Impact of staff posture on airborne particle distribution in an operating theatre equipped with ultraclean-zoned ventilation

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ABSTRACT

Airborne particles released from surgical team members are major sources of surgical site infections (SSIs). To reduce SSI risk, ultraclean-zoned ventilation (UZV) systems have been widely applied, supplementary to the main operating theatre (OT) ventilation. Usually, OT ventilation performance is determined without considering the influence of staff-member posture and movements. Whether the surgeon's posture during surgery influences particle distribution within the surgical area is not well analysed and documented.

In this paper, two positions (bending and straighten up) representing the most common surgeon and staff postures in an OT, were analysed. The investigation used computational fluid dynamics to solve the governing equations for airflow and airborne particle dispersion.

Results indicate that bending posture increases the overall number of suspended particles in the surgical area by disrupting the particle-free airflows introduced by the UZV screen. More attention should be paid to staff work practices, since UZV efficiency is highly sensitive to the improper work experience.

KEYWORDS: posture, ultraclean-zoned ventilation, operating theatre, contaminant distribution, computational fluid dynamics

1. INTRODUCTION

Airborne particles released from surgical team members are the major source of surgical site infections (SSIs). SSIs are the main medical and economic causes of surgical quality problems, with 98 percent of contaminants found in surgical wounds coming from ambient air (Whyte, Hodgson, & Tinkler, 1982). The bacteria suspended in the operating theatre (OT) air may contaminate a wound directly by sedimentation or indirectly by contaminating sterile instruments. Reducing airborne particle concentration is typically managed by increasing staff clothing system performance (Sadrizadeh & Holmberg, 2014c), improving OT ventilation efficiency (Sadrizadeh, Holmberg, & Tammelin, 2014), and reducing the number and activity of people in the OT (Sadrizadeh, Tammelin, Ekolind, & Holmberg, 2014). Currently, the most efficient OT ventilation system is ultraclean laminar airflow (LAF) (Sadrizadeh & Holmberg, 2014a); however, installation is relatively cost-inefficient and the resulting clean zone provided primarily addresses the surgical table and OT personnel, leaving some sterile instruments outside the protection area.

Though an ultraclean-zoned ventilation (UZV) unit was recently examined as an addition to conventional turbulent-mixing OT ventilation both experimentally (S. Friberg, Ardnor, Lundholm, & Friberg, 2003; Pasquarella et al., 2007) and numerically (Sadrizadeh & Holmberg, 2014b), the impact of staff posture on particle distribution within the surgical zone has been rarely investigated. Some previous works did indicate that staff movement might affect pathogen distribution (Chow & Wang, 2012). The on-site measurements and numerical simulation of deposited airborne particles in two OTs by Zhang et al. (Rui, Guangbei, & Jihong, 2008) also showed that team member movement could change surgical area particle distribution. The authors (Sadrizadeh & Holmberg, 2014b) recently examined the UZV as an extension to a turbulent-mixing operating suite. However, the effect of human posture on the examined UZV performance was disregarded.

Therefore, the present study numerically investigated surgical staff posture and UZV unit performance and thus addressing particle distribution within the surgical critical zone.

2. METHODOLOGIES

A square-shaped OT with the physical configuration shown in Fig. 1 was chosen as the physical model. The dimensions were 7 m × 7 m × 3.2 m (H). The OT used a turbulent-mixing ventilation system with total airflow rate of 2 m^3/s, air temperature of 20 °C and turbulence intensity of 5 percent. The air is exhausted out by four floor-level outlets located at the parallel plane of the two side walls. Two medical devices and one medical lamp with heat-load of 350 W and 250 W were considered. In total, nine surgical staff were considered, with each staff member constituting a heat source of 195 W, released from exposed surfaces. The relative positions of furnishings and surgical staff are shown in Fig. 1. A constant skin surface release rate of 5 colony-forming units (CFUs)/s was adopted. Two instrument tables and one surgical table, each equipped with UZVs, were considered. Central air velocity of 0.4 m/s was assigned to the all three UZVs, as suggested by Sadrizadeh and Holmberg (2014b).

