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Surgical clothing systems in laminar airflow operating room: a numerical assessment

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Summary This study compared two different laminar airflow distribution strategies — horizontal and vertical — and investigated the effectiveness of both ventilation systems in terms of reducing the sedimentation and distribution of bacteria-carrying particles. Three different staff clothing systems, which resulted in source strengths of 1.5, 4 and 5 CFU/s per person, were considered. The exploration was conducted numerically using a computational fluid dynamics technique. Active and passive air sampling methods were simulated in addition to recovery tests, and the results were compared. Model validation was performed through comparisons with measurement data from the published literature. The recovery test yielded a value of 8.1 min for the horizontal ventilation scenario and 11.9 min for the vertical ventilation system. Fewer particles were captured by the slit sampler and in sedimentation areas with the horizontal ventilation system. The simulated results revealed that under identical conditions in the examined operating room, the horizontal laminar ventilation system performed better than the vertical option. The internal constellation of lamps, the surgical team and objects could have a serious effect on the movement of infectious particles and therefore on postoperative surgical site infections.

Abbreviations: AAS, active air sampling; BCP, bacteria-carrying particle; CFD, computational fluid dynamics; CFU, colony-forming units; LAF, (ultraclean) laminar airflow; OR, operating room; PAS, passive air sampling; SSI, surgical site infection.

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Introduction

Surgical site infections (SSIs) are the most common nosocomial infections that result from surgery. These infections contribute to higher patient mortality and considerably longer hospitalization and impose severe demands on healthcare services [1]. Patients who develop deep SSIs suffer from severe pain, insecurity and isolation [2]. The main cause of SSI is bacterial contamination that is suspended in the operating room (OR) air, mainly from infected skin squames that are shed by staff members. It is generally accepted that *Staphylococcus aureus* is the main relevant bacterial species found in ORs and is the most common cause of SSIs [3—5]. The postoperative infection rate generally depends on several factors, which include the level of airborne bacteria and the quality of the air within the OR. An appropriate ventilation system is the primary means for acquiring a safe and healthy indoor OR environment to preserve air quality and for diluting and removing airborne bacteria, anesthetic gases, and odors from the surgical zone. The OR ventilation system should also provide comfortable working conditions and an appropriate level of thermal comfort for the personnel to facilitate their work during an operation. There is a significant difference concerning the ability of various airflow systems to prevent bacterial emission into the OR surgical area.

The most common ventilation systems used in ORs today are ultraclean ventilation systems commonly known as laminar airflow (LAF) ventilation systems. Alternative methods include mixing and displacement ventilation, which differ from LAF systems primarily in terms of the methods used to supply and extract air.

LAF ventilation is an air distribution strategy for supplying air in a parallel manner through the OR. This is achieved by providing large volumes of air with a uniform flow field over the clean zone. The idea is to swipe away or wash out any microbiological contamination from the surgical zone and prevent bacteria-carrying particles (BCPs) from being encountered in the wound area. This ventilation system offers high air-change efficiency at a low supply-air velocity to control air contaminant transport. Depending on the configuration of the diffusers, it may be possible to introduce a single- or multi-zone area.

What remains unclear is which type of LAF ventilation system — that is, vertical or horizontal — is most appropriate to use during infection-prone surgeries. Several studies have been conducted that explored the relative merits of each LAF system [6—11].

Indoor obstacles, including surgical personnel, medical lamps and equipment, are considered to be the main factors that influence airflow patterns, and they can easily affect the unidirectional airflow pattern of a vertical LAF system [12,13]. It has been reported that the heads of OR personnel are sometimes positioned directly above the surgical site in the LAF stream from the ceiling down to the wound [14]. This can cause BCPs to fall directly into the wound. It has been shown that vertical LAF enhances BCP sedimentation by adding an inertial impaction factor [15].

To avoid these vertical airflow pattern disadvantages in ORs, a horizontal LAF has been suggested as an alternative [6,16]. A unidirectional lateral ventilation system will avoid obstacles, such as surgeons and medical lamps; however, it is very sensitive to internal staff member and equipment constellations that are present in ORs. The literature has discussed that improper positioning of OR surgical team members when horizontal airflow systems are utilized may increase infection rates [16].

The purpose of the present study was to assess and explore the performance of these two unidirectional ventilation scenarios in reducing the BCP concentration/sedimentation level in the surgical zone.

Materials and methods

The case study

The OR spatial arrangement, which has been used in other authors' previous work [17,18], was chosen as the physical model for the current study. The OR was designed for Nya Karolinska Sjukhuset, a hospital under construction in Stockholm. The OR dimensions were L 8.5 m × W 7.7 m × H 3.2 m, with the physical configuration shown in Fig. 1. The internal configuration of the OR personnel and other objects within the OR were appropriately arranged based on the DIN 1946-4 [19].

Ventilating air at a temperature of 20 °C was introduced to the OR with a total air volume flow rate of 2.5 m^3/s, which gave a nominal exchange rate of 47 h^{-1}. Ten surgical staff members were observed in upright stationary positions and mostly surrounded the operating table. A detailed validation of the airflow field was performed in terms of velocity and temperature [17] as well as particle distribution [20] between the numerical results and measured data. The agreements are within the limits required for engineering accuracy. However, the aspect was beyond the scope of the present study and is therefore not discussed here.