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EDITORIAL

Advancing the Science of Bioaerosol Exposure Assessment

Research on bioaerosols has experienced, and continues to experience, stellar growth. This is evident in the rocketing number of scientific articles published during recent years (double the number in 2013 compared to 2003 based on keywords on Web of Science and about 10% of the articles in the last volume of *Annals of Occupational Hygiene*). This outbreak of research is due, among others, to (i) an emerging interest in the role of environmental exposure to biological agents (in public and occupational health), (ii) the development of new biotechnologies used in some industrial sectors, and (iii) the access to news molecular tools allowing finer and faster bioaerosols characterization. Bioaerosols are defined as airborne particles including fungal spores and hyphae, bacteria, endotoxin, β(1→3)-glucans, mycotoxin or high-molecular-weight allergens, and organic dusts in general that is composed of or derived from biological matter. They are found everywhere on earth. Indeed, environmental bacteria, viruses, and fungi are a part of our natural environment, having co-evolved with all the other living organisms, including humans. However, due to the presence of great amounts of organic matter, the release of bioaerosols can be very high in certain industrial sectors (for instance: agriculture, waste management, textile, and wood industries). In addition to infectious diseases, they can also cause allergic, toxic, or irritant reactions. The presence of high levels of bioaerosols is frequently the result of the natural colonization of an organic substrate present in the workplace but may also be integral to the processes at work and are deliberately added (for instance: breweries, wineries, and biotechnology production). Each bioaerosol sample is unique as its composition varies in time and space (abundance and diversity of species, quantity of pro-inflammatory components such as endotoxins and β-d-glucans). This often leads not only to high variation between samples from the same workplace, which can be due to external factors, but also to the dynamic evolution of the colonized substrate and the fast multiplication rate of microorganisms. These variations in airborne concentrations are often considerably large compared to chemical pollutants. Bioaerosols from some typical work sectors are associated with well-known diseases (for instance: farmer's lung in agriculture or the byssinosis in cotton industry).

In this issue, four articles focus on bioaerosol problems in four very different workplaces. In two studies (Madsen *et al.*, 2014; Simon and Duquenne, 2014), bioaerosols were measured in occupational situations where microorganisms are used deliberately: as agents of cheese maturation in a French cheese factory and as biopesticides in a Danish potted plant production site, respectively. Another study from Denmark (Basinas *et al.*, 2014) explored the influence of farm characteristics and the specific work tasks performed by dairy farmers on their personal exposure to organic dust and endotoxins. The fourth study (van Kampen *et al.*, 2014) estimated the airborne microbial load in German composting plants by using different quantification methods and also explored the influence of the workplace characteristics and work processes associated with the highest levels of exposure. Taken together, these four articles

highlight (i) the complexity of reliably measuring and characterizing the airborne microorganism communities and/or their components and (ii) the difficulty in determining which factor or which specific work task is associated with the greatest level of exposure. They show that occupational biological risks can be estimated using a variety of different methods and that each situation is unique and requires specific methodology. Culture-dependent methods are by far the most widely used procedures for assessing the microbiological content of bioaerosols. However, it is now widely accepted that such methods significantly underestimate the total quantity of microorganisms present since the vast majority of them cannot be cultivated (Oppliger *et al.*, 2008; Fallschissel *et al.*, 2010). Moreover, dead airborne bacteria or fungi retain their allergenic or toxic properties and are therefore also relevant to any occupational health assessment. The indirect measurement of microorganism levels by measuring their components (traditionally, endotoxins for Gram-negative bacteria and β-d-glucans for fungi) is another very frequently used method that allows researchers to take into account the concentration of biological components related to health effects since these two components have inflammatory properties. However, measuring only endotoxins or β-d-glucans could be limiting because they are specific to certain microorganisms. Thus, in the future, in order to better estimate the risks related to the physiological effects of bioaerosols on humans, it will be necessary to develop new methods, or to better use existing ones, for the measurement of relevant indicators. For example, we need to know whether other bacterial or fungal components can induce an inflammatory reaction or a cytotoxic effect. Moreover, it is also essential to have a better knowledge on the physiological effects of a mixture of microorganisms since synergistic effects can occur. This is precisely what two of the studies presented in this issue have done by using *in vitro* cellular tests.

Madsen *et al.* (2014) have measured the total inflammatory potential of bioaerosol samples by using a granulocyte-like cell assay that measures markers of oxidative stress produced by cells exposed to those samples. This test had been developed to assess microbial contamination of medicines and was recently used to assess the total inflammatory potential of bioaerosols (Timm *et al.*, 2006, 2009). van Kampen *et al.* (2014) have measured the pyrogenic activity of bioaerosol samples by using a whole blood assay that measured the cytokines (pro-inflammatory markers) released by blood cells exposed to those samples. This test was first described in 2005 (Kindinger *et al.*, 2005) and was then modified to assess occupational microbial exposure (Liebers *et al.*, 2009). Both of these tests could be useful to investigate the mechanism of action of different mixture of bioaerosols and deserve researcher's attention.

In parallel to the assessment of the inflammatory or cytotoxic potential of bioaerosols, we need to have a better understanding of the exact composition of airborne microbial communities (also called microbiota). Simple molecular techniques such as quantitative polymerase chain reaction are of major interest, allowing larger scale sampling studies and evaluation of exposure to agents for which only short averaging time measurements could be taken in the past. Today, the characterization and comparison of microbial communities, and the detection of changes in their species composition, can be also carried out using next-generation DNA sequencing technologies. These new analytical methods are cheaper and faster than traditional sequencing. They have been applied to assess the diversity of microorganisms not only in different human or animal microbiota but also in air samples. They enable us to describe the fine-scale structure of entire microbial communities, thus allowing the detection not only of the most dominant microbial community members but also of rare taxa. It is, therefore, now possible to study how environmental factors shape bacterial communities as well as which factors determine the presence, abundance, and diversity of species within them. However, one has to be conscious that these technologies have still a lot of analytical constraints and cannot be currently applied 'in the field' to assess occupational risks. But, even if it is not immediately useful for occupational hygienists, the development and use of new measurement techniques are of great importance; they help us to gain ever greater insights into exposure to biological agents in occupational settings. The tests measuring the physiological effects of bioaerosols, together with recent developments in molecular technology, may enable substantial advances in the near future. We can fairly say that bioaerosol sciences are currently still in a developmental phase and that a lot of important new discoveries are waiting to be made in

the coming years which will be, one day, very useful for applied occupational hygiene.

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