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Numerical simulation of the impact of surgeon posture on airborne particle distribution in a turbulent mixing operating theatre

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ABSTRACT

Airborne particles released from surgical team members are major sources of surgical site infections. To reduce the risk of such infections, ultraclean-zoned ventilation systems have been widely applied, as a complement to the ventilation of the main operating theatre. The function of ventilation in an operating theatre is usually determined without considering the influence of the staff members' posture and movements. The question of whether the surgeon's posture during an on-going operation will influence particle distribution within the surgical area has not yet been explored in depth or well documented.

In the present study we analysed data from investigation of two positions (bending and straightened up), which represent the most common surgeon and staff-member postures. The investigation was performed by applying the computational fluid dynamics methodology to solve the governing equations for airflow and airborne particle dispersion. Ultraclean-zoned ventilation systems were examined as an addition to the conventional operating theatre. We examined three distinct source strengths (mean value of pathogens emitted from one person per second) due to the variety of staff clothing systems.

In the upright posture, the screen units reduced the mean air counts of bacteria and the mean counts of sedimenting bacteria to a standard level for infection-prone surgeries in the surgical area. However, the performance of this system could be reduced drastically by improper work experience. Surgical garments with a high protective capacity result in lower source strength and thus reduces the particle concentration within the surgical area. These results are useful for developing best practices to prevent or at least reduce the infection rate during a surgical intervention.

1. Introduction

An infection that extends within the surgical wound margins following a surgical procedure is commonly referred to as a surgical site infection (SSI). Postoperative SSIs are serious healthcare-associated infections that contribute to higher rates of patient morbidity and mortality and increase hospitalisation time and patient dissatisfaction. A severe SSI can cause significant pain and affect various aspects of the patients' lives, often permanently [1]. It is generally accepted that Staphylococcus aureus (S. aureus) is the main relevant bacterial species found in an operating theatre (OT) [2,3] and the most common cause of SSI [4]. This is a matter of great concern, since commonly used antibiotics may fail to cure these types of infections due to the increasing resistance of S. aureus to conventional drugs. In 1974, only 2% of S. aureus infections in the United States were methicillin-resistant. That figure had increased

Abbreviations: BCP, Bacteria-carrying particle; CFD, Computational fluid dynamics; CFU, Colony-forming units; DO, Discrete ordinates; DRW, Discrete random walk; HEPA, High-efficiency particulate absorption air filter; LAF, (Ultraclean) laminar airflow; LPT, Lagrangian particle tracking; OT, Operating theatre; RANS, Reynolds-Averaged Navier Stokes; RNG, Re-Normalisation Group; SSI, Surgical site infection; UZV, Ultraclean-zoned ventilation.

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to 22% by 1995, to 64% by 2004 [5], and to 70% by 2008 [6]. The danger posed by growing resistance to antibiotics has been described as a global threat – a “ticking time bomb” – that should be ranked alongside terrorism on the list of threats to the human race [7,8].

It is well known that personnel working in the OT are the main source of airborne bacteria. They can disseminate infectious particles into their surrounding environment even in the absence of any symptoms of skin problems. The bacteria suspended in the OT air may contaminate a wound, either directly by sedimentation from the air, or indirectly by contaminated sterile instruments. A person releases about 10^4 skin scales per minute during walking activities, 10% of which carry bacteria [3]. However, the amount of discharged microorganisms varies widely – even more than 12-fold – between individuals and sampling days [9]. It has been reported that skin fragments carrying bacteria have a wide size distribution of 4–60 μm, with an average size of 12 μm [10,11].

These contaminations can usually be reduced by preventing staff clothing from shedding bacteria to the air [9,12–14]; by using an efficient ventilation system to dilute and extract the contaminants from the OT [15–20]; and by reducing the number of people and their activity in the OT [21–23].

Surgical staff posture is very diversified depending of type of the surgery, available medical facilities and several other influential factors. Yu et al. [24] conducted a field observation study to quantify surgeon postures and they showed that posture adjustments occur frequently during ongoing surgeries.

Few studies have investigated the impacts of staff posture on particle distribution within the surgical zone. Some previous works have indicated that staff movement might have a significant effect on the distribution of pathogens [25,26]. The on-site measurements and numerical simulation of deposited airborne particles in two OTs by Zhang et al. [27] showed that the movement of surgical team member could change the particle distribution within the surgical area.

