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Particle and bioaerosol characteristics in a paediatric intensive care unit

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ABSTRACT

The paediatric intensive care unit (PICU) provides care to critically ill neonates, infants and children. These patients are vulnerable and susceptible to the environment surrounding them, yet there is little information available on indoor air quality and factors affecting it within a PICU. To address this gap in knowledge we conducted continuous indoor and outdoor airborne particle concentration measurements over a two-week period at the Royal Children's Hospital PICU in Brisbane, Australia, and we also collected 82 bioaerosol samples to test for the presence of bacterial and viral pathogens. Our results showed that both 24-hour average indoor particle mass (PM_{10}) (0.6–2.2 $\mu g\ m^{-3}$, median: 0.9 $\mu g\ m^{-3}$) and submicrometer particle number (PN) (0.1–2.8 $\times\ 10^3$ p cm^{-3}, median: 0.67 $\times\ 10^3$ p cm^{-3}) concentrations were significantly lower ($p < 0.01$) than the outdoor concentrations (6.7–10.2 $\mu g\ m^{-3}$, median: 8.0 $\mu g\ m^{-3}$ for PM_{10} and 12.1–22.2 $\times\ 10^3$ p cm^{-3}, median: 16.4 $\times\ 10^3$ p cm^{-3} for PN). In general, we found that indoor particle concentrations in the PICU were mainly affected by indoor particle sources, with outdoor particles providing a negligible background. We identified strong indoor particle sources in the PICU, which occasionally increased indoor PN and PM_{10} concentrations from 0.1 $\times\ 10^3$ to 100 $\times\ 10^3$ p cm^{-3}, and from 2 $\mu g\ m^{-3}$ to 70 $\mu g\ m^{-3}$, respectively. The most substantial indoor particle sources were nebulization therapy, tracheal suction and cleaning activities. The average PM_{10} and PN emission rates of nebulization therapy ranged from 1.29 to 7.41 mg min^{-1} and from 1.20 to 3.96 p min^{-1} $\times\ 10^{11}$, respectively. Based on multipoint measurement data, it was found that particles generated at each location could be quickly transported to other locations, even when originating from isolated single-bed rooms. The most commonly isolated bacterial genera from both primary and broth cultures were skin commensals while viruses were rarely identified. Based on the findings from the study, we developed a set of practical recommendations for PICU design, as well as for medical and cleaning staff to mitigate aerosol generation and transmission to minimize infection risk to PICU patients.

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1. Introduction

Maintaining high levels of indoor air quality in hospitals is important for protecting both staff and patients (Jung et al., 2015). The transmission of infectious diseases within hospitals poses a significant health risk and is of significant clinical concern (Cornejo-Juarez et al., 2015). Despite the implementation of infection control policies, transmission of infections within hospitals continues to occur (Siegel et al., 2007; Assiri et al., 2013). These transmissions could be patient-to-patient, visitor-to-patient, patient-to-health care worker and health care worker-to-patient.

The available evidence about the airborne spread of infection is limited, although transmission has been described for tuberculosis, measles, chickenpox and pertussis and multidrug-resistant non-tuberculous mycobacterium (Leclair et al., 1980; Bloch et al., 1985; Dharmadhikari et al., 2012; Warfel et al., 2012; Bryant et al., 2016). Other studies have suggested opportunistic spread of influenza virus and respiratory syncytial virus (RSV) via an airborne route (Roy and Milton, 2004; Killingley and Nguyen-Van-Tam, 2013; Luongo et al., 2016; Kulkarni et al., 2016). Further, Zingg et al. (2015) and Arefian et al. (2016) pointed out to the possibility of poor indoor air quality resulting in increased morbidity for health care workers, extended patient hospitalization as a result of hospital-acquired illnesses and also to increased economic costs.

Typically, hospitalized patients are triaged according to illness and level of care required, with the most critical patients admitted to an intensive care unit (ICU). Critically ill neonates, infants and children are cared for separately within the paediatric intensive care unit (PICU) (Bennett and Bion, 1999). A number of factors have been associated with increased risk of infection transmission among hospitalized patients. These include the increased number of airborne particles generated by activities such as suction, nebulization and cleaning especially at times when patient admissions are highest and when seasonal viruses are at their peak (Eidelman et al., 2009; Leung et al., 2014; WHO, 2014). Parents, guardians, visitors and hospital staff who are shedding viruses also increase the risk of hospital-acquired infection and contribute to increased particle concentration (Voirin et al., 2009). The quality of the air supply within the PICU environment is also important, as airborne pollutant exposure may affect the health of staff and patients. Currently, only one study has been conducted to investigate indoor bioaerosol characteristics in the PICU (Li and Hou, 2003).

