Minimizing the airborne particle migration to the operating room during door opening

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Abstract. Airborne bacteria that enter an open wound during surgery can result in post-operative infections, commonly referred to as surgical site infections (SSIs). The level of contaminants is usually lower in the operating rooms (ORs) in contrast to adjacent corridors. Penetration of particles carrying bacteria through the doorway during a door opening gives rise to the OR contaminant level as door-opening and passage may occur every 2.5 minutes during a given surgical activity. The authors had previously conducted a successful research study to reduce the contaminant migration from an anteroom, through the doorway, into an Airborne Infection Isolation Room (AIIR). In contrast to the AIIRs, the ORs are usually over-pressured related to the surrounding environments. However, both ORs and AIIRs share the same interest in avoiding air exchange between the room and the adjacent space. This paper, built upon the previous research achievement, proposes an innovative design solution to reduce the bacteria penetration to the ORs during a door opening and staff passage. Previously achieved results from CFD simulation and laboratory measurement confirmed that installing a ventilation unit that supplies a high air volume into the OR through low-velocity wall diffusers, may significantly reduce the contaminant migration to the OR during door-opening activities.

1. Introduction
SSIs resulting from airborne contamination are caused by skin particles. When a person moves, he or she releases 10 000 skin particles each minute and about 10 % of these are bacteria carrying particles [1]. Airflow behaviour in ORs can control and decrease the risk of surgical site infections (SSI) by applying proper ventilation system for moving bacteria carrying particles from the wound zone [2]. Some ORs have high air exchange rates and mixing ventilation to dilute the particle concentration in the air, while other supply ultra clean air provided through LAF roof (laminar air flow) to prevent bacteria carrying particles entering the open wound during the surgery.

Several room categories in a hospital that are kept at higher or lower pressure than their adjacent spaces. This is respectively to protect persons or equipment inside the room from the surroundings or to protect the surroundings from the persons or other influences inside of the room. ORs are kept at a positive pressure of about 15 Pa with regard to adjoining spaces [3]. However, opening a door causes any pressure differences to cease, allowing airborne contaminants to freely escape to the adjacent spaces.

Typical reasons for traffic flow in an operating room can be expert consultation, need for more instruments, lunch or coffee breaks, team member leaving or entering after incision or before closure or social visits [4]. The level of CFUs/m³ are usually much higher in areas adjacent to the OR and several studies have confirmed that door openings and passing personnel through the door increases the risk of contamination in an OR [5][6][7]. Although door openings should be kept at a minimum to reduce air exchanges, such door openings are unavoidable. The number of door openings can rise up to 37 opening per hour, based on the type of the surgery, and in some types of surgery it can be even more [8]. The suggested solution to reduce air exchange caused by door opening and passage is based on previous
research about how to reduce air exchange in normal patient rooms. In this paper, we will discuss how an air flow barrier can be installed in an anteroom to reduce corridor air from entering the OR.

2. Method

2.1 The idea
The initial idea, as illustrated in Figure 1 (a) below, was to install a unit that extracts air from the patient room, filtrates the air through high-efficiency particulate air (HEPA) filters and reintroduces the air in the anteroom through large wall diffusers. The diffusers were located in the anteroom on the wall facing the corridor to provide a unidirectional air flow towards and through the patient room door when the door was open. This created an airflow door barrier to prevent air from escaping the patient room in order to protect other patients and hospital staff from the infected patient. This solution has been tested with both CFD simulation and in laboratory with promising results.

Figure 2 (b) shows the installed unit in an OR anteroom. In this case, the aim is to protect the patient from the surroundings to reduce the risk of SSI by limiting bacteria carrying particles in the corridor from entering the anteroom when the surgical staff enters or exits the room during an ongoing surgery. The diffusers are therefore located on the opposite side of the anteroom, facing the corridor. The air flow barrier provides a unidirectional air flow through the corridor door when the door is opened.

When surgical staff enters the anteroom the air exchange is significantly reduced and thus reduces the bacteria carrying particles entering the OR when the staff continues into the OR.

2.2 CFD model and laboratory layout
Both CFD simulations and laboratory measurements has been performed to analyse the flows induced by the movement of a hinged door and by the person passing through the doorway. A more detailed description about the applied methods for the CFD simulations and laboratory experiments can be found in Harsem et al. [9] [10] [11] [12].

Figure 2 below shows the layout of the anteroom and the adjacent corridor. The anteroom area is 5.8 m². The corridor represented here has a 19.8 m² enclosed area, but this will, of course, vary greatly in different hospitals. The OR itself is on the left of the anteroom and it is assumed that the layout of this room is less important, since the aim is to prevent spreading bacteria carrying particles from the corridor to the anteroom before proceeding to the OR. The background ventilation rate yielded an air exchange rate of 4 ACH in both the anteroom and the corridor with balanced ventilation, i.e. no pressure difference between the rooms. The inlet temperature was 18.5 °C and the room temperature was 22.5 °C in both rooms. The door area, separating the anteroom and the corridor was 2.5 m² and there was a 2 cm gap below the door. In each cycle, the door opened 45 degrees towards the corridor. In the baseline case,
the rooms had normal balanced ventilation with only the background ventilation in both the corridor and the anteroom. Then three cases with an air door barrier were tested, respectively by applying 300 L/s, 500 L/s and 1000 L/s diffuse airflow rates. The idea is to extract and filtrate the corridor air through a pre-filter and HEPA filter and then supply the air through two 1.95 m² corner diffusers in the anteroom. The desired effect is to achieve a diffuse air flow, with the necessary velocity across the open door area, to suppress the air escaping the corridor when the door opens and someone is passing through.