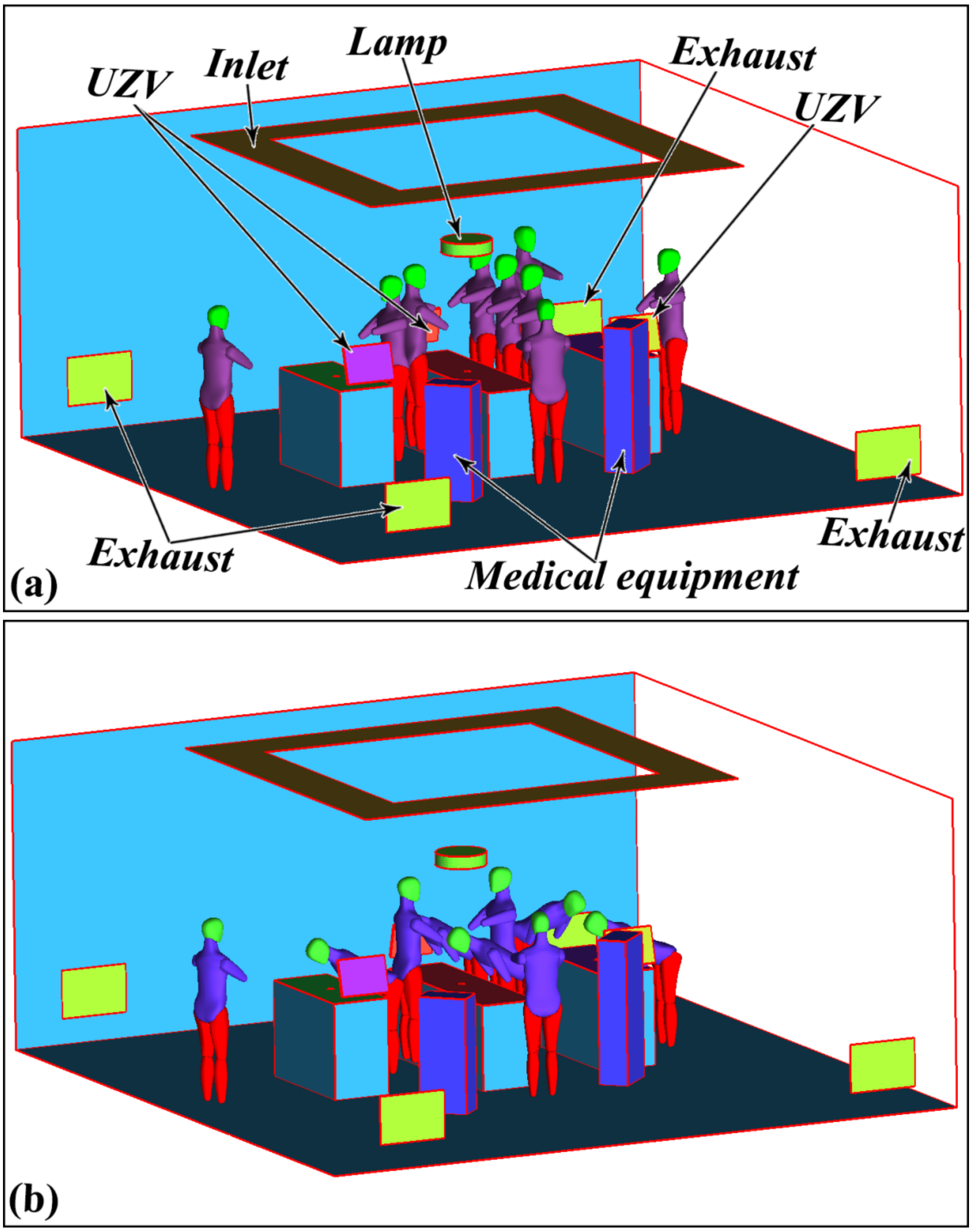

Fig. 1: Isometric view of operating room; staff members in a) upright posture, b) bending posture

ANSYS Fluent software was used to solve the Navier-Stokes and energy equations in a 3D computational domain. The realizable k-ε turbulence model was implemented to predict the airflow and Lagrangian DRW particle tracking method was used to calculate individual trajectories of particles.

To investigate the influence of surgeon posture on the airflow field and airborne particle distribution, two different scenarios were simulated and then compared. The first scenario involved upright posture, with all surgical staff standing upright (see Fig. 1-a). The second scenario considered the bending posture, with some of the surgical staff bent over the tables to represent the most common surgeon and staff-member postures, as is shown in Fig. 1-b. The numerical models were already successfully validated against experimental data available in the literature (Sadrizadeh, Holmberg, et al., 2014; Sadrizadeh, Tammelin, et al., 2014) and thus it is not repeated here.

3. RESULTS AND DISCUSSION

The airflow field for both the examined postures is illustrated by the velocity contour plot in Fig. 2. Bending over the instrument and surgical tables may reduce OT ventilation system performance and more particles can accumulate within the surgical area. SSI risk may drastically increase since the human body, a major contaminant source, is located at the upstream in relation to the instruments and wound area.