The aim of this study was to improve our knowledge of indoor airborne particle and bioaerosol characteristics in a PICU environment. The objectives were: (1) to measure indoor and outdoor particle number (PN) and particle mass (PM_{10}) concentrations for two weeks continuously and simultaneously; (2) to identify particle sources and estimate particle emission rates; (3) to assess the filtration efficiency of the building ventilation system filters; (4) to analyze the spatial distribution and variation of particle concentrations; and (5) to collect bioaerosol samples and identify examples of airborne bacteria or viruses.

The main reasons for measuring particle concentrations and particle sizes are to understand the airborne particle size distribution and the type of airborne aerosol particle; identify the possible source of the particles; and assess their effect on human health.

It is, however, important to note that this study did not seek to investigate or establish whether microbial transmission occurred between patients, or between patients and visitors.

2. Experimental methods and data processing

2.1. The sampling site

This study was conducted in a PICU at the Royal Children's Hospital, Brisbane, Australia. The floorplan of the PICU is shown in Fig. 1. The PICU consisted of 8 beds, of which Bed 1 and Bed 2 were located in separate rooms, and the others were situated in a common area. The size of this PICU is approximately 231 m^2. A nurses' station was located in the centre of the PICU. A mechanical air-handling unit (AHU) with two-stage filtration provided a constant flow of supply air to the PICU. The first stage filters (dry media filters) functioned in the same way as those in a typical mechanical ventilation system, with a filtration efficiency of 45–65%, while the second stage filters were high efficiency particulate air filters (HEPA) (Econocell Filters, Australia). There were four return air outlets, which were located above Beds 5 and 6, between Beds 5 and 6, and in the visiting room. In general, the first and second stage (HEPA) filters of the ventilation system were changed after approximately 1–2 years and 2–3 years, respectively.

2.2. Instrumentation and data collection

2.2.1. Particle number (PN)

Indoor supermicrometer $PN_{0.5–20\ \mu m}$ concentration and size distribution (from 0.5 to 20 μm) were measured using a TSI Model 3312A Ultraviolet Aerodynamic Particle Sizer (UVAPS, TSI Incorporated, Shoreview, MN, USA), with a time resolution of 20 s. Indoor supermicrometer particle number $PN_{0.3–25\ \mu m}$ concentration and size distribution (from 0.3 to 25 μm) were measured using a TSI AeroTrak Handheld Particle Counter 9306 (OPC, TSI Incorporated). The two instruments provided information on indoor spatial variations of supermicrometer particle concentration. Indoor and outdoor total submicrometer $PN_{0.005–3\ \mu m}$ concentrations were measured using three TSI Model 3787 Condensation Particle Counters (CPC, TSI Incorporated) in the size range from 0.005 to 3 μm, and with a time resolution of 10 s (indoor) or 20 s (outdoor). Two of the instruments were operated indoors and one sampled outdoor air and was located next to the AHU outdoor air intake. One TSI Model 3007 CPC and one TSI P-Track were used for short-term (daytime) indoor total submicrometer $PN_{0.01–1\ \mu m}$ and $PN_{0.02–1\ \mu m}$ measurements, respectively.

2.2.2. Particle mass (PM_{10}) concentration (mass concentration of particles with an aerodynamic diameter smaller than 10 μm)

Indoor and outdoor PM_{10} concentrations were simultaneously measured by a TSI DustTrak-DRX and a TSI DustTrak II, respectively. Given that this work focused on an area with multiple potential sources of particles, including sources of particles larger than 2.5 μm (e.g. human-generated aerosols, resuspension etc.), it was appropriate to measure particle mass concentrations in terms of PM_{10}, rather than $PM_{2.5}$.

2.2.3. Indoor bioaerosols

Indoor bioaerosol samples were collected using a Coriolis μ Air Sampler (Bertin Technologies, France). Each sample, consisting of 3 m^3 of air collected at 0.3 m^3 per minute, was drawn into a conical sterile tube containing 15 ml of saline solution (0.85% NaCl). Normal saline or 0.9% sodium chloride is not mandatory, but is the preferred solution for bacterial manipulations as it is an isotonic solution and therefore the osmotic pressure of the bacterial cells is maintained. Saline is also a suitable medium to retain viral integrity prior to nucleic acid extraction for PCR. Due to the high flow rate used for sampling, it was possible that some of the liquid became aerosolized during sample collection. To contain these particles and prevent them from being released into the indoor air of the PICU, the instrument was placed in a plastic bag, with a HEPA filter at its outlet to remove any particles generated by the Coriolis μ Air Sampler.

Time series of indoor and outdoor CO_2, temperature and relative humidity were measured by a TSI Q-Traks (TSI 7545).

2.2.4. Other parameters

Supply and return air velocities were monitored using a TSI Model 8330 anemometer (VelociCalc) and a TSI Model 8705 DP-Calc