USA, 2002.
46. Nanosystems, P. Lipid Nanoparticles. Available online: <http://www.precisionnanosystems.com/areas-of-interest/formulations/lipid-nanoparticles> (accessed on 13 August 2020).
47. Muzzalupo, R.; Tavano, L. Niosomal drug delivery for transdermal targeting: Recent advances. *Res. Rep. Transdermal Drug Deliv.* **2015**, *4*, 23–33. [CrossRef]
48. Pulicharla, R.; Zolfaghari, M.; Brar, S.K.; Cledon, M.; Drogui, P.; Surampalli, R.Y. Cosmetic Nanomaterials in Wastewater: Titanium Dioxide and Fullerenes. *J. Hazard. Toxic. Radioact. Waste* **2016**, *20*, B4014005. [CrossRef]
49. Al-Bedairy, M.; Alshamsi HA, H. Environmentally Friendly Preparation of Zinc Oxide, Study Catalytic Performance of Photodegradation by Sunlight for Rhodamine B Dye. *Eurasian J. Anal. Chem.* **2018**, *13*, 1–9. [CrossRef]
50. Kaul, S.; Gulati, N.; Verma, D.; Mukherjee, S.; Nagaich, U. Role of Nanotechnology in Cosmeceuticals: A Review of Recent Advances. *J. Pharm.* **2018**, *2018*, 1–19. [CrossRef] [PubMed]
51. Chaudhri, N.; Soni, G.C.; Prajapati, S.K. Nanotechnology: An Advance Tool for Nano-cosmetics Preparation. *Int. J. Pharm. Res. Rev.* **2015**, *4*, 28–40.
52. Nanda, S.; Arun, N.; Lohan, S.; Kaur, R.; Singh, B. *Nanobiomaterials in Galenic Formulations and Cosmetics*; William Andrew: Norwich, NY, USA, 2016; Volume 10.
53. Borowska, S.; Brzoska, M.M. Metals in cosmetics: Implications for human health. *J. Appl. Toxicol.* **2015**, *35*, 551–572. [CrossRef]
54. Wang, J.J.; Sanderson, B.J.; Wang, H. Cyto- and genotoxicity of ultrafine TiO<sub>2</sub> particles in cultured human lymphoblastoid cells. *Mutat. Res.* **2007**, *628*, 99–106. [CrossRef]
55. Oberdörster, G.; Oberdörster, E.; Oberdörster, J. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. *Environ. Health Perspect.* **2005**, *113*, 823–839. [CrossRef]
56. Colvin, V.L. The potential environmental impact of engineered nanomaterials. *Nat. Biotechnol.* **2003**, *21*, 1166–1170. [CrossRef]
57. Chen, J.; Dong, X.; Zhao, J.; Tang, G. In vivo acute toxicity of titanium dioxide nanoparticles to mice after intraperitoneal injection. *J. Appl. Toxicol.* **2009**, *29*, 330–337. [CrossRef]
58. Liu, H.; Ma, L.; Zhao, J.; Liu, J.; Yan, J.; Ruan, J.; Hong, F. Biochemical toxicity of nano-anatase TiO<sub>2</sub> particles in mice. *Biol. Trace Elem. Res.* **2009**, *129*, 170–180. [CrossRef]
59. Zhao, J.; Li, N.; Wang, S.; Zhao, X.; Wang, J.; Yan, J.; Ruan, J.; Wang, H.; Hong, F. The mechanism of oxidative damage in the nephrotoxicity of mice caused by nano-anatase TiO<sub>2</sub>. *J. Exp. Nanosci.* **2010**, *5*, 447–462. [CrossRef]
60. Song, B.; Liu, J.; Feng, X.; Wei, L.; Shao, L. A review on potential neurotoxicity of titanium dioxide nanoparticles. *Nanoscale Res. Lett.* **2015**, *10*, 342–358. [CrossRef] [PubMed]
61. Nazarenko, Y.; Zhen, H.; Han, T.; Liroy, P.J.; Mainelis, G. Potential for inhalation exposure to engineered nanoparticles from nanotechnology-based cosmetic powders. *Environ. Health Perspect.* **2012**, *120*, 885–892. [CrossRef] [PubMed]
62. Adawi, H.I.; Newbold, M.A.; Reed, J.M.; Vance, M.E.; Feitshans, I.L.; Bickford, L.R.; Lewinski, N.A. Nano-enabled personal care products: Current developments in consumer safety. *NanoImpact* **2018**, *11*, 170–179. [CrossRef]
63. Environment & Society Portal. Report of the World Commission on Environment and Development: Our Common Future. Available online: <http://www.environmentandsociety.org/mml/un-world-commission-environment-and-development-ed-report-world-commission-environment-and> (accessed on 27 August 2020).
