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Pilot study of sources and concentrations of size-resolved airborne particles in a neonatal intensive care unit

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ABSTRACT

Infants in neonatal intensive care units (NICUs) are vulnerable to environmental stressors. Few studies have reported on airborne particles in the NICU environment. During a four-day pilot study in a private-style NICU, we measured size-resolved particle number (PN) concentrations with 1-min resolution. The investigation included simultaneous sampling in an unoccupied baby room and in an incubator of an otherwise normally functioning NICU. Background submicron (0.3–1 μm) particle levels in the room were 3–4 orders of magnitude lower than outdoors, owing to high-efficiency particulate filtration of supply air. Airborne supermicron particles were detected in the room; their presence was attributed primarily to emissions from occupant movements. The fraction of in-room PN detected within an infant incubator ranged from 0.2 for particles >10 μm to 0.6 for particles with diameter 0.3–0.5 μm. The incubator humidifier was a strong additional source of particles smaller than 5 μm. Activities by researchers, designed to simulate caregiver visits, were associated with elevated particle concentrations across all measured size ranges, and were particularly discernible among larger particles. Concentrations increased with the number of occupants and with the duration and vigor of activities. The highest levels were observed when fabrics were handled. Against the low background in this environment, even small occupancy-associated perturbations – such as from a brief entry – were discernible. Measurements from a second NICU in a different US region were found to be broadly similar. A notable difference was higher submicron particle levels in the second NICU, attributed to elevated outdoor pollution.

1. Introduction

The inhalation of airborne particles is known to be associated with risks of increased mortality, respiratory illnesses and other adverse health effects of infants and children [1–3]. Preterm infants in neonatal intensive care units (NICUs) are particularly vulnerable to health harm resulting from environmental exposures [4]. Moreover, the airborne route may play a role in the dispersal of microbes indoors [5]. However, limited published information is available on the sources and concentrations of airborne particles in the NICU environment.

In the most detailed prior description of air quality in a NICU in the United States, Domanico et al. [6] compared levels of environmental parameters and patient progress in an open-style vs. private- (or bay-) style NICU. The authors reported that the private-style facility was associated with "fewer apneic events, reduced nosocomial sepsis and mortality, as well as earlier transitions to enteral nutrition" and better infants' progress. Though specific causal factors were not isolated, the study showed that staff activity was correlated with higher levels of airborne coarse particles (>2 μm), carbon dioxide and noise, and that exposure to these agents was reduced in the private-style configuration. In a few other studies where NICU air quality parameters were monitored, microbes in airborne particles were assessed using culturing methods, and the mechanical ventilation system and renovation activities were assessed as potential sources. Ryan et al. [7] found that enhanced ultraviolet germicidal irradiation of HVAC cooling coils significantly decreased the number of culturable microbes in

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the HVAC system and in the NICU, in air and on surfaces. The reduced environmental loads were linked, in turn, to decreases in tracheal microbial colonization of infants, and reductions in ventilator-associated pneumonia. A study in Belgium by Mahieu et al. [8] found that renovation activities in a NICU were linked to increases in airborne concentrations of *Aspergillus* spp. but with no corresponding increases in nasopharyngeal colonization of neonates. No relationship was demonstrated between patient occupant density and air concentrations in that study. The importance of surfaces and their cleaning for controlling outbreaks of specific organisms and eradicating sources of potential pathogens in NICUs has been highlighted in a few prior studies [9–11]. Other NICU environmental parameters previously studied in relation to prevention of nosocomial infections have included noise, illumination, medical equipment hygiene, microbes on surfaces, overcrowding, and the importance of inhibiting free mixing across rooms [11–16].

The study by Domanico et al. [6] provided important preliminary evidence in support of the hypothesis that human activity is a significant source of coarse particles in the NICU environment. That study left many questions open for future research. Particle levels were presented in relative terms without associated units, limiting the comparability of findings to other environments. The study did not differentiate among particle sizes, even though size can be associated with distinct sources, constituent materials, and potential health impacts. Particles smaller than 2 μm, though important for health, were not evaluated. The relative contributions of airborne particles from outdoor air versus occupancy were not probed, and the modulation of room levels by the incubator was not investigated. To contribute new knowledge regarding airborne particle sources, levels, and influencing factors pertinent for understanding neonatal exposure, we undertook a study of aerosol characteristics in the NICU environment. The overall effort resulted in two interrelated studies with distinct outcomes. Elsewhere, we report on the results of a yearlong measurement campaign [17] that enables inferences about the sources of airborne particles in an ordinarily operating NICU baby room (i.e., without researcher control over human occupancy and activity conditions).

