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Major Article

Do surgeons and surgical facilities disturb the clean air distribution close to a surgical patient in an orthopedic operating room with laminar airflow?

Guangyu Cao DSc [a,*], Madeleine C.A. Storås MSc [a], Amar Aganovic MSc [a], Liv-Inger Stenstad MSc [b], Jan Gunnar Skogås MSc [b]

[a] *Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway*
[b] *St. Olavs Hospital, Trondheim, Norway*

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Background: Airflow distribution in the operating room plays an important role in ensuring a clean operating microenvironment and preventing surgical site infections (SSIs) caused by airborne contaminations. The objective of this study was to characterize the airflow distribution in proximity to a patient in an orthopedic operating room.

Methods: Experimental measurements were conducted in a real operating room at St. Olav's Hospital, Norway, with a laminar airflow system. Omnidirectional anemometers were used to investigate the air distribution in the operating zone, and 4 different cases were examined with a real person and a thermal manikin.

Results: This study showed that the downward airflow from the laminar airflow system varies in each case with different surgical arrangement, such as the position of the operating lamp. The results indicate that the interaction of thermal plumes from a patient and the downward laminar airflow may dominate the operating microenvironment.

Conclusions: The airflow distribution in proximity to a patient is influenced by both the surgical facility and the presence of medical staff. A thermal manikin may be an economical and practical way to study the interaction of thermal plumes and downward laminar airflow. The provision of higher clean airflow rate in the operating microenvironment may be an effective way to prevent the development of SSIs caused by indoor airborne contamination.

In modern hospitals, surgical site infections (SSIs) are the most common hospital-acquired infections for surgical patients, accounting for 36% of nosocomial infections.[1-3] Tremendous efforts have been made to understand the general and procedure-specific patient risk factors for SSIs. Although improvements in the prophylactic and therapeutic antibiotic treatments of surgical patients have been achieved to reduce SSIs, the effects of indoor airflow distribution on SSIs in operating rooms (ORs) have not been clearly understood. A few important factors influencing the development of SSIs, especially in clean surgical procedures (infection rate < 3%), are related to airborne exogenous microorganisms.[4] Bacterial contamination in OR air may emerge from skin squames shed by personnel.[5] Some types of surgery have a higher risk of infection than others (e.g., implant and orthopedic surgeries) and should be performed in an ultraclean atmosphere.[6] The type of surgery will also determine the layout of the OR, which will influence infection prevention and control.

The ventilation system of an OR is crucial for preventing the exposure of the patient and surgical staff to hazardous emissions.[7] The provision of clean air has several functions in an OR, such as to reach an appropriate level of thermal comfort; to control factors such as temperature, humidity, and air circulation; to minimize the migration of airborne bacteria; and to dilute indoor pollutants. After the Second World War, ventilation in hospitals was introduced for contamination control, and high-efficiency particulate air (HEPA) filters

* Address correspondence to Guangyu Cao, Dr. (Sc.), Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1b, 7491 Trondheim, Norway.

E-mail address: guangyu.cao@ntnu.no (G. Cao).

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were developed to achieve a low level of airborne contamination in the supply airflow.[8] HEPA filters should remove 99.97% of particles larger than 0.3 µm.[9,10] Since bacteria-carrying particles in ORs range in size from 5 µm to 60 µm, and the bacteria itself may range from 1 µm to 15 µm, it is implied that the air supplied through HEPA filters is sterile with regard to bacterial contamination.[11-13] Ultraclean ventilation systems and laminar airflow (LAF) systems have been widely used in ORs to improve the cleanliness of indoor air. An ultraclean air system, which combined LAF and HEPA filters, was patented in 1960.[11] Ultraclean air is internationally defined as air containing fewer than 10 colony-forming units per m^3 (CFU/m^3).[5,11] To prevent bacterial emission into the surgical area, the ventilation airflow system must be carefully designed. However, even when the particle source location and the number of air changes per hour are the same, different airflow distribution methods have different particle-removal efficiencies.

A recent study defined the small zone close to the operating site as the operating microenvironment; the rest of the operating zone may be defined as the operating macroenvironment.[14] This study revealed that indoor airflow patterns and the use of various surgical facilities play an important role in determining air cleanliness in the operating microenvironment. Measurement results showed that the particle concentration (0.3-3.0 µm) increased when the angle of the operating lamps was changed from 45° to horizontal. However, an increase in the measured particle concentration did not result in an increase in the measured CFU, which may indicate that CFU may be affected by other factors. Bacteria-carrying airborne contaminants may be transferred from person to person via various respiratory activities, such as breathing and coughing.[15,16] One early study found that the measured bacterial and particle concentrations close to the operating field and at the level of the instrument table were 20-fold lower in operating theaters with LAF ceilings than in ORs without ultraclean ventilation systems.[17] In a survey of German orthopedic departments performing hip prosthesis surgery, 69% used ORs with LAF.[18] In New Zealand, LAF systems were used in 49% of total hip replacement and 53% of total knee replacement surgeries in 2008.[19] However, few clinical studies demonstrate a convincing correlation between decreased SSI rates and the use of LAF. Recent analyses suggest increased postoperative SSI rates in ORs with LAF.[20] Other studies showed significantly higher SSI rates after knee prosthesis surgery and significantly higher SSI rates after hip prosthesis surgery using LAF.[21,22] The recently published World Health Organization guideline suggests that LAF systems should not be used to reduce the risk of SSI for patients undergoing total arthroplasty surgery.[23]

