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Occupational dermal exposure to nanoparticles and nano-enabled products: Part 2, exploration of exposure processes and methods of assessment

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ABSTRACT

Over the past decade, the primary focus of nanotoxicology and nanoenvironmental health and safety efforts has been largely on inhalation exposure to engineered nanomaterials, at the production stage, and much less on considering risks along the life cycle of nano-enabled products. Dermal exposure to nanomaterials and its health impact has been studied to a much lesser extent, and mostly in the context of intentional exposure to nano-enabled products such as in nanomedicine, cosmetics and personal care products. How concerning is dermal exposure to such nanoparticles in the context of occupational exposures? When and how should we measure it?

In the first of a series of two papers (Larese Filon et al., 2016), we focused our attention on identifying conditions or situations, i.e. a combination of nanoparticle physico-chemical properties, skin barrier integrity, and occupations with high prevalence of skin disease, which deserve further investigation. This second paper focuses on the broad question of dermal exposure assessment to nanoparticles and attempts to give an overview of the mechanisms of occupational dermal exposure to nanoparticles and nano-enabled products and explores feasibility and adequacy of various methods of quantifying dermal exposure to NOAA. We provide here a conceptual framework for screening, prioritization, and assessment of dermal exposure to NOAA in occupational settings, and integrate it into a proposed framework for risk assessment.

1. Introduction

Over the past decade, the primary focus of nanotoxicology and nanoenvironmental health and safety has been largely on inhalation exposure to engineered nanomaterials, at the production stage, and much less so along the life cycle of nano-enabled products. Dermal exposure to nanomaterials and its health impact has been studied to a much lesser extent, and mostly in the context of intentional exposure to nano-enabled personal care products and cosmetics (SCCP, 2007) and drug carrier systems (Hansen and Lehrs, 2012; Lademann et al., 2013). In contrast, unintentional occupational exposure to engineered nanomaterials has been addressed in only a few studies (Baron et al., 2003; Maynard et al., 2004; van Duuren-Stuurman et al., 2010; Methner et al., 2012). Much of the research on dermal exposure to nanoparticles has focused on the question of dermal penetration (Krug, 2014). While dermal penetration of nanomaterials is understandably an issue of fundamental importance in the context of systemic uptake, drug carrier efficiency and health effects, other aspects of dermal exposure, such as inadvertent ingestion by hand-to-mouth transfer, aggravation of

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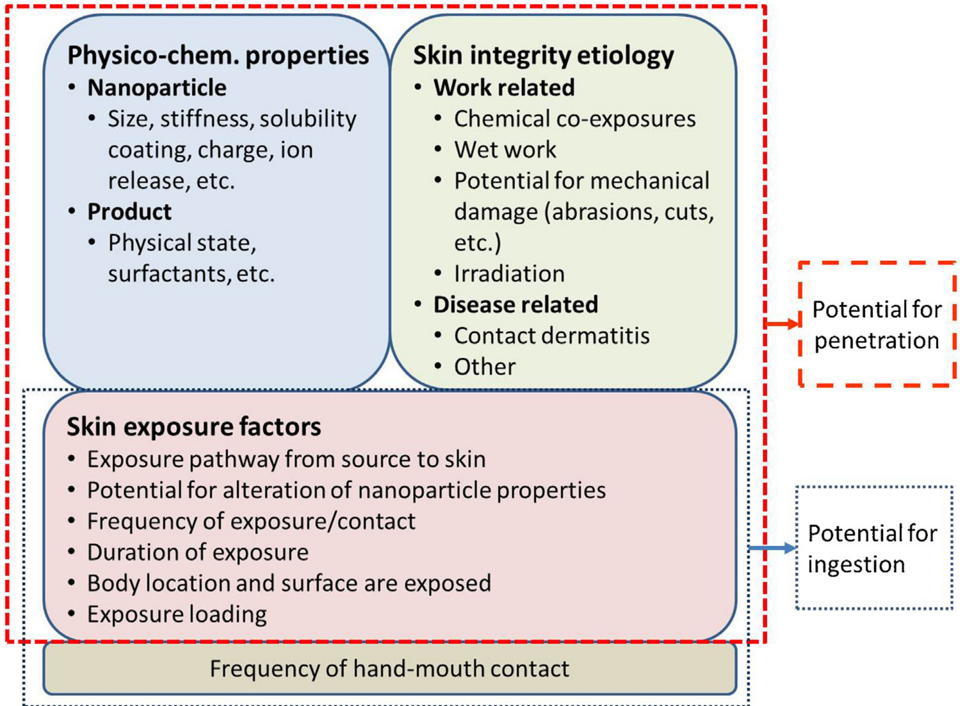