Surgical staff members began to use certain clothing system at the beginning of the 20th century [28] and considerable efforts have been made to improve the design of OT clothing. Recently, Tammelin et al. [29,30] conducted a series of experimental studies to examine the role of surgical garments and their protective capacity. These studies indicated that different clothing may result in a wide range of source strengths (mean value of pathogens emitted from one person per second), which highly influences the particle concentration in clean rooms. In a patient care room, Zhao et al. [31] examined different posture and gestures of the nurse and found that BCPs that emitted from a standing nurse may rarely reach the patient, although those BCPs can easily reach the patient when the nurse is bending over the patient.

Whyte et al. [32] compared the performance of polyester fabric clothing with total-body exhaust gowns, disposable and conventional cotton clothing. They conclude that the polyester clothing was much superior to conventional cotton clothing, and almost the same as both disposable clothing and the total-body exhaust gowns.\

It is generally accepted that laminar airflow (LAF) is the most efficient air distribution system for the OT, it is relatively cost-inefficient and difficult to apply in retrofitting practice in existing hospital operating rooms.

There is a great chance for the sterile instruments to be placed outside of LAF protective area, since the surgical table, personnel, and other medical equipment usually occupy this zone.

An additional ultraclean-zoned ventilation (UZV) screen unit was recently examined successfully, both experimentally [33–36] and numerically [14,37,38], and used as complement to the main OT ventilation. UZV was found to constitute a valuable complement to the OT ventilation in reducing OT bacterial load. We recently examined the UZV as an extension to a turbulent mixing operating suite [14]. However, the effect of human posture on the performance of examined UZV was disregarded.

Based on the above, the purpose of the present study is to assess and explore the effect of human posture and clothing systems on particle distribution in a turbulent mixing OT equipped with ultraclean-zoned airflow screen unit.

2. Methods

The physical arrangement of the examined OT, which has been adopted in our previous works [20,21,37], was considered as a computational domain. The OT is measured as L 8.5 m × W 7.7 m × H 3.2 m. The relative positions of all the furnishings and surgical staff are shown in Fig. 1.

Ventilating air originated to the OT via 24 diffusers in the ceiling and extracted through four exhaust openings at floor level. The supply air volume and temperature at the ceiling inlet were 2000 l/s and 20° C, respectively. In order to prevent contaminant penetration to the OT from the outside, the entire OT was kept under a positive pressure of 15 Pa in relation to the surroundings. Nine members of surgical staff, positioned mainly around the operating table, were considered. Each person was a heat source of 116 W/m^2. We also considered a patient lying on the operating table with a

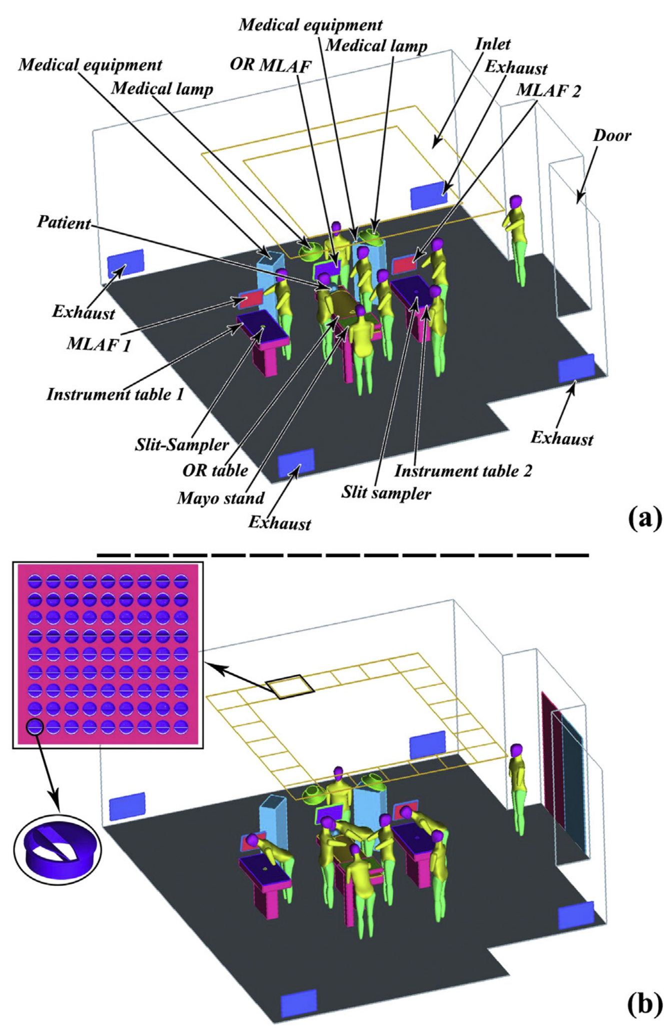

Fig. 1. An isometric view of the operating theatre model.