64. Liobikienė, G.; Bernatoniene, J. Why determinants of green purchase cannot be treated equally? The case of green cosmetics: Literature review. *J. Clean. Prod.* **2017**, *162*, 109–120. [CrossRef]
65. Krauter, J. In-Cosmetics 2018: Evonik Focuses on Naturalness. Available online: <https://www.cosmeticsdesign-europe.com/Article/2018/10/16/Evonik-hones-in-on-naturals-and-sustainability> (accessed on 28 August 2020).
66. Xanthos, D.; Walker, T.R. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. *Mar. Pollut. Bull.* **2017**, *118*, 17–26. [CrossRef] [PubMed]

67. Cosmetics Europe. Over 97% of Plastic Microbeads already Phased out from Cosmetics–Cosmetics Europe Announces. Available online: <https://cosmeticseurope.eu/news-events/over-97-plastic-microbeads-already-phased-out-cosmetics-cosmetics-europe-announces> (accessed on 28 August 2020).
68. Sahota, A. *Sustainability: How the Cosmetics Industry Is Greening Up*; Wiley: West Sussex, UK, 2014; Volume 1.
69. Motta, W.H.; Issberner, L.-R.; Prado, P. Life cycle assessment and eco-innovations: What kind of convergence is possible? *J. Clean. Prod.* **2018**, *187*, 1103–1114. [[CrossRef](#)]
70. Krishna, M., IV; Manickam, V. *Environmental Risk Assessment*; Elsevier: Oxford, UK, 2017; Volume 1, pp. 135–150.
71. United States Environmental Protection Agency. *Exposure Factors Handbook*; EPA: Washington, DC, USA, 2011.
72. Nazarenko, Y.; Zhen, H.; Han, T.; Lioy, P.J.; Mainelis, G. Nanomaterial inhalation exposure from nanotechnology-based cosmetic powders: A quantitative assessment. *J. Nanopart. Res. Interdiscip. Forum Nanoscale Sci. Technol.* **2012**, *14*, 1229–1242. [[CrossRef](#)]
73. Deepthi, Y.; Shiva Nagendra, S.M.; Gummadi, S.N. Characteristics of indoor air pollution and estimation of respiratory dosage under varied fuel-type and kitchen-type in the rural areas of Telangana state in India. *Sci. Total Environ.* **2019**, *650*, 616–625. [[CrossRef](#)]
74. Fytianos, G.; Rahdar, A.; Kyzas, G.Z. Nanomaterials in Cosmetics: Recent Updates. *Nanomaterials* **2020**, *10*, 979. [[CrossRef](#)]
75. EPA. IAQ Standards and Guidelines (EPA and ASHRAE Standard). Available online: <https://foobot.io/guides/iaq-standards-and-guidelines.php#:~:text=Air%20quality%20is%20a%20volatile,identify%20and%20reduce%20hazardous%20substances> (accessed on 30 September 2020).
76. Balásházy, I.; Hofmann, W.; Heistracher, T. Local particle deposition patterns may play a key role in the development of lung cancer. *J. Appl. Physiol.* **2003**, *94*, 1719–1725. [[CrossRef](#)]



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).