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Airborne particle dispersion to an operating room environment during sliding and hinged door opening

Sasan Sadrizadeh[a,b,c,*], Jovan Pantelic[c], Max Sherman[b], Jordan Clark[b], Omid Abouali[d]

[a] KTH Royal Institute of Technology, Fluid and Climate Technology, Stockholm 10044, Sweden
[b] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA
[c] Center for the Built Environment, University of California, Berkeley, CA 94720, USA
[d] School of Mechanical Engineering, Shiraz University, Shiraz, Iran

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ABSTRACT

Background: Operating rooms (ORs) are usually over-pressurized in order to prevent the penetration of contaminated air and the consequent risk of surgical site infection. However, a door-opening can result in the rapid disappearance of pressure and contaminants can then easily penetrate into the surgical zone. Therefore, a broad knowledge and understanding of OR ventilation systems and their protective potential is essential for optimizing the surgical environment.
Objectives: This study investigated the air quality and level of airborne particles during a single and multiple door-opening cycles in an operating room supplied by a turbulent-mixing ventilation system.
Methods: The exploration was carried out numerically using computational fluid dynamics. Model validation was performed to ensure the validity of the achieved results. The OR was initially over-pressurized by approximately 15 Pa, relative to the adjacent corridors. Both sliding and hinged doors were simulated and compared.
Results: Penetration of bacteria carrying particles from the corridors to the OR can be successfully restricted by using a positive-pressure system. However, the results clearly indicate that frequent door opening can interfere with airflow ventilation systems, alter the pressure gradient, and increase the infection risk for the patient undergoing surgical intervention. Door-opening disturbs the airflow field and could result in containment failure.

Introduction

Surgical site infection (SSI) is the third most common class of hospital-acquired infection and ranks amongst the leading causes of death within the surgical patient population [1,2]. It is generally agreed that airborne pathogens found frequently in surgical sites are primarily *Staphylococcus aureus* released from the skin flora of the surgical staff. This bacteria is the leading cause of SSI and just a small amount of it can initiate a severe infection at the surgical site [3]. Hospital-acquired infection ranks amongst the leading causes of death within the surgical patient population.

Preserving a sterile field in an operating room (OR) is crucial to successful outcomes in surgical interventions. Hospitals and health care facilities are equipped with a state-of-the-art surgical suite, including an airflow system that keeps the OR at a pressure slightly higher than the surrounding corridors. However, ORs normally have doors leading to less controlled areas, such as patient prep rooms and corridors and the process of door-opening and closing in an OR may occur frequently during an ongoing surgical procedure [4]. This can allow for the infiltration of contaminated air to the surgical area.

Airborne particle transmission to the ORs is normally restricted by the use of a positively pressurized OR [5]. The intentional over-pressurization causes air to flow out of the OR when doors open, which prevents adjacent air from penetrating into the OR. However, the pressurization systems can become overwhelmed when doors open too many times in quick succession or stay open too long. When the door is opened, the OR ventilation system fails to maintain the required positive pressure difference within the room in relation to the adjacent areas, and results in contaminant dispersion to the surgical zone. Door opening leads to a failure in isolation

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[*] Corresponding author at: Division of Fluid and Climate Technology, School of Architecture and the Built Environment, KTH Royal Institute of Technology, Stockholm, Sweden.
E-mail addresses: SSadrizadeh@lbl.gov, Sasan@berkeley.edu (S. Sadrizadeh).

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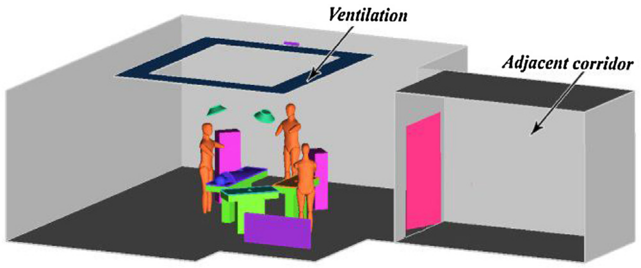

Fig. 1. Isometric view of the OR model and an adjacent corridor.

conditions and results in penetration of contaminated air from the adjacent area into the OR.

Changing surrounding parameters such as door opening and passage through the door can drastically change the airflow pattern and thus affect the airborne particle motions. For example, door can alter the organized airflow streams by adding turbulence, which may facilitate the dispersion of airborne microorganisms [6]. Air density differences caused by temperature variation can also set up a large airflow exchange between the OR and adjacent areas. Opening a hinged door leads to a sweeping action, which can move a significant volume of infectious air through the open doorway [7].

Several studies have explored the impact of OR door-openings on air quality [8–10], but experimental tests of this have proven to be difficult. The number and duration of door openings are correlated to type and length of surgery. It has been shown that door opening occurs every two and half minutes even in infection-prone surgeries such joint arthroplasties [4].

