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Review

Measurement techniques of exposure to nanomaterials in the workplace for low- and medium-income countries: A systematic review

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A B S T R A C T

Nanotechnology offers many opportunities but there is still considerable uncertainty about the health risks and how to assess these.In the field of risk analysis for workers potentially exposed to nano-objects and their agglomerates and aggregates (NOAA) different methodological approaches to measure airborne NOAA have been proposed.This study proposes a systematic review of scientific literature on occupational exposure to NOAA in the workplace with the aim to identify techniques of exposure measurement to be recommended in low- and medium-income countries.We gathered scientific papers reporting techniques of NOAA exposure measurements in the workplace, we summarized the data for each eligible technique according to PRISMA guidelines, and we rated the quality of evidence following an adapted GRADE approach.We found 69 eligible studies to be included in qualitative synthesis: the majority of studies reported a moderate quality and only two studies demonstrated the use of a high quality exposure measurement technique.The review demonstrates that a basic exposure measurement, i.e. evidence for the presence or absence of NOAA in the workplace air, can be achieved with moderate (40 techniques) to high (2 techniques) quality; comprehensive exposure measurement, that allow the quantification of NOAA in the workplace, can be achieved with moderate (11 techniques) to high (2 techniques) quality.The findings of the study also allowed to finalize a list of requirements that must be fulfilled by an effective measurement technique (either basic or comprehensive) and to highlight the main weaknesses that need to be tackled for an effective affordability evaluation of measurement techniques to be recommended in low- and medium-income countries.

Contents

1. Introduction 1090
2. Methods 1090
    2.1. Search strategy 1091
    2.2. Selection of studies 1091
    2.3. Inclusion and exclusion criteria 1091
    2.4. Rating the quality of evidence 1093
3. Results 1093
    3.1. Information Sources 1093
    3.2. Summary of studies characteristics 1093
    3.3. Quality assessment 1093
    3.4. Reliability analysis 1094

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3.5. Affordability analysis 1095
4. Discussion and conclusions 1095
Acknowledgments 1096
Appendices A–E Supplementary data 1096
References 1096

1. Introduction

In the last fifteen years an exponential development of nanotechnologies (NTs) worldwide has been recognized. In fact, the most updated databases identified over 1800 nanomaterials (NMs) enabled products available on the market (Vance et al., 2015) and forecasts suggest that the NT based global market will achieve $3 trillion globally by 2020 (Roco, 2011). Furthermore, NTs have been included among the "Key Enabling Technologies" (European Commission, 2012) of the EU Horizon2020 Strategy and they are expected to be a major global source of new employment (Chen et al., 2013; European Parliament, 2014). Finally, NTs opportunities may introduce benefits for low- and medium-income countries (LMI) in terms of access to safe water, reliable energy sources, health care, and education (Invernizzi et al., 2008).

Parallel to the great potential expressed by nanoscale materials, scientific efforts are currently dedicated to understanding the potential adverse health effects of nano-objects and their agglomerates and aggregates (NOAA) on workers health and safety. Several studies have demonstrated that NOAA can be much more reactive than their corresponding bulk form, due to the large active surface area per mass unit (Oberdorster et al., 2005; Hubbs et al., 2013) and may have novel biological properties (Pietroiusti and Magrini, 2014). Furthermore, NMs can induce oxidative stress, inflammation and indirect DNA damage, and the size and shape of NMs are determining factors in cell damage induction (Ursini et al., 2012). The results of some in vivo studies on rats and mice, led the IARC in 2014 to classify a particular type of Carbon Nanotubes (CNTs), the MWCNT-7, as possibly carcinogenic to humans (group 2B) (Grosse et al., 2014).

Although the debate among the scientific community is still open to identify the parameters better representing NOAA toxicity (Maynard and Aitken, 2007; Brouwer et al., 2012), numerous methodological approaches to assess workers exposure to airborne NOAA have been proposed. The measurement of exposure to NOAA is a critical step in the analysis of the potential risks for workers and the distinction of engineered nano-objects from the background is highly important to understand the contribution of specific sources (Schulte et al., 2016). In 2015, after a review of the major strategies published, OECD promoted a harmonized three-tiered approach for measuring and assessing the airborne exposure to engineered nano-objects in the workplace, with the aim also to balance costs and effectiveness of investigation efforts (OECD, 2015).

Given that a measurement strategy can be defined as "a necessary framework for an appropriate selection of all parameters associated with a measurement campaign that is considered relevant to the objectives pursued by the project study" (Brouwer et al., 2012), workplace investigations need to take into account also the instruments choice, the methods to distinguish the process sources from the background and the data analysis (Kuhlbusch et al., 2011). The availability, implementation, use and maintenance of effective measurements require a considerable economic effort in terms of instruments and human resources (Morawska et al., 2012). The analysis of reliable and affordable techniques to measure workers exposure to NOAA may be a key question to improve risk assessment and management (Vogel et al., 2014) even in contexts with low resources such as LMI countries.

In this view, the main aim of this paper was to review scientific literature on occupational exposure to NOAA in order to identify the most recommended technique of exposure measurement in the workplace, for workers potentially exposed in LMI countries.

Therefore, we used a systematic approach following an accepted framework (Morgan et al., 2016). Our specific objectives were to gather scientific papers reporting techniques of NOAA exposure measurements in workplaces, to summarize the data as reported in studies for each eligible technique according to PRISMA guidelines (Moher et al., 2009), and to rate the quality of evidence following an adapted GRADE approach (Balshem et al., 2011).

2. Methods

A systematic review of the literature was conducted to determine what is, among techniques to measure exposure to nanomaterials in the workplace, the most recommended method for workers potentially exposed in LMI countries.

For the specific aim of this systematic review, the following definitions have been adopted (Table 1).

To be able to answer the question using a systematic review, the PICO (P for Participants, I for Intervention, C for Comparison, and O for Outcomes) (Morgan et al., 2016) approach was used. It is a model widely used as an approach for formulating questions and search strategies. In particular, for each component, we need to answer to the following questions (Higgins and Green, 2011):

- Participants: What are the characteristics of the patient or population (demographics, risk factors, pre-existing conditions, etc.)? What is the condition or disease of interest?
- Interventions: What is the intervention under consideration for this patient or population?
- Comparisons: What is the alternative to the intervention (e.g. placebo, different drug, surgery)?
- Outcomes: What are the relevant outcomes (e.g. quality of life, change in clinical status, morbidity, adverse effects, complications)?

This approach is widely used in evidence-based health care and it has been adapted to our study in order to guarantee the scientific accuracy that is a major characteristic of a systematic review.

Therefore, we defined four PICO components as follows: Participants were the workers potentially exposed to NOAA, Interventions were the techniques of exposure measurement to NOAA in the workplace, Comparisons were the commonly used techniques of exposure measurement to NOAA in the workplace and Outcomes were the reliable and affordable techniques of exposure measurement to NOAA in the workplaces.

In summary, the scope of this systematic review needed to address the two following questions:

1. In workplaces, which exposure measurement techniques are used and how they produce a reliable measurement of exposure to nanomaterials?
2. Which simple and cheap exposure measurement technique does still provide a reliable and affordable measurement of exposure to nanomaterials that can be recommended in LMI countries?