The commercial CFD code ANSYS Fluent was used in the CFD simulations. In the overset mesh approach, the temporally changing geometry was modelled using separate meshes for the “background” (rooms) as well as for each moving object (door and person). The meshes are combined by the code using special handling in the regions where they overlap. As an example, Figure 3 shows the resulting mesh structure at one specific time during the passage.

The laboratory experiments were performed in a full-scale laboratory representing the CFD model with the same temperature conditions, airflow rates and internal loads. SF6 tracer gas was injected in the corridor and allowed to reach steady state before any door openings were carried out. A lab personnel, representing a surgical staff, walked through the door from the corridor side, pushed an automatic door operator and entered the anteroom before coming to a complete stop in the middle of the room. The system started in synchronization with the movement of the door using the same signals as the door.
operator. Since it is not possible to filtrate tracer gas, valves were turned in synchronization with the
door opening to let outdoor air through the diffusers in the anteroom. The SF6 gas that was transferred
from the corridor was measured from the exhaust in the anteroom side. The air volume transfer was
calculated as:

$$V = Q_{eff} \int_{0}^{\infty} \frac{c_e(t)dt}{c_0},$$

where $Q_{eff}$ is the effective airflow rate of the anteroom, $C_e$ is the measured tracer concentration in the
anteroom exhaust and $c_0$ is the steady state tracer concentration in the patient room.

### 3. Results

Table 1 summarizes the results from the CFD simulations and the corresponding laboratory experiments.
Figure 4a-d shows the CFD simulation of the moment just after a person has entered the anteroom from
the corridor side. Each case consisted of opening and walking through a hinged door connecting the
anteroom and the corridor. In the baseline case, i.e. without any air flow barrier, between 730 litres and
780 litres of air was transferred from the corridor to the anteroom. Figure 4a shows that the air exchange
is both due to the pressure pulse from the door movement and the wake behind the person.

When applying an air flow barrier of 300 L/s through the corridor door, the air exchange was
reduced drastically. The CFD simulation induced an air transfer of 220 litres, while the corresponding
laboratory measurements resulted in 190 litres of air transferred from the corridor to the anteroom. Figure 4b shows that the pressure pulse from the door movement is almost completely supressed, while
the wake behind the person is still quite strong. When increasing the diffuse air flow through the door
to 500 L/s, as seen in figure 4c, the air transfer was 110 litres in the CFD simulation and 150 litres in
the laboratory experiments. Introducing 1000 L/s through the corner diffusers when opening the door,
duced 30 litres of air exchange in the CFD simulation and 110 litres in the laboratory experiments.
Figure 4d shows that some air is still transferred between the rooms, but the reduction compared to the
baseline case is significant.

| Cases   | Diffuse air flow [L/s] | Air transfer – CFD simulation [L] | Air transfer – Laboratory experiments [L] |
|---------|------------------------|----------------------------------|-----------------------------------------|
| Base line | 0.0                   | 780                             | 730                                     |
| Case 1  | 300                    | 220                             | 190                                     |
| Case 2  | 500                    | 110                             | 150                                     |
| Case 3  | 1000                   | 30                              | 110                                     |
4. Discussion
Anterooms usually have interlocks to allow the air to dilute before the surgical staff can proceed into the OR. The air exchange rate (ACH) in the anteroom might be high, but since the dilution of air is not linear, the time to completely flush a room can be several minutes even with 12 ACH. By installing an air flow barrier, the surgical staff will be allowed to enter and exit the OR more frequently without risking an increased CFU level in the operating room.

The airflow velocity through the open door is of importance. If the velocity flow through the door is too high, it can set up a counter flow in the other direction that increases the air exchange. It is thus necessary to carefully control the flow in the rooms to prevent mixing of air through the door opening. This means that the area of the diffusers had to be of a certain size to make sure that the air velocity is not too high. Thus, the location of the wall diffusers in the anteroom can be problematic. Some ORs have anterooms with surgical wash basins, but these rooms are typically quite small and already have quite a bit of equipment in them. Some ORs do not have anterooms at all (door opens directly to the corridor). One solution could be to install the units inside the OR itself. However, this may influence the existing air flows in the room, especially if a LAF roof is installed. If the diffusers were to be installed in an OR with mixing ventilation, these issues might be less problematic. Further research on the placement of the diffusers and its influence of the existing ventilation air flows is needed. Also, it would be beneficial to test the solutions in an anteroom with positive pressure relative to the corridor.

Our results show that it is certainly possible to reduce the amount of potentially contaminated air from the corridor into the anteroom by employing a system that supplies high airflow rates diffusely from the anteroom to the corridor during door openings. The system will be tested more thoroughly in future laboratory experiments and CFD simulations.

Figure 4. CFD simulations of person entering the anteroom (blue) from the corridor side (red). a) No air flow barrier. b) 300 L c) 500 L d) 1000 L
5. Conclusion
This paper proposes a method that potentially can be implemented to an OR to protect the surgical zone from corridor contaminations. The suggested solution is based on previous research on how to reduce air exchange in normal patient rooms in cases where airborne infection isolation rooms (AIIRs) are unavailable or scarce. In this paper, we argue that the results are applicable to ORs that have anterooms between the corridor and the operating room. By installing an air flow barrier in the anteroom, the air exchange due to door opening and passage can be significantly reduced and thus contribute to lowering the risk for SSI in the operating room.

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