An air velocity above 0.2 m/s via a doorway effectively prevents the spread of airborne contaminants out of the isolation room when a door is opened [9]. Hayden et al. [11] showed that opening and passing through the door causes great volumes of air to migrate from one room to the other. This volume may include infectious particles and cause a devastating complication for the patient. Scaltriti et al. [12] reported a strong correlation between OR door-openings and elevated airborne bacterial counts. Ritter et al. [13] found no significant difference in counts of bacteria-carrying particles (BCPs) between closed and swinging doors. Stocks et al. [14] drew the same conclusion.

Preventing airborne contaminant migration during door-opening is an issue of prime importance. However, the questions as to how much a door opening may increase the level of airborne particles in the ORs and what frequency of door opening can cause a failure in contaminant control are still unknown.

This study aims to assess the effect of door-openings on airborne contamination level in the OR and addresses the above-mentioned questions. Computational fluid dynamics (CFD) are used to determine airflow and particle movement in the OR during simulated surgery and evaluate the effectiveness of the ventilation system in protecting the surgical field from contamination. It also examines if opening doors reduced this effectiveness.

Method

An operating room with overall dimensions of $8.5\,\text{m} \times 7.7\,\text{m} \times 3.2\,\text{m}$ was considered for the computational model. The inlet air was introduced to the room at a total airflow rate of $2.5\,\text{m}^3/\text{s}$ and a temperature of 20 °C. The ceiling diffusers were recessed from the false ceiling and covered a projected area of $8.9\,\text{m}^2$. The temperature of the adjacent corridor air which led to the OR during door-opening was 24 °C. The OR was maintained under a positive pressure of 15 Pa relative to the adjacent corridor. Fig. 1 shows an isometric view of the OR model.

The staff members had a surface area of $1.7\,\text{m}^2$, and released a heat flux of 110 W each from exposed surfaces. At the same time, each surgical staff member was considered a contaminant source, releasing infectious particles at a rate of 300 colony-forming units (CFU)/min, yielding a source strength of 5 CFU/s per person [15]. The patient itself was considered a source of bacteriological contaminants with source strength (mean value of airborne particles emitted each second from one person) of 1.5 CFU/s. The size distribution of particles carrying bacteria were considered in the range of 5–60 μm in diameter. The hospital type and the sampling time are factors that affect the level of CFU within the hospital environment [16]. However, it was assumed here a volumetric airborne contamination of $180\,\text{CFU/m}^3$ in the adjacent corridor. The two pieces of medical equipment and the two surgical lamps contributed uniform heat dissipation of 450 W and 320 W, respectively.

The total door-opening takes 16 s, including 3 s for opening or closing movement and 10 s for open-hold position. A time-accurate simulation was conducted and the unsteady air contaminant level was measured over the entire OR space.

Airflows through doorways

The driving mechanisms for airflow through doorways are a combination of several factors including density differences (as a result of temperature differences), human passage through the door, mechanical ventilation and pressure difference as well as the door motion [17,18]. Experimental analysis proved that the door pumping effect is negligible for a temperature difference of above 3–5 °C and typical door swing speeds [17].

The total volumetric airflow through a half doorway during a single door opening can be calculated as the following [8]:

$$V_d = \frac{1}{3} t_e C_d W H^{\frac{3}{2}} \sqrt{2g \frac{T_c - T_o}{T_c + T_o}} \tag{1}$$

Here, W and H are referring to the opening dimension, t_e is the total door-opening time, g is gravitational acceleration. T_c and T_o are the corridor and OR air temperatures in Kelvin. C_d is the discharge coefficient which is a function of airflow direction and pressure differences across the opening. Various studies have used a value of approximately 0.65 for the door-opening, which agrees with theoretical considerations [19].

Assuming a constant door swing speed, the equivalent door-opening time in case of hinged door can be formulated as:

$$t_e = \left\{ t_h \sin\theta + \frac{(t_o + t_c)}{\theta} \left(1 - \cos\theta\right) \right\} \tag{2}$$

where θ is the maximum opening angle in rad, t_h is open-hold time, t_o and t_c are open and closing times respectively. At a maximum door-opening angle of $\pi/2$ for a hinged door, or fully opened sliding door, the equivalent door-opening time, t_e, can be calculated:

$$t_e = \left\{ t_h + \frac{2}{\pi} (t_o + t_c) \right\} \tag{3}$$

In the case of a sliding door, moving at a constant speed, a factor of 0.5 will replace $2/\pi$ in Eq. (3).

Computational fluid dynamics and mathematical modeling

Bacteriological monitoring of OR air during surgical activities is still a common practice in hospitals and health care facilities. Direct measurement always needs more technical personnel to be involved in the OR which poses several ethical and logistical constraints to such experimental research studies. It is also requiring physical activities which may not be possible in the design stage.

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