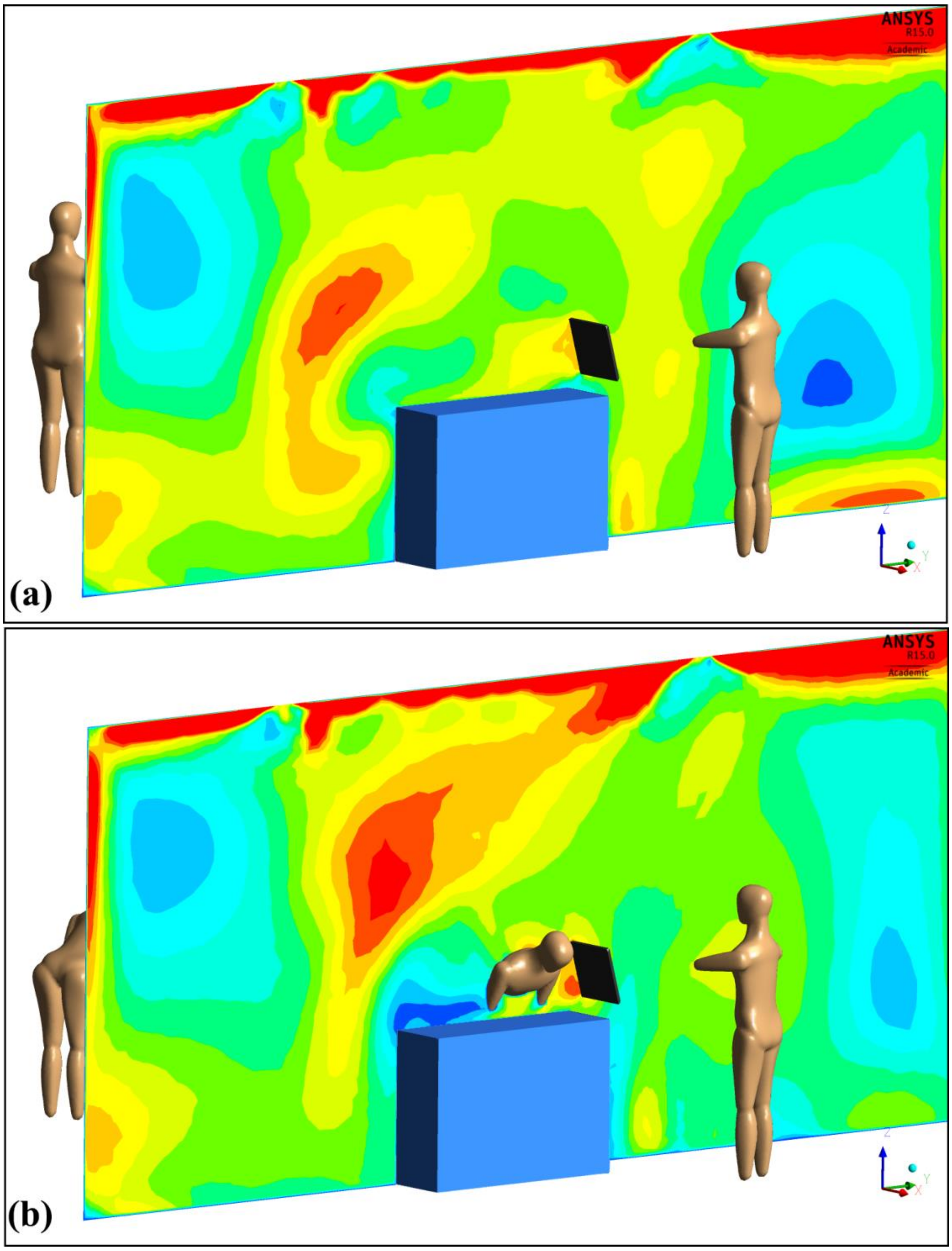

Fig. 2: Velocity contour plot; Staff members in a) upright posture, b) bending posture

Fig. 3 shows the velocity vector plots in the same location as Fig. 2 and documents how unidirectional airflows from the UZV screen could easily disrupt by improper positioning of obstacles such as the human body.