The reason for these conflicting practices and recommendations is the lack of scientific understanding of the dynamic airflow distribution in the operating microenvironment under operating conditions. ORs contain many transient phenomena that may cause significant changes to the time-resolved air distribution pattern in ORs (e.g., opening of doors). However, very few studies have been done on the airflow distribution in proximity to a patient in ORs with LAF. The objective of this study was to characterize the airflow distribution in proximity to a patient in 1 OR at St. Olav's Hospital with an LAF system.

MATERIAL AND METHODS

The orthopedic OR

All measurements were conducted in a real OR at St. Olav's Hospital in Trondheim, Norway, which has been used since 2009. The OR has an area of 56 m^2 with an 11-m^2 area of LAF zone that is surrounded by 1.1-m-long partial walls (Fig 1). The OR has 2 exhaust ducts, each consisting of 2 0.27 m x 0.71 m wall-mounted, low-level exhaust outlets. The operating table was placed in the middle of the LAF zone. The temperature in the room was controlled by a temperature sensor for the exhaust air, which was set to 22 °C. The relative humidity was approximately 28% during the measurements. The supply temperature was 20 ± 1 °C. The door of the OR was kept closed during the measurements. The supply air velocity at the LAF diffuser outlet was approximately 0.3 m/s. The designed supply air in the orthopedic OR was 12,850 m^3/h, comprising 3800 m^3/h of outdoor air and 9050 m^3/h of recirculated air. The air change rate of the OR was 23 air changes per hour (ACH) during all measurements.

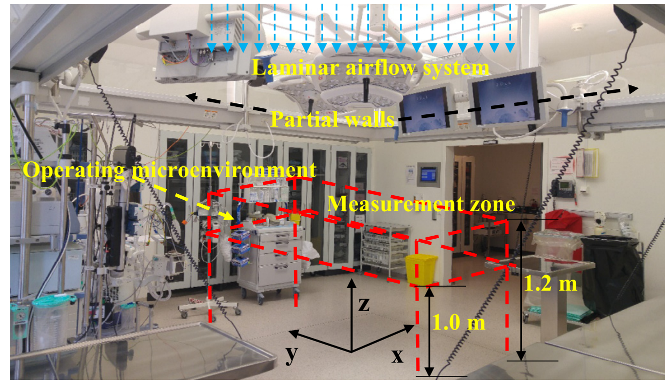

Fig 1. Photo of the operating room with the medical equipment.

Thermal manikin and thermal dummy

A male thermal manikin was employed to simulate a patient in an OR. The thermal manikin was made of glass fiber and was dressed in light clothing with an insulation capacity of approximately 0.08 m^2 K/W.[24] The manikin was assumed to have a metabolic rate equal to 46 W/m^2 of body surface area, which is based on the activity level for a reclining person. The manikin was divided into 16 different body parts when estimating the surface area, as Tanabe et al. did for their experiment in 1994.[25] The total heat output was therefore calculated to be 91.87 W for the thermal manikin, according to the calculated surface area and estimated metabolic rate. Two control strategies of the heating system were combined: the temperature constant and supply power constant for controlling the surface temperature and power supply, respectively.[26] The surface temperature was controlled by 3 different sensors that measured the temperature in the head and upper body and the temperature in the arms and legs. The system was set to heat until it reached the desired value given by a control panel. If the current value falls below the set value, the system starts to reheat the manikin. The surface temperature of the thermal manikin was measured several times during the measurement with an infrared thermo detector (Bosch PTD 1, Pobert Bosch GmbH, Leinfelden-Echterdingen, Germany), to ensure the correct surface temperature in the range of 32-34 °C.

Measurement conditions

In this study, 4 different cases were investigated to characterize the airflow distribution in proximity to a patient in an OR with LAF. Cases 1-3 employed a real person to simulate a patient; Case 4 used a thermal manikin instead. An overview of the 4 cases is presented in Table 1. This study tried to compare the thermal plumes generated by a thermal manikin without breathing function and a real person. During the measurement, the breathing airflow rate of