In the present paper, we report on the results of a weeklong pilot-scale effort conducted in an empty patient room in an otherwise normally functioning NICU. The circumstances allowed for researcher control over human occupancy and activity conditions. The use of an empty room also enabled sampling to be conducted from within the infant incubator under a range of operational conditions. Consequently, the pilot study not only informed the development of the full-year sampling campaign, but also provided new information and insight about an important, yet data-poor, indoor environment.

Specifically, the objectives of the present work were (a) to characterize particle number concentrations in a private-style NICU room across a range of simulated occupancy conditions and (b) to assess the factors influencing those levels. By measuring particle levels indoors, outdoors, and inside neonatal incubators, we sought to evaluate the relationships among concentrations at the three locations in relation to particle size, human activity, and incubator operation parameters. A brief subsequent monitoring investigation in a second NICU in a different part of the United States was conducted to test whether the findings from the first NICU would be reinforced in another setting.

2. Materials and methods

2.1. Study site

Experiments were conducted in a private-style NICU located in a large hospital building in the western United States. The site was selected based on convenience and access. Physical features of the NICU included hard tile flooring, no visible green plants or water damage, and no obvious dust accumulation on visible surfaces or any visible signs of air infiltration. The NICU had no operable windows. Smoking and pets were not permitted in the unit. Staff and visitors followed hygiene protocols upon entry that included hand-washing and exchanging clothes for laundered scrubs. Street shoes were retained and, in some instances, street clothes continued to be worn under the scrubs for warmth. Critically ill patients were housed in rooms that formed a semicircle around the nurse's station so that they could be closely monitored with visual contact. The experimental room for this study was situated at one end of the NICU away from this core. The volume of the room was assessed as 30 m^3 based on physical dimensions (length, width, height). The side of the room adjacent to the hallway had a large door, which was left open to mimic typical use conditions. The doorway had a curtain that was usually open, but was occasionally drawn closed. The experimental room was not cleaned during the weeklong study. The three patient rooms closest to it were not in regular use for infant care and were used, instead, for equipment storage and maintenance.

2.2. Mechanical ventilation

Ventilation air was supplied to the room from a heating, ventilating, and air conditioning (HVAC) system. The HVAC system was equipped with an economizer that varied the percentage of recirculated air in the supply stream based on the outdoor air temperature. Recirculated air was drawn from the NICU and from other parts of the building, mixed with filtered outdoor air, and cooled. Cooling coils were treated with UV germicidal irradiation. The mixed supply air was then heated and humidified according to thermostatic demand, and treated with high-efficiency particulate arrestance (HEPA) filters. The ventilation specifications included a requirement for at least six air changes per hour for the entire NICU, of which at least a third was required to be outdoor air. The actual air-exchange rate of the test room was not measured. The air in the test room was deemed to be well mixed, based on the supply airflow rate, position of ceiling-mounted air delivery and exhaust devices and the physical dimensions of the room.

2.3. Experimental protocols and instruments

The monitoring campaign was conducted during 17–21 June 2013. Continuous sampling in the test room was initiated on 18 June at 00:00 (Eastern Time Zone) and lasted 3.6 days. Air quality parameters were measured from a central location in the infant room, and from the interior of an operating, but empty infant incubator. Sampling was conducted with 1 min time resolution to capture the dynamic response to rapidly changing conditions. Particle number (PN) concentrations larger than 0.3 μm were measured with particle counters (model HHPC 6+, Beckman Coulter Life Sciences, Palatine, IL, USA) in six size bins according to optical diameter: 0.3–0.5, 0.5–1, 1–2, 2–5, 5–10, and >10 μm.

Supplementary parameters monitored and logged included carbon dioxide (model SBA-5, PP Systems, Amesbury, MA, USA; and model 820, LI-COR Biosciences, Lincoln, NE, USA) and temperature and relative humidity (HOBO U12, Onset Computer Corp., Bourne, MA, USA). A light/movement passive infrared (PIR) sensor (HOBO UX90-006, Onset Computer Corp., Bourne, MA, USA) with a range of 12 m was positioned at the door of the room, facing outward, to record occupant movements near the open doorway. Carbon dioxide data from the room were not acquired during the last sampling day because of instrument malfunction. However, carbon dioxide levels in the incubator closely tracked levels in the room