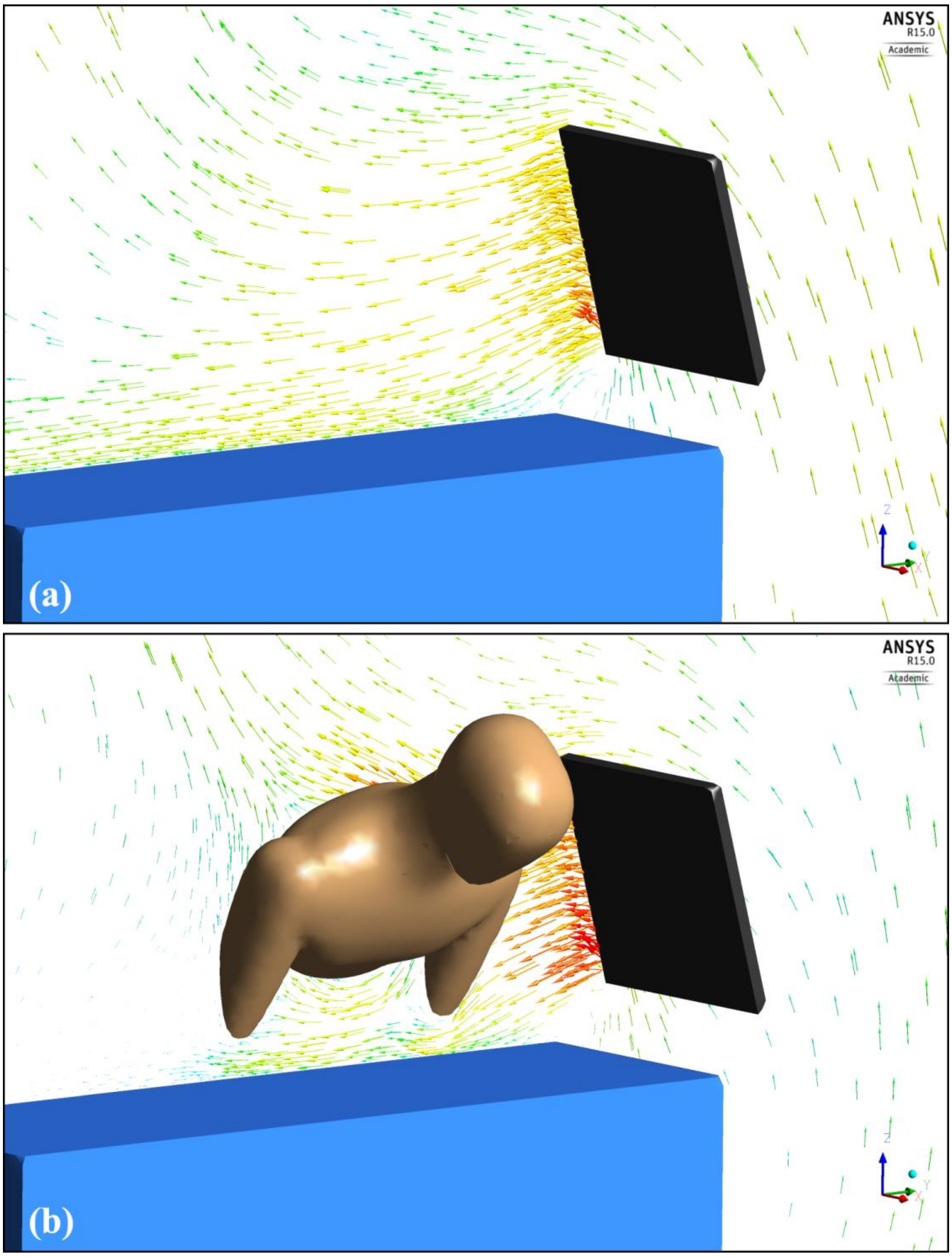

Fig. 3: Velocity vector plot; Staff members in a) upright posture, b) bending posture

Particle simulation, in upright posture scenario, shows that UZV unit can reduce volumetric particle concentration above the tables to less than 2 CFU/m^3, well below the recommended bacteriological OT air limitation of 10 CFU/m^3 for infection-prone surgeries (B. Friberg, Friberg, & Burman, 1999). By contrast, in the bended posture scenario, the CFU concentration increased beyond the CFU limitation, up to six times within the surgical area, thus increasing the chance of SSI.

4. CONCLUSIONS

In this study, the influence of staff posture on airflow structure and contaminant distribution was numerically examined. Two distinct posture scenarios of the surgical team, that is, standing and bending, were simulated and compared.

Results show that improper posture and work experience significantly reduce UZV unit performance. When all surgical staff stands upright, the lateral supply airflow from the UZV screen can introduce particle-free air, resulting in a CFU concentration of less than 2 cfu/m^3. It is highly recommended to limit activities in the area between the UZV diffusers and open wounds or instruments. To have a proper outcome, it is highly important to make sure that all OT personnel understand how work should be performed, and how the ventilation system functions, especially when UZV units are used to supplement the OT main ventilation.

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