Fig. 1. Parameters relevant for penetration/permeation and ingestion of nanoparticles.

preexisting skin disease, and skin sensitization effects, have been overlooked.

1.1. Definitions

In this paper, the term nanoparticle includes both engineered and incidental nanoparticles, as well as their agglomerates and aggregates (ISO, 2011). Nanoparticles embedded in nano-enabled products, such as pastes, paints, glues, etc., are potential sources of dermal exposure to nanoparticles. The term NOAA (nano-objects, and their aggregates and agglomerates) is used to refer inclusively to such embedded nanoparticles.

In the first of a series of two papers (Larese Filon et al., 2016), we focus our attention on identifying conditions or situations, i.e. a combination of nanoparticle physico-chemical and toxicological properties (such as skin sensitization) and skin barrier integrity that deserve further investigation from the perspective of skin penetration and local skin effects. This is illustrated in the upper part of Fig. 1 which summarizes the parameters relevant for the potential for penetration and inadvertent ingestion of nanoparticles.

This second paper focuses on the broad question of skin exposure assessment to nanoparticles (the bottom part of Fig. 1) and attempts to give an overview of the mechanisms of occupational dermal exposure to NOAA or nano-enabled products and provide evidence of dermal exposure for identified job titles. Moreover, we explore the feasibility and adequacy of various methods of quantifying dermal exposure to NOAA. This paper builds on the findings and recommendations of the first paper to provide a conceptual framework for dermal exposure assessment to NOAA and preliminary risk assessment.

2. Concepts of occupational dermal exposure to NOAA or nano-embedded products

For inhalation exposure modeling, the concept of the source domains was developed by Schneider et al. (2011). This model is considered useful also in the context of dermal exposure. The source domains (SD) reflect different mechanisms of nanoparticle release and, consequently, possible different properties of released nano-aerosols. Moreover, the source domain naturally integrates exposures during various life cycle stages of the NOAA. We linked the concept of source domains to the conceptual framework for dermal exposure (Schneider et al., 1999), which was developed to describe the various pathways and the underlying mechanisms resulting in skin contamination. The framework has been further expanded in the current work to also incorporate possible health consequences of dermal exposure. The conceptual model is presented in Fig. 2. Sources are subdivided into the four source domains, which may release NOAA to the local source zone. Transfer of nanoparticles and agglomerates to the skin can result from: direct skin contact with bulk materials; direct deposition from the air; and transfer to skin from contact with contaminated surfaces and other objects. Contaminated hands (and other anatomical parts) may transfer nanoparticle contamination to the peri-oral region, consequently resulting in oral intake and ingestion.

The near-field zone (NF) represents the air volume surrounding the worker and the far-field (FF) the remaining room volume.

Direct contact is described as the direct transport from the bulk zone to the skin or clothing, i.e. migration from source to skin, without becoming airborne. This route of transport differs from other routes, since it is not affected by the air zone and takes place in the near field zone only (NF). Direct contact may occur by touching NOAA containing powders/liquid dispersion or resulting from spills or splashes either directly on the skin or immersion of hands in the powder or the dispersion. For these scenarios the state and composition of the NOAA is assumed to be the same as at the source (bulk zone). Most often exposed body parts are the hands.

Deposition of particles on skin or objects in an air flow is governed by processes like impaction due to inertia, gravitational settling, interception, diffusion/Brownian motion, electrophoresis, and thermophoresis. Surface roughness has been found to be an important parameter significantly influencing NOAA deposition on walls and furniture, but also on human head and skin (Andersson et al., 2004). Andersson et al. (2004, 2006), Byrne et